Exhibit I

Comment Letters and Attachments on the

Revised Environmental Impact Report (RDEIR)

Comment Letter 1

BLACK GOLD ASPHALT, INC.

RECEIVED
MAR 14 2012
MONO COUNTY
Community Development

March 6, 2012

Mr. Steve Shipley, Chairman
Mono County Planning Commission
PO Box 347
Mammoth Lakes, CA 93546

Dear Commissioner Shipley:

I am writing in support of Ormat Technologies' proposed geothermal expansion called the M-1 Replacement Project at the Mammoth Pacific, L.P. facility located just east of the Town of Mammoth Lakes.

1-01 As discussed in the Draft Environmental Impact Report and "*Economic Benefits of Proposed M-1 Geothermal Power Replacement Plant, Mono County, California,*" the M-1 project will provide some $46.1 million of new investment in materials, equipment and services to the area. The proposed expansion will create approximately 100 construction jobs in Mono County and will generate significant state and local tax revenues and additional property taxes in a county that lost more than 240 construction jobs between 2007 and 2009 as the recession reduced the demand for new residential and commercial space.

Ormat has demonstrated a strong commitment to working with local contractors and companies in the area. Black Gold Asphalt has worked on or benefited from the Mammoth Pacific project and supports this new project at that facility.

Black Gold Asphalt supports reputable developers and operators like Ormat that responsibly develop geothermal resources. Please call me at (760) 934-8616 if you have any questions or need more information.

Best Regards,

Rick Gorges
Black Gold Asphalt

cc: Scott Burns, Director, Mono County Community Development Department

Comment Letter 2

March 6, 2012

Mr. Steve Shipley, Chairman
Mono County Planning Commission
PO Box 347
Mammoth Lakes, CA 93546

Dear Commissioner Shipley:

I am writing in support of Ormat Technologies' proposed geothermal expansion called the M-1 Replacement Project at the Mammoth Pacific, L.P. facility located just east of the Town of Mammoth Lakes.

As discussed in the Draft Environmental Impact Report and "*Economic Benefits of Proposed M-1 Geothermal Power Replacement Plant, Mono County, California,*" the M-1 project will provide some $46.1 million of new investment in materials, equipment and services to the area.
2-01 The proposed expansion will create approximately 100 construction jobs in Mono County and will generate significant state and local tax revenues and additional property taxes in a county that lost more than 240 construction jobs between 2007 and 2009 as the recession reduced the demand for new residential and commercial space.

Ormat has demonstrated a strong commitment to working with local contractors and companies in the area. (Doug Clair Construction, Inc.) has worked on or benefited from the Mammoth Pacific project and supports this new project at that facility.

(Doug Clair Construction, Inc.) supports reputable developers and operators like Ormat that responsibly develop geothermal resources. Please call me at (760) 937-7441 if you have any questions or need more information.

Best Regards,

Doug Clair

cc: Scott Burns, Director, Mono County Community Development Department

Comment Letter 3

Molina Janitorial Services

MJS

Mammoth Lakes
California

RECEIVED
MAR 12 2012
MONO COUNTY
Community Development

March 6, 2012

Mr. Steve Shipley, Chairman
Mono County Planning Commission
PO Box 347
Mammoth Lakes, CA 93546

Dear Commissioner Shipley:

I am writing in support of Ormat Technologies' proposed geothermal expansion called the M-1 Replacement Project at the Mammoth Pacific, L.P. facility located just east of the Town of Mammoth Lakes.

3-01

As discussed in the Draft Environmental Impact Report and "*Economic Benefits of Proposed M-1 Geothermal Power Replacement Plant, Mono County, California,*" the M-1 project will provide some $46.1 million of new investment in materials, equipment and services to the area. The proposed expansion will create approximately 100 construction jobs in Mono County and will generate significant state and local tax revenues and additional property taxes in a county that lost more than 240 construction jobs between 2007 and 2009 as the recession reduced the demand for new residential and commercial space.

Ormat has demonstrated a strong commitment to working with local contractors and companies in the area. Molina Janitorial Services has worked on or benefited from the Mammoth Pacific project and supports this new project at that facility.

Molina Janitorial Services supports reputable developers and operators like Ormat that responsibly develop geothermal resources. Please call me at (760) 935-4443 if you have any questions or need more information.

Best Regards,

Juan Molina

Juan Molina
Owner
Molina Janitorial Services

cc: Scott Burns, Director, Mono County Community Development Department

Comment Letter 4

Thomas
FUELS · LUBRICANTS · CHEMICALS

March 6, 2012

Mr. Steve Shipley, Chairman
Mono County Planning Commission
PO Box 347
Mammoth Lakes, CA 93546

Dear Commissioner Shipley:

I am writing in support of Ormat Technologies' proposed geothermal expansion called the M-1 Replacement Project at the Mammoth Pacific, L.P. facility located just east of the Town of Mammoth Lakes.

4-01 As discussed in the Draft Environmental Impact Report and "*Economic Benefits of Proposed M-1 Geothermal Power Replacement Plant, Mono County, California,*" the M-1 project will provide some $46.1 million of new investment in materials, equipment and services to the area. The proposed expansion will create approximately 100 construction jobs in Mono County and will generate significant state and local tax revenues and additional property taxes in a county that lost more than 240 construction jobs between 2007 and 2009 as the recession reduced the demand for new residential and commercial space. Not to mention the recent MMSA layoffs. I believe this will be exactly what the local community needs.

Ormat has demonstrated a strong commitment to working with local contractors and companies in the area. Thomas Petroleum / Eastern Sierra Oil has worked on or benefited from the Mammoth Pacific project for many years and supports this new project at that facility.

Thomas Petroleum / Eastern Sierra Oil supports reputable developers and operators like Ormat that responsibly develop geothermal resources. Please call me at (760) 872-4645 if you have any questions or need more information.

Best Regards,

Jim M Dade

Jim McDade
Terminal Mgr,
Bishop CA. Warehouse
Thomas Petroleum / Eastern Sierra Oil Co.

cc: Scott Burns, Director, Mono County Community Development Department

THOMAS PETROLEUM, LLC
Western Region Home Office
1117 North 400 East
P. O. Box 540730
North Salt Lake, UT 84054

Comment Letter 5

From: Dave Harvey [mailto:davidharvey760@yahoo.com]
Sent: Thursday, March 08, 2012 12:16 PM
To: Dan Lyster; Scott Burns
Subject: CURE / M-1 Replacement Project

Dan & Scott

Please review my attachments and add to the public record. Should you have any questions please call.

Regards,
Dave
cell 760 914 3452

Attachments:

CURE Letter0001.pdf	599 KB
LA Times Articals CURE.docx	10.0 KB

Geothermal Institute of Mammoth

Mono County Economic Development Department
Mono County Community Development Department
ATTN: Dan Lyster & Scott Burns
PO Box 2415
Mammoth Lakes, Ca 93546

RE: CEQA process for the M-1 Replacement Project

Dear Mr. Lyster & Mr. Burns

5-01

I am writing this letter to address the abuses of CURE (California Unions for Reliable Energy). The "Malicious" tactics and blatant self-serving misuse of the CEQA process shows a mockery by this organization with regards to "real" environmental issues. It has become painfully clear that the only objective of the actions of CURE is to obtain a project labor agreement (PLA). I would request that you enter my letter and the two (2) supporting LA Times articles (attached) into the Administrative Record for the M-1 Replacement project and circulate to the Mono County Planning Commission.

Clearly, CURE's goal of a project labor agreement (PLA) does not support the County's General Plan to hire locally which MPLP has tried to do over its 25 year history. The facts are that many local contractors are not union. Thus, union workers would likely come from outside of Mono County, not supporting the local workforce.

The CEQA process has always been a valuable tool of Law, with the sole intent to protect and address environmental issues. Should we allow labor unions to exploit environment law for ulterior motives we effectively dilute the real purpose of this law.

5-02

GIM is in support of the M-1 Replacement project at the Casa Diablo geothermal site, and is also supportive of the use of local labor.

Respectfully,

David Harvey, CEO
Geothermal Institute of Mammoth
The Harvey Family Charitable Foundation a 501(c)(3) nonprofit Corp

PO Box 16, Mammoth Lakes, CA 93546 760 914 3452 davidharvey760@yahoo.com

Los Angeles Times | ARTICLE COLLECTIONS

← Back to Original Article

Labor coalition's tactics on renewable energy projects are criticized

Three California unions criticize CURE for challenging construction projects on environmental grounds, then dropping objections after CURE's affiliate wins contracts to supply workers. CURE says it aims to protect people and the environment.

February 05, 2011 | By Marc Lifsher, Los Angeles Times

Reporting from Sacramento — Three California unions are accusing a rival labor coalition of using "shameful" tactics to win exclusive contracts for building renewable power plants — tactics they said delay new jobs and add to each project's costs.

Unions representing carpenters, laborers and operating engineers criticized California Unions for Reliable Energy for challenging construction projects on environmental grounds — then dropping objections after its main affiliate, the State Building & Construction Trades Council of California, wins lucrative contracts to supply workers.

Since 2000, CURE has participated in environmental hearings for all 12 renewable energy projects proposed for the Southern California desert, filing more than 1,300 requests for data about water, air pollution and endangered animal species, according to the California Energy Commission.

To date, the building trades council has signed contracts to build one geothermal project and seven solar projects, and CURE has dropped objections to those plants. CURE has suits pending against two developers that did not sign labor agreements, and it is no longer pursuing claims on two other projects.

The contracts give the council control over setting work rules, including hiring. The council enlists members of CURE's affiliated unions — boilermakers, electrical workers, plumbers and pipefitters — and, if needed, other, less costly union workers such as carpenters.

Some deals come with payments of as much as $400,000 to CURE for a trust that promotes the industry. CURE and the council operate out of the same Sacramento office and have the same top executive, Robert Balgenorth.

State Energy Commissioner Jeffrey Byron said that CURE is entitled to participate in power plant licensing proceedings and that it sometimes provides useful research and expert witnesses. But he's skeptical of the coalition's motives.

"It does strain credibility when you have an organization called CURE that is concerned with the desert tortoise and wildlife habitat and turns around and disappears when a project labor agreement is signed. Then it takes credit for improvements to the project to justify its existence," he said.

CURE countered that it was motivated by a desire to protect the environment. Sophisticated labor groups, said CURE's lawyer, Marc D. Joseph, understand that any complex project must meet stringent environmental standards.

"This is not the 1960s," Joseph said. "People in the building trades are not stupid. They understand that their economic future depends on developing projects in an environmentally sustainable way."

CURE's intervention in power plant licensing hearings is aimed at making sure that construction workers and residents of nearby communities are protected from environmental dangers, Balgenorth said. A subsequent project labor agreement is "a tool to make sure labor standards are set in place and the owners have what they need," he said.

In an industry publication last September, Balgenorth denounced the carpenters union's leaders as being "anti-worker" and involved in a "transparent attempt to snatch more than the carpenters' fair share of good jobs away from the building trades workers."

CURE, of course, isn't the only group challenging power plant construction on environmental grounds. The Quechan Native American tribe, for instance, has filed a lawsuit against the federal government in an attempt to block construction of Tessera Solar's Imperial Valley solar power plant in the Sonoran Desert.

CURE's motives were questioned six years ago by Riverside and Roseville, Calif., officials, but an Energy Commission inquiry concluded that the staff did not have enough information to determine whether CURE leveraged the environmental review process to win project labor agreements.

The intra-labor dispute erupted in the last year as President Obama and now California Gov. Jerry Brown have looked to alternative energy and other environmental projects to help the nation and the state create jobs and spur the economic recovery.

Obama wants to reduce the nation's reliance on oil, and Brown wants to build enough renewable plants over the next nine years to power nearly every home in the state.

The carpenters and other two unions said the threat of CURE lawsuits could drive private-sector renewable-energy developers to other states or even out of business at a time when California has a 12.5% unemployment rate, the second-highest in the nation.

CURE is "here for one reason, which is to extract or shoehorn this company, this industry, into a project labor agreement that is not only costly and restrictive but inappropriate under the circumstances," Daniel Curtin, director of the California Conference of Carpenters, testified last year at an Energy Commission hearing about solar plant licensing.

"To use the environmental issues to extract this is really shameful," he said.

Desperately needed renewable energy jobs are being "held hostage" by CURE's legal wrangling, said Jose Mejia, director of the California State Council of Laborers. Such delays, he said, could threaten a project's financing, eligibility for federal government tax breaks and contracts to supply power to electric utilities.

Tim Cremins, a lobbyist for the California-Nevada Conference of Operating Engineers, said his union was allied with the carpenters and the laborers, but he declined to comment further.

Executives and agents for renewable energy companies wouldn't comment on CURE's tactics, saying they feared it could create new political or labor problems.

An industry trade group official, Jan Smutny-Jones of the Independent Energy Producers Assn. of California, described CURE as "professional litigants" that exploit loopholes in the California Environmental Quality Act.

"The big problem," he said, "is that time is of the essence for all of these projects. They need to get built, and they are under contract [to supply power] to utilities. They don't have a lot of time for lawsuits used to extract concessions from developers."

CURE turns such time constraints to its advantage, Smutny-Jones said.

In August 2009, CURE intervened in proceedings for the Palen Solar Power Project in eastern Riverside County. Last October, after reaching a project labor agreement, CURE announced it had resolved environmental concerns, which included potential effects on groundwater, vegetation and wildlife.

At the nearby Blythe Solar Power Project, CURE signed a project labor agreement in July, after it had filed requests for information about air pollution and habitat for fringe-toed lizards, woodpeckers, prairie falcons, bats and other animals.

One of the pending CURE suits alleges that U.S. Interior Secretary Ken Salazar violated federal environmental laws by allowing the Genesis Solar Energy Project to be built on public land in Riverside County, where it would imperil Colorado River water supplies.

Neither the Obama administration nor the developer, NextEra Energy Inc., would comment.

The second pending lawsuit alleges that the state commission failed to protect desert tortoises sufficiently in approving construction of the Calico Solar Project in San Bernardino County. Calico's developers refused to comment, but the commission called the complaint groundless.

"The project was exhaustively analyzed, substantially improved and, ultimately, it was approved only after the commission imposed major changes and conditions that ensured that it would comply with all applicable laws," the commission said in a Jan. 10 legal brief.

Altogether in the last decade, CURE has won more than 40 contracts for conventional, natural-gas-fired power plants and alternative-energy installations, the coalition's Balgenorth wrote in the September labor publication.

Gov. Brown, whose election last November was boosted by millions of dollars in political contributions from labor unions, was careful about wading into the controversy.

"We must be sensitive to the environmental impacts of these projects but also move forward with alacrity to meet the state's energy, jobs and climate-change needs," Brown spokesman Evan Westrup said.

marc.lifsher@latimes.com

Firms turning to environmental law to combat rivals

California's landmark act on environmental quality is credited with preserving scenic landscapes but is now slowing key projects and spawning a flurry of litigation. Changes are urged.

November 14, 2011 | By Nicholas Riccardi, Los Angeles Times

To halt a competing project near USC, Conquest Student Housing turned to a legal weapon that one of its co-owners allegedly compared to a crude bomb: cheap and destructive.

Conquest owned 17 buildings that rented to USC students. When the developer Urban Partners proposed erecting a new complex to house 1,600 students, Conquest sued under California's landmark environmental law.

It then filed similar challenges to unrelated Urban Partners projects elsewhere in the state. Conquest withdrew its challenges only after Urban Partners filed a federal racketeering lawsuit.

The legal tussle was possible because California is one of three states that require private projects to comply with its own environmental law. That measure, the California Environmental Quality Act, is credited with helping preserve swaths of the Sierra Nevada, Mojave Desert and coastline. But as state politicians scramble to assure voters they are trying to create jobs, they have turned on the 40-year-old law and the cottage industry of litigation it has spawned.

"These are the laws that allow a solo bird-watcher to protect an endangered animal, but they're being used by a sophisticated real estate entity to kneecap the competition," said Dan Rosenfeld, the principal at Urban Partners who handled the University Gateway development.

The law requires project developers to go through a lengthy, public process detailing environmental effects and how they will be mitigated. The findings can be challenged in court by virtually any local party.

Though there are other ways to derail projects through litigation, CEQA challenges have become notorious. In September, Gov. Jerry Brown signed a law to allow a football stadium proposed for downtown Los Angeles to avoid drawn-out CEQA litigation. He signed a second bill that would allow an unspecified number of other major projects to gain the same treatment. With less fanfare, he signed a bill last month that would ease the requirements for some urban projects that otherwise meet planning standards.

At a ceremony in downtown Los Angeles for the stadium bill, Brown, who as mayor of Oakland unsuccessfully tried to get that city's downtown exempted from CEQA, thundered: "There are too many damn regulations."

Environmental groups, which argue that the law has been a net benefit to California's economy, are alarmed by the drift. "People in Sacramento, the elected — at least most of them — have bought into the meme that CEQA is a job killer," said David Pettit, a senior attorney with the Natural Resources Defense Council. "We are going to see more inroads on CEQA."

Business groups, which have yearned for decades to revise the law, are pessimistic. They argue that modifications to CEQA have been too narrow. Democrats who control the Legislature are unlikely to move more aggressively because they are too beholden to environmental groups and unions, which sometimes use CEQA for leverage in contract fights, business leaders contend.

Allan Zaremberg, president of the California Chamber of Commerce, said the exceptions so far seem to benefit only politically connected players such as Anschutz Entertainment Group, which is developing the Los Angeles stadium.

"Some people may say, 'What do I need to do to be a part of that?'" Zaremberg said. "'Do I need to be a bigger player in the legislative process?'"

Brown's administration is drafting rules that would determine which projects could qualify for fast-tracked review.

"We're making a genuine attempt to get CEQA more streamlined," said Ken Alex, director of the governor's Office of Planning and Research.

CEQA dates from 1970, when then-Gov. Ronald Reagan signed a law creating a process of public review and environmental mitigation for all state-funded projects. The law's application was significantly broadened after activists sued under CEQA to block a privately funded condominium project in the Sierra. The California Supreme Court's ruling in 1972 that CEQA applied to private projects that required action by a public body — like a zoning change or a variance — was later codified by the Legislature.

Other states followed California's lead in drafting state environmental laws. But only New York and Washington extended the their laws' reach to private development, and Washington's is far less stringent, said Daniel R. Mandelker, a law professor at Washington University in St. Louis.

In the ensuing decades, CEQA lawsuits have been used to spare houses in South Los Angeles from demolition for the Century Freeway, block a golf course in a canyon full of bighorn sheep near Palm Springs and ensure better traffic mitigation at the Hollywood and Highland project. It also has become a weapon in battles between rival developers or builders and labor unions.

In Glendale, the owners of the Glendale Galleria mall filed a CEQA lawsuit against a proposed new mall, losing the litigation but delaying the project by several months. In Sacramento, a union trying to organize workers at Sutter General Hospital filed a CEQA lawsuit to hamstring the hospital's $500-million expansion. One coalition of labor groups that advocates for environmental improvements in projects has drawn criticism because it also seeks agreements that developers employ union members.

Less than 1% of all projects in the state face CEQA lawsuits, according to the Public Policy Institute of California, but developers say they spend millions "bulletproofing" their environmental documents to fend off a challenge.

"The assertion of environmental claims for economically motivated reasons is a big part of CEQA practice," said Michael Zischke, a San Francisco land use attorney.

Environmental advocates say the focus on why groups use CEQA is misplaced. "You shouldn't really be looking at motivations of petitioners," said Doug Carstens, an environmental lawyer in Santa Monica who often files CEQA complaints. "Even if it's a solely economically motivated actor, if they're promoting transparency, good government, why not?"

Carstens said he thinks CEQA was a boon for California's economy. "Who wants to come to a state where the beaches are degraded and the traffic is gridlocked?" he said. "Do we want a race to the bottom? Do we want to become like one of those other states people run away from when they're coming to California?"

Rosenfeld, who left Urban Partners to work for Los Angeles County Supervisor Mark Ridley-Thomas, agrees that good environmental laws are good for business and development. But his experience working on the University Gateway project convinced him that CEQA litigation should be reined in.

Conquest challenged the Gateway project, contending it did not include enough parking spots. It then began to challenge other Urban Partnership projects in downtown Los Angeles, Sun Valley and Glendale. It also sued to stop a project in a Seattle suburb under Washington's less stringent CEQA-style law.

In papers filed with the racketeering lawsuit, Urban Partners alleged that a Conquest official warned another competitor that "we should think of him and Conquest like 'Al Qaeda,' adding that it does not cost a lot to build a 'bomb' and cause extensive damage to a development project, and that it only takes a single person to cause serious harm to real estate projects using CEQA."

Conquest officials did not return a call for comment or respond to multiple emails. Jack Rubens, the Los Angeles attorney who handled only the initial complaint against the Gateway project for Conquest, said: "We had very solid grounds for filing that lawsuit."

nicholas.riccardi@latimes.com

Comment Letter 6

JOY ENGINEERING

Engineering Contractors

1584 Wolf Meadows Lane
Portola, CA 96122
530-832-5760

Calif. Lic. # 395555
Nev. Lic. #0050700

March 12, 2012

Mr. Steve Shipley, Chairman
Mono County Planning Commission
PO Box 347
Mammoth Lakes, CA 93546

Dear Commissioner Shipley:

6-01 I am writing in support of Ormat Technologies' proposed geothermal expansion called the M-1 Replacement Project at the Mammoth Pacific, L.P. facility located just east of the Town of Mammoth Lakes.

As discussed in the Draft Environmental Impact Report and "*Economic Benefits of Proposed M-1 Geothermal Power Replacement Plant, Mono County, California,*" the M-1 project will provide some $46.1 million of new investment in materials, equipment and services to the area. The proposed expansion will create approximately 100 construction jobs in Mono County and will generate significant state and local tax revenues and additional property taxes in a county that lost more than 240 construction jobs between 2007 and 2009 as the recession reduced the demand for new residential and commercial space.

Ormat has demonstrated a strong commitment to working with local contractors and companies in the area. Joy Engineering has worked on or benefited from the Mammoth Pacific project and supports this new project at that facility.

Joy Engineering supports reputable developers and operators like Ormat, that responsibly develop geothermal resources. Please call me at (530) 832-5760 if you have any questions or need more information.

Best Regards,

Eric Jones

cc: Scott Burns, Director, Mono County Community Development Department

Comment Letter 7

Town of Mammoth Lakes
P.O. Box 1609
Mammoth Lakes, CA, 93546
Ph: (760) 934-8989
Fax: (760) 934-7493

Mono County Economic Development Department
Attn: Dan Lyster
PO Box 2415
Mammoth Lakes, CA 93546

March 23, 2012

Dear Mr. Lyster,

Re: Recirculated Draft EIR, Mammoth Pacific I Replacement Project

7-01 Thank you for the opportunity to review the Recirculated Draft EIR for the Mammoth Pacific I Replacement Project. As noted in the EIR, the proposed project is located in proximity to the Town of Mammoth Lakes, and within the Town's Planning Area, and the development of this project is therefore of interest to the Town.

Staff has reviewed the content of the Recirculated Draft EIR, and believes that the analysis provided, and the mitigation measures specified, adequately address the potential environmental impacts of the project.

Sincerely,

Ellen Clark, Senior Planner

cc: Jo Bacon, Mayor

Comment Letter 8

CALIFORNIA
Water Boards

EDMUND G. BROWN JR.
GOVERNOR

MATTHEW RODRIQUEZ
SECRETARY FOR
ENVIRONMENTAL PROTECTION

Lahontan Regional Water Quality Control Board

March 30, 2012

File: Environmental Doc Review
Mono County

Dan Lyster
Mono County Economic Development Department
P.O. Box 2415
Mammoth Lakes, CA 93546
Email: dlyster@mono.ca.gov

COMMENTS ON THE REVISED DRAFT ENVIRONMENTAL IMPACT REPORT (EIR) FOR THE MAMMOTH PACIFIC I REPLACEMENT PROJECT, MAMMOTH LAKES, MONO COUNTY, STATE CLEARINGHOUSE NO. 2011022020

The California Regional Water Quality Control Board (Water Board) staff reviewed the Revised Draft Environmental Impact Report (EIR) for the above-referenced project (Project). It is our understanding that the Revised Draft EIR is being circulated to provide public review of additional Project information and supplemental documentation, including new baseline biological resources information not provided with the prior environmental document review. In summary, the proposed Project is to construct a new geothermal power facility, referred to as "M-1," to replace the existing MP-1 geothermal facility. The existing MP-1 geothermal power plant is located approximately 1200 feet northeast of the intersection of Highway 395 and State Route 203 within the existing Casa Diablo geothermal complex. The construction of M-1 would not require the construction of any new office buildings or structures with the exception of 1) a substation constructed on the north side of the Project site, and 2) the installation of concrete headwalls and sluice gates within natural drainage channels on site to provide for area-wide emergency spill containment within the project area. M-1 would retain the use of the existing geothermal well field, pipeline system and ancillary facilities. The dismantling process of MP-1 is expected to require a maximum of 2 years.

Comments on the Proposed Project

For reference, our comments on the prior Draft EIR, dated August 26, 2011, are also attached. Our specific comments on the Revised DEIR are provided below.

8-01

1. On page 4-124, under heading "Jurisdictional Waters," the following is stated: "There are no waters, wetlands, or riparian habitat areas on the project site that qualify as jurisdictional resources with respect to the Corps or the [California Department of Fish and Game (CDFG)]." Please be advised that all groundwater and surface waters are jurisdictional waters of the State. Surface waters include, but are not limited to, drainages, streams, washes, ponds, pools, or wetlands, and may be permanent or intermittent and either natural or manmade. The surface drainages and swales on the Project site, as described in the Revised

8-01 Cont.

Draft EIR, are considered jurisdictional waters of the State. While some waters of the State are "isolated" from waters of the U.S., determinations of the jurisdictional extent of the waters of the U.S. are made by the United States Army Corps of Engineers (USACE). Projects that have the potential to impact surface waters will require the appropriate jurisdictional determinations. These determinations are necessary to discern if the proposed surface water impacts will be regulated under section 401 of the Clean Water Act (CWA) or through dredge and fill waste discharge requirements (WDRs) issued by the Water Board.

We request that the Project proponent consult with the USACE and perform the necessary jurisdictional determinations for surface waters within the Project area. In areas where USACE does not take jurisdiction, the Water Board generally delineates waters of the State based on distinct geomorphic flow indicators with or without clearly definable bed and bank features.

8-02

2. "Hydromitigation Measure 1" describes the installation of concrete headwalls and placement of sluice gates within natural drainage channels on the site. These actions are considered a discharge of fill material to a surface water. The Project proponent is directed to consult with the USACE, the Water Board, and CDFG prior to being issuance a grading permit.

8-03

3. "Hydro Design Feature 3" identifies the placement of silt fences within drainage swales at the exit point of the site to filter sediment during construction. Please be aware that silt fences are **not** effective sediment control best management practices (BMPs) in areas of higher flow velocities. An effective combination of sediment and erosional control BMPs must be implemented and maintained at all times during construction.

8-04

4. The Revised Draft EIR does not describe long-term BMPs that will be used at equipment storage and staging areas to avoid erosion or other impacts to surface waters or adjacent areas. Spill control measures and strategies must also be identified and implemented for all storage and staging areas.

Permitting Requirements

A number of activities associated with the proposed Project appear to have the potential to impact waters of the State and, therefore, may require permits issued by either the State Water Resources Control Board (State Water Board) or Lahontan Water Board. The required permits may include:

8-05
- Land disturbance of more than 1 acre may require a CWA, section 402(p) stormwater permits, including a National Pollutant Discharge Elimination System (NPDES) General Construction Stormwater Permit, obtained from the State Water Board, or individual stormwater permit obtained from the Lahontan Water Board;
- Water diversion and/or dewatering activities may be subject to discharge and monitoring requirements under NPDES General Permit, Limited Threat Discharges to Surface Waters, Board Order R6T-2008-0023, issued by the Lahontan Water Board; and
- Streambed alteration and/or discharge of fill material to a surface water may require a CWA, section 401 water quality certification (WQC) for impacts to federal waters (waters of the U.S.), or dredge and fill WDRs for impacts to non-federal waters, both issued by the Lahontan Water Board.

The Project proponent should be advised of the permits that may be required, as outlined above. Should Project implementation result in activities that will trigger these permitting actions, the Project proponent must consult with Water Board staff. Information regarding these permits, including application forms, can be downloaded from our web site at http://www.waterboards.ca.gov/lahontan/.

If you have any questions regarding this letter, please contact me at (760) 241-7376 (jzimmerman@waterboards.ca.gov) or Patrice Copeland, Senior Engineering Geologist, at (760) 241-7404 (pcopeland@waterboards.ca.gov).

Sincerely,

Patrice J Copeland

for: Jan M. Zimmerman, PG
Engineering Geologist

Encl: Water Board Comment Letter dated August 26, 2011

cc: State Clearinghouse (SCH 2011022020)
Tammy Branston, California Department of Fish and Game
(via email, tbrantston@dfg.ca.gov)
Bruce Henderson, United States Army Corps of Engineers
(via email, Bruce.A.Henderson@usace.army.mil)
Robert Leidy, Wetlands Regulatory Office, USEPA, Region 9
(via email, Leidy_Robert@epamail.epa.gov)

JZ/rp\CEQA Review\MammothReplacement

California Regional Water Quality Control Board
Lahontan Region

Matthew Rodriquez
Secretary for Environmental Protection

Victorville Office
14440 Civic Drive, Suite 200, Victorville, California 92392
(760) 241-6583 • Fax (760) 241-7308
www.waterboards.ca.gov/lahontan

Edmund G. Brown Jr.
Governor

August 26, 2011

Mono County Economic Development Department
Dan Lyster
PO Box 2415
Mammoth Lakes, CA 93546
Dlyster@mono.ca.gov

THE MAMMOTH PACIFIC I REPLACEMENT PROJECT, DRAFT ENVIRONMENTAL IMPACT REPORT (EIR), MAMMOTH LAKES, MONO COUNTY

The California Regional Water Quality Control Board (Water Board) staff reviewed and has the following comments of the above-referenced project. The construction of a new geothermal power facility, referred to as "M-1", is proposed to replace the existing MP-1 geothermal facility. The existing MP-1 geothermal power plant is located approximately 1200 feet northeast of the intersection of HWY 395 and State Route 203. The location for the proposed binary power plant is located on APN 037-050-002, approximately 500 feet from the existing MP-1 Plant. The M-1 site is located within the existing Casa Diablo geothermal complex.

The MP-1 site will remain operational during the construction of M-1. Once M-1 is operational MP-1 will begin being dismantled, upon completion of the dismantle, the grounds will be used as an equipment storage yard. The construction of M-1 would not require the construction of any new office buildings or structures with the exception of a substation constructed on the north side of the project site. M-1 would retain the use of the existing geothermal well field, pipeline system and ancillary facilities. The dismantling process of MP-1 is expected to require a maximum of 2 years.

Authority

The State Water Resources Control Board (SWRCB) and the Water Board regulate discharges of waste in order to protect water quality and, ultimately, the beneficial uses of waters of the state. State law assigns responsibility for protection of water quality in the Lahontan Region (Region) to the Water Board.

Permits

Activities associated with the Project may require permits issued by the State Water Board or Lahontan Water Board. A Clean Water Act, section 402, subdivision (p) stormwater permit, including a National Pollutant Discharge Elimination Systems (NPDES) General Construction Stormwater Permit, will be required for land disturbance associated with the Project. The NPDES permit requires the development of a Stormwater Pollution Prevention Plan and implementation of best management practices (BMPs)

In your Stormwater Pollution Prevention Plan and in the EIR, please include the specific stormwater runoff control measures and best management practices that will be used during both the pre-and post-construction phases of the Project. Information regarding permits, including application forms, can be downloaded from the Water Board's web site (http://www.waterboards.ca.gov/lahontan/). If the Project is not subject to federal requirements, activities that involve fill or alteration of surface waters, including drainage channels, may still be subject to state permitting.

Please include both on-site and off-site stormwater management strategies and BMPs as part of the planning process for both pre-and post-construction phases of the project. The project must incorporate measures to ensure that stormwater generated by the project is managed on-site both pre-and post-construction. Please state who will be responsible for ensuring both construction phase and post-construction BMPs and required maintenance.

Potential Impacts to Waters of the State and Waters of the U.S.

The M-1 construction site is tributary to Mammoth/Hot Creek, approximately one mile to the south, thus any spills or releases of soil or other material from the site would have potential to impact surface water or riparian habitat. Surface waters include, but are not limited to, drainages, streams, washes, ponds, pools, or wetlands, and may be permanent or intermittent. Waters of the State may include waters determined to be isolated or otherwise non-jurisdictional by the U.S. Army Corps of Engineers (USACE).

We request that measures be incorporated into the project to identify all surface waters drainages and wetlands at the proposed M-1 location and to avoid these areas by providing buffer zones where possible. If the project alters drainages, then we request that the project be designed such that it would maintain existing hydrologic features and patterns to the extent feasible. If any disturbance of surface areas or riparian areas is proposed, the project proponent should be directed to consult with the USACE, the Department of Fish and Game, and the Water Board prior to being issued a grading permit.

Low Impact Development Strategies and Stormwater Control

The project description should identify features for the post-construction period that will control stormwater on site or prevent pollutants from non-point sources from entering and degrading surface or groundwaters. The foremost method of reducing impacts to watersheds from urban development is "Low Impact Development" (LID), the goals of which are to maintain a landscape functionally equivalent to predevelopment hydrologic conditions and to minimize generation of non-point source pollutants. LID results in less surface runoff and potentially less impacts to receiving waters, the principles of which include:

- Maintaining natural drainage paths and landscape features to slow and filter runoff and maximize groundwater recharge;
- Reducing impervious cover created by development and the associated transportation network;
- Managing runoff as close to the source as possible; and
- The use of best management practices (BMPs) during construction and demolition.

Equipment Storage Yard

Measures must also be described for long term BMPs that will be used at the Equipment Storage Yard to avoid erosion or other impacts to surface waters or adjacent areas. The Draft EIR explains measures to manage hazardous materials and control spills at the M-1 Facility.

Spill control measures and strategies must also be identified and implemented for the equipment storage yard.

Thank you for the opportunity to review the proposed Project. If you have any questions regarding this letter, please contact me at (760) 241-7413 or by email CMitton@waterboards.ca.gov

Sincerely,

C. L. Mitton

Cindi Mitton, P.E.
Senior Engineer

S:\CINDI\ Mammoth_Pacific_I_Replacement.doc

Comment Letter 9

ADAMS BROADWELL JOSEPH & CARDOZO
A PROFESSIONAL CORPORATION

ATTORNEYS AT LAW

DANIEL L. CARDOZO
THOMAS A. ENSLOW
TANYA A. GULESSERIAN
MARC D. JOSEPH
ELIZABETH KLEBANER
RACHAEL E. KOSS
ROBYN C. PURCHIA
ELLEN L. TRESCOTT

OF COUNSEL
THOMAS R. ADAMS
ANN BROADWELL

601 GATEWAY BOULEVARD, SUITE 1000
SOUTH SAN FRANCISCO, CA 94080-7037

TEL: (650) 589-1660
FAX: (650) 589-5062
eklebaner@adamsbroadwell.com

SACRAMENTO OFFICE

520 CAPITOL MALL, SUITE 350
SACRAMENTO, CA 95814-4721

TEL: (916) 444-6201
FAX: (916) 444-6209

March 26, 2012

BY EMAIL AND U.S. MAIL

Mono County Economic Development Department
ATTN: Dan Lyster
P.O. Box 2415
Mammoth Lakes, CA 93546
dlyster@mono.ca.gov

Re: **Comments on the Revised Draft Environmental Impact Report for the Mammoth Pacific I Replacement Project, California Clearinghouse Number 2011022020**

Dear Mr. Lyster:

We are writing on behalf of California Unions for Reliable Energy ("CURE") to provide comments on the Revised Draft Environmental Impact Report ("RDEIR") prepared by Mono County ("County"), pursuant to the California Environmental Quality Act ("CEQA"),[1] for the Mammoth Pacific I Replacement ("M-1") unit, a geothermal power plant facility with a net generating capacity of approximately 18.8 megawatts ("MW"), proposed by Ormat Nevada, Inc ("Applicant"). The Applicant seeks a conditional use permit from the County to build, route, and reroute geothermal pipelines; construct a substation and transmission line; develop and operate, and eventually decommission, the M-1 unit; and to eventually demolish and decommission the existing Mammoth Pacific Unit I ("MP-I") power plant and ancillary facilities. The MP-I unit and the M-1 unit will operate simultaneously for approximately two years. The RDEIR, and these comments, refer to the proposed M-1 unit, substation, transmission line and ancillary pipeline facilities together with the eventual decommissioning of the MP-I unit as the "Project" for the purpose of CEQA.

9-01 The Project requires a conditional use permit from Mono County; variances from County land use regulations authorizing construction of an overhead

[1] Pub. Resources Code, §§ 21000 et seq.

9-01 Cont. transmission line and construction within 100 feet of the exterior property line; and an Authority to Construct and Permit to Operate from the Great Basin Unified Air Pollution Control District. Although not identified in the RDEIR, the Project also requires the County to amend the Mono County General Plan to authorize the Applicant to develop geothermal facilities within 500 feet of a watercourse within the Hot Creek Buffer Area.

The Project is located on private land owned by the Applicant within the Casa Diablo geothermal development complex, northeast of the intersection of Highway 395 and Route 203 and approximately two miles east of Mammoth Lakes in Mono County, California. The existing MP-I facility includes a binary geothermal power plant with a design capacity of 14 MW, associated well field, production and injection fluid pipelines, and ancillary facilities. The proposed M-1 facility includes: (1) a binary geothermal power plant with an estimated net generating capacity of 18.8 MW, consisting of vaporizers, turbine generators, air-cooled condensers, preheater pumps, a water separator and piping; (2) a fire water storage tank; (3) an electrical shelter; (4) two n-pentane storage tanks; (5) a machinery room; (6) a main electrical room; (7) an electrical substation; (8) either a 1,000-foot or 500-foot interconnection transmission line to connect the M-1 substation to the existing Casa Diablo substation; (9) an above-ground geothermal production pipeline connecting the M-1 facility to the existing well field via existing pipeline networks; (10) an above-ground injection pipeline, connecting the M-1 facility to the existing injection well field via existing pipeline networks; (11) one diesel-powered 800 brake horse power (bhp) emergency generator; and (12) a diesel-powered nominal 400 bhp firewater pump generator.

9-02 We are pleased to note that the County made substantial revisions to the DEIR, supplemented its analysis of Project impacts, and recirculated the DEIR for further public review and comment, consistent with CURE's comments on the 2011 Draft Environmental Impact for the Mammoth Pacific I Replacement Project.[2] Unfortunately, the RDEIR retained some of the major analytical deficiencies and informational gaps identified in our previous comments and must be revised. In particular, the RDEIR fails to include a complete Project description and to provide a legally defensible environmental baseline for wildlife resources, including special status species, mule deer, the endangered Owens tui chub, hydrological resources within the Project impact area, and the existing intensity of geothermal power production within the Casa Diablo geothermal complex, and to identify the Project's

[2] *See* California Unions for Reliable Energy, Comments on the Draft Environmental Impact Report for the Mammoth Pacific I Replacement Project, August 26, 2011 ("CURE's DEIR Comments").

9-02 Cont.

conflicts with the Mono County General Plan. As a result of these significant data gaps, the conclusion in the RDEIR that the Project's potentially significant impacts have been reduced to a less than significant level lacks basis. The RDEIR also fails to disclose and mitigate the Project's significant air pollutant emissions, and the Project's potentially significant impacts on vegetation depletion due to geothermal power production, mule deer migration corridors and habitat, and land use. The RDEIR also fails to include an analysis of the Project's water supply impacts and an adequate analysis of the Project's cumulative impacts with respect to air quality, mule deer, and thermal resources. The RDEIR also violates CEQA's prohibition on piecemealing environmental review by failing to evaluate this Project together with the Applicant's proposed Casa Diablo IV facility. The numerous defects in the County's analysis, set forth in greater detail in the following paragraphs, are fatal errors. Based upon our review of the RDEIR, County records, as well as pertinent public records in the possession of other agencies, we conclude that the RDEIR, must be withdrawn, and the County must prepare a revised DEIR which fully complies with CEQA.

9-03

Finally, the County may not approve the Project until the Applicant demonstrates compliance with the Land Use and Conservation and Open Space Elements of the Mono County General Plan, which prohibit the Applicant from developing the Project within 500 feet of a watercourse and which require the Applicant to: document, through entitlements or will serve letters, that the Applicant secured sufficient water supplies to meet the Project's demand; prepare a written analysis of the cumulative hydrologic and biologic impacts of the Project together with the existing Casa Diablo geothermal complex facilities; submit baseline hydrologic and biologic monitoring plans to the County; and prepare a baseline report of hydrologic and biologic resources.

9-04

We prepared these comments with the assistance of air quality expert James Clark, Ph.D., biology expert Scott Cashen, M.S., hazardous materials expert Matthew Hagemann P.G., C.Hg., and David Marcus, M.A., Energy and Resources. Their technical comments are attached hereto and submitted in addition to the comments in this letter. Accordingly, the County must address and respond to the comments of Dr. Clark, Mr. Cashen, Mr. Hagemann, and Mr. Marcus separately.

I. STATEMENT OF INTEREST

CURE has an interest in enforcing environmental laws that encourage sustainable development and ensure a safe working environment for its members. Environmentally detrimental projects can jeopardize future jobs by making it more difficult and more expensive for industry to expand in Mono County, and by making it less desirable for businesses to locate and people to live in the County, including the Project vicinity. Continued degradation can, and has, caused construction moratoriums and other restrictions on growth that, in turn, reduces future employment opportunities. CURE's members live, work, recreate and raise their families in Mono County, including in and around Mammoth Lakes. Accordingly, CURE's members would be directly affected by the Project's adverse environmental impacts. CURE's members may also work on the Project itself. They will, therefore, be first in line to be exposed to any hazardous materials, air contaminants, and other health and safety hazards that exist onsite.

II. THE RDEIR FAILS TO SATISFY CEQA'S PURPOSE AND GOALS

CEQA has two basic purposes, neither of which the RDEIR satisfies. First, CEQA is designed to inform decisionmakers and the public about the potential, significant environmental effects of a project.[3] CEQA requires that an agency analyze potentially significant environmental impacts in an EIR.[4] The EIR should not rely on scientifically outdated information to assess the significance of impacts.
9-05
The EIR's evaluation of impacts should be based on "extensive research and information gathering," including consultation with state and federal agencies, local officials, and the interested public.[5] To be adequate, the EIR should demonstrate the lead agency's good faith effort at full disclosure.[6] Its purpose is to inform the public and responsible officials of the environmental consequences of their decisions ***before*** they are made. For this reason, the EIR has been described as "an environmental 'alarm bell' whose purpose is to alert the public and its responsible officials to environmental changes before they have reached ecological points of no return.[7] Thus, the EIR protects not only the environment but also informed self-government."[8]

Second, CEQA directs public agencies to avoid or reduce environmental damage when possible by requiring alternatives or mitigation measures.[9] The EIR

---

[3] Cal. Code Regs., tit. 14, § 15002, subd. (a)(1) (hereafter "CEQA Guidelines").
[4] *See* Pub. Resources Code, § 21000; CEQA Guidelines, § 15002.
[5] *Berkeley Keep Jets Over the Bay Comm. v. Board of Port Comm.* (2001) 91 Cal. App.4th 1344, 1367 and *Schaeffer Land Trust v. San Jose City Council* (1989) 215 Cal.App.3d 612, 620.
[6] CEQA Guidelines, § 15151; *see also Laurel Heights I* (1998) 47 Cal.3d 376, 406.
[7] *County of Inyo v. Yorty* (1973) 32 Cal.App.3d 795, 810.
[8] *Citizens of Goleta Valley v. Bd. of Supervisors* (1990) 52 Cal.3d 553, 564 (citations omitted).
[9] CEQA Guidelines, § 15002(a)(2)-(3); *Berkeley Keep Jets Over the Bay Comm.,* 91 Cal.App.4th at 1354.

9-05 Cont. serves to provide public agencies, and the public in general, with information about the effect that a proposed project is likely to have on the environment and to "identify ways that environmental damage can be avoided or significantly reduced."[10] If a project has a significant effect on the environment, the agency may approve the project only upon a finding that it has "eliminated or substantially lessened all significant effects on the environment where feasible," and that any unavoidable significant effects on the environment are "acceptable due to overriding concerns" specified in CEQA section 21081.[11]

The RDEIR fails to satisfy these basic purposes of CEQA. Specifically, the RDEIR fails to reflect a good faith effort at public disclosure by failing to accurately describe the Project, set forth an adequate environmental baseline, or identify the Project's potentially significant impacts on air quality, biological and hydrological resources, land use, and water supply. These significant informational gaps in the County's analysis preclude any meaningful evaluation of the Project's potential impacts. As a result, the RDEIR's conclusions regarding the Project's environmental impacts are unsupported. In sum, the RDEIR fails to inform decisionmakers and the public of the Project's potentially significant environmental effects and to reduce damage to the environment ***before*** it occurs.

III. THE PROJECT DESCRIPTION IS INADEQUATE

9-06 The RDEIR does not meet CEQA's requirements because it fails to include a complete and accurate Project description, rendering the entire analysis inadequate. An accurate and complete project description is necessary to perform an adequate evaluation of the potential environmental effects of a proposed project. In contrast, an inaccurate or incomplete project description renders the analysis of environmental impacts inherently unreliable. Without a complete project description, the environmental analysis under CEQA will be impermissibly narrow, thus minimizing the project's impacts and undercutting public review.[12]

CEQA places the burden of environmental investigation on the government rather than the public. One of the most obvious deficiencies in the County's analysis is its failure to describe the Project in the context of the Casa Diablo geothermal complex. It is impossible for the public to make informed comments on a project of unknown proportions:

[10] CEQA Guidelines, § 15002 subd. (a)(2).
[11] CEQA Guidelines, § 15092, subd. (b)(2)(A)-(B).
[12] *See, e.g., Laurel Heights Improvement Association v. Regents of the University of California* (1988) 47 Cal.3d 376.

> A curtailed or distorted project description may stultify the objectives of the reporting process. Only through an accurate view of the project may affected outsiders and public decision-makers balance the proposal's benefit against its environmental costs . . . .[13]

The RDEIR states that the existing geothermal well field, pipeline system and ancillary facilities will be maintained with the addition of the M-1 unit.[14] The RDEIR also states that new interconnection pipelines will be constructed for the M-1 unit, which will connect the facility to existing production and injection pipelines that ultimately connect to the Casa Diablo geothermal complex production and reinjection well fields.[15] However, the RDEIR fails to provide an illustration of the existing pipeline networks. The RDEIR also fails to provide a map, or otherwise describe, the production and injection well fields on which the M-1 plant will rely. These omissions violate the basic requirement that an EIR must include a map of the proposed Project.[16]

9-06
Cont.

We recognize that the County requested that the Applicant provide a map of the existing pipelines on the M-1 site to determine whether existing pipelines would have to be removed as part of Project approval.[17] The Applicant responded to the County as follows:

> We have a drawing of the pipeline network at Casa Diablo, but it is not tied to ground features or [*sic*] have drawings of the plants, it [*sic*] extremely complex and complicated and would only create confusion in the reader. We don't see any value of placing this figure in the EIR or any attachments.[18]

The Applicant's rationale is inconsistent with one of the principal goals of CEQA and the purpose of the EIR: the full disclosure of the potential environmental effects of a project.

CEQA requires the County to include a map of the Project facilities in the RDEIR. Failure to provide this information is prejudicial because the County proposes to mitigate many of the Project's significant impacts through the ecological

---

[13] *County of Inyo v. City of Los Angeles* (1977) 71 Cal.App.3d 185, 192-193.
[14] RDEIR, pp. 2-14-15.
[15] *Ibid.*
[16] CEQA Guidelines, § 15124 subd. (a).
[17] Project file, MP-I Recirculated Draft EIR Preliminary List of Technical Information Needed.
[18] *Id.*

9-06 Cont.

monitoring and spill prevention plans that apply to the entire Casa Diablo complex.[19] The public cannot comment on the efficacy of these measures without a complete illustration of the Casa Diablo geothermal complex. The County must require the Applicant to, at a minimum, provide a map depicting how the Project will be integrated into the Casa Diablo geothermal complex to permit those not involved in preparing the RDEIR to understand the Project under review.

9-07

IV. THR DESCRIPTION OF THE ENVIRONMENTAL SETTING IS INADEQUATE

The RDEIR employs an inaccurate and incomplete baseline, thereby skewing the impact analysis. An accurate description of the environmental setting is important because it establishes the baseline physical conditions against which a lead agency can determine whether an impact is significant. The failure to adequately describe the existing setting contravenes the fundamental purpose of the environmental review process, which is to determine whether there is a potentially substantial, adverse change compared to the existing setting. CEQA requires the lead agency to include a description of the physical environmental conditions in the vicinity of a project as they exist at the time environmental review commences.[20] The EIR must also describe the existing environmental setting in sufficient detail to enable a proper analysis of project impacts.[21] The RDEIR fails on both accounts. CEQA requires the County to gather and disclose the relevant data in a revised DEIR.

A. The RDEIR Fails to Provide Adequate Baseline Data on Wildlife

In *Galante Vineyards v. Monterey Peninsula Water Management District*, the Fourth District Court of Appeals found that an Air Quality section that briefly described the area as "sparsely populated, with no industry other than several vineyards" was inadequate under CEQA, because it failed to discuss a significant

[19] *See*, *e. g*., RDEIR, p. 4-72, Bio Mitigation Measure 1; *id*. at pp. 4-134-135, Hydro Mitigation Measures 1-3.
[20] CEQA Guidelines, § 15125, subd. (a); *see also Communities For A Better Environment v. South Coast Air Quality Management Dist.* (2010) 48 Cal.4th 310, 321.
[21] *Galante Vineyards v. Monterey Peninsula Water Management District* (1997) 60 Cal.App.4th 1109, 1121-22.

aspect of the environmental baseline in sufficient detail.[22] The RDEIR's description of the environmental baseline for wildlife resources suffers from a similar error.

The RDEIR's description of existing wildlife and habitat is limited to the following:

9-07 Cont.

> A list of common wildlife species that could potentially occur in the Project area was compiled and is provided as Table 19 (Paulus 2011).[23]

This abbreviated description is too incomplete to inform the public and decision makers regarding the current environmental setting. The RDEIR fails to state where and when the enumerated species were identified and their abundance, or to describe their use of the Project site. As a result, the scope of the Project's impacts on wildlife resources cannot be determined. "A prejudicial abuse of discretion occurs if the failure to include relevant information precludes informed decisionmaking and informed public participation, thereby thwarting the statutory goals of the EIR process."[24] The RDEIR must be revised to include site-specific information on the biological resources that currently occur in the Project area.

B. The RDEIR Fails to Include Baseline Data on Special Status Wildlife

9-08

CEQA requires the County to include in the RDEIR "a description of the physical environmental conditions in the vicinity of the project, as they exist at the time environmental analysis is commenced, from both a local and regional perspective."[25] Under CEQA, "special emphasis should be placed on environmental resources that are rare or unique to that region and would be affected by the project."[26] CEQA further requires the County to demonstrate in the EIR that "the significant environmental impacts of the proposed project were adequately investigated and discussed."[27] "The EIR must permit the significant effects of the project to be considered in the full environmental context."[28] The RDEIR fails to meet these requirements.

---

[22] *See id.*
[23] RDEIR, p. 4-59.
[24] *Kings County Farm Bureau v. City of Hanford* (1990) 221 Cal.App.3d 692, 712; *see also City of Fremont v. San Francisco Bay Area Rapid Transit Dist.* (1995) 34 Cal.App.4th 1780, 1790.
[25] CEQA Guidelines § 15125 subd. (a).
[26] CEQA Guidelines § 15125 subd. (c).
[27] *Ibid.*
[28] *Ibid.*

The RDEIR's analysis of baseline conditions for special status wildlife suffers from the same prejudicial defect as the RDEIR's analysis of baseline wildlife conditions: utter lack of relevant information. The RDEIR's discussion of the environmental setting for special status species is limited to the following:

9-08 Cont.

> Table 20 lists all of the special status wildlife species known to occur in the Project vicinity as identified through a search of the CNDDB database for special status species within the area defined by the nine USGS 7.5-minte topographic quadrangle maps centered on the "Old Mammoth" quadrangle in which the MP-I Replacement Project is located.[29]

This abbreviated description is too vague and incomplete to inform the public and decisionmakers regarding current conditions. The RDEIR fails to state where and when the enumerated species were identified and their abundance, or to describe their use of the Project site. As a result, the scope of the Project's impacts on special status species cannot be determined. "A prejudicial abuse of discretion occurs if the failure to include relevant information precludes informed decisionmaking and informed public participation, thereby thwarting the statutory goals of the EIR process."[30] The RDEIR must be revised to include site-specific information on the biological resources that currently occur in the Project area.

C. The RDEIR Fails to Provide Baseline Data on Mule Deer

9-09

The mule deer is an important game species and the impacts of geothermal development on the Round Valley and Casa Diablo deer herds have been a longstanding management concern of both the California Department of Fish and Game and Mono County.[31] The RDEIR omits a discussion of the environmental setting with respect to mule deer.[32] This defect violates CEQA. The County must prepare a revised DEIR that includes a description of the baseline conditions for mule deer. Absent adequate baseline data, the Project's impacts on the mule deer cannot be reliably assessed.

---

[29] RDEIR, p. 4-59.
[30] *Kings County Farm Bureau v. City of Hanford* (1990) 221 Cal.App.3d 692, 712; *see also City of Fremont v. San Francisco Bay Area Rapid Transit Dist*. (1995) 34 Cal.App.4th 1780, 1790.
[31] CURE's DEIR Comments, August 26, 2011, Exhibit B (Cashen Comments), p. 3.
[32] *See* RDEIR, pp. 4-53-4-59.

D. The RDEIR's Discussion of Mule Deer Use of the Project Site is Unsupported

CEQA requires an agency's conclusions to be supported by substantial evidence. CEQA defines substantial evidence as "facts, reasonable assumptions predicated upon facts, and expert opinion supported by facts."[33] "[E]vidence which is clearly inaccurate or erroneous . . . is not substantial evidence."[34] Similarly, expert analysis that lacks adequate foundation does not constitute substantial evidence for the purpose of CEQA.[35] The RDEIR references the Paulus "site specific mule deer survey" for the M-1 site and the Paulus resident deer survey prepared for the Casa Diablo, Basalt Canyon and Upper Basalt Areas.[36] According to the RDEIR, "the relevant findings of the surveys were integrated" into the baseline biological resources survey report, attached as Appendix D to the RDEIR.

9-09 Cont.

As detailed in the comments of biologist Scott Cashen, attached as Exhibit A, the Paulus survey results lack adequate foundation and, therefore, do not constitute substantial evidence. In particular, the Paulus surveys omit the statistical methods that were used to answer the objectives of the studies, lack an adequate description of the study methodology, fail to disclose highly relevant information regarding current deer migration patterns, fail to examine deer use of the Project impact area during the spring, and contain numerous other deficiencies which render them scientifically unreliable.[37] The County must require the Applicant to prepare adequate surveys to investigate the nature of mule deer use of the Project site and that baseline data must be included in a revised DEIR.

E. The RDEIR Fails to Include Baseline Data on the Federally Endangered Owens Tui Chub

9-10

On August 5, 1985, the U.S. Fish and Wildlife Service ("FWS") listed the Owens tui chub as an endangered species under the Federal Endangered Species Act.[38] The Owens tui chub historically inhabited streams, rivers, springs and irrigation ditches in the Owens Basin, in Mono and Inyo Counties.[39] Finding that

[33] Pub. Resources Code § 21082.2 subd. (c).
[34] *Id.*; *see also* CEQA Guidelines § 15384 subd. (a)-(b).
[35] *See Lucas Valley Homeowners Association v. County of Marin* (1991) 233 Cal.App.3d 130,157.
[36] *See* RDEIR, p.4-65.
[37] Cashen Comments, attached as **Exhibit A**, pp. 2-4.
[38] U.S. Fish and Wildlife Service, Department of the Interior, *Endangered and Threatened Wildlife and Plants; Endangered Status and Critical Habitat Designated for the Owens Tui Chub* Final Rule, 50 Fed. Reg., 31,592, August 5, 1985.
[39] *Ibid.*

the Owens tui chub had been extirpated from much of its range – viable populations are known only in two locations in Mono County –, the FWS designated a portion of Hot Creek as critical habitat for the Owens tui chub.[40] Hot Creek is located approximately 0.6 miles from the Project site.[41] Substantial evidence shows that ongoing geothermal extraction resulted in thermal spring discharge decreases.[42] A study conducted in 2000 concludes that at the Hot Creek Hatchery, the thermal water component in the springs declined by 30-40% since 1990.[43] Because a hydrological connection exists between the Casa Diablo geothermal complex and Owens tui chub critical habitat and because the Applicant proposes to extend power production activities by replacing the aging MP-I unit, the RDEIR should have
9-10 included baseline data regarding the Owens tui chub. The RDEIR omits this
Cont. information.

A prejudicial abuse of discretion occurs if the failure to include relevant information precludes informed decision making and informed public participation, thereby thwarting the statutory goals of the EIR process.[44] An EIR must include detail sufficient to enable those who did not participate in its preparation to understand and to consider meaningfully the issues raised by the proposed project.[45] The RDEIR is inadequate because it fails to disclose information necessary to evaluate the significance of the Project's impacts on the Owens tui chub and its critical habitat. The RDEIR does not reflect any efforts on the part of the County to obtain recent biological monitoring data and disclose that information to the public and decisionmakers. The County must include baseline data on both the endangered Owens tui chub and critical habitat in a revised DEIR. Absent this information, the public and decisionmakers cannot consider the Project in its full environmental context.

9-11

F. The RDEIR Fails to Provide an Adequate Baseline for Water Resources

An EIR must describe the existing environmental setting in sufficient detail to enable a proper analysis of project impacts.[46] The RDEIR fails to include a

[40] *Id.* at 31,594.
[41] RDEIR, p. 4-123.
[42] CURE Comments, August 26, 2011, Exhibit B, p.6.
[43] *Ibid.*
[44] *Al Larson Boat Shop, Inc. v. Board of Harbor Commissioners* (1993) 18 Cal.App.4th 729, 748.
[45] *Association of Irritated Residents v. County of Madera* (2003) 107 Cal.App.4th 1383, 1390.
[46] *Galante Vineyards v. Monterey Peninsula Water Management District* (1997) 60 Cal.App.4th 1109, 1121-22.

discussion of the environmental setting with respect to surface waters and geothermal fluid at the Casa Diablo geothermal complex. The RDEIR states:

The geothermal fluids produced for the Project would be the same as those produced from the Casa Diablo geothermal wells supporting the existing MP-I power plant. As noted above, these fluids reside in the deeper geothermal aquifer underlying Long Valley. Geothermal fluid pumped from geothermal wells is very hot and under high pressures. The geothermal fluid production and injection pipeline network supporting the existing MP-I power plant would not change with the Project.[47]

9-11 Cont.

The RDEIR's discussion of the surface hydrology baseline, in relevant part, provides:

> A small, unnamed stream flows through the project site area between the existing MP–I plant site and the proposed M–1 plant site. The stream has historically intercepted flow from the hot springs in the Casa Diablo area and the drainage empties into a marshy area near Mammoth Creek [also known as Hot Creek] about 0.6 mile southeast of the existing MP-I plant site. No other streams or surface waters are located within the Project area, nor are there any cold springs, seeps or wet swales. Mammoth Creek is located approximately 0.6 mile south and southeast of the proposed M-1 plant site. Isolated hot springs, fumaroles and thermal soils exist in the Project vicinity.[48]

The RDEIR does not describe the geothermal resource at the Casa Diablo geothermal complex in sufficient detail to enable a proper analysis of Project impacts.

What the RDEIR fails to disclose is the existing condition of these water resources. Specifically, the USGS has collected data showing that temperature declines have occurred at the Casa Diablo geothermal springs, and these declines are attributed in part to the operation of the Casa Diablo geothermal complex.[49] Discharge of the thermal springs is critical for maintenance of the Hot Creek Fish Hatchery.[50] The County's failure to include this information in the RDEIR prevents the public and decisionmakers from seeing the Project in its full environmental

---

[47] RDEIR, p. 4-124.
[48] RDEIR, pp. 4-123-124.
[49] CURE DEIR Comments, August 26, 2011, Exhibit C, p. 1.
[50] *Id.* at p. 3.

9-11 Cont.

context. Accordingly, the RDEIR's discussion of the baseline water resources at the Project site is inadequate under CEQA. The County should prepare a revised RDEIR which includes current data regarding temperature trends and documents the observed temperature and discharge declines.

9-12

G. The RDEIR Fails to Establish a Baseline for Geothermal Resource Extraction

CEQA requires a comparison of project impacts against the actual baseline, not the maximum permitted baseline.[51] The RDEIR states that "the geothermal fluid production and injection pipeline network supporting the existing MP-I power plant would not change with the Project."[52] This assumption is predicated on the Applicant's claim that the ***maximum potential*** geothermal production would not increase as a result of the Project because the Project does not include an expansion of the existing well field and because the engineering constraints of existing power generation facilities prevent the Applicant from producing above the maximum potential rate.[53] The Applicant's claims regarding the maximum power production potential of the Casa Diablo geothermal complex are irrelevant to the County's obligations under CEQA.

It is well established that the baseline environmental setting for CEQA review is the existing environment; not the hypothetical environmental setting that could exist under existing permit conditions.[54] Substantial evidence shows that the existing MP-I facility has been operating substantially below maximum design capacity. According to the most recent data from the California Energy Commission, the MP-I facility has been operating at half capacity from 2007-2010.[55] CEQA requires the County to assess whether the incremental increase in power production as a result of the new M-1 facility may significantly impact the Project area hydrology and biological resources as compared to the existing, not the hypothetical, environment. The RDEIR fails to do this. The RDEIR must be revised to disclose the current intensity of power production activities at the Casa Diablo geothermal complex and evaluate whether the ***incremental increase*** in

---

[51] *CBE v. SCAQMD* (2010) 48 Cal.4th 310, 321-322, 322, n. 6-7 (discussing, among other cases, *EPIC*, *supra*, 131 Cal.App.3d at p. 354 and *Save Our Peninsula Com. v. Monterey County Bd. of Supervisors* (2001) 87 Cal.App.4th 99, 121).
[52] RDEIR, p. 4-124.
[53] RDEIR, Appendix B, "Supplemental Project Technical Information," p. 1.
[54] *CBE v. SCAQMD* (2010) 48 Cal.4th 310, 321-322, 322, n. 6-7; *see also*, CEQA Guidelines §15125.
[55] Letter from David Marcus to Elizabeth Klebaner, attached as **Exhibit B**.

9-12 Cont.

power production will result in a potentially significant impact on biological and hydrological resources as compared to existing conditions.

H. The RDEIR Fails to Include an Adequate Land Use Baseline

9-13

The description of the environmental setting in an EIR must "discuss any inconsistencies between the proposed project and applicable general plans and regional plans."[56] The RDEIR fails to disclose that the Project conflicts with the Land Use and Conservation/Open Space Elements of the Mono County General Plan. The Mono County General Plan prohibits geothermal development within 500 feet of a surface watercourse within the Hot Creek Buffer Zone.[57] Pursuant to the Mono County General Plan, all projects in the Resource Extraction Designation must comply with the 500 foot setback requirement.[58] According to the RDEIR, the Project is located in an area designated "Resource Extraction" under the Mono County General Plan.[59] However, the RDEIR fails to disclose that the Project conflicts with the General Plan because it will violate the mandatory 500-foot setback requirement.[60] The County must prepare a revised DEIR that identifies the Project's inconsistency with the Mono County General Plan.

V. THE RDEIR'S AIR QUALITY IMPACT ANALYSIS IS INADEQUATE

A. The RDEIR Fails to Disclose the Project's ROG Emissions

9-14

According to the RDEIR, "the transition period during which both MP-I and M-1 operations would overlap may be up to a maximum of two years after the M-1 plant is commissioned."[61] The RDEIR's air quality analysis is deficient because it does not disclose the Project's estimated reactive organic compounds ("ROG") emissions in the time period during which M-1 and MP-I would be in simultaneous operation.[62] Daily emissions from the MP-I plant equal approximately 500 pounds per day.[63] However, the RDEIR fails to disclose the anticipated daily emissions from the M-1 and MP-I facilities during their simultaneous operation, and the

---

[56] CEQA Guidelines § 15125 subd. (d).
[57] County of Mono Community Development Department (2010) Mono County General Plan, Land Use Element, Chapter 15, section 15.070(B)(1); *id.* Conservation/Open Space Element, Objective D, Action 1.13, p. V-43.
[58] *Id.*, Chapter 15, section 15.070 A.
[59] RDEIR, p. 1-5 and p. 1-6, Fig. 3.
[60] *See* RDEIR, pp. 1-3-4.
[61] RDEIR, p. 2.
[62] *See* RDEIR, p. 4-43.
[63] RDEIR, p. 4-43.

9-14 Cont. anticipated daily emissions from the M-1 facility once MP-I is decommissioned. The County must include this data in a revised DEIR.

B. The RDEIR's Conclusion Regarding the Project's Significant Air Pollutant Emissions is Unsupported

9-15 The RDEIR concludes that the Project's operational emissions are insignificant because the Project will not violate any air quality standard or contribute substantially to an existing or project air quality violation.[64] This conclusion is invalid because it is unsupported. In the RDEIR, the County relies on CEQA significance thresholds adopted by the Imperial County Air Pollution Control District ("ICAPCD").[65] Under the ICAPCD's CEQA significance thresholds, operational emissions of ROGs are significant if they equal or exceed a rate of 55 lbs per day.[66] The Applicant estimates that the M-1 facility would emit ROGs at a rate of up to 205 pounds per day.[67] Accordingly, the Project will result in a significant impact to air quality.

The RDEIR concludes that Project impacts will not be significant because the Applicant will control emissions to a rate of 37.4 tons annually (or approximately 205 pounds per day), representing a 60 percent decrease in ROG emissions as compared to the aging MP-I plant.[68] Again, this conclusion is invalid because it lacks basis. First, the RDEIR does not require the Applicant to limit operations of MP-I and M-1 such that there is no net increase in emissions during their period of simultaneous operation.[69] Thus, the County cannot conclude that the Project's daily emissions will be below the 55 pound per day threshold. Second, as detailed by Dr. Clark, the RDEIR and the attached appendices lack documentation regarding the efficacy of the proposed emission control equipment.[70] As such, the Applicant's claimed reduction in emissions cannot be verified.[71] The County must provide substantial evidence to support its conclusion that the Project impacts will be less than significant. Therefore, at a minimum, the County must require the Applicant to provide technical specifications in order to validate the claimed reductions in ROG emissions. Third, even after Applicant's claimed

---

[64] RDEIR, p. 4-44.
[65] RDEIR, p. 4-41.
[66] RDEIR, p. 4-44.
[67] *Ibid.*
[68] RDEIR, p. 4-43.
[69] Clark Comments, attached as **Exhibit C**.
[70] *Id.*
[71] *Id.*

9-15 Cont.

reductions, the data in the RDEIR reflect that emissions will be significantly above the 55 pound per day significance threshold. Absent data regarding daily emissions and verifiable emission reductions, the County lacks the substantial evidence to conclude that the Project's significant ROG emissions have been reduced to a less than significant level.

VI. THE RDEIR'S BIOLOGICAL IMPACTS ANALYSIS IS INADEQUATE

A. The RDEIR's Conclusions Regarding the Project's Impacts on the Owens Tui Chub are Unsupported

The RDEIR states that "there have been historic concerns that cumulative geothermal development in Long Valley may directly affect the subsurface hydrology associated with these springs."[72] The RDEIR acknowledges that continued geothermal fluid production may result in potentially significant impacts to the federally endangered Owns tui chub:

9-16

> the Owens tui chub and the designated critical aquatic habitat supported by these springs has the potential to be affected by changes in spring flow rate, temperature, or chemistry that could potentially result from changes to groundwater production, long-term geothermal fluid production or other factors . . . .[73]

The RDEIR then dismisses the potential for a significant impact with the following analysis:

> The proposed MP-I Replacement Project would not change the existing MP-I well field or rate of geothermal production or injection. As such there would be no change on the effects of the existing geothermal production or injection reservoirs . . . . [other than return of slightly warmer injection fluid] . . . . The return of slightly warmer injection fluid would diminish whatever adverse effect on the injection reservoir that may be occurring from the existing return of slightly cooler injection fluid . . . . Based on this assessment there would be no potential for significant adverse impacts on the Owens tui chub critical habitat as a result of the proposed Project.[74]

[72] RDEIR, p. 4-70.
[73] RDEIR, p. 4-71.
[74] *Ibid.*

9-16 Cont. The County's conclusions are invalid because they are unsupported. First, the RDEIR lacks baseline data on the Owens tui chub, therefore, it is impossible to determine the significance of the Project's impact on the Owens tui chub. Second, as detailed in these comments, the aging MP-I facility has been operating at half capacity.[75] Thus, even if the ***maximum potential*** production and injection rates will not change as a result of the Project, the Project will increase power production above current conditions. The County is required to identify the magnitude of the incremental increase and determine whether the increase would result in a significant impact on the Owen tui chub and its critical habitat in a revised DEIR.

B. The RDEIR Fails to Identify and Address the Project's Potentially Significant Impact on Vegetation Depletion

9-17 An EIR must identify and focus on the possible significant environmental impacts of a proposed project.[76] In 2006, the USGS began collecting data on tree kills.[77] As explained by biologist Scott Cashen, there is little doubt that tree kills are linked to geothermal power production activities and this effect is documented at the Casa Diablo geothermal complex.[78] In response to Mr. Cashen's comments, the RDEIR states:

> [T]here has been ***speculation*** that use of geothermal resource in the Casa Diablo area may affect vegetation. A cause and effect relationship has not been established, but the issue should be studied with respect to future projects that would increase utilization of the resource or expand wellfield development.[79]

The above response is misleading because it mischaracterizes scientific evidence showing that geothermal power production has an adverse affect on vegetation by causing increased emissions of carbon dioxide. Substantial evidence in the record shows that geothermal power production at Casa Diablo adversely affects vegetation.[80] Moreover, the RDEIR employs an incorrect legal standard to determine that no further study is necessary. Contrary to the County, CEQA does not require the County, or the public, to demonstrate a cause and effect relationship to conclude that an impact exists. CEQA requires analysis and mitigation if

[75] Marcus Comments, attached as **Exhibit B**.
[76] Pub. Resources Code, § 21100 subd. (b)(1); CEQA Guidelines, § 15126, subd. (a).
[77] CURE DEIR Comments, August 26, 2011, Exhibit B, p. 6.
[78] *Ibid*.
[79] RDEIR, p. 5-11 (emphasis).
[80] *See*, *generally*, **Exhibit A** (Cashen Comments).

substantial evidence shows that the Project's impacts are potentially significant. CEQA's evidentiary standard is met and exceeded in this case.

9-17 Cont.

As described by Scott Cashen, the U.S. Geological Survey ("USGS") has been collecting data at tree-kill areas near Casa Diablo since 2006.[81] The data reveal the tree-kill areas have elevated carbon dioxide and soil temperature levels, both of which can directly or indirectly (i.e., through stress) kill trees.[82] As detailed by Cashen, the USGS confirmed that "the high concentration of thermal and diffuse carbon dioxide degassing areas around the power plant leaves little doubt that some areas owe their existence to the geothermal operations."[83] The USGS also confirmed that the continued expansion of the tree-kill areas has been highly correlated with geothermal operations.[84]

There is ample scientific evidence that the Project would contribute to additional tree kills over the course of its 30-year operational life.[85] As further explained by Cashen, tree kills have broad implications on sensitive resources and the ecology of the Project region. In addition to modifying habitat, elevated carbon dioxide levels at the tree-kill sites pose a hazard to wildlife, particularly species that occur at or below ground level.[86] The County is required to analyze the Project's potentially significant impacts on vegetation and wildlife in a revised EIR.

C. The RDEIR Fails to Identify Potentially Significant Impacts on Mule Deer

9-18

The Project would result in the partial closure of a migration route used by deer. The RDEIR states: "[t]he biological survey assessment of deer movement through the existing MP-I project area concludes that partial closure of the movement corridors located between the existing MP-I and MP-II/PLES-I plant sites for the proposed M-1 plant site would not substantially change the use of the movement corridor by resident deer."[87] This conclusion is invalid because it is unsupported. As described in these comments, the County lacks adequate baseline data to determine the significance of the Project's impacts on mule deer.

---

[81] **Exhibit A** (Cashen Comments), p. 7.
[82] *Ibid.*
[83] *Id.* at pp. 7-9.
[84] *See id.*
[85] *See ibid.*
[86] *Ibid.*
[87] RDEIR, p. 4-66.

9-18 Cont.

The record overwhelmingly supports the conclusion that the Project's impacts on mule deer will be significant. First, the Project may cause deer to be redirected onto U.S. Highway 395. This impact is significant.[88] Second, the Project would significantly impact deer by causing deer distribution to shift to less suitable habitat.[89] Third, substantial evidence shows that deer migration routes can be significantly affected by small amounts of development.[90] Finally, the Applicant's own data supports the finding that the Project will significantly impact mule deer fitness and survival rates due to removal of forage, restriction of movement corridors and obstruction of access to water.[91] The County is required to prepare a revised DEIR which discloses these impacts, analyzes their significance, and proposes mitigation that can reduce these impacts to a less than significant level.

9-19

VII. THE RDEIR'S CONCLUSIONS REGARDING THE PROJECT'S IMPACTS ON GEOTHERMAL FLUID ARE UNSUPPORTED

The RDEIR states:

> Because the new M-1 plant would also consist of a closed loop geothermal system, the cold geothermal fluid would be returned to the geothermal reservoir via the geothermal injection wells ***essentially replacing the produced hot geothermal fluid*** circulated through the binary power plant facilities (see Figure 4). ***No net impact would occur to the geothermal reservoir or cold groundwater levels or supplies***.[92]

This conclusion is invalid because it is unsupported. The RDEIR states that geothermal production will actually increase as a result of the Project because the M-1 facility is capable of processing more geothermal fluid than the existing MP-I facility.[93] The RDEIR also states that production capacity of the existing MP-I facility has been "severely restricted," and that the shortfall in production at MP-I cannot be made up by increasing production at the PLES-I and MP-II facilities.[94] Indeed, as detailed in these comments, MP-I has been producing energy at half

[88] *See* **Exhibit A** (Cashen Comments), p. 5.
[89] *Id.*
[90] *Id.* at pp. 5-6.
[91] *See id.* at p. 6.
[92] RDEIR, p. 4-131 (emphasis added).
[93] RDEIR, p. 4-131.
[94] *Ibid.* ("The Power Purchase Agreements between MPLP and SCE are unique to each of the three plants; a decline in power generated at one plant cannot be made up at another.")

9-19 Cont.

capacity in the last several years of its operation. As such, the RDEIR supports the conclusion that the Project will increase geothermal power production as compared to current conditions.

The RDEIR's conclusion that "since 1990, when MP-II and PLES-I went into commercial operation, there have been no significant impacts to hydrological receptors" is unsupported.[95] Substantial evidence shows that less than 10% of the fluid injected at Casa Diablo moves into the production zone and that most flows away from the well field within the injection reservoir.[96] Additionally, the fact that in 2005 the Applicant had to expand the geothermal well field in order to maintain energy production levels casts significant doubt on the conclusion in the RDEIR that thermal resource extraction activities at the Casa Diablo geothermal complex are benign.[97] The Project would further exacerbate the current rate of depletion of thermal resources. The County must prepare a revised DEIR which considers the Project's potentially significant impacts on the geothermal resources and the Casa Diablo hydrologic system.

9-20

VIII. THE RDEIR FAILS TO IDENTIFY THE PROJECT'S POTENTIALLY SIGNIFICANT LAND USE IMPACTS

In the RDEIR, the County concluded that the Project's impacts to land use are insignificant and require no further analysis. This determination is incorrect. The Project conflicts with the Land Use and Conservation/Open Space Elements of the Mono County General Plan, which prohibits geothermal development within 500 feet of a surface watercourse within the Hot Creek Buffer Zone.[98] The proposed M-1 replacement plant would be located in an area designated "Resource Extraction" under the Mono County General Plan.[99] Pursuant to the Mono County General Plan, all projects in the Resource Extraction Designation must comply with the 500 foot setback requirement, unless the Plan is amended through the "Specific Plan" process.[100]

---

[95] RDEIR, p. 4-132.
[96] CURE DEIR Comments, August 26, 2011, Exhibit C, p. 4.
[97] *See* CURE DEIR Comments, August 26, 2011, Section X.
[98] County of Mono Community Development Department (2010) Mono County General Plan, Land Use Element, Chapter 15, section 15.070(B)(1); *id.* at Conservation/Open Space Element, Objective D, Action 1.13, p. V-43.
[99] RDEIR, p. 1-5 and p. 1-6, Fig. 3.
[100] *Id.*, Chapter 15, section 15.070 A.

CEQA requires an assessment of any inconsistencies between the Project and applicable general plans and regional plans.[101] A significant impact on land use and planning would occur if the Project would "[c]onflict with any applicable land use plan, policy, or regulation of any agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect."[102] The RDEIR appears to acknowledge that the Project conflicts with applicable setback requirements, but fails to further consider this significant impact.[103] This deficiency renders the RDEIR inadequate under CEQA.

9-20 Cont.

CEQA requires the County to identify and discuss the Project's conflict with the 500 foot setback requirement in the EIR. In *Endangered Habitats League, Inc. v. County of Orange*, Orange County prepared an EIR to evaluate area plans for two sites.[104] Although the EIR analyzed the project's consistency with applicable land use plans, the court invalidated the EIR because the County failed to identify and discuss the project's conflict with a General Plan.[105] Here too, the County failed to identify the Project's conflict with the Mono County General Plan.

The Project's conflict with the Mono County General Plan is a potentially significant impact which the County is required to analyze in an EIR. The CEQA Guidelines are explicit: an "EIR shall discuss any inconsistencies between the proposed project and applicable General Plans and regional plans."[106] The purpose of this requirement is to determine – in the context of a General Plan's policies, objectives and standards – whether a particular project will have a significant impact on the environment. A project's impacts are significant, for the purpose of CEQA, if they are greater than, or conflict with, those deemed acceptable in a General Plan.[107] The County must prepare a revised DEIR which evaluates the Project's conflict with the General Plan and requires the Applicant to modify the Project to conform to the General Plan.

---

[101] CEQA Guidelines § 15125, subd. (a).
[102] CEQA Guidelines Appendix G, section IX(b).
[103] *See* RDEIR, p. 3-4.
[104] *Endangered Habitats League, Inc. v. County of Orange* (2005) 131 Cal.App.4th 777, 781.
[105] *Id*. at 796.
[106] CEQA Guidelines § 15125(d). An "applicable plan" is one that has been adopted and thus legally applies to a project. (*Chaparral Greens v. City of Chula Vista* (1996) 50 Cal.4th 1134, 1145, fn 7.)
[107] *See Oro Fino Gold Mining Corp. v. County of El Dorado* (1990) 225 Cal.App.3d 872, 882.

IX. THE RDEIR FAILS TO INCLUDE AN ANALYSIS OF THE PROJECT'S WATER SUPPLY IMPACTS

9-21

The RDEIR fails to include an adequate analysis of the environmental impacts associated with supplying water to the Project. The Supreme Court set forth the principles governing water supply analysis under CEQA in *Vineyard Area Citizens for Responsible Growth v. City of Rancho Cordova ("Vineyard")*.[108] In *Vineyard*, the Court held that an EIR fails to meet CEQA's purpose and goals if it fails to address the following four issues. First, an EIR must identify a project's water supply with a sufficient degree of certainty to allow decision makers to "evaluate the pros and cons of supplying the amount of water that the project will need."[109] Second, an EIR evaluating a multi-phase or a planned land use project must assume that all phases of the project will be built, "and must analyze, to the extent reasonably possible, the impacts of providing water to the entire project."[110] Third, the water sources identified in the EIR "must bear a likelihood of actually proving available."[111] As explained by the Court:

> An EIR for a land use project must address the impacts of *likely* future water sources, and the EIR's discussion must include a reasoned analysis of the circumstances affecting the likelihood of the water's availability.[112]

Fourth, where it is "impossible to confidently determine that anticipated future water sources will be available," the EIR must discuss possible replacement sources or alternatives and "the environmental consequences of those alternatives."[113] The *Vineyard* court acknowledged that "the burden of identifying likely water sources for a project varies with the stage of project approval involved."[114] However, the Court explained that to satisfy CEQA's information goals, an EIR must "adequately address the reasonably foreseeable *impacts* of supplying water to the project," including the impacts associated with reliance on alternative sources, if the proposed water supply fails to materialize.[115]

---

[108] *Vineyard Area Citizens for Responsible Growth, Inc. v. City of Rancho Cordova* (2007) 40 Cal.4th 412.
[109] *Id*. at 430-31 citing *Santiago County Water Dist. v. County of Orange* 118 Cal.App.3d at 829.
[110] *Id*.
[111] *Id*. at 432.
[112] *Id*. at 432 (emphasis in original).
[113] *Id*.
[114] *Id*. at 434.
[115] *Id*. (emphasis in original).

The RDEIR fails to meet the *Vineyard* informational standard. The RDEIR states:

9-21 Cont.

> Civil contractors would supply construction water from the Mammoth Community Water District . . . . An estimated 20,000 gallons per day (g/d) of water would be used for dust control, 10,000 g/d for portable sanitation facilities, and 5,000 g/d for miscellaneous potable water needs.[116]

However, the RDEIR fails to address whether the Applicant's water demand will be met.[117] Under CEQA, a water source identified in the EIR "must bear a likelihood of actually proving available."[118] The County must prepare a revised DEIR which describes the likelihood that the Applicant's identified water source will be available and the impacts of delivering construction water to the Project site.[119]

X. THE CUMULATIVE IMPACTS DISCUSSION IN THE RDEIR IS INADEQUATE

9-22

CEQA requires consideration of the incremental impacts caused by a project, together with other past, present, and reasonably probable future projects, including projects outside of the lead agency's jurisdiction.[120] As the CEQA Guidelines instruct, a cumulative impact is one "which is created as a result of the combination of the project evaluated in the EIR together with other projects causing related impacts."[121] The potentially significant impacts of the proposed Project must be considered in conjunction with the impacts from these other projects.

> [T]he statutory injunction to assess "the incremental effects of an individual project ... in connection with the effects of *past projects*, the effects of other current projects, and the effects of probable future

[116] RDEIR, p. 2-13.
[117] *See* RDEIR, p. 3-7.
[118] *Vineyard* at 432.
[119] *Ibid.*
[120] CEQA Guidelines, § 15064(h)(1); *see also* 15355, subd. (b) ["The cumulative impact from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable probable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time."]; see *also Los Angeles Unified School Dist. v. City of Los Angeles* (1997) 58 Cal.App.4th 1019, 1024-1025.
[121] CEQA Guidelines, § 15130 subd. (a)(1) (emphasis added).

projects" (Pub. Resources Code, § 21083, subd. (b)(2), italics added) signifies an obligation to consider the present project in the context of a realistic historical account of relevant prior activities that have had significant environmental impacts.[122]

Thus, a legally adequate "cumulative impacts analysis" views a particular project over time and in conjunction with other related past, present, and reasonably foreseeable, probable future projects whose impacts might compound or interrelate with those of the project under review.[123] A lead agency's cumulative impact analysis is invalid under CEQA if it fails to adequately reflect the severity and significance of a project's cumulative impacts.[124]

9-22
Cont.

> The primary determination is whether it was reasonable and practical to include the projects and whether, without their inclusion, the severity and significance of the cumulative impacts were adequately reflected.[125]

"The disparity between what was considered and what was known is the basis upon which . . . [a court] will find abuse of discretion."[126]

The RDEIR fails to include an analysis of the Project's cumulative impacts on air quality and public health and biological and water resources together with the existing MP-I, MP-II, PLES-I, and Basalt Canyon Pipeline facilities, the proposed 33 MW Casa Diablo IV facility, and the proposed expansion of the Casa Diablo well field in connection with the Casa Diablo IV project.[127] The County's failure to prepare a cumulative impact analysis which considers the entire Casa Diablo geothermal complex is an abuse of discretion because the County has access to the necessary data. Air quality emissions data on the Casa Diablo geothermal complex is available from the Great Basin Unified Air Pollution Control District. The

---

[122] *Environmental Protection Information Center v. California Dept. of Forestry and Fire Protection* (2008) 44 Cal.4th 459, 524 (emphasis in original).
[123] *See* CEQA Guidelines, § 15355 subd. (b) ("Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time"); *see also Communities for a Better Environment v. Cal. Resources Agency* (2002) 103 Cal.App.4th 98, 117.
[124] See CEQA Guidelines, § 15130 subd. (b); see also *San Franciscans for Reasonable Growth v. City and County of San Francisco* (1984) 151 Cal.App.3d 61, 72-73.
[125] *Kings County Farm Bureau v. City of Hanford* (1990) 221 Cal.App.3d 692, 723.
[126] *Id.*
[127] *See* Great Basin Unified Air Pollution Control District, Notice of Preparation of an Environmental Impact Statement/Environmental Impact Report for the Casa Diablo IV Geothermal Development Project.

9-22 Cont.

County maintains and has access to hydrological and biological monitoring data for the existing facilities under the terms of the PLES-I settlement agreement and pursuant to the Mono County General Plan. Finally, the Applicant is currently preparing a joint EIR/EIS in connection with pending federal and local environmental review of the proposed Casa Diablo IV project. The County's failure to include in the RDEIR an adequate analysis of the Project's cumulative impacts on air quality, public health, biological resources and area hydrology cannot be justified.

9-23

A. The RDEIR Fails to Include an Adequate Cumulative Air Quality and Public Health Impact Analysis

To begin to determine whether the Project's impacts are cumulatively considerable, the County must add the Project's air quality impacts to those from past, present and reasonably foreseeable future projects.[128] In this case, the County was, at a minimum, required to consider the Project's air quality impacts in combination with the MP-I, MP-II, PLES-I, Casa Diablo geothermal complex production pipeline networks and geothermal and reinjection well fields, the Basalt Canyon Pipeline, the proposed Casa Diablo IV facility, and the Casa Diablo IV well field expansion project. The RDEIR fails to consider the combined air quality impacts of these existing facilities and projects. In particular, the cumulative impact analysis fails to consider ROG emissions from the MP-I facility, the Casa Diablo geothermal complex production pipeline networks and geothermal and reinjection well fields, and the Basalt Canyon Pipeline.[129] This analytical deficiency renders the analysis invalid for the purpose of CEQA. The County must prepare a revised DEIR which considers the Project's air quality impacts together with past, present, and reasonably foreseeable projects.

9-24

B. The RDEIR Fails to Identify the Project's Cumulatively Considerable ROG Emissions

The RDEIR concludes that the Project would not result in cumulatively considerable ROG emissions.[130] This conclusion is unsupported and contradicted by the information presented in the RDEIR. The RDEIR provides that the combined ROG emissions from the PLES-I and MP-II facilities total approximately 1,336

---

[128] *See Communities for a Better Environmental v. California Resources Agency* (2002) 103 Cal.App.4th 98, 117-21; *see also* CEQA Guidelines § 15130 subd. (a).
[129] *See* RDEIR, p. 5-10.
[130] RDEIR, p. 5-10.

pounds per day,[131] the estimated daily ROG emissions from the MP-I facility equal approximately 500 pounds per day,[132] the estimated daily ROG emissions from the proposed Casa Diablo IV facility equal approximately 512 pounds per day, and the estimated, uncontrolled daily ROG emissions from the Project equal approximately 205 pounds per day.[133] Dr. Clark has shown that the combined emissions from the MP-I, MP-II, PLES-I, Casa Diablo IV and the Project are significant.

9-24 cont.

As described by Dr. Clark, assuming that the MP-I and M-1 facilities will be operated at 50% capacity during the period of simultaneous operation, their combined ROG emission rate would be 350 pounds per day.[134] The cumulative emission rate during that two-year commissioning period would be approximately 1,686 pounds per day), far in excess of the 55 pounds per day significance threshold.[135] Following the decommissioning of MP-I facility, the cumulative emissions from the Casa Diablo Geothermal Complex would be more than 1,000 pounds per day, well in excess of the 55 pounds per day significance threshold.[136] The Project's contribution to emissions from the Casa Diablo IV project is cumulatively considerable, accounting for approximately 205 pounds per day. The County must prepare a revised DEIR which identifies the Project's cumulatively considerable ROG emissions and proposes mitigation to reduce this impact to a less than significant level.

C. The RDEIR Fails to Address the Project's Cumulatively Considerable Impacts on Mule Deer

9-25

Whereas the initial DEIR impermissibly deferred analysis of the Project's cumulative impacts on mule deer,[137] the RDEIR now fails entirely to address the Project's cumulative impacts on mule deer, as required by CEQA.[138] To determine whether the Project's impacts are cumulatively considerable, the County was required to consider the Project's impacts on mule deer together with those from past, present and reasonably foreseeable future projects.[139] The RDEIR fails to include the legally required analysis because the RDEIR does not evaluate the

---

[131] RDEIR, p. 5-10.
[132] RDEIR, p. 4-43.
[133] *Id.*
[134] *Ibid.*
[135] *See* **Exhibit C** (Clark Comments).
[136] *Ibid.*
[137] *See* CURE's DEIR Comments, August 26, 2011, p. 33.
[138] *See* RDEIR, pp. 5-10-5-13; *see also* **Exhibit A** (Cashen Comments), pp. 9-10.
[139] *See Communities for a Better Environmental v. California Resources Agency* (2002) 103 Cal.App.4th 98, 117-21;*see also* CEQA Guidelines § 15130 subd. (a).

combined impacts of the Project together with those of the MP-I, MP-II, PLES-I, Casa Diablo IV, Basalt Canyon Pipeline, and the remaining Casa Diablo geothermal complex facilities.

9-25 Cont.

Substantial evidence shows that the Project's impacts on mule deer may be cumulatively considerable. The Project is located within a mule deer migration zone. Geothermal brine pipelines and other Project features may obstruct deer movement within this zone.[140] The Round Valley deer herd is currently stressed and in decline. Because the Project will affect habitat used by the herd, it will exacerbate current stresses that have led to the decline.[141] As described by Cashen, nutritional limits on survival and recruitment of deer in Round Valley clearly indicate "bottom-up" limitation on deer dynamics.[142] Consequently, further restrictions on use of habitat, or additional destruction of habitat, would have an additive effect in terms of decreasing the number of deer that comprise the population.[143] The Project's cumulatively considerable impact on mule deer must be evaluated and mitigated in a revised DEIR.

D. The RDEIR Fails to Address Cumulatively Considerable Impacts on Thermal Resources

9-26

To determine whether the Project's impacts on thermal resources are cumulatively considerable, the County was required to consider the Project's impacts together with those from past, present and reasonably foreseeable future projects.[144] The RDEIR fails to comply with CEQA by failing to consider the Project's impacts together with the Casa Diablo IV, MP-II, PLES-I, Basalt Canyon Pipeline, and existing Casa Diablo facilities and well fields.[145] Substantial evidence shows that the combined impacts of these projects on thermal resources may be significant. As described by technical expert Matthew Hagemann, the proposed Casa Diablo IV project includes the drilling of up to 14 new production wells over the life of the plant.[146] The proposed expansion will almost double existing power generation activities.[147] The County must prepare a revised DEIR that includes an

---

[140] *See* CURE's DEIR Comments, August 26, 2011, Exhibit B, pp. 3-4, 7; DEIR, p. 4-58.
[141] CURE's DEIR Comments, August 26, 2011, Exhibit B, p. 9.
[142] **Exhibit A** (Cashen Comments), p. 10.
[143] *Ibid.*
[144] *See Communities for a Better Environmental v. California Resources Agency* (2002) 103 Cal.App.4th 98, 117-21; *see also* CEQA Guidelines § 15130 subd. (a).
[145] RDEIR, pp. 5-16-17.
[146] Hagemann Comments, attached as **Exhibit D**.
[147] *Ibid.*

9-26 cont.

analysis of the Project's cumulative impacts on thermal resources and proposes all mitigation necessary to reduce that impact to a less than significant level.

XI. THE RDEIR VIOLATES CEQA'S PROHIBITION ON PIECEMEALED REVIEW

CEQA mandates "that environmental considerations do not become submerged by chopping a large project into many little ones – each with a minimal potential impact on the environment – which cumulatively may have disastrous consequences."[148] CEQA prohibits such a "piecemeal" approach and requires review of a Project's impacts as a whole.[149] Accordingly, a public agency may not segment a large project into two or more smaller projects in order to mask serious environmental consequences. Here, the RDEIR fails to consider the entire Project by failing to analyze the Applicant's separately proposed Casa Diablo IV unit together with this Project in one DEIR. This approach violates CEQA.

9-27

The *Arviv Enterprises v. South Valley Area Planning Commission* ("*Arviv*") case is directly on point here.[150] In *Arviv*, the Court found that a housing developer's plan to divide a 21-home development into several smaller pieces – first 5 homes, then 2 homes, then 14 homes, each with successive mitigated negative declarations – violated CEQA. Concluding that the applicant had improperly described the project, the Court held that a single EIR was required to analyze and mitigate the effects of the entire 21-home development. The court explained that:

> the significance of an accurate project description is manifest, where, as here, cumulative environmental impacts may be disguised or minimized by filing numerous, serial applications.[151]

Similarly here, the County's environmental document fails to consider the Applicant's entire plan of development and expansion for the Casa Diablo geothermal complex.

The instant Project and the concurrently proposed, but separately evaluated, Casa Diablo IV project are just another component of the ongoing, iterative

---

[148] *Bozung v. Local Agency Formation Commission* (1975) 13 Cal.3d 263, 283-84; *City of Santee v. County of San Diego* (1989) 214 Cal.App.3d 1438, 1452.
[149] CEQA Guidelines, § 15378, subd. (a); *Burbank-Glendale-Pasadena Airport Authority v. Hensler* (1991) 233 Cal.App.3d 577, 592.
[150] *Arviv Enterprises v. South Valley Area Planning Commission* (2002) 101 Cal.App.4th 1333, 1346.
[151] *Id.*

expansion of the Casa Diablo geothermal complex. In 1986, just one year after the MP-I facility commenced operation, Mammoth Pacific L.P. ("MPLP") sought to develop three additional generating facilities – the 15 MW MP-II unit, the 15 MW MP-III unit, and the 15 MW PLES-I unit – totaling 45 MW in gross generating capacity adjacent to the MP-I unit. MPLP sought County authorization to develop the MP-II and MP-III units, and separately filed an application to develop the PLES-I project with the U.S. Bureau of Land Management ("BLM"). The MP-III facility was not developed as initially proposed; however, the MP-II and PLES-I
9-27 Cont. facilities both commenced operation in 1990. Notably, the PLES-I unit was approved in the midst of significant controversy regarding the unit's potential impacts to surface hydrothermal features in the Casa Diablo area and its vicinity and the unit's potential impacts to the Hot Creek Hatchery and the Hot Creek Gorge.[152]

In 2005, MPLP sought and received local and federal approval to construct the 3-mile Basalt Canyon Pipeline to carry hot geothermal fluid from a new geothermal field in the Inyo National Forest to the MP-I and MP-II units. The Basalt Canyon Pipeline Project was undertaken by MPLP because the temperature of the geothermal resource at the MP-I and MP-II well field dropped so significantly that the well field could not sustain power generation needs.[153] The Applicant and current owner of MPLP, Ormat Nevada Inc., presently holds authorizations for additional exploratory drilling activities in the vicinity of the Casa Diablo geothermal complex.[154]

Continuing with this trend of creeping development, the Applicant now seeks to double the generating capacity of the existing complex through the instant approval and the separate federal approval of the proposed 33 MW Casa Diablo IV

---

[152] The Sierra Club and the California Department of Fish and Game appealed BLM's decision to conduct limited environmental review of the project, causing BLM to prepare an Environmental Impact Statement pursuant to NEPA and to establish a detailed monitoring system to limit and avoid impacts to geothermal resources and related impacts to critical habitat for the federally-endangered Owens tui chub. PLES-I EIS/SEIR, pp. 1-2-1-3; *see also* Resolution 86-16, A Resolution of the Planning Commission of the County of Mono Urging the Bureau of Land Management to Prepare an Environmental Impact Statement for the Proposed Geothermal Expansion at Casa Diablo.
[153] Basalt Canyon Pipeline Project DEIR, p. 1-2 ("Pipeline DEIR").
[154] In 2002 and 2005, the Applicant received approvals for additional geothermal exploration projects in the vicinity of the Casa Diablo geothermal complex. Pipeline DEIR, p. 1-5.

facility.[155] The Project and the Casa Diablo IV project are clearly related to each other and, therefore, should have been analyzed as one project in a single EIR.[156] As acknowledged in the RDEIR, the Project and the Casa Diablo IV project are owned and will be operated by the same entity, share a common geothermal well field and will be operated out of a common control room located on the existing MP-I project.[157] The County's failure to analyze the Casa Diablo IV project together with the Project violates CEQA's prohibition on piecemealed review. The contention in the RDEIR that the Project and the Casa Diablo IV are separate projects because the Applicant intends to enter into separate power purchase agreements (with the same purchaser, Southern California Edison) for the capacity generated by these facilities is simply not credible. The Applicant's plans for selling the capacity have no bearing on the County's requirement to analyze the whole of the project under CEQA. The County must prepare a revised EIR that evaluates the Project's impacts together with those of the Casa Diablo IV project.

9-27 Cont.

XII. THE COUNTY MAY NOT APPROVE THE PROJECT UNTIL THE APPLICANT DEMONSTRATES COMPLIANCE WITH THE MONO COUNTY GENERAL PLAN

9-28

Under California law, a general plan serves as a "charter for future development"[158] and embodies "fundamental land use decisions that guide the future growth and development of cities and counties."[159] The general plan has been aptly described as "the constitution for all future developments" within a city or county.[160] The "propriety of virtually any local decision affecting land use and development depends upon consistency with the applicable general plan and its elements."[161, 162] The consistency doctrine has been described as the "linchpin of California's land use and development laws; it is the principle which infuses the

[155] *See* Ormat Technologies, Inc., Form 10-k, December 31, 2011, item 1 Business, *available at* http://www.sec.gov/Archives/edgar/data/1296445/000119312512089532/d261816d10k.htm#tx261816_1. The referenced section is attached as **Exhibit E**.
[156] *Plan for Arcadia v. City Council of Arcadia* (1974) 42 Cal.App.3d 712, 723, 726.
[157] RDEIR, p. 5-7.
[158] *Lesher Communications, Inc. v. City of Walnut Creek* (1990) 52 Cal.3d 531, 54.
[159] *City of Santa Ana v. City of Garden Grove* (1979) 100 Cal.App.3d 521, 532.
[160] *Families Unafraid to Uphold Rural El Dorado County v. Board of Supervisors of El Dorado County* (1998) 62 Cal.App.4th 1334, 1335.
[161] The elements that must be included in every general plan include land use, circulation, housing, conservation, open-space, noise and safety. (Gov. Code § 65302.)
[162] *Citizens of Goleta Valley v. Board of Supervisors of County of Santa Barbara* (1990) 52 Cal.3d 553, 570.

concept of planned growth with the force of law."[163] Thus, land use decisions must be consistent with a city's general plan.[164]

A project is inconsistent, and may not be approved, "if it conflicts with a general plan policy that is fundamental, mandatory, and clear."[165] In, *Endangered Habitats League, Inc. v. County of Orange*, the court determine that a general plan policy establishing concrete levels of service for particular intersections was "fundamental, mandatory, and clear."[166] In that case, the relevant policy provided as follows:

9-28 Cont.

> LOS C shall . . . be maintained on Santiago Canyon Road links until such time as uninterrupted segments of roadways (i.e. no major intersections) are reduced to less than three miles.[167]

The policy further required compliance to be evaluated according to the county's traffic manual.[168] Similarly, here, the Project conflicts with "fundamental, mandatory and clear" criteria set forth in the Mono County General Plan, as follows:

1. The Mono County General Plan requires the County to deny a permit if the Applicant has not "demonstrated the availability or entitlement to a supply of water adequate to meet the needs of the proposed project."[169]

   The RDEIR and the County's Project file do not include a will serve letter, or any other documentation, showing the availability or entitlement to the supply of water necessary to meet the Applicant's construction water demand.

2. The Mono County General Plan requires that "prior to the issuance of any permit for either geothermal exploration or development within the Hot Creek Buffer Zone, the MCEDD [Mono County Economic Development Department] shall prepare a written analysis of the

---

[163] *Corona-Norco Unified School District v. City of Corona* (1993) 17 Cal.App.4th 985, 994.
[164] *Id.*; Gov. Code § 65860(a).
[165] *See Endangered Habitats League, Inc. v. County of Orange* (2005) 131 Cal.App.4th 777, 782-83.
[166] 131 Cal.App.4th 777, 782-83.
[167] *Id*. at 783.
[168] *Ibid.*
[169] Mono County General Plan, Conservation Open Space Element, Water Resources and Water Quality, Objective B, Policy 6, Action 6.3, p. V-21.

cumulative hydrologic and biologic impacts of the proposed project and other development projects of any kind or nature that may individually or cumulatively affect springs, streams, fumaroles, or significant biologic resources within the zone. The analysis shall be a part of the record."[170]

As detailed in these comments, the record does not contain a written analysis of the cumulative hydrologic and biologic impacts of the Project together with other facilities and projects in the Casa Diablo geothermal complex.

9-28 Cont.

3. The Mono County General Plan requires the Applicant to submit draft hydrologic and biologic monitoring plans to the MCEDD "[**d**]**uring the permit processing period**."[171]

A review of the County's Project file reflects that the Applicant has not submitted biologic and hydrologic monitoring plans to the County.

4. The Mono County General Plan requires the Applicant to "prepare a baseline data report to be included as part of the hydrologic and biologic resource monitoring plans that identifies all significant hydrologic and biologic baseline information available for the project area."[172]

As detailed in these comments, the record does not contain baseline data for biologic and hydrologic resources, including the current intensity of power production activities, baseline data for the Owens tui chub, or data regarding the temperature and flows of surface waters and thermal resources.

5. The Mono County General Plan prohibits geothermal development within 500 feet of a surface watercourse within the Hot Creek Buffer Zone.[173]

---

[170] *Id*. at Conservation Open Space Element, Energy Resources, p. V-40, Objective C, Policy 1, Action 1.3, p. V-40.
[171] *Id*. at Objective D, Policy 1, Action 1.1, p. V-41 (emphasis added).
[172] *Id*. at Objective D, Policy 1, Action 1.5, p. V-41 (emphasis added).
[173] *Id*. at Objective D, Policy 1, Action 1.13 p. V-43 (emphasis added); *see also* Land Use Element, Development Standard 15.070 (B)(d).

9-28 Cont.

> As described in these comments, the Project conflicts with the above prohibition. Also, the RDEIR fails to identify, analyze, or propose mitigation to eliminate the Project's conflict with the General Plan.

The Project may not be approved until the Applicant demonstrates compliance with the above requirements. As proposed, the Project violates State law.

XIII. THE PROJECT REQUIRES A GENERAL PLAN AMENDMENT

9-29

The RDEIR states that the Applicant may obtain a variance for "setback reductions from property line(s), and setback reductions from streams designated by a blue line on USGS topographic maps."[174] The RDEIR appears to refer to the Project's conflict with the setback requirement established by the Mono County General Plan Land Use Development Standards and Conservation and Open Space Element, which prohibit development within 500 feet on either side of a surface watercourse within the Hot Creek Buffer Zone.[175] Contrary to the RDEIR, a general plan cannot be amended by a variance. Nor can consistency with this general plan prohibition be achieved through a variance under the County Code.

Since the General Plan is the "constitution for all future developments," an inconsistent resolution, ordinance or other action is "invalid at the time it is passed."[176] A General Plan modification requires a lengthy public process including public hearings, environmental review and public deliberation. Allowing piecemeal amendment of the General Plan through a variance under the County Code is nonsensical and would render the General Plan meaningless. This situation is similar to that in *Endangered Habitats League, Inc. v. County of Orange*, where the lead agency adopted a methodology to analyze traffic impacts that was different than the one set forth in the General Plan.[177] The court held that the County was required to apply the methodology set forth in the General Plan.[178] Similarly here, the County is required to act in accordance with the Mono County General Plan. If the Applicant is unwilling to modify the Project, the County may not approve the Project absent an amendment to the Mono County General Plan.

---

174 RDEIR, p.3-4.
175 *See* Mono County General Plan, Conservation Open Space Element, Energy Resources , Objective D, Policy 1, Action 1.13 p. V-43 (emphasis added); *see also* Land Use Element, Development Standard 15.070 (B)(d).
176 *Lesher Communications v. City of Walnut Creek* (1990) 52 Cal.3d 531, 544.
177 131 Cal.App.4th 777, 782-83.
178 *Ibid.*

9-30

XIV. CONCLUSION

The RDEIR fails as an informational document because it does not adequately describe the Project or disclose baseline data regarding biological resources, hydrology and the existing degradation of surface and thermal flows as a result of power production activities, or identify the Project's conflict with the Mono County General Plan. The RDEIR also fails to analyze the impacts of delivering water to the Project and to identify and evaluate the Project's potentially significant and cumulatively considerable impacts on air quality, wildlife resources, and area hydrology. As a result, the County cannot conclude that the Project's impacts have been mitigated to a less than significant level. The RDEIR also violates CEQA's prohibition on piecemealed review by failing to consider the Project together with the Casa Diablo IV project. For these reasons, the RDEIR must be withdrawn and a revised DEIR prepared that adequately analyzes and mitigates the Project's potentially significant environmental impacts. Finally, the County may not approve the Project until the Applicant modifies the Project to comply with the Mono County General Plan.

Sincerely,

Elizabeth Klebaner

EK:vs
Attachments:
Exhibit A – Comments of Scott Cashen, attaching Attachments A-G; Curriculum Vitae of Scott Cashen; and Curriculum Vitae of Vernon Bleich
Exhibit B – Letter from David Marcus to Elizabeth Klebaner; Curriculum Vitae of David Marcus
Exhibit C – Comments of James Clark; Curriculum Vitae of James Clark
Exhibit D – Comments of Matthew Hagemann; Curriculum Vitae of Matthew Hagemann
Exhibit E – Excerpt from Ormat Technologies, Inc., Form 10-k, December 31, 2011

Scott Cashen, M.S.—Independent Biological Resources and Forestry Consultant

March 23, 2012

Ms. Elizabeth Klebaner
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080

Subject: Comments on the Revised Draft Environmental Impact Report for the Mammoth Pacific I Replacement Project

Dear Ms. Klebaner:

This letter contains my comments on the Revised Draft Environmental Impact Report ("RDEIR") prepared for Mammoth Pacific Limited Partnership's ("Applicant") proposed Mammoth Pacific I Replacement Project. The project involves replacing the aging Mammoth Pacific Unit I (MP–I) power plant with a new, more modern and efficient binary power plant (M–1), while maintaining the existing geothermal wellfield, pipeline system and ancillary facilities. The RDEIR analyzes two potential locations for the M-1 power plant. The "proposed" location is on private land approximately 500 feet northeast of the existing MP-I facility, whereas the "alternative" location is on public land approximately one-quarter mile north of MP-I. Based on the information provided in the RDEIR, I assume the project would be constructed at the "proposed" location. Hereafter, I refer to the project at the proposed location as the "Project." However, many of the issues discussed herein would also apply to a project at the alternative location.

I am an environmental biologist with 20 years of professional experience in wildlife ecology, forestry, and natural resource management. To date, I have served as a biological resources expert for over 35 projects, the majority of which have been renewable energy facilities. My experience in this regard includes testifying before the California Energy Commission and assisting various clients with evaluations of biological resource issues. My educational background includes a B.S. in Resource Management from the University of California at Berkeley, and a M.S. in Wildlife and Fisheries Science from Pennsylvania State University.

I have gained particular knowledge of the biological resource issues associated with the Project through my work on other projects in the Sierra Nevada. The comments contained herein are based on this knowledge, as well as my review of the environmental documents prepared for the Projects, a review of scientific literature pertaining to biological resources known to occur in Mono County, consultations with numerous biological resource experts, and the knowledge and experience I have acquired during more than 20 years of working in the field of natural resources management. In addition, the comments pertaining to mule deer were prepared after several consultations with Dr. Vernon Bleich, a recognized expert on mule deer, and a former senior environmental scientist with the California Department of Fish and Game.

The RDEIR Relies on Inadequate Baseline Data on Deer Use of the Project Region

9A-01 The RDEIR relies on two deer studies that were conducted in the Project area: (1) Paulus's *Fall 2011 Resident Deer Survey for the Casa Diablo, Basalt Canyon, and Upper Basalt Geothermal Areas*; and (2) Paulus's *Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area.*[1] I have the following comments pertaining to these two studies:

9A-02

1. Migration, particularly that which occurs over long distances, is one of the most threatened biological phenomena. Research has demonstrated a marked decrease in the proportion of deer migrating from Round Valley to the west side of the Sierra Crest.[2] Clearly, there are two cohorts of migrants: those that move west of the crest, and those that remain on the east side. The cause of the shift in the proportion of animals that moved to the west side in 1985 (84%) versus the current proportion that moves to the west side (~55%) has not been adequately investigated. However, the shift demonstrates that there are ongoing (likely anthropogenic) impacts to deer that use the Project area. The deer studies (and RDEIR) prepared for the Project fail to: (a) disclose the aforementioned information; or (b) discuss the importance of the Project site in maintaining migratory processes exhibited by the Round Valley deer herd.

9A-03

2. Neither study examined deer use of the project areas during the spring. It is possible that springtime conditions would dictate different movement corridors, or strategies for deer, compared to those in the fall. As a result, the analyses presented in the RDEIR are based on incomplete information and Project impacts to deer during spring cannot be assessed (including the estimated number of deer and migratory corridors that would be impacted).

9A-04

3. The biologist surveyed deer tracks along several transects. The way "transects" were selected, and their alignments (i.e., along roads) has a potentially confounding effect on the results, rendering them unreliable. For example, "Transect GG" was established parallel to the anticipated deer movement pattern, whereas "Transect AA" was established perpendicular to the anticipated movement pattern.[3] This inconsistency skews the results of the surveys considerably because a transect perpendicular to a linear movement corridor is more apt to show evidence of use than one running parallel to such a corridor.

9A-05

4. Statistical comparisons between transects, across time, or the interaction thereof, cannot be made with the data that are presented in the reports. For example, the transects varied in length. Because data obtained from the transects were not standardized (e.g., number of tracks per mile of transect), the calculations, and much of the analyses presented in the report, are impossible to interpret. Moreover, the sampling effort was inconsistent. For example, transects were surveyed twice per week during part of the study period, but only

---

[1] Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area. *See also* Paulus J. 2011 Oct 30. Fall 2011 Resident Deer Survey for the Casa Diablo, Basalt Canyon, and Upper Basalt Geothermal Areas.

[2] Monteith KM, VC Bleich, TR. Stephenson, BM Pierce, MM Conner, RW Klaver, RT Bowyer. 2011 Timing of seasonal migration in mule deer: effects of climate, plant phenology, and life-history characteristics. Ecosphere 2(4):art47. doi:10.1890/ES10-00096.1 (Attachment A)

[3] Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area, Figure 1.

9A-05 Cont.

once per week during the other part of the study period. To help rectify these issues, to enable meaningful interpretation of the results, and to provide the opportunity to detect changes in the index of deer use between seasons and among transects (and across years, as specified in the general plan), data from the studies need to be expressed in a manner that allows such comparisons. Thus, the investigator should consider expressing data in the context of tracks encountered/transect unit/survey day, or in some other manner that will facilitate the aforementioned comparisons; the assistance of an applied statistician would prove helpful in resolving this issue.

9A-06

5. The author described the location of "Transect GG" as "a reliable location for monitoring crossing frequency and timing."[4] This conclusion appears to be arbitrary, because it does not appear that any evaluation, other than a subjective one, was completed before deriving the conclusion. Moreover, transects were not established randomly, but were tied to existing roads. Thus, the data provide a track-count index specific to each of the roads (transects), rather than a track-count index that reflects the abundance of deer in the study area. Consequently, the author's inferences can be applied to the roads only, rather than to the entire study area.

9A-07

6. Although the number of deer tracks detected in the study area is an index of deer use, the number of tracks may not accurately reflect the number of deer using the study area. Although the author acknowledges this limitation, he subsequently applies the data beyond their capability. For example, the author concluded that the main use of the Project area by deer is as a movement corridor.[5] The data obtained in the studies cannot be used to derive this conclusion for several reasons. First, the author had no way of knowing whether tracks were deposited by migrating deer or resident deer. At best, the author would have been forced to make assumptions on the class of deer that deposited the tracks based on the time of year, and perhaps the direction of the tracks. Such assumptions would be extremely tenuous due to the overlap in the categories of deer present during the sampling period (i.e., migrating and resident deer were both present). Second, even if one assumes tracks can be linked to a specific category of deer (i.e., migratory or resident), any comparisons must necessarily rely on the assumption that bias is constant. It is unlikely that this assumption was met due to differences in behavior between migratory and resident categories of deer. For example, migratory deer are likely to exhibit directional movement, whereas resident deer are more likely to exhibit random movement. If this occurred in the study area, one can assume most migrating deer crossed a transect once, whereas there is a much greater probability that most resident deer crossed multiple times. Because this difference was not (nor could it have been given the resources available to the investigator) quantified (or approximated), the data cannot be used to support the conclusion that deer use the Project area primarily as a movement corridor.

[4] Id, Figure 2.

[5] [BRA] Paulus J. 2011 Dec 20. Assessment of Biological Resources M-1 Replacement Power Plant at Casa Diablo Mono County, California. RDEIR, Appendix D, p. 24.

9A-08

7. The author alludes to the movement by deer to water, but such movements should not be the only ones of concern.[6] Moreover, it is unclear how he concluded that movement to water was the primary reason deer were using the study area.

9A-09

8. My ability to interpret the results of the studies is inhibited by:
   a. the author's inconsistent use of the terms resident, migratory, and "residency;"[7]
   b. omission of the statistical methods that were used to answer the objectives of the studies; and
   c. the lack of an adequate description of the study methodology such that the results could be interpreted in a meaningful manner.

9A-10

9. The study methods are so poorly stated that anyone attempting to replicate the study would not be able to do so. This is problematic given the requirement in the RDEIR for additional deer monitoring studies that can be used to evaluate deer use of the Project area in relation to the baseline.

The Project Will Result in Potentially Significant Impacts to Mule Deer

The Project site is used by mule deer during the spring and fall when deer are transitioning between their winter and summer ranges.[8] Mule deer also occupy the Project area during summer or winter, or as year-round residents.[9] The mule deer is an important game species, and the impacts of geothermal development on the Round Valley and Casa Diablo deer herds have been a longstanding management concern of both the California Department of Fish and Game ("CDFG") and Mono County.

9A-11

The Mono County General Plan states: "[d]evelopment may be prevented in any part of a deer migration zone upon a finding that it will interfere with adopted regulations of the California Department of Fish and Game and the goals of the CDFG deer herd management plans."[10] The RDEIR does not provide a discussion of the compatibility between the Project and CDFG's deer herd management plans. Similarly, because the RDEIR does not make reference to or describe the goals of the deer management plans, I cannot independently assess the Project's compliance with the Mono County General Plan.

9A-12

The Project would result in the partial closure of a migration route used by deer.[11] The RDEIR states: "[t]he biological survey assessment of deer movement through the existing MP-I project

---

[6] Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area, p. 8.

[7] For example, *See* Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area, p. 8. In this case the term "residency" applies to deer that were *present* in the Project area in December, but not necessarily "resident" deer according to the operational definition.

[8] County of Mono Community Development Department. 2010. Mono County General Plan. Bridgeport, CA. (Drafted July 1997 and Revised 2010). Conservation /Open Space Element-2010, Figure 1.

[9] Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area, p. 8. *See also* Ferranto SP. 2006. Conservation of mule deer in the eastern Sierra Nevada. M.S. Thesis, University of Nevada, Reno. 129 pp.

[10] RDEIR, p. 4-53.

[11] BRA, p. 25.

9A-12 Cont.

area concludes that partial closure of the movement corridors located between the existing MP-I and MP-II/PLES-I plant sites for the proposed M-1 plant site would not substantially change the use of the movement corridor by resident deer."[12] The RDEIR lacks the basis for this conclusion. As the RDEIR subsequently acknowledges, "[t]here are not sufficient data to speculate how migrating deer would respond to the proposed change from partial blockage by a pipeline rack to partial blockage by a power plant."[13]

9A-13

The RDEIR ultimately concludes the Project would not have a significant impact on mule deer or mule deer movement through the Casa Diablo area.[14] This conclusion is not supported by information provided in the RDEIR and in other sources.

First, the RDEIR indicates "[i]f movement patterns of either resident or migratory deer are thwarted by the increase in noise, lighting and traffic at this corridor, the animals could be redirected to the west of MP-I fencing and possibly onto U.S. Highway 395 with increased frequency."[15] In this regard, the Town of Mammoth Lakes concluded "indirect impacts including an increased incidence of deer kills on U.S. Highway 395, would in the cumulative context of other regional developments, be *significant and unavoidable*."[16]

9A-14

Second, researchers examining habitat selection of mule deer before and during development of a natural gas field observed shifts in the distribution of deer toward less-preferred and presumably less-suitable habitats as development progressed.[17] The researchers concluded (a) the avoidance of, or lower use of, areas near development creates indirect losses of habitat that are substantially larger in size than the direct losses; (b) that these habitat losses have the potential to reduce carrying capacity and result in population-level effects (i.e., survival or reproduction); and (c) deer did not acclimate or habituate to well pads.[18] The results of the aforementioned study indicate the Project could indirectly impact habitat use by deer, and that this impact would be potentially significant. The deer survey report that was prepared for the Project provides additional evidence that the Project could cause the deer to shift to less-preferred habitat. The report states: "it will not be tenable to assume these animals can simply move to a nearby similarly scrub-covered or forested area. Habitat that loses nightly accessibility to Mammoth Creek and Murphy Gulch, or is too far from these resources, would be very different from the habitat now being used."[19] Although the RDEIR discusses the indirect impacts that could occur to deer movement corridors, it does not analyze the consequences of deer being displaced to potentially less-suitable habitats as a result of the Project.

9A-15

Third, Polfus (2011) concluded that any increase in development has the potential to

[12] RDEIR, p. 4-66.
[13] Id.
[14] Id, p. 4-67.
[15] Id.
[16] Town of Mammoth Lakes. 2007 May. Final Environmental Impact Report: Town of Mammoth Lakes 2005 General Plan Update, p. 5-10.
[17] Sawyer H, RM Nielson, F Lindzey, LL McDonald. 2006. Winter Habitat Selection of Mule Deer Before and During Development of a Natural Gas Field. Journal of Wildlife Management 70(2):396-403. (Attachment B)
[18] Id.
[19] Paulus J. 2011 Oct 30. Fall 2011 Resident Deer Survey for the Casa Diablo, Basalt Canyon, and Upper Basalt Geothermal Areas, p. 11.

9A-15 Cont.

significantly affect mule deer migrations, and that migration corridors can be negatively impacted by even small amounts of development.[20] These conclusions were based on a comprehensive review of scientific literature.

9A-16

Finally, the conclusions in the RDEIR contradict, and are unsupported by, the conclusions made by the Applicant's deer expert. The Applicant's expert concluded the following:

1. The removal of forage, or the restriction of movement corridors (especially to water), could reduce the fitness of deer and affect survivorship.[21]
2. "[t]he likelihood that these [aforementioned adverse] effects will occur *is plausible*."[22]
3. "[a]dditional human activity and operational lighting and noise associated with power plant operation, power plant decommissioning, and storage yard activities could potentially discourage resident deer use of the corridor between MP-I and MP-II/PLES-I for nightly movement to water."[23]
4. "[d]eer attempting to overwinter would be sensitive to any project elements that would function as barriers to night movement between forest (forage and cover) resources and heated refuge areas that are of course very limited in extent."[24]
5. "[m]igratory deer that presumably are less adapted to local developments may be thwarted in their movement along traditional paths that pass through the existing corridor between MP-I and MP-II/PLES-I."[25]
6. "[t]he new noise and activity at the M-1 power plant could potentially reduce [deer] usage of the SCE easement that it abuts."[26]

The aforementioned issues provide considerable evidence that the Project will cause potentially significant impacts on mule deer. Moreover, those impacts could be different between "resident" animals (defined here as those that include the project area within their home ranges on a year-round basis) and migratory individuals (defined here as those that occupy the project site on a seasonal, or transitory basis).

[20] Polfus JL. 2011. Literature review and synthesis on the effects of residential development on ungulate winter range in the Rocky Mountain West. Report prepared for Montana Fish, Wildlife and Parks. Helena, MT. Available at: fwp.mt.gov/fwpDoc.html?id=51645, p. 47. (Attachment C).
[21] Id.
[22] Id.
[23] Paulus J. 2011 Dec 29. Fall 2011 Migratory Deer Survey for the M-1 Project Site at the Casa Diablo Geothermal Area, p. 8.
[24] Id, p. 9.
[25] Id.
[26] Id.

The Project Will Result in Potentially Significant Impacts on Tree Kills and Wildlife

Since 2006 the U.S. Geological Survey ("USGS") has collected data at tree-kill areas near Casa Diablo. The data reveal the tree-kill areas have elevated CO_2 and soil temperature levels, both of which can directly or indirectly (i.e., through stress) kill trees.[27]

Tree kills have broad implications on sensitive resources and the ecology of the Project region. In addition to modifying habitat, elevated CO_2 levels at the tree-kill sites pose a hazard to wildlife, particularly species that occur at or below ground level. Indeed, smoke cartridges that produce carbon monoxide and carbon dioxide gases are commonly used to kill gophers and other "pest" species.[28] Although the effects of elevated CO_2 levels on wildlife have not been studied at the Casa Diablo sites, I believe it is likely that elevated CO_2 levels have caused heightened
9A-17 mortality among select taxa (e.g., reptiles and small mammals). Heightened mortality among these taxa could have implications on the entire ecological community.

The RDEIR provides scant discussion of the tree kills near Casa Diablo. It simply refers to the tree kills as "natural surface manifestations that change over time."[29] The RDEIR then states:

> there has been speculation that use of the geothermal resource in the Casa Diablo area may affect vegetation (Bergfeld and Evans 2011). A cause and effect relationship has not been established, but the issue should be studied with respect to future projects that would increase utilization of the resource or expand wellfield development. However, the proposed MP-I Replacement Project would not change the utilization of the existing geothermal wellfield or expand wellfield development. Therefore, the Project would have no adverse incremental cumulative impacts on the geothermal resource and would not add to the impacts of geothermal operations on vegetation, if any are established.[30]

These statements do not accurately disclose the relationship between the Project and tree kills.

First, the information provided in Bergfeld and Evans (2011) should not be characterized as "speculation." Bergfeld and Evans are senior scientists employed by the U.S. Geological Survey ("USGS"). These scientists have been studying tree kills at the Long Valley Caldera since 2006. Their research has led them to the following inferences and conclusions:

1. "[m]any of these kills occurred during the mid-1990s and were associated with early power-plant operations at Casa Diablo (Bergfeld and others, 2006)."[31]
2. "[o]ur findings indicate that the [new tree-kill] areas have developed as a response to changes in the shallow hydrologic system. Some of the changes are likely related to fluid

[27] Bergfeld D, WC Evans. 2011, Monitoring CO2 emissions in tree kill areas near the resurgent dome at Long Valley Caldera, California: U.S. Geological Survey Scientific Investigations Report 2011-5038, 22 p. (Attachment D).
[28] Engeman RM, GW Witmer. 2000. Integrated management tactics for predicting and alleviating pocket gopher (*Thomomys* spp.) damage to conifer reforestation plantings. USDA National Wildlife Research Center - Staff Publications. Paper 180. http://digitalcommons.unl.edu/icwdm_usdanwrc/180
[29] RDEIR, p. 5-11.
[30] Id.
[31] Bergfeld D, WC Evans. 2011, Monitoring CO_2 emissions in tree kill areas near the resurgent dome at Long Valley Caldera, California: U.S. Geological Survey Scientific Investigations Report 2011-5038, p. 5.

production at the power plant, but at distal sites the changes are more likely related to seismicity and uplift of the dome."[32]

9A-17 Cont.

3. "changes in the size of kill zones, increases in soil temperatures or steam discharge, and changes in CO_2 emissions most likely reflect the response of the shallow hydrothermal system to geothermal fluid production at the Casa Diablo power plant."[33]
4. "[o]ur early work (Bergfeld and others, 2006) indicated that about 8.7 metric tonnes of CO_2 per day (t/d) were emitted from these kill zones, with the highest discharge occurring in areas within a few km of the Casa Diablo geothermal power plant, and that most of the kill zones developed as a response to changing conditions in the shallow hydrothermal system."[34]
5. "[w]ithout sufficient pressure support, the shallow hydrothermal system [at Shady Rest] would respond to the 2006 onset of fluid production at the 5725 and 6625 wells. Variations in CO_2 emissions since that time may reflect adjustments in the shallow reservoir to the fluid production."[35]
6. "[t]he presence of isobutane in gas samples at Basalt Canyon shows that volatiles from the injectate have reached the underlying area. The pressure support provided by the injectate would stabilize the depth of boiling in the reservoir and, consequently, would control the upflow of steam and CO_2, producing more constant CO_2 emissions."[36]
7. "[t]he presence of isobutane in gas samples from sites in and around Basalt Canyon suggests that geothermal fluid production directly effects fluid upflow in the region close to the power plant."[37]
8. "[t]he appearance of this gas [H_2S] at the surface may signal increased drawdown of water levels near the geothermal productions wells."[38]

Second, the statement in the RDEIR that a cause and effect relationship has not been established is misleading. The tree-kill sites have elevated CO_2 and soil temperature levels, both of which can directly or indirectly (i.e., through stress) kill trees. Thus, the cause (i.e., high CO_2 and soil temperatures) and effect (i.e., tree mortality) can be inferred with relative certainty.

Because the information presented in the RDEIR conflicts with information published by the USGS, I solicited additional information from the USGS scientists (i.e., Bergfeld and Evans) that have been studying the tree-kill sites near Casa Diablo. The scientists provided the following statements addressing the discrepancies between the information presented in their publications and the information in the RDEIR:

[32] Bergfeld D, WC Evans, JF Howle, CD Farrar. 2006. Carbon Dioxide Emissions from Vegetation-Kill Zones Around the Resurgent Dome of Long Valley Caldera, Eastern California USA. Journal of Volcanology and Geothermal Research 152 (2006): 140-156. Abstract available at: www.sciencedirect.com/science/article/pii/S0377027305003550. (Attachment E)
[33] Bergfeld D, WC Evans.2011, Monitoring CO_2 emissions in tree kill areas near the resurgent dome at Long Valley Caldera, California: U.S. Geological Survey Scientific Investigations Report 2011-5038, p. 1.
[34] Id.
[35] Id, p. 9.
[36] Id, p. 8.
[37] Id, p. 1.
[38] Id.

1. "[w]e stand behind the wording in our published reports, including: 'The high concentration of thermal and diffuse CO_2 degassing areas around the power plant leaves little doubt that some areas owe their existence to the geothermal operations.' This is more inference than speculation."[39]

9A-17 Cont.

2. "[w]e have not pinpointed the exact cause of tree death, nor do we attribute every dead tree to geothermal operations, but the relation between the overall timing and pattern of vegetation kill and changes in geothermal operations is clear. We stand behind: '...changes in the size of kill zones, increases in soil temperatures or steam discharge, and changes in CO_2 emissions most likely reflect the response of the shallow hydrothermal system to geothermal fluid production at the Casa Diablo power plant.' The formation of steaming ground is a well-known impact of development at geothermal sites world-wide. The cause and effect relation is largely established even if the precise mechanism by which the trees die is not established."[40]

3. "[t]he size of the kill areas is expanding under the current production regime. However, a relocation of the power plant that does not involve changes to the fluid production/injection scheme would not be expected to speed up or otherwise alter this process."[41]

Based on the information provided above, there is ample scientific evidence that the Project would contribute to additional tree kills. Specifically, because the continued expansion of the tree-kill areas has been highly correlated with geothermal operations, one can infer that the Project would contribute to additional expansions of the tree-kills over the course of its 30-year operational life. The RDEIR lacks baseline information on the Project's contribution to tree-kills, and because it circumvents any analysis of the issue, the magnitude of the issue cannot be properly evaluated.

The Project's Impact on Mule Deer is Cumulatively Considerable

9A-18

The Project, in conjunction with other projects, has the potential to cause cumulatively considerable impacts to deer, especially with the addition of the CD-4 facility to the Casa Diablo geothermal complex. However, the analysis in the RDEIR of cumulative impacts to deer from the Project and CD-4 is limited to the statement that:

> The addition of the proposed M-1 plant site and CD-4 project would expand the affected area of development east of U.S. Highway 395 near Casa Diablo Hot Springs and impinge on the remaining corridors for wildlife movement through the area. Constraints on wildlife movement through the area could be cumulatively significant if future development is undertaken in a manner which prevents wildlife to readily pass north-south between Mammoth Creek and the habitat north of the Casa Diablo geothermal complex.[42]

The analysis presented in the RDEIR is insufficient for several reasons. First, the RDEIR fails to establish the context of the impact such that it cannot be adequately interpreted. Specifically, the

[39] 2012 Mar 19 email communication from WC Evans to S Cashen. (Attachment F)
[40] Id.
[41] Id.
[42] RDEIR, p. 5-11.

RDEIR does not (a) use existing information on the currently proposed CD-4 to assess whether the two projects combined would hinder movement to and from Mammoth Creek; (b) identify corridors that would remain on the landscape under the cumulative impacts scenario; or (c) provide evidence that supports an inference that any remaining corridors would be viable.

Second, the RDEIR lacks any analysis of impacts to other types of deer movement (i.e., besides movement to and from Mammoth Creek). These include movement among foraging resources, cover, and reproductive sites; and movement between summer and winter ranges.

9A-18 Cont.

Third, potentially significant cumulative impacts to deer are not limited to impacts on movement. They also include permanent habitat loss, loss of forest cover, loss of special use areas, stress (e.g., from disturbance), and altered predator-prey relationships. The RDEIR provides no analysis of the Project's contribution to these potentially significant cumulative impacts.

Fourth, existing development already has had a detrimental impact on the Round Valley deer herd.[43] Consequently, analysis conducted for the Project needs to consider the cumulative impacts that all past, present and probable future projects are likely to have on the entire Round Valley deer herd. The RDEIR did not take this approach, but instead focused on impacts to the subset of the herd that was present on the Project site during the latter half of 2011.[44]

Nutritional limits on survival and recruitment of deer in Round Valley clearly indicate "bottom-up" limitation on deer dynamics.[45] Consequently, further restrictions on use of habitat, or additional destruction of habitat, would have an additive effect in terms of decreasing the number of deer that comprise the population. This conclusion is supported by the deer study that was conducted for the Project, and by other mule deer studies.[46]

Based on the issues identified above, the RDEIR lacks adequate analysis of the Project's contribution to cumulative impacts to deer. Moreover, it is my professional opinion that the Project's impacts to deer may be cumulatively considerable given the CD-4 project.

9A-19

The RDEIR Fails to Propose Effective Mitigation Measures to Reduce the Project's Potentially Significant Impacts to All Sensitive Biological Resources

A. Tree-Kills

The RDEIR lacks any mitigation for impacts to tree-kills despite the clear relationship to geothermal operations. To be consistent with Mono County's General Plan, the Applicant needs

---

[43] Ferranto SP. 2006. Conservation of mule deer in the eastern Sierra Nevada. M.S. Thesis, University of Nevada, Reno, p. 50.

[44] BRA, p. 25.

[45] A bottom-up limitation is one in which population dynamics are limited by nutrient supply and productivity. *See* Monteith KL, VC Bleich, TR Stephenson, BM Pierce. 2009. Population Dynamics of Mule Deer in the Eastern Sierra Nevada: Implications of Nutritional Condition. Available at: mcbadeer.com/DFG_ROUND_VALLEY_STUDY.pdf

[46] Id. *See also* Paulus J. 2011 Oct 30. Fall 2011 Resident Deer Survey for the Casa Diablo, Basalt Canyon, and Upper Basalt Geothermal Areas, p. 11. *See also* USDA Forest Service, Pacific Northwest Research Station. 2012 Mar. Seasonal Neighbors: Residential Development Encroaches on Mule Deer Winter Range in Central Oregon. Science Findings 140. Available at: www.fs.fed.us/pnw/sciencef/scifi140.pdf. (Attachment G).

9A-19 Cont.

to prepare a written analysis of the impacts that the Project and other development projects may individually or cumulatively have on tree-kills.[47] The Applicant should then develop a monitoring plan subject to review by the County, CDFG, USGS, and other relevant resource agencies. As was done for hydrologic resources in the Project area, specific triggers for additional mitigation should be established in conjunction with the monitoring plan. Once Project operations commence, the tree-kills should be monitored to determine the extent of additional impacts to vegetation and other biological resources. If the monitoring indicates geothermal operations have contributed to additional tree kills, then Mono County should take the actions necessary to reduce any adverse effects to less-than-significant levels.

9A-20

B. Deer

I have the following comments pertaining to the mitigation measures that have been proposed for impacts to mule deer:

1. Mitigation proposed in the RDEIR includes the following: "[c]onstraints to wildlife movement through the Casa Diablo Hot Springs area shall be evaluated as part of any new development project proposed in the area."[48] Proposed mitigation also includes: "[c]onducting baseline deer studies of proposed projects in the Casa Diablo Hot Springs area and monitoring deer use within and near a new proposed project."[49] These measures will not reduce impacts to a less than significant level because they are too vague. The Applicant must be required to conduct monitoring efforts in accordance with specific criteria to ensure scientifically reliable results. The monitoring plan should account for:

    a. the appropriate timing of the proposed monitoring efforts in relation to project activities (i.e., before, after, or during construction);

    b. the duration of the proposed monitoring efforts (i.e., number of years);

    c. other essential elements of the study plan, including the study area, sampling scheme, and response variable(s) that will be examined;

    d. the statistical techniques that will be used to analyze changes in deer use, including the techniques (e.g., power analysis) that should be employed to determine the amount of sampling necessary to detect changes at a pre-specified probability; and

    e. triggers for remedial actions, and the suite of remedial actions that may be necessary, if impacts to deer are detected.

    In short, the Applicant needs to establish a monitoring plan capable of providing reliable information on changes in deer use of the Project area. To be consistent with the objectives of Mono County's General Plan, the Project application should not be considered until the monitoring plan is approved by Mono County and CDFG.

2. The RDEIR concludes the implementation of the proposed mitigation measures would reduce the cumulative impact from the existing and proposed projects on mule deer and

[47] RDEIR, p. 4-50, Goal 1.
[48] Id, p. 5-11.
[49] Id, p. 5-12.

9A-20 Cont.

other wildlife to a level that would not be cumulatively significant.[50] For the reasons described in these comments, the conclusion that impacts would not be cumulatively significant is unfounded and speculative. Furthermore, because the RDEIR does not identify success standards for the proposed mitigation, or remedial actions that will be taken if significant impacts unfold (e.g., deer movement through the Project site ceases), it lacks a mechanism for ensuring impacts would be less than significant.

Sincerely,

Scott Cashen, M.S.
Senior Biologist

[50] Id.

Attachment A

esa ECOSPHERE

Timing of seasonal migration in mule deer: effects of climate, plant phenology, and life-history characteristics

Kevin L. Monteith,[1,2,†] Vernon C. Bleich,[1,2] Thomas R. Stephenson,[1,2] Becky M. Pierce,[1,2] Mary M. Conner,[2,4] Robert W. Klaver,[3] and R. Terry Bowyer[1]

[1]*Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA*
[2]*California Department of Fish and Game, Bishop, California 93514 USA*
[3]*U.S. Geological Survey, Earth Resources Observation and Science Center, Sioux Falls, South Dakota 57198 USA*

Abstract. Phenological events of plants and animals are sensitive to climatic processes. Migration is a life-history event exhibited by most large herbivores living in seasonal environments, and is thought to occur in response to dynamics of forage and weather. Decisions regarding when to migrate, however, may be affected by differences in life-history characteristics of individuals. Long-term and intensive study of a population of mule deer (*Odocoileus hemionus*) in the Sierra Nevada, California, USA, allowed us to document patterns of migration during 11 years that encompassed a wide array of environmental conditions. We used two new techniques to properly account for interval-censored data and disentangle effects of broad-scale climate, local weather patterns, and plant phenology on seasonal patterns of migration, while incorporating effects of individual life-history characteristics. Timing of autumn migration varied substantially among individual deer, but was associated with the severity of winter weather, and in particular, snow depth and cold temperatures. Migratory responses to winter weather, however, were affected by age, nutritional condition, and summer residency of individual females. Old females and those in good nutritional condition risked encountering severe weather by delaying autumn migration, and were thus risk-prone with respect to the potential loss of foraging opportunities in deep snow compared with young females and those in poor nutritional condition. Females that summered on the west side of the crest of the Sierra Nevada delayed autumn migration relative to east-side females, which supports the influence of the local environment on timing of migration. In contrast, timing of spring migration was unrelated to individual life-history characteristics, was nearly twice as synchronous as autumn migration, differed among years, was related to the southern oscillation index, and was influenced by absolute snow depth and advancing phenology of plants. Plasticity in timing of migration in response to climatic conditions and plant phenology may be an adaptive behavioral strategy, which should reduce the detrimental effects of trophic mismatches between resources and other life-history events of large herbivores. Failure to consider effects of nutrition and other life-history traits may cloud interpretation of phenological patterns of mammals and conceal relationships associated with climate change.

Key words: climate change; life-history characteristics; mule deer; NDVI; nutritional condition; *Odocoileus hemionus*; plant phenology; risk averse; risk prone; Sierra Nevada; snow depth; trophic mismatch.

Received 17 September 2010; revised 25 October 2010; accepted 29 October 2010; final version received 6 April 2011; published 27 April 2011. Corresponding Editor: M. Festa-Bianchet.

Citation: Monteith, K. L., V. C. Bleich, T. R. Stephenson, B. M. Pierce, M. M. Conner, R. W. Klaver, and R. T. Bowyer. 2011. Timing of seasonal migration in mule deer: effects of climate, plant phenology, and life-history characteristics. Ecosphere 2(4):art47. doi:10.1890/ES10-00096.1

[4] Present address: Pacific Southwest Research Station, USDA Forest Service, Davis, California 95618 USA.
† E-mail: montkevi@isu.edu

Introduction

Climate change is expected to alter ecosystem structure and function, including community composition and distributions of species (Walther et al. 2002). Overwhelming evidence from long-term research supports the influence of climate change on phenology (i.e., timing of seasonal activities) of plants and animals (Stenseth et al. 2002, Badeck et al. 2004, Gordo and Sanz 2005). Spring activities of numerous taxa have occurred progressively earlier and in the direction expected from climate change since the 1960s, including breeding by birds, arrival of migrant birds, appearance of butterflies, chorusing and spawning of amphibians, and flowering in plants (Walther et al. 2002, Parmesan and Yohe 2003 for reviews). Corresponding delays in the initiation of autumn events also have been reported, but those phenological shifts are less apparent (Walther et al. 2002, Carey 2009). For example, during a 42-year study of migration in eight species of birds, three species advanced, three delayed, and two did not change the timing of autumn migration (Adamik and Pietruszkova 2008). Indeed, the timing of seasonal activities may be one of the simplest processes to track changes in the ecology of a species responding to climatic change (Walther et al. 2002). Addressing questions related to climate change, however, requires long-term studies to disentangle influences of large-scale climate and individual life-history patterns on phenological events.

Migration is a well-recognized life-history strategy involving numerous taxa over the globe (Baker 1978, Swingland and Greenwood 1983, Fryxell et al. 1988, Alerstam et al. 2003); effective conservation actions are necessary to maintain intact patterns of migration (Berger 2004, Bolger et al. 2008). Nevertheless, our understanding of the biology of migration by large herbivores is fragmentary, and consequences of climate change on those phenological patterns remain largely unknown (Bolger et al. 2008, Wilcove 2008). In strongly seasonal environments, large herbivores typically migrate between discrete ranges, which is thought to have evolved in response to the dynamic patterns of forage quality and availability (Morgantini and Hudson 1989, Albon and Langvatn 1992, Hebblewhite et al. 2008), predation risk (Fryxell et al. 1988), and weather patterns (Nelson and Mech 1981, Loft et al. 1989, Kucera 1992, Grovenburg et al. 2009). Indeed, migrants often acquire a selective advantage through enhanced fitness (Dingle 1985, Fryxell et al. 1988), avoid resource bottlenecks by obtaining access to greater food supplies in larger and less densely inhabited ranges, and obtain forage in the most nutritious phenological stages (McCullough 1985, Fryxell and Sinclair 1988, Fryxell et al. 1988, Albon and Langvatn 1992, Holdo et al. 2009, Zeng et al. 2010).

At most mid- to high-latitude regions, frost-free periods have increased with a concomitant 10% decrease in snow cover since the late 1960s (Walther et al. 2002). Temporal and spatial advance in seasonal resource availability by a warming climate may reduce the reproductive success of animals that fail to adjust life-history events to correspond with temporal changes in peak forage availability, resulting in a trophic mismatch (Post and Forschhammer 2008, Post et al. 2008). Nevertheless, large herbivores may be capable of adjusting their timing of migration to enhance nutrient gain in an attempt to compensate for the trophic mismatch at a large spatial scale (Post and Forschhammer 2008), unless their migratory patterns are fixed by day length rather than other environmental cues (Garrott et al. 1987, Post and Forschhammer 2008). If large herbivores respond to milder winter conditions with flexibility in timing of migration, animals should depart winter range earlier in spring and remain on summer ranges for a longer duration in autumn to gain access to forage under circumstances of reduced intraspecific competition (Albon and Langvatn 1992), increased plant diversity (Mysterud et al. 2001), and at a more nutritious phenological stage (Klein 1965, Pettorelli et al. 2007, Hamel et al. 2009). Consequently, natural selection should favor those individuals that respond to climatic change by timing seasonal migration to correspond with phenological advances in plant growth, resulting in improved nutritional gains (White 1983, Mysterud et al. 2001, Voeten et al. 2009).

Although effects of climatic patterns and plant phenology on the timing of migratory events for large herbivores have been documented (Albon and Langvatn 1992, Kucera 1992, Nelson 1995, Sabine et al. 2002, Fieberg et al. 2008), the influence of intrinsic factors, such as age, location of summer residency (which may differ for populations using the same winter range), and reproductive and nutritional state, rarely have been considered (White et al. 2010). Failure to recognize other important factors related to individual life-history characteristics may lead to spurious correlations between indices of climate and the timing of migration.

The behavioral responses of an individual may be affected by their current nutritional state. For instance, studies of avian ecology have suggested that the timing of long-distance migration in bird species may be under strong endogenous control (Mitrus 2007, Pulido 2007). Despite the well-recognized carry over of nutritional condition from the energetic costs and benefits from previous seasons (Parker et al. 2009), few studies have considered whether differences in nutritional condition among individuals affect the timing of migration by large herbivores (Bolger et al. 2008). Maternal females, or those in poor nutritional condition, may be less able to afford the presumed risk associated with altering timing of migration (Ruckstuhl and Festa-Bianchet 1998, Ciuti et al. 2006). Large herbivores are long-lived and those in adequate nutritional condition have the opportunity to reproduce annually; consequently, females should adopt a strategy to promote their survival and opportunity for future reproduction, while simultaneously protecting their current reproductive investment (Stearns 1992).

Most knowledge on timing and synchrony of migration in large herbivores has been derived from short-term studies, which limits the probability of observing variable weather conditions (Fieberg et al. 2008), and precludes the evaluation of effects of large-scale climate on migratory events (Forchhammer and Post 2004). Our objective was to assess a long-term dataset to evaluate effects of climatic conditions, plant phenology, and individual life-history characteristics of mule deer (*Odocoileus hemionus*) in the western Great Basin on timing and synchrony of seasonal migration. Our first objective was to evaluate the influence of extrinsic variables including, broad-scale climate, local weather, and plant phenology on timing of migration. Global climate change is expected to alter the phenological patterns of life-history events for numerous taxa, including seasonal migration by vertebrates (Walther et al. 2002, Forchhammer and Post 2004). Effects of winter weather and snow depth, as well as progression in plant phenology, on timing of seasonal movements by large herbivores have been well documented (Garrott et al. 1987, Kucera 1992, Albon and Langvatn 1992, Sabine et al. 2002, Fieberg et al. 2008, Zeng et al. 2010). Therefore, we expected current weather conditions, driven by broad-scale climate, to influence the timing of seasonal migrations among mule deer. Furthermore, progression in plant phenology, particularly in spring, should correspond to the timing of migratory events between seasonal ranges across years. Following the identification of extrinsic factors that affected seasonal migration of mule deer, we evaluated the influence of intrinsic factors among individual mule deer on timing of migration. We hypothesized that timing of migration would be influenced by individual life-history characteristics including nutritional condition, reproductive status, age, and location of summer residency. Migration by large herbivores is a spectacular phenomenon occurring across a wide array of landscapes, however, many of these migrations are imperiled by anthropogenic disturbances, which is likely indicative of major ecological changes (Berger 2004, Bolger et al. 2008, Wilcove 2008). Our approach will provide a better understanding of the mechanisms underpinning this biological process and should aid in the conservation of these large, vagile mammals and their unique behaviors.

Study Area

We monitored the timing of migration for a population of mule deer that wintered on the east side of the Sierra Nevada in Round Valley (37°24′ N, 118°34′ W), Inyo and Mono counties, California, USA (Fig. 1). Mule deer inhabited approximately 90 km^2 of Round Valley during November-April, but the size of this area was dependent on snow depth (Kucera 1988). Annual snow depth in a drainage adjacent to Round Valley (Station ID: RC2, California Department of Water Resources) was highly variable during our study; the coefficient of variation of snow depth in April was 57% and ranged from 25.4 to 139.7 cm. Precipitation in the study area is strongly seasonal, with 75% occurring between November

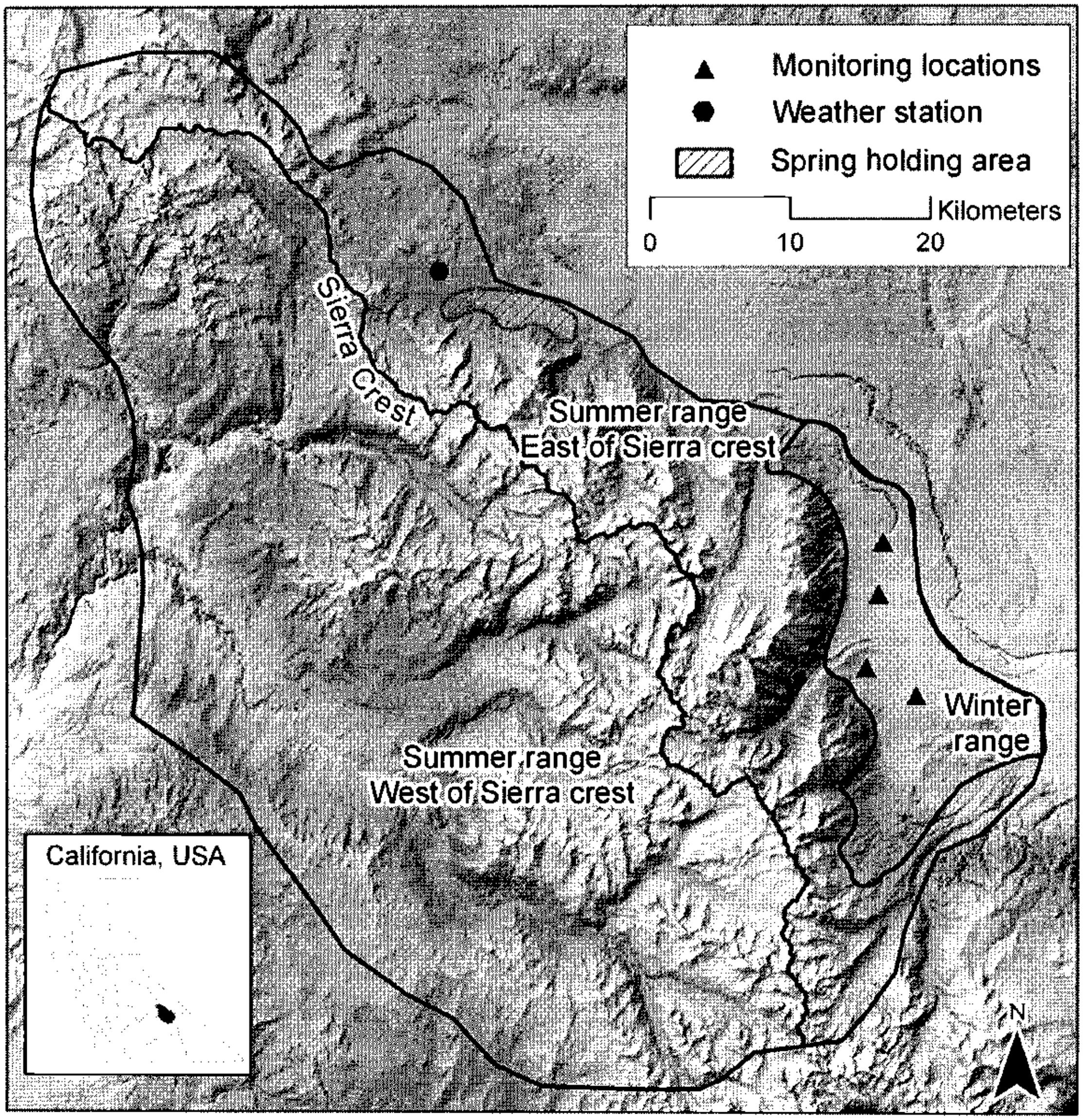


Fig. 1. Seasonal ranges occupied by female mule deer during winter, and the distinct ranges on both sides of the crest of the Sierra Nevada (Sierra crest), California, USA during summer. The four monitoring locations on winter range are indicated as well as the spring holding area for deer and location of the weather station near Mammoth Lakes, California.

and March (Kucera 1988). Daily temperatures near Mammoth Lakes, California, USA during 1999–2009 ranged from −27 to 33°C (Western Regional Climate Center). The region is typified by dry, hot summers (June–September), short, mild autumns with cooling temperature and increasing precipitation (October), and long, cold winters, with most annual precipitation accumulating as snow (November–April). Spring is short and characterized by decreasing precipitation and increasing temperatures (May; Fig. 2).

Round Valley is bounded to the west by the

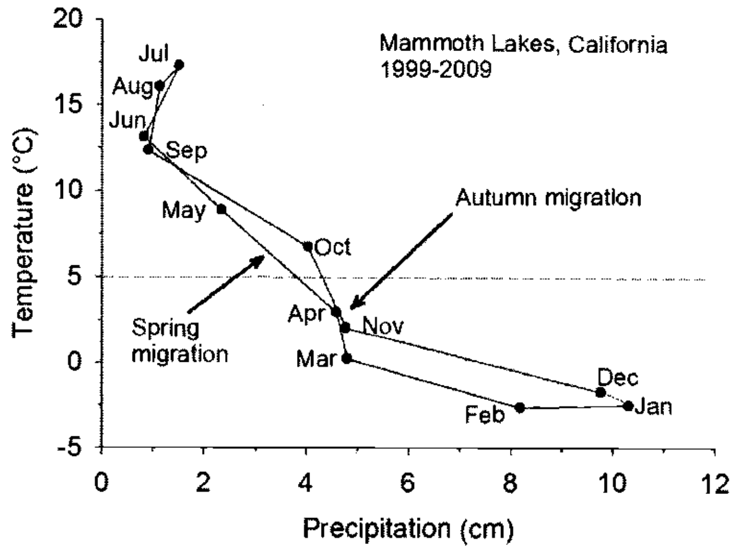


Fig. 2. Climograph of the mean monthly temperature and precipitation at Mammoth Lakes, California, USA, 1999–2009, which is located adjacent to summer range and the traditional migratory route for mule deer occupying winter range in Round Valley. Autumn and spring migration correspond to average timing of seasonal migration, 1999–2009, and dashed line represents an index to a temperature threshold (5°C) for growth of plants (Chapin 1983).

Sierra Nevada, to the south by large boulders and granite ridges of the Tungsten Hills and Buttermilk Country, and to the east by US Highway 395. The northern end of Round Valley gradually rises from the valley floor at 1,375 m to the top of the Sherwin Grade at 2,135 m. Open pastures comprised about 18.3 km^2 of the eastern portion of the valley; 3.2 km^2 was low-density residential housing (Pierce et al. 2004). Vegetation in Round Valley was characteristic of the western Great Basin and sagebrush-steppe ecosystem (Storer et al. 2004).

Summer range for mule deer that winter in Round Valley occurred on both sides of the crest of the Sierra Nevada (hereafter Sierra crest; Fig. 1) at elevations ranging from 2,200 to >3,600m (Kucera 1988). Winter storms from the Pacific Ocean deposit moisture as they move up the western slope with a substantial rain shadow, resulting in a more arid landscape on the eastern slope, where the Great Basin Desert begins (Storer et al. 2004, Bleich et al. 2006). The dense pine-fir (*Pinus-Abies*) stands and rivers on the west side of the Sierra crest contrast with the sparse forests transitioning to sagebrush scrub with only a few small streams on the east side. Indeed, the formidable Sierra crest sharply delineates the western slope from the eastern slope of the Sierra Nevada, and is traversable only by a series of passes that increase in elevation from north to south (Kucera 1988). Mule deer typically migrate northward and westward to high-elevation ranges in spring (Kucera 1992, Pierce et al. 1999); most migrate over the aforementioned passes to the west side of the Sierra Crest (Fig. 1), while some remain on the east side (Kucera 1992, Pierce et al. 2000). Prior to completion of migration to summer range, mule deer from Round Valley make extensive use of a spring holding area at higher elevation (>1,200 m) located on the east side of the Sierra Nevada, just southeast of Mammoth Lakes, California, USA (Kucera 1992; Fig. 1). Mule deer often remain on the spring holding area until snow on summer range has receded (Kucera 1992).

Methods

Animal capture

During March 1997–2009 and November 2002–2008, we captured adult female (>1 yr old) mule deer on winter range in Round Valley using a hand-held net gun fired from a helicopter (Krausman et al. 1985). We hobbled and blindfolded each animal prior to moving it by helicopter to a central processing station with shelter for animals and handling crews. To allow age determination by cementum annuli (Matson's Laboratory, Milltown, Montana, USA), we removed one incisiform canine using techniques described by Swift et al. (2002); this procedure has no effect on body mass, percent body fat, pregnancy rate, or fetal rate of mule deer (Bleich et al. 2003). We fitted each animal with standard, VHF radiocollars (Telonics, Inc., Mesa, Arizona, USA; Advanced Telemetry Systems, Isanti, Minnesota, USA) equipped with a mortality sensor. We attempted to maintain radiocollars on >75 adult females by capturing new, unmarked animals to replace animals lost to mortality.

We conducted ultrasonography using an Aloka 210 portable ultrasound device (Aloka, Wallinford, CT), with a 5-MHz transducer, to measure maximum thickness of subcutaneous fat deposition at the thickest point cranial to the cranial process of the tuber ischium to the nearest 0.1 cm (Stephenson et al. 2002). We complemented ultrasonography with palpation to determine a body-condition score, validated for mule deer (Cook et al. 2007), to estimate nutritional condition of deer that have mobilized subcutaneous fat reserves (<5.6% ingesta-free body fat). We calculated rLIVINDEX as subcutaneous rump-fat thickness plus rump body-condition score (Cook et al. 2007). We then used rLIVINDEX to calculate ingesta-free body fat (IFBFat), where $\mathrm{IFBFat} = 2.920 \times \mathrm{rLIVINDEX} - 0.496$ (Cook et al. 2007). During deer captures in March, we used an ultrasound with a 3-MHz linear transducer to determine pregnancy and fetal rates (number of fetuses per female) of females during the second one-third of gestation (Stephenson et al. 1995).

During each autumn, we attempted to determine reproductive status of all marked females as they arrived on winter range in late-October through November. We located radiocollared females using ground-based telemetry and stalked to within visible range of deer (<200 m). We observed each female using binoculars or spotting scopes until we could confidently determine the number of young-at-heel. We identified the number of young-at-heel by observing nursing and other maternal behavior (Miller 1971), and determined recruitment status based on the presence or absence of young-at-heel identified each autumn. Animal capture and research methods were approved by an independent Institutional Animal Care and Use Committee at Idaho State University (protocol #: 650-0410), were in accordance with guidelines of research on large mammals by the American Society of Mammalogists (Ganon et al. 2007), and followed California Department of Fish and Game protocols for wildlife restraint.

Timing of migration

We determined the presence or absence of radiomarked mule deer on winter range with radio telemetry from four monitoring locations, which were strategically distributed across Round Valley during 1999–2009 (Fig. 1). Although we did not attempt to determine exact locations of animals by triangulation, the topography of the Sierra Nevada that bounded Round Valley on three sides conveniently blocked the signal of animals that were not present in the valley. We conducted telemetry from fixed-wing aircraft to locate animals that were not present in Round Valley. Aerial telemetry also was used to locate all females on their summer range during mid-summer and to categorize animals based on the side of the Sierra crest (east or west) that they occupied (Fig. 1).

We attempted to monitor animals from the ground a minimum of 3 days per week beginning on 1 October and continuing through 30 April each winter. Logistical constraints during some years, however, affected the frequency and duration of monitoring. We censored animals that died prior to migration in either autumn or spring because, in some instances, we were unable to determine exact date of death. We assumed that censoring of individuals was independent of the migratory strategy exhibited by deer.

Local weather and climate

We obtained data on daily weather from a station located near the town of Mammoth Lakes, California, USA (Western Regional Climate Center 1998–2009), which was near the summer range of deer, and was immediately adjacent to the traditional migratory route and spring holding area for mule deer from Round Valley (Kucera 1992; Fig. 1). Daily data on weather were not available for winter range; therefore, we used weather data from the nearby station at Mammoth Lakes, California, for all analyses (Appendix). Because deer also likely respond to changing weather patterns rather than simply absolute daily measurements of weather (Sabine et al. 2002, Grovenburg et al. 2009), we calculated a metric of change in weather to represent a change in weather on a particular day relative to previously experienced weather patterns. This metric reflected the difference in the daily weather relative to the mean of that particular weather variable during the previous 2 weeks, which we arbitrarily chose to represent the relative magnitude of change in weather on a day.

Annual weather patterns in the western US have been correlated with the annual mean of the southern oscillation index (SOI; Trenberth and Hurrell 1994, Marshal et al. 2002, Stenseth et al. 2003). Accordingly, we used the standardized SOI (National Oceanic and Atmospheric Administration, Climate Prediction Center) as a measure of variation in large-scale climate (Stone et al. 1996). For autumn migration, we used the annual mean of the SOI during the previous October through September, and for spring we used the mean SOI during the previous April through March in migration models.

Plant phenology

Temperature is one of the most critical factors influencing phenology in plants (Rachlow and Bowyer 1991). Therefore, we calculated an index to growth and senescence of plants based on mean daily temperatures (Chapin 1983). For each spring, we calculated the number of growing-degree days per day (the number of degrees that the mean daily temperature was >5°C, summed across all previous days beginning on 1 January) as an index to growth of plants (Chapin 1983). For each autumn, we calculated a metric of senescence of plants by the opposite of growing-degree days, which we termed senescent-degree days (the number of degrees that the mean daily temperature was <5°C, summed across all previous days beginning on 15 September).

The normalized difference vegetation index (NDVI) is derived from satellite imagery that measures the greenness of vegetation. NDVI is sensitive to environmental change (Pettorelli et al. 2005), is associated with fluctuations in dietary quality (Christianson and Creel 2009, Hamel et al. 2009), and thus, is related to numerous aspects of the ecology of large herbivores (Loe et al. 2005, Pettorelli et al. 2007). From the Earth Resources and Observation Science Center of the U.S. Geological Survey, we obtained a time series of 14-day composite NDVI with 1-km^2 spatial resolution recorded by the Advanced Very High Resolution Radiometer aboard the polar-orbiting weather satellites of the National Oceanic and Atmospheric Administration. Data were further processed to remove effects of atmospheric contamination with the method of Swets et al. (1999). We extracted mean NDVI values for each 2-week interval from 1999–2009 for pixels that occurred within the winter range and spring holding area for mule deer (Kucera 1988; Fig. 1). We extracted data for the spring holding area rather than the extensive summer range occupied by deer from Round Valley (Fig. 1), because habitat on the spring holding area was comparable with that occurring on winter range and deer made extensive use of holding areas in spring (Kucera 1992). We calculated a daily NDVI for both areas by interpolating between 14-day composites of NDVI, assuming a linear progression between change in NDVI composites and time increment for each period. We also expected deer to respond to progressive changes in NDVI; therefore, analogous to metrics of change for weather variables, we also calculated a metric of daily change in NDVI by the difference in daily NDVI relative to the mean NDVI during the previous 2 weeks. To describe annual deviations in patterns of green-up and senescence, we used program TIMESAT (Jönsson and Eklundh 2004) to calculate variables derived from NDVI data including: Julian date of onset of spring and onset of autumn, rate of increase in NDVI at the beginning of the season, rate of decrease in NDVI at the end of the season, and maximum and minimum NDVI for seasonal ranges (Reed et al. 1994, Pettorelli et al. 2005).

Statistical analyses

We evaluated relationships between the annual mean (October–September) of the SOI and the corresponding annual sum in snowfall and precipitation, and the annual average of mean daily temperature using linear regression (Neter et al. 1996), with one-tailed tests, because the direction of the expected relationships have been established previously (Trenberth and Hurrell 1994, Marshal et al. 2002). We used two-tailed t-tests to evaluate differences in annual phenological metrics between winter range and the spring holding area (Zar 1999), to determine if patterns of plant phenology differed between seasonal ranges.

Daily weather.—We used principal component analysis (PCA) of local weather data, based on the variance–covariance matrix (McGarigal et al. 2000), to reduce the dimensionality of those variables and derive independent composite variables that described daily weather. In the PCA, we included 12 variables representing absolute daily weather and a metric of change in daily weather for: minimum, maximum, and average temperature (°C), snowfall (cm), snow depth (cm), and precipitation (cm). We selected 5 principal components because they each explained >1% of the variation in daily weather and were biologically relevant (Appendix). Principal component 1 explained 74.2% of the variation in daily weather and represented an absolute measure of daily depth of snow from lower (negative loadings) to higher snow depths (positive loadings). Principal component 2 explained 12.1% of the variation in daily weather and reflected daily changes in snow depth from decreasing snow depth (negative loadings) to increasing snow depth (positive loadings). Absolute daily temperatures from cold temperatures (negative loading) to warm temperatures (positive loading) were represented by principal component 3, which explained 8.1% of the variation in daily weather. Daily snowfall and precipitation from lower (negative loadings) to higher (positive loadings) was reflected by principal component 4, which explained 3.0% of the variation in daily weather. Finally, a metric of change in daily temperatures from cooling temperatures (negative loadings) to warming temperatures (positive loadings) was represented by principal component 5, which explained 1.7% of the variation in daily weather.

Migration timing.—We censored 1 deer that was resident all year on winter range in Round Valley, and 2 deer that failed to return to winter range in 2006 and 2007. We censored those individuals because we were not interested in testing hypotheses regarding mixed-migration strategies (Nicholson et al. 1997); ≥99% of deer in Round Valley were obligate migrators. We also chose to restrict analyses of timing of migration in autumn to the period between 15 September and 31 December, because events beyond that date in any particular year were sparse. Restriction of analyses for autumn migration resulted in the censoring of 14 migratory events that occurred after 31 December, during 1999–2009. We also censored 1 migratory event during spring migration when an individual deer migrated on 15 January, whereas all other migratory events occurred after 6 March.

Logistical constraints precluded continuous sampling to identify the exact day of departure and arrival on winter range in our study. Average monitoring interval per season ranged from 11.5 days for autumn 1999 to 1.3 days for spring 1999. Average censor interval for migratory events per season ranged from 20 days for autumn 2000 to 1 day for spring 2002. The timing of a migratory event could only be attributed to an interval of time. Data collected under this coarse sampling regime are known as interval-censored and require proper accounting for the uncertainty of the timing of events (Johnson et al. 2004, Fieberg and DelGiudice 2008).

To properly account for interval-censored data, we applied the method of Johnson et al. (2004) to calculate a robust measure of mean date of migration and a corrected measure of the SD of the distribution of migratory events to determine synchrony (Gochfeld 1980). This method is an extension of Sheppard's correction, which allows unequal sampling intervals (bin size; Johnson et al. 2004). We used the method of Johnson et al. (2004) and the associated 95% CI to evaluate differences in timing of migration among years, recruitment status of females in autumn (presence of young-at-heel), and summer residency (east versus west side of the Sierra crest). We used multiple-regression analysis (Neter et al. 1996) to evaluate the relationship between annual mean and synchrony (SD) of seasonal migration with annual metrics of large-scale climate and plant phenology including: annual

SOI; Julian date of onset of spring and onset of autumn; and rate of increase or decrease in NDVI between seasons, respectively. Before interpreting results of our multiple-regression analyses, we evaluated residual plots for compliance with assumption of normality and homogeneity of variance (Neter et al. 1996). We did not include annual averages of local weather variables in the multiple-regression analysis, because of collinearity with SOI and Julian date of onset of spring ($r > 0.50$). We examined fit of multiple regression models with R^2_{adj} and the contribution of each variable by reporting partial correlations ($r^2_{partial}$; Neter et al. 1996, Zar 1999). We determined whether mean date of seasonal migration of mule deer was advancing or receding during 1999–2009 using simple linear regression (Neter et al. 1996). We also used linear regression to determine if there were directional changes in annual precipitation, snowfall, mean temperature, SOI, Julian date of start of season, and Julian date of end of season relative to time (Neter et al. 1996).

Migration modeling.—We adopted methods of survival analysis that have been developed for interval-censored data, which are used to analyze data addressing the time of a specific event (Dinsmore et al. 2002); events in our study were the dates of arrival to and departure from winter range. We used interval-censored models to evaluate effects of extrinsic and intrinsic factors on the distribution of migratory events for seasonal migration in mule deer. We estimated daily probability of not migrating as a function of Julian date using the nest-survival option in Program MARK (White and Burnham 1999, Dinsmore et al. 2002) and subsequently, we calculated daily probability of migrating as one minus the daily probability of not migrating. These models were developed to analyze nest-survival data (Dinsmore et al. 2002), but provide a powerful tool to investigate other biological phenomena, including timing of migration in relation to time-specific and individual-based covariates (Fieberg and DelGiudice 2008). Nevertheless, nest-survival models do not account for repeated measurements between years (although it does account for them within years). We partitioned our dataset into individuals monitored during $\leq$3 years versus individuals monitored $>$3 years and calculated mean date of seasonal migration ($\pm$95% CI) using Johnson et al. (2004) to evaluate whether repeated monitoring of some individuals had an effect on our analyses. There was no difference in timing of migration between individuals monitored for $\leq$3 years compared with $>$3 years, which indicated that repeated sampling of individuals likely did not have a strong influence on our analyses.

Input files for Program MARK included three variables required for each deer: the day since the beginning of the interval that the deer was available to migrate (i), the day the deer was monitored immediately prior to a migratory event (j), and the day the deer was monitored immediately after a migratory event (k; notation follows Dinsmore et al. 2002). We scaled the beginning of the monitoring interval for each season (i) so that the first day of the monitoring interval was the same Julian date across all years. For autumn, j_i represented the last observation when absent from winter range, and k_i represented the first observation on winter range. For spring, j_i represented the last day present on winter range, and k_i represented the subsequent observation when absent from winter range. Each autumn, a few individuals arrived on winter range prior to the initiation of monitoring of radio signals in Round Valley. In those instances, we assigned j_i as 15 September of the current autumn, which we assumed was prior to the earliest date expected for individuals to arrive on winter range. Each spring, a few individuals also remained on winter range when we ceased monitoring in Round Valley. For those individuals, we assigned k_i to 15 May of the current spring, which we assumed was the latest date any individual would be expected to depart winter range.

We employed an information-theoretic approach to identify extrinsic and intrinsic factors that influenced timing of migration in mule deer. In the first stage of the modeling, we examined all possible combinations of extrinsic predictor variables that might influence timing of migration in mule deer: annual SOI, daily weather variables and weather change metrics from the PCA, growing- or senescent-degree days, daily range-specific NDVI and change in NDVI, and a quadratic time-trend. We included year as a nuisance parameter to account for variation among years that was not specifically addressed by our other annual environmental variables. We also fit a quadratic time-trend that allowed daily probability of migration to follow a curvilinear pattern, which we expected to occur because seasonal patterns of migration commonly occur in a pulse with tails on either side (Garrott et al. 1987, Kucera 1992, Brinkman et al. 2005, Grovenburg et al. 2009). We expected potential interactions between principal components for weather and NDVI, but did not include those interactions because of multicollinearity between the interaction terms and principal components representative of those weather variables ($r > 0.70$). For each model, we calculated Akaike's information criterion adjusted for small sample size (Akaike 1973; AIC_c), ΔAIC_c, and Akaike weight (w_i; Burnham and Anderson 2002). We then calculated model-averaged parameter estimates and unconditional standard errors (SE) for each predictor variable (Burnham and Anderson 2002). We determined if model-averaged parameter estimates differed from zero by examining whether their 95% CI, based on unconditional SEs, overlapped zero. We evaluated the relative importance of variables based on their importance weights, which we calculated as the sum of w_i across all models that contained a particular variable (Burnham and Anderson 2002).

After we identified the extrinsic variables that affected the timing of seasonal migration among mule deer, we added intrinsic covariates characterizing the life-history of groups (e.g., summer residency) and individuals (e.g., nutritional condition), to evaluate whether life-history traits among individuals affected their timing of migration. We partitioned the dataset to include only those individuals where data on life-history characteristics were available. We believe the sample of individual animals with data on life-history characteristics was representative of the population, because we attempted to determine reproductive status of all marked females on winter range during autumn, captured 50% of collared females in November, and attempted to capture every marked female each March.

We modeled all possible combinations of the extrinsic variables that were significant (based on 95% *CI*) in the first stage of the modeling approach, and individual life-history characteristics that we hypothesized would affect the timing of seasonal migration including: age (years); summer residency (east versus west side of the Sierra crest); nutritional condition (ingesta-free body fat; IFBFat); fetal rate (for spring migration only); and recruitment (presence or absence of young-at-heel for autumn migration only). We also evaluated interactions based on ΔAIC_c and confidence intervals of interaction terms for life-history characteristics (e.g., recruitment × IFBFat), and between life-history characteristics and daily weather (e.g., IFBFat × PC1). None of the interactions we investigated were significant, or resulted in a significant improvement of model fit. Interaction terms were removed from subsequent analyses. For both spring and autumn models, we also included age as a quadratic term (age^2) to allow timing of migration to be a curvilinear function of age. Finally, we again used model averaging, 95% CI, and importance weights to evaluate the effects of life-history characteristics on the timing of migration (Burnham and Anderson 2002). Following the identification of important life-history variables on the timing of migration by mule deer, we calculated the daily probability of migration for east- and west-side females (i.e., summer residency), for females in relatively poor nutritional condition (4% IFBFat), and good nutritional condition (18% IFBFat), and for old (12.4 years old) and young females (2.4 years old) to illustrate the effects of age, summer residency, and nutritional condition on the daily probability of seasonal migration of mule deer. All assigned values for each life-history characteristic were within the range we observed for deer in Round Valley and were in accordance with that reported for mule deer elsewhere (Gaillard et al. 2000, Cook et al. 2007).

Results

We monitored spring and autumn migration of radiocollared mule deer each year during 1999–2009. We documented 850 and 882 migratory events by mule deer in the autumn and spring, respectively, by monitoring 297 individual deer for 1 to 22 seasonal migrations. During 1999–2009, female mule deer resided on summer range ($\bar{X} = 191$, $SD = 12.6$ days) 10% longer than on winter range ($\bar{X} = 174$, $SD = 8.9$ days). The southern oscillation index (SOI) was negatively related to total snowfall ($\beta = -129.6$, $r^2 = 0.26$, $P = 0.053$), and approached a significant positive relationship with mean annual temperature ($\beta = 0.54$, $r^2 = 0.17$, $P = 0.13$), but exhibited little correlation with total precipitation ($\beta = -7.32$, $r^2 = 0.06$, $P = 0.36$; Appendix). In addition, there was no directional change during 1999–2009 in annual precipitation ($\beta = -2.06$, $r^2 = 0.02$, $P = 0.67$), snowfall ($\beta = -10.61$, $r^2 = 0.02$, $P = 0.65$), average temperature ($\beta = 0.06$, $r^2 = 0.10$, $P = 0.34$), SOI ($\beta = 0.04$, $r^2 = 0.01$, $P = 0.80$), Julian date of start of season ($\beta = -0.40$, $r^2 = 0.01$, $P = 0.85$), or Julian date of end of season ($\beta = -2.54$, $r^2 = 0.15$, $P = 0.24$).

Julian date of onset of spring (as derived from NDVI) was similar between seasonal ranges, but rate of green-up differed and occurred at more than twice the rate on the spring holding area compared with winter range (Table 1). Likewise, date of the onset of senescence was similar between ranges, whereas the rate of senescence was significantly faster on the spring holding area (Table 1). Maximum greenness of vegetation, as indicated by peak values in NDVI, was significantly greater on the spring holding area compared with winter range (Table 1). Moreover, during 1999–2009, daily mean NDVI remained significantly greater (based on 95% CI) on the spring range compared with winter range in Round Valley from 2 April until the end December (Fig. 3). Annual minimum values of NDVI during winter did not differ between seasonal ranges (Table 1), which would be expected when snow covered those ranges. Nevertheless, snow cover was sparse during some winters in Round Valley.

Autumn migration

Snowfall during October ranged from 0 to 110 cm (CV = 196%), whereas mean daily temperature ranged from 4.2 to 10.2°C (CV = 28%), during 1999–2009. Despite such variation in winter weather during October, mean date of autumn migration (28 October) for mule deer only ranged from 18 October to 8 November, and generally was not different among years (Fig. 4). In addition, mean date of autumn migration coincided with the onset of winter as temperatures declined below 5°C, and winter precipitation began to increase (Fig. 2). Mean date of annual migration did not exhibit directional change during 11 years ($\beta = -0.21$, $r^2 = 0.01$, $P = 0.74$). Multiple-regression analysis revealed little relation between annual metrics of large-scale climate and plant phenology, and the annual mean and synchrony of autumn migration ($R^2_{adj} = 0.35$, $P = 0.12$, $R^2_{adj} = 0.23$, $P = 0.20$, respectively). Synchrony (SD) within years was highly variable ranging from 17.1 to 62.1 days (mean SD = 39.0 days).

Migration models that included year received nearly 100% of the Akaike weight. Indeed, model-averaged daily probability of migration varied considerably in shape and magnitude among years, and the annual cumulative proportion of mule deer migrating increased at different rates among years (Fig. 5). Although mean date of autumn migration did not differ statistically during 1999–2009, based on predictive models, the date at which 90% of adult female mule deer had completed autumn migration ranged from 29 October in 2004 when early snowfall and cold temperatures occurred, to 2 December in 1999, which was characterized by a mild autumn (Fig. 5).

Extrinsic factors affecting the daily probability of autumn migration among years included daily snow depth (PC1), daily temperature (PC3), daily snowfall (PC4), and daily change in temperature (PC5; Table 2). Daily probability of migration increased as daily snowfall and snow depth increased, and as daily temperature and rate of change in temperature decreased. Based on Akaike importance weights, those four weather variables all had comparable roles in determining the daily probability of autumn migration in female mule deer (Table 2). For example, early snowfall in the absence of cold temperatures caused only modest increases in the daily probability of migration (Fig. 6a, b), whereas snowfall events coincident with cold and declining temperatures resulted in dramatic increases in the expected proportion of individual deer migrating that day (Fig. 6b, c).

Metrics of plant senescence, including daily senescent degree-days, daily NDVI, daily change in NDVI, end of season date, and rate of decrease in NDVI at end of season, received minimal support (importance weights <0.51) and their model-averaged parameter estimates did not differ from zero (Table 2). Indeed, mean date of autumn migration occurred prior to senescence of plants on summer range (Fig. 3), which supports the association between patterns of

Table 1. Mean, SE, and statistical results from t-tests to evaluate differences in annual phenology metrics between winter range and the spring holding area (Fig. 1) for mule deer in the Sierra Nevada, California, USA, 1999–2009. Phenology metrics were calculated following Reed et al. (1994).

	Seasonal range				t-test		
	Winter		Spring				
Phenology metric	Mean	SE	Mean	SE	t	df	P
Date of onset of spring†	92.50	4.30	94.60	4.70	0.33	20	0.750
Rate of increase in NDVI	0.03	2×10^{-3}	0.07	4×10^{-3}	7.10	20	<0.001
Date of end of season†	364.60	5.00	366.20	6.50	0.19	20	0.850
Rate of decrease in NDVI	0.03	3×10^{-3}	0.07	7×10^{-3}	5.30	20	<0.001
Maximum NDVI	0.34	0.01	0.60	7×10^{-3}	19.30	20	<0.001
Minimum NDVI	0.11	0.01	0.15	0.02	1.80	20	0.083

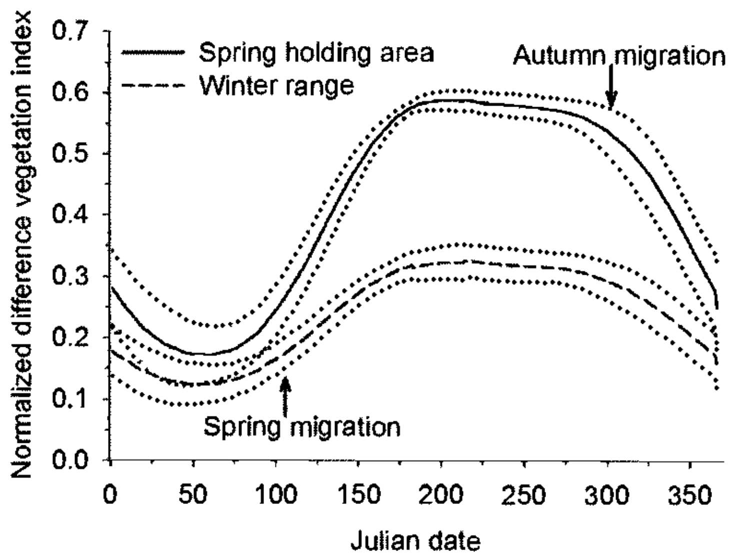


Fig. 3. Normalize difference vegetation index (NDVI) for winter range in Round Valley and the spring holding area (Fig. 1) for mule deer in the Sierra Nevada, California, USA, 1999–2009. Data are mean ±95% CI (dotted lines), and were scaled between 0 and 200. Arrows for autumn and spring migration correspond to average timing of seasonal migration.

winter weather and autumn migration.

Spring migration

During 1999–2009, mean snow depth adjacent to the spring holding area (Fig. 1) during April varied considerably from 0.13 to 87.7 cm (CV = 179%), while mean daily temperatures for April ranged from 0.54 to 5.4°C (CV = 60%). Mean date of departure from winter range for mule deer in Round Valley during 1999–2009 was 18 April, which was coincident with the onset of spring as precipitation declined and temperatures increased above 5°C (Fig. 2). Mean date of spring migration differed among years (Fig. 4), with early departure dates in 2002 and 2007, and delayed departure in 2005 and 2006. Mean date of spring migration did not exhibit a directional change during 1999–2009 ($\beta = -0.02$, $r^2 < 0.001$, $P = 0.98$). Spring migration (SD = 17.3 days) within years was significantly more synchronous than autumn migration (SD = 39.0 days; $t = 4.15$, $df = 20$, $P = 0.001$). Although there was no relation between annual metrics of climate and plant phenology, and synchrony of spring migration

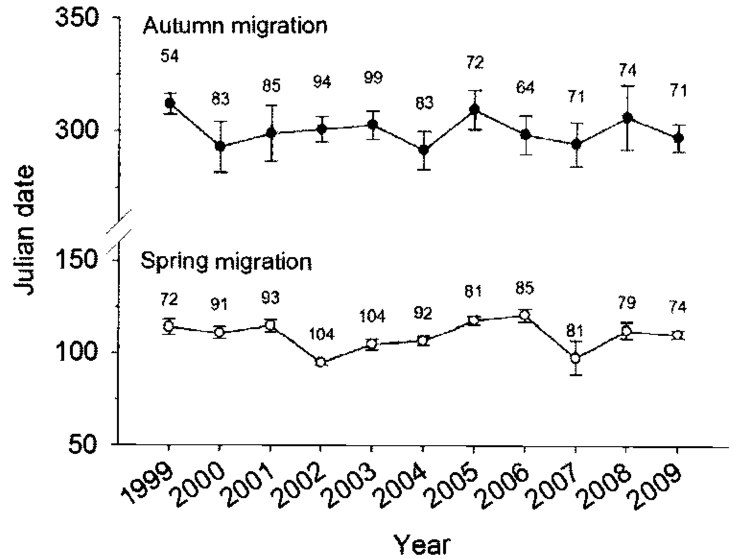


Fig. 4. Mean Julian date (±95% CI) of spring and autumn migration for female mule deer occupying winter range in Round Valley in the eastern Sierra Nevada, California, USA, 1999–2009. Values above means are number of deer monitored during each season.

(R^2_{adj} < 0.001, P = 0.77), a strong relationship existed between those metrics and annual mean date of migration (R^2_{adj} = 0.71, P = 0.014). Both SOI and Julian date of onset of spring were positively related to the mean date of spring migration, but SOI (β = 5.90, $r^2_{partial}$ = 0.20) accounted for slightly more variation in date of spring migration than the Julian date of onset of spring (β = 0.33, $r^2_{partial}$ = 0.15).

Interval-censored models for spring migration supported an effect of year, with models that contained year having nearly 100% of the Akaike weight (Table 2). The shape and magnitude of the daily probability of spring migration varied markedly among years, as did the date of initiation and trajectory of the cumulative proportion of deer departing winter range (Fig. 7). Of the variables we hypothesized to influence the timing of spring migration, only daily snow depth (PC1), daily NDVI, and daily ΔNDVI had high importance weights and model-averaged parameter estimates that differed from zero (Table 2). As absolute daily snow depth decreased with a concomitant increase in daily NDVI and a positive ΔNDVI, daily probability of departure from winter range increased. Indeed, years of low snow depth with early increases in NDVI resulted in earlier initiation and mean dates of spring migration (Fig. 8b), whereas late snowfall events delayed spring migration (Fig. 8a). Moreover, years with substantial snowfall and later green-up resulted in substantial delays in departure from winter range by mule deer (Fig. 8c). Based on model-averaged estimates of the cumulative proportion migrated in spring, the date at which 90% of adult females had completed spring migration ranged from 13 April in 2002, which was characterized by low snow depth with early advances in plant phenology (Fig. 7, 8b), to 3 May in 2006, when heavy snow pack delayed advances in plant phenology (Fig. 7, 8c).

Effects of life-history characteristics

Following the identification of the extrinsic variables that influenced patterns of seasonal migration of mule deer, we subset our data to include only those individuals for which we had complete data on life-history characteristics in each season. For autumn migration, we obtained data on location of summer residency (side of the Sierra crest), age (years), recruitment (presence of young-at-heel), and nutritional condition (ingesta-free body fat; IFBFat) in November for 312

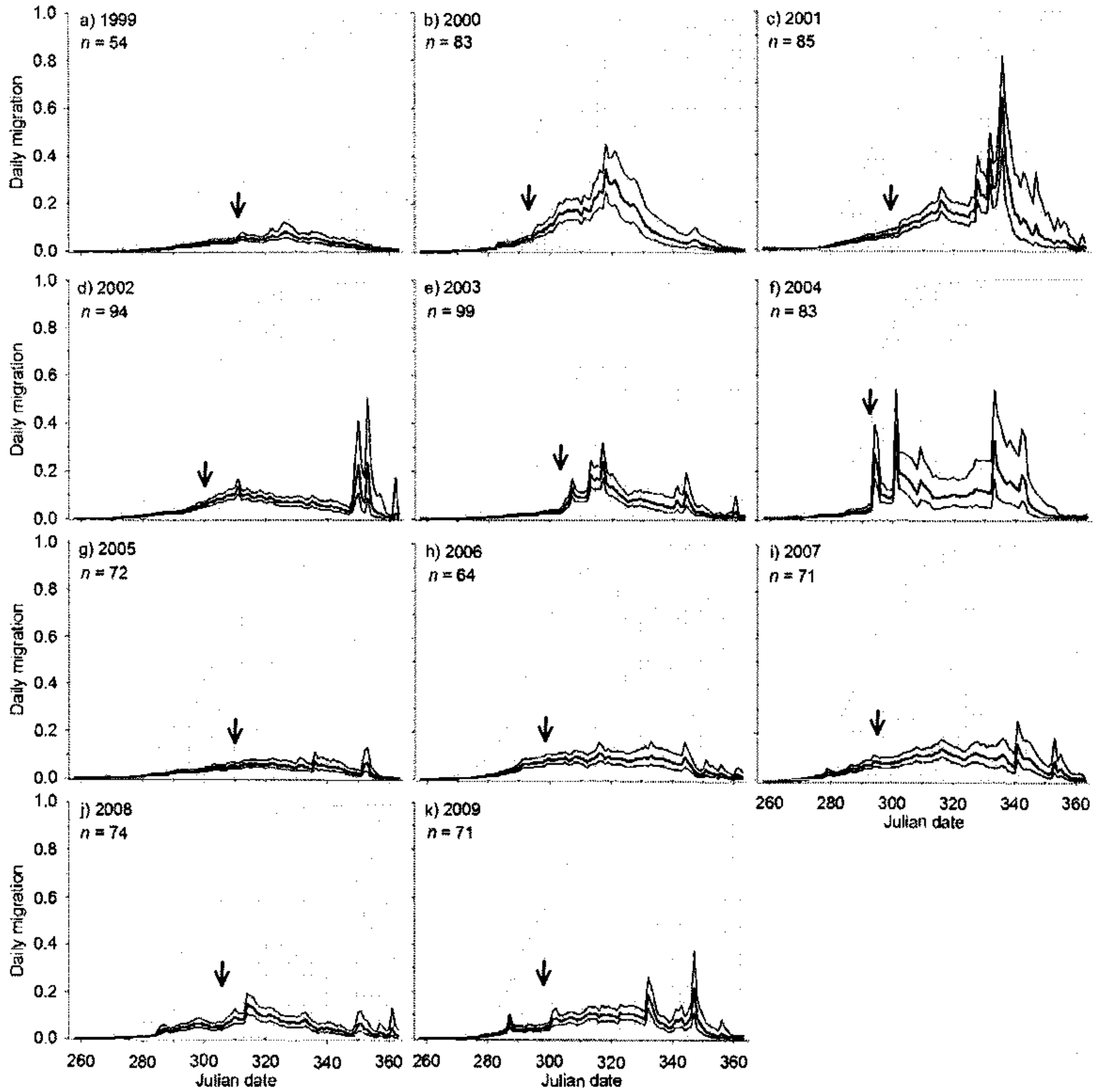


Fig. 5. Model-averaged estimates of the daily probability of migration (heavy line ±95% CI) and cumulative proportion migrated (shaded region) during autumn for adult (>1 year old) female mule deer relative to Julian date, Sierra Nevada, California, USA, 1999–2009. Black arrows indicate mean date of migration.

adult females during 7 years, 2002–2008. Of those females, 153 summered on the east side of the Sierra crest, and 159 on the west side. Age of females monitored in autumn ranged from 1.4 years to 15.4 years ($\bar{X} = 7.4$ years, SD = 2.8), and IFBFat ranged from 0.5% to 23.4% ($\bar{X} = 8.7\%$, SD = 5.3).

For spring migration, we obtained data on summer residency, age, fetal rate and IFBFat in March for 720 females during 11 years, 1999–2009. Of those females, 316 summered on the east-side of the Sierra crest and 404 summered on the west-side. Age of females monitored during spring ranged from 1.8 to 15.8 years ($\bar{X} = 6.8$ years, SD = 2.7), and fetal rate (number of fetuses per female) ranged from 0 to 3 ($\bar{X} = 1.6$, SD = 0.6). Ingesta-free body fat in March ranged from 0.5% to 15.5% ($\bar{X} = 5.1\%$, SD = 2.5), and was

Table 2. Model-averaged parameter estimates, 95% confidence intervals (95% CI), and Akaike importance weights for interval-censored models describing the relationship between the daily probability of autumn and spring migration of mule deer and 13 extrinsic variables, Sierra Nevada, California, USA, 1999–2009. Asterisks adjacent to parameter estimates indicate 95% CI do not overlap zero.

	Autumn				Spring			
		95% CI				95% CI		
Parameter	Estimate	Lower	Upper	Importance weight	Estimate	Lower	Upper	Importance weight
PC1	0.75*	0.12	1.37	0.85	−0.99*	−1.36	−0.62	1.00
PC2	0.22	−0.11	0.55	0.58	0.09	−0.03	0.20	0.59
PC3	−0.69*	−0.96	−0.41	1.00	0.13	−0.02	0.28	0.68
PC4	0.13*	0.01	0.24	0.84	1×10^{-3}	−0.04	0.04	0.26
PC5	−0.58*	−0.82	−0.35	1.00	0.06	−0.04	0.16	0.50
Degree-days	-2×10^{-3}	-6×10^{-3}	1×10^{-3}	0.51	-5×10^{-4}	-2×10^{-3}	9×10^{-4}	0.10
NDVI	0.72	−1.52	2.94	0.37	53.42*	46.02	60.78	1.00
ΔNDVI	3.20	−3.26	9.60	0.33	93.98*	28.42	159.32	0.99
Seasondate	-2×10^{-5}	-8×10^{-5}	2×10^{-5}	1×10^{-3}	-1×10^{-3}	-9×10^{-3}	6×10^{-3}	4×10^{-3}
ΔSeason	1×10^{-5}	-4×10^{-5}	7×10^{-5}	6×10^{-4}	n/a	n/a	n/a	n/a
SOI	8×10^{-4}	-8×10^{-4}	2×10^{-3}	1×10^{-3}	n/a	n/a	n/a	n/a
T	0.16*	0.13	0.18	1.00	0.11*	0.07	0.15	1.00
TT	-1×10^{-3}*	-1×10^{-3}	-1×10^{-3}	1.00	-1×10^{-3}*	-2×10^{-3}	-1×10^{-3}	1.00
Year	n/a	n/a	n/a	1.00	n/a	n/a	n/a	1.00

Notes: Factors in interval-censored models for seasonal migration included: daily snow depth (PC1), daily metric of change in snow depth (PC2), daily temperature (PC3), daily snowfall and precipitation (PC4), daily metric of change in temperature (PC5), cumulative degree days above or below 5°C for spring and autumn, respectively (degree-days), daily normalized difference vegetation index (NDVI), daily change in NDVI relative to previous 14 days (ΔNDVI), Julian date of start and end of season for spring and autumn respectively (Seasondate), rate of increase and decrease in NDVI at changing seasons for spring and autumn respectively (ΔSeason), mean of the southern oscillation index during 1 year previous to season (SOI), quadratic time trend (T and TT), and year (Year). Year was included as a nuisance parameter in models, however, the parameter estimates for each year are not biologically meaningful and were thus, not included.

significantly lower than IFBFat in November ($t = 14.4$, $df = 1{,}030$, $P < 0.001$).

Autumn migration.—Daily snow depth (PC1), absolute daily temperature (PC3), change in daily temperature (PC5), and the quadratic time trend all maintained their importance and significance for explaining the phenology of autumn migration in mule deer when life-history characteristics were included (Table 3). Daily snowfall (PC4) maintained a high importance weight, but the model-averaged parameter estimate was no longer significant. In addition, the effect of year as a nuisance parameter declined substantially in importance, compared with the first stage of the analysis that included only extrinsic variables (Table 3). Partitioning our dataset from 11 to 7 years may have affected that result; nevertheless, 2002–2008 included years with both extremes in weather patterns and expected probability of migration (Fig. 5).

Mean date of autumn migration was nearly identical between females with young-at-heel and those without young (Fig. 9a). Indeed, the model-averaged parameter estimate for recruitment status was not significant (Table 3). Three other life-history characteristics of individual mule deer, however, were highly important and significant for explaining timing of autumn migration: summer residency, age, and nutritional condition. Mean date of autumn migration between females that summered on either side of the Sierra crest approached a significant difference during most years, with east-side females generally exhibiting earlier dates of migration (Fig. 9b). Accordingly, interval-censored models of migration indicated that summer residency affected the daily probability of migration with east-side females arriving to Round Valley earlier than west-side females (Table 3). Older females had a lower daily probability of migration and, thus, tended to migrate to winter range later than younger females (Table 3). Lastly, ingesta-free body fat of individual females was negatively related to the daily probability of migration. Therefore, females in poor nutritional condition arrived to winter range earlier than females in good nutritional condition.

For example, on Julian date 300 during 2005, predictive models indicated that only 11% of young females in poor nutritional condition

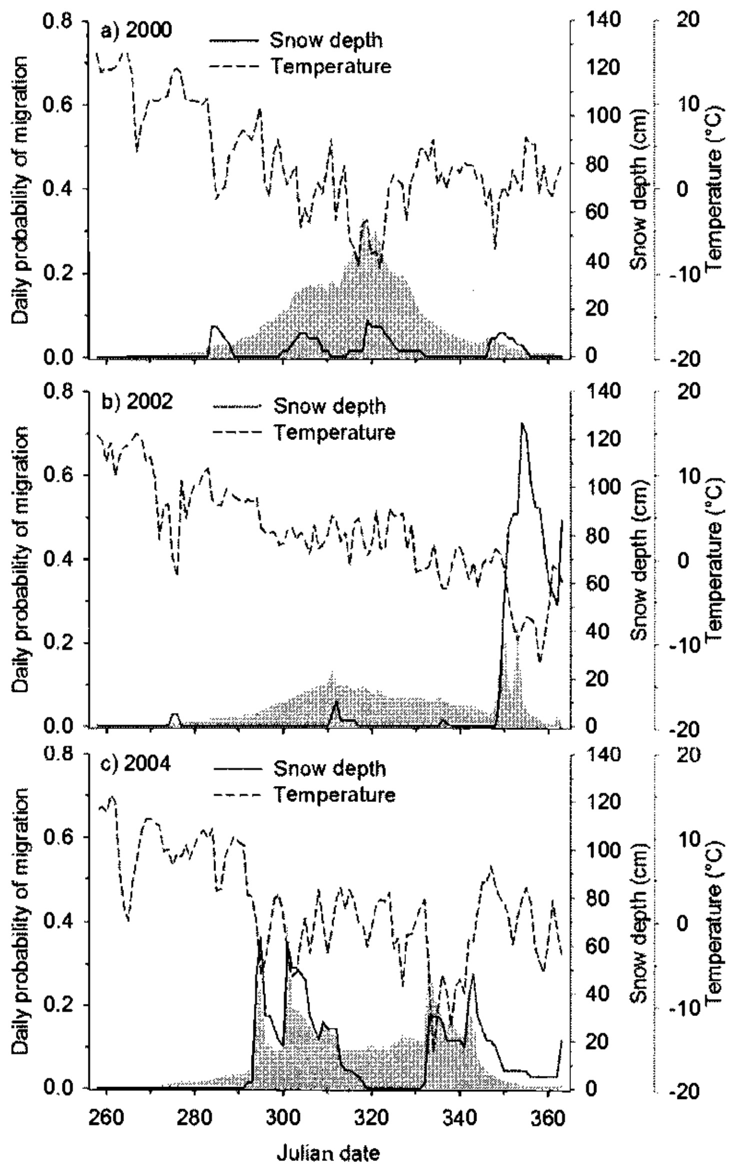


Fig. 6. Model-averaged estimates of the daily probability (shaded region) of autumn migration for adult (>1 year old) female mule deer, daily snow depth (cm), and average daily temperature relative to Julian date, Sierra Nevada, California, USA, during 3 years exhibiting differences in severity of autumn weather: 2000 (a), 2002 (b), and 2004 (c).

remained on summer range compared with 51% of old females in good nutritional condition (Fig. 10a). Furthermore, daily probability of migration for east-side females was higher than west-side females, with further effects of nutritional condition (Fig. 10d). On Julian date 300 during 2007, 92% of east-side females in poor nutritional condition had migrated to winter range, whereas 74% of west-side females in similar nutritional condition had migrated (Fig. 10c).

Spring migration.—In the second stage of the analysis that included life-history characteristics,

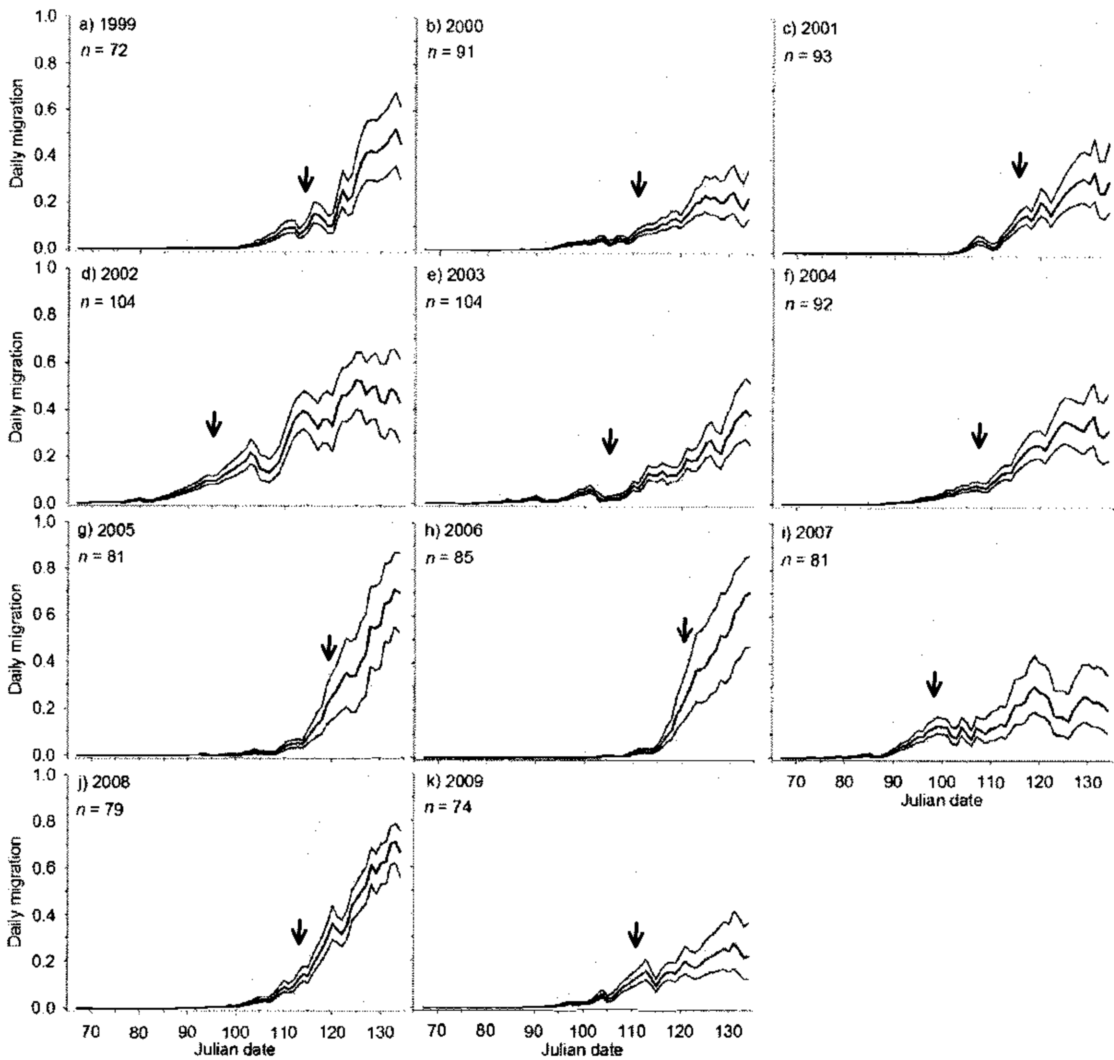


Fig. 7. Model-averaged estimates of the daily probability of migration (heavy line ±95% CI) and cumulative proportion migrated (shaded region) during spring for adult (>1 year old) female mule deer relative to Julian date, Sierra Nevada, California, USA, 1999–2009. Black arrows indicate mean date of migration.

departure from winter range by mule deer in spring was coincident with decreased snow depth (PC1) and increasing plant growth (NDVI and ΔNDVI), which was identical to the first stage of modeling that included only extrinsic factors. We did not detect significant effects of individual life-history characteristics on the daily probability of migration in spring (Table 4). Based on importance weights, summer residency, nutritional condition, and fetal rate were of negligible value in explaining patterns of spring migration. Likewise, mean date of departure from winter range was nearly identical for east-side and west-side females (Fig. 9a). Although the importance weight for age was >0.7, the model-average parameter estimate overlapped zero (Table 4).

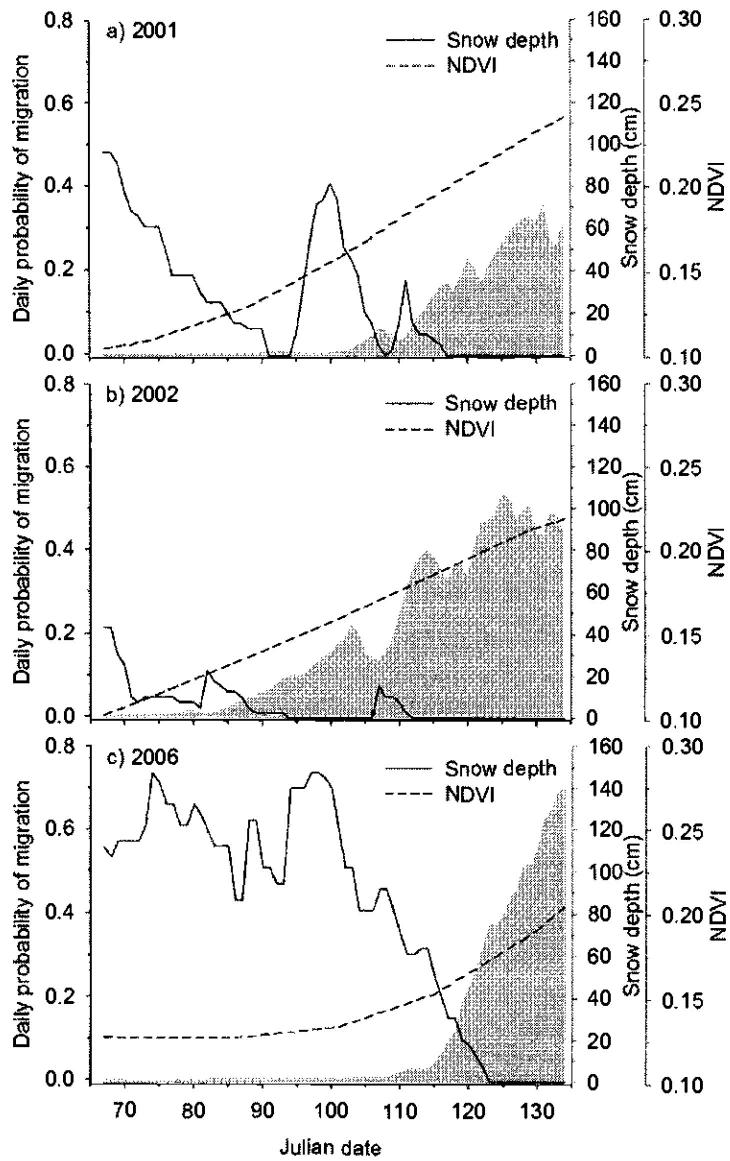


Fig. 8. Model-averaged estimates of the daily probability (shaded region) of spring migration for adult (>1 year old) female mule deer, daily snow depth (cm), and daily normalized difference vegetation index (NDVI) relative to Julian date, Sierra Nevada, California, USA, during 3 years exhibiting different patterns of snow melt and plant phenology: 2000 (a), 2002 (b), and 2006 (c).

Discussion

Long-term studies across a range of environmental conditions may be the key to understanding large-scale effects of climate on the phenological events of animals (Fieberg et al. 2008), a daunting task, especially for large, vagile mammals (McCullough 1979, Pierce et al. 2000, Stewart et al. 2005). Long-term and intensive study of a population of mule deer in the Sierra Nevada, California, USA, allowed us to monitor patterns of migration during years that encom-

Table 3. Model-averaged parameter estimates, 95% confidence intervals (95% CI), and Akaike importance weights for interval-censored models describing the relationship of the daily probability of autumn migration of mule deer with six extrinsic variables (variables that differed from zero in first stage of modeling), and four individual-based covariates with a quadratic term for age, Sierra Nevada, California, USA, 2002–2008. Asterisks adjacent to parameter estimates indicate 95% CI do not overlap zero.

Parameter	Autumn			
		95% CI		
	Estimate	Lower	Upper	Importance weight
PC1	0.87*	0.40	1.35	0.97
PC3	−0.99*	−1.39	−0.59	1.00
PC4	0.10	−0.24	0.04	0.64
PC5	−0.75*	−1.03	−0.47	1.00
T	0.20*	0.13	0.26	1.00
TT	-1×10^{-3}*	2×10^{-3}	-8×10^{-4}	1.00
Year	n/a	n/a	n/a	0.35
Age	−0.07*	−0.13	−0.01	0.98
Age^2	1×10^{4}	-2×10^{3}	2×10^{3}	0.22
Summer Residency	0.66*	0.36	0.95	1.00
IFBFat	−0.04*	−0.06	−0.01	0.94
Recruitment	3×10^{-3}	-5×10^{-3}	0.01	0.03

Notes: Extrinsic factors in interval-censored models for autumn migration with individual covariates included: daily snow depth (PC1), daily temperature (PC3), daily snowfall and precipitation (PC4), daily metric of change in temperature (PC5), quadratic time trend (T and TT), and year (Year). Year was included as a nuisance parameter in models, however the parameter estimates for each year are not biologically meaningful and were thus, not included. Individual covariates included: age in years (Age), side of Sierra crest occupied during summer (Summer residency), nutritional condition in November measured as ingesta-free body fat (IFBFat), and the presence or absence of young-at-heel in autumn (Recruitment).

passed a wide array of severity in patterns of weather, and consequently, plant phenology. This dataset allowed us to disentangle the influence of a suite of climatic and life-history variables thought to be responsible for migratory behavior (Table 5). These hypotheses included effects of broad-scale climate, weather patterns, plant phenology, and the effects of life-history characteristics on migration of individual deer (Table 5).

In support of our hypotheses, patterns of local weather and plant phenology were related to the timing of seasonal migration in mule deer, with some detectable effects of large-scale climate (Table 5). Although annual mean date of autumn migration was not statistically different among years, the phenological patterns of autumn migration among individuals varied markedly and were driven by the severity of arriving winter weather. In contrast, mean date of spring migration differed among years and was related to the southern oscillation index (SOI), and onset of spring green-up. Within years, phenological patterns of spring migration were more synchronous than autumn migration, and were clearly associated with snow melt and plant phenology. We also hypothesized, however, that life-history characteristics of individual females would influence their patterns of seasonal migration (Table 5). In accordance with that hypothesis, patterns of autumn migration were affected by location of summer residency, age, and nutritional condition of individual females. Females that summered on the east side of the Sierra crest tended to arrive at Round Valley earlier than females that summered on the west side (Table 5). In addition, older females and those in good nutritional condition remained on summer ranges longer in autumn compared with young females and those in poor nutritional condition (Table 5). During spring migration, however, life-history characteristics of individual females had little influence on timing of migration, which was closely linked to snow depth and plant phenology (Table 5).

The acquisition of continuous data on timing of migration or other life-history events under field conditions is challenging and sometimes impossible to achieve (Garrott et al. 1987, Johnson et al. 2004, Pulido 2007, Fieberg et al. 2008, Meunier et al. 2008), unless animal location data are obtained from collars with global positioning system technology (White et al. 2010). Because of logistical constraints, we were unable to monitor presence or absence of mule

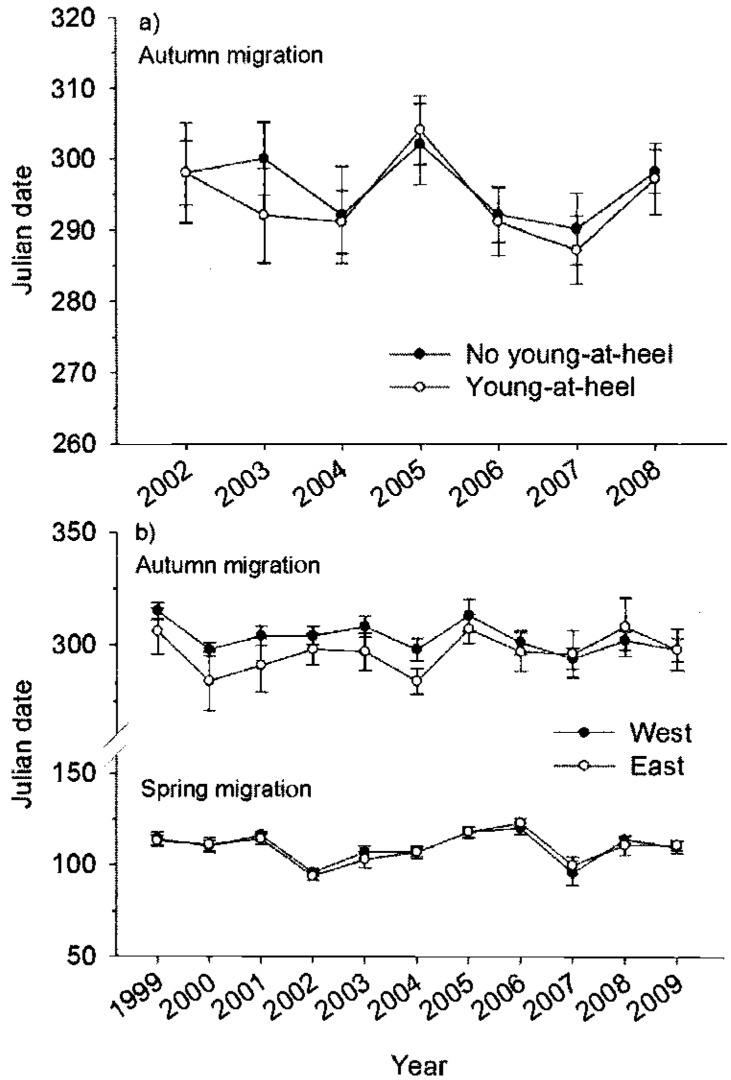


Fig. 9. Mean Julian date (±95% CI) of autumn migration of mule deer (a) relative to reproductive status, 2002–2008; and (b) mean Julian date (±95% CI) of spring and autumn migration relative to the location of summer residency (east or west of the crest of the Sierra Nevada), 1999–2009 for mule deer occupying winter range in Round Valley in the eastern Sierra Nevada, California, USA.

deer on winter range on a daily basis or at regularly spaced intervals (bins). The usual technique for coping with the absence of known dates of life-history events has been to assign the event date to the median date within the interval the event was known to occur (Nelson 1995, Sabine et al. 2002, Meunier et al. 2008). That procedure, however, often underestimates variance, may affect the estimates of regression parameters, and thus, bias their interpretation (Johnson et al. 2004, Fieberg and DelGiudice 2008). We used a procedure for estimating the timing of life-history events developed by Johnson et al. (2004), which is unbiased and allows for unequal time intervals (bins) in sampling, thereby providing a valid comparison of the mean dates and synchrony among years or groups of animals.

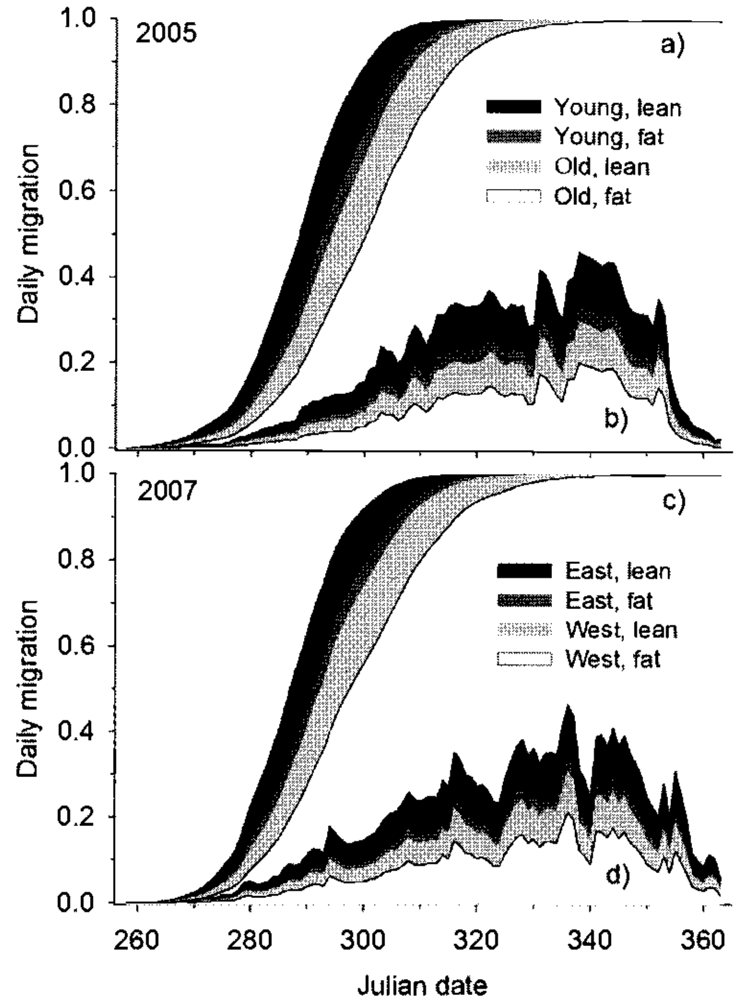


Fig. 10. Model-averaged estimates of the cumulative proportion migrated (a,c) and daily probability of migration (b,d) during autumn for adult (>1 year old) female mule deer illustrating the effects of age (young = 2.4 years old, old = 12.4 years old) and nutritional condition (lean = 4% IFBFat, fat = 18% IFBFat) during 2005 (a, b), as well as the effects of summer residency (east or west of the crest of the Sierra Nevada) and nutritional condition during 2007 (c, d), Sierra Nevada, California, USA.

Despite the marked variability in the timing of migration among individuals within a single population (Brinkman et al. 2005, Fieberg et al. 2008, Grovenburg et al. 2009), seasonal migration often is interpreted at the population level by using point estimates or thresholds in relation to summarized weather patterns. Consequently, the distribution of migratory events among individuals within a season has received little attention until recently (e.g., Meunier et al. 2008, Fieberg et al. 2008). Failure to incorporate the broad range of heterogeneity in timing of migration among individuals likely has hampered our understanding of the factors that affect the phenological patterns of migration of large herbivores. Indeed, analyses at the level of the population fail to ascertain the various migratory strategies among individuals or to identify the selective pressures operating on individuals (Williams 1966, Dingle 2006). To overcome the limitations of analyses at

Table 4. Model-averaged parameter estimates, 95% confidence intervals (95% CI), and Akaike importance weights for interval-censored models describing the relationship of the daily probability of spring migration of mule deer with five extrinsic variables (variables that differed from zero in first stage of modeling), and four individual-based covariates with a quadratic term for age, Sierra Nevada, California, USA, 1999–2009. Asterisks adjacent to parameter estimates indicate 95% CI do not overlap zero.

	Spring			
		95% CI		
Parameter	Estimate	Lower	Upper	Importance weight
PC1	−0.97*	−1.29	−0.64	1.00
NDVI	61.37*	61.23	61.50	1.00
ΔNDVI	99.57*	28.18	170.97	0.95
T	0.11*	0.06	0.16	1.00
TT	-1×10^{-3}*	-2×10^{-3}	-1×10^{-3}	1.00
Year	n/a	n/a	n/a	1.00
Age	−0.02	−0.07	0.03	0.76
Age^2	-4×10^{-4}	-2×10^{-3}	1×10^{-3}	0.15
Summer residency	0.01	−0.02	0.03	0.08
IFBFat	2×10^{-3}	−0.01	0.02	0.34
Fetalrate	-2×10^{-3}	−0.04	0.04	0.23

Notes: Extrinsic factors in interval-censored models for spring migration with individual covariates included: daily snow depth (PC1), daily normalized difference vegetation index (NDVI), daily change in NDVI relative to previous 14 days (ΔNDVI), quadratic time trend (T and TT), and year (Year). Year was included as a grouping variable in models, however the parameter estimates for each year are not biologically meaningful and were thus, not included. Individual covariates included: age in years (Age), side of Sierra crest occupied during summer (summer residency), nutritional condition in March measured as ingesta-free body fat (IFBFat), and fetal rate in March (Fetalrate).

Table 5. Hypotheses and general predictions tested regarding timing of migration for mule deer in the Sierra Nevada, California, USA, during autumn and spring, and the relative support (Yes or No) and direction of the relationship (+ or −) where relevant, 1999–2009.

Hypotheses	Predictions	Autumn	Spring
Broad-scale climate	SOI	No	Yes (+)
Weather patterns	Snow depth	Yes (+)	Yes (−)
	Snowfall	Yes (+)	No
	Temperature	Yes (−)	No
Plant phenology	Degree days	No	No
	NDVI	No	Yes (+)
	Onset of season	No	No
Life-history characteristics	Age	Yes (−)	No
	Nutritional condition	Yes (−)	No
	Summer residency	Yes	No
	Recruitment - Fetalrate	No	No

Notes: Abbreviations are: southern oscillation index (SOI), and normalized difference vegetation index (NDVI). Degree days represent the cumulative degree days above or below 5°C for spring (growing-degree days) and autumn (senescent-degree days), respectively.

the population level, we employed interval-censored, time-to-event models in program MARK, which incorporated the distribution of migratory events to assess their relationship to annual metrics of climate and plant phenology, time-specific covariates of local weather patterns and plant phenology, and allowed the integration of covariates specific to each individual monitored (sensu Dinsmore et al. 2002). Although there are potential weaknesses in using interval-censored models in program MARK, which include the absence of goodness-of-fit testing and the inability to account for repeated sampling of individuals between years, the congruence between migration models and direct hypothesis testing (Johnson et al. 2004) support the legitimacy of this approach.

Autumn migration

The initiation and daily probability of migration for mule deer during autumn was affected by changes in the severity of winter weather, namely increasing snow depth with coincident cooling temperatures (Fig. 6). Increased snow depth with concurrent reduction in ambient temperature results in a concomitant increase in the energetic costs associated with thermoregulation and locomotion in cervids (Telfer and Kelsall 1979, Parker et al. 1984). Furthermore, depth of snow experienced by large herbivores has direct effects on availability of forage (Fancy and White 1985), thereby affecting nutritional condition and probability of winter survival (Garroway and Broders 2005). During most years, however, a large proportion ($\geq$43%) of our marked animals already had migrated to winter range prior to the onset of severe winter weather (i.e., occurrence of snow with average temperatures below freezing) when daily probability of migration was highest (Fig. 5). Likewise, white-tailed deer commonly migrate in response to, and prior to, the accumulation of substantial snow (Nelson 1995, Sabine et al. 2002, Brinkman et al. 2005, Grovenburg et al. 2009).

By delaying autumn migration, deer risk being "trapped" on summer range by sudden winter storms that would increase nutritional, thermoregulatory, and locomotive costs (Parker et al. 1984), and may increase susceptibility to predation or other sources of mortality (Berger 1986, Patterson and Messier 2000, Bleich and Pierce 2001). Nevertheless, individuals that delay autumn migration, but successfully arrive on winter range, may benefit from a greater abundance, diversity, and higher-quality forage on summer range (Albon and Langvatn 1992, Mysterud et al. 2001). Forage quality in our study, as indicated by NDVI, remained significantly higher on summer range throughout autumn (Fig. 3), which supports the energetic advantage of mule deer remaining on summer ranges as long as possible. Even slight changes in diet quality through time can have multiplicative effects on the net energy available for somatic investment, growth, and reproduction (White 1983, Parker et al. 2009).

Spring migration

Mean date of departure from winter range by mule deer in the eastern Sierra Nevada differed over 11 years in response to the duration of snow cover and the timing of plant green-up. We documented strong association between daily snow depth and the probability of spring migration by mule deer. The parameter estimate for the relationship between change in snow depth (PC2) and daily migration for mule deer, however, was not significant, which indicated that the absolute depth of snow was more important in affecting long-distance movement by mule deer than was the rate of snow accumulation or disappearance (Table 2). Likewise, delayed spring migration following winters with heavy snow pack, and early migration in years with low snow pack and early vegetation green-up is common among large herbivores (Garrott et al. 1987, Nelson 1995, Brinkman et al. 2005, Grovenburg et al. 2009, White et al. 2010). The effect of snow pack on large herbivores can severely restrict mobility and exhaust energy reserves (Parker et al. 1984). During all years except 2003, when a late snowstorm occurred in mid-April, mean date of spring migration occurred when snow depth on the spring holding area was $\leq$12 cm. That snow depth is well below the point at which energy costs of locomotion for mule deer increase significantly (25 cm), regardless of the density of snow (Parker et al. 1984).

Migration to higher elevation during spring may allow the selection of the same plant at an earlier phenological stage (Klein 1965, Morgantini and Hudson 1989), when protein and digestibility are highest (Van Soest 1994, Barboza et al. 2009, Parker et al. 2009). Timing of altitudinal migration of red deer and North American elk (*Cervus elaphus*) coincided with the phenological delay in emergent vegetation at higher elevation (Morgantini and Hudson 1989, Boyce 1991, Albon and Langvatn 1992). Multiple altitudinal movements by golden takin (*Budorcas taxicolor*) in China were determined by the corresponding fluctuations in plant phenology and solar radiation (Zeng et al. 2010). Likewise, female mule deer departed winter range as NDVI began to increase and, thereafter, the daily probability of migration increased in response to both the absolute and daily change in NDVI (Table 2; Fig. 8).

Spring migration for female mule deer was nearly twice as synchronous as autumn migration (Fig. 4). Nutritional demands of pregnant females increase throughout gestation, with most fetal growth (>90%) occurring during the last one-third of gestation (Moen 1978, Robbins and Robbins 1979, Pekins et al. 1998). Inadequate nutrition during gestation may result in fetal loss (Verme 1965), low birth weight and reduced probability of survival of young (Keech et al. 2000, Lomas and Bender 2007), and life-long consequences on the physical characteristics and quality of the individual (Hamel et al. 2009, Monteith et al. 2009). Extended duration of confinement on a traditional winter range can lead to depletion of available browse resulting in increased competition for limited forage (Nicholson et al. 2006). Mule deer wintering in Round Valley exhibited progressive shifts in diet from their main winter forage (*Purshia tridentata*) to forage of low nutritional value (*Artemesia tridentata*) as winter progressed and as population density increased (Kucera 1997, Pierce et al. 2004). Therefore, departure from winter range as soon as snow cover and foraging conditions allow was probably advantageous for mule deer in Round Valley.

Effects of life-history characteristics

The general stimulus for autumn migration is thought to be severe winter weather (Kucera 1992, Sabine et al. 2002, Brinkman et al. 2005, Grovenburg et al. 2009). The great variation among individuals within a single population, however, cannot be explained by this factor alone, especially because weather patterns generally are consistent across local areas. We tested the hypothesis that life-history characteristics of individuals would affect the timing of seasonal migration by incorporating individual-based covariates into interval-censored models. Although individual life-history characteristics were not related to timing of spring migration, location of summer residency, age, and nutritional condition were strongly related to the timing of autumn migration by female mule deer (Table 3).

Females that summered on the east-side of the Sierra crest generally arrived on winter range earlier than west-side females (Fig. 10b). Females inhabiting the west side occupied vast expanses of the Sierra Nevada, and migrated farther than females that occupied the more arid landscape on the east side of the Sierra crest (Kucera 1992). We do not believe greater distances migrated by females from the west side of the Sierra crest were responsible for their delayed arrival on winter range. Although autumn migration is typically rapid with little delay following severe weather (Kucera 1992), females summering on the west side of the Sierra crest may take advantage of comparatively milder conditions after crossing the crest for foraging and resting before proceeding to winter range (Sawyer et al. 2009). Likewise, Mysterud (1999) and White et al. (2010) reported little correlation between the timing of autumn migration and distance migrated in roe deer (*Capreolus capreolus*) and North American elk, respectively. The absence of a relationship between location of summer residency and the phenology of spring migration (Table 4) implies that individuals respond to their local environment. The population of mule deer occupied similar habitat within 90 km^2 in Round Valley during winter, whereas habitats and environmental conditions on summer range, which encompassed >2,800 km^2, differed markedly on either side of the Sierra crest (Bleich et al. 2006). We postulate that behavioral responses of individuals are implemented at fine-scales in the local environment they occupy; this pattern, in conjunction with individual life-history characteristics, holds the greatest potential to influence the timing of seasonal migration.

Understanding age-specific patterns in life-history traits remains a central issue in the ecology of iteroparous organisms (Stearns 1992, Nussey et al. 2008). The terminal-investment hypothesis predicts that mothers should exhibit increased investment in reproduction as they age in relation to their residual reproductive value (Clutton-Brock 1984, Bercovitch et al. 2009). Old female (sensu Gaillard et al. 2000) mule deer in the Sierra Nevada risked encountering severe weather by delaying autumn migration (Fig. 10), and were thus risk-prone (Stephens and Krebs 1986) with respect to the potential loss of foraging opportunities as a result of deep snow. Consequently, old females occupied summer range longer, which provided increased diversity and higher quality forage (Fig. 3), along with less intraspecific competition, when compared with the limited forage and high-density of animals on winter range (Morgantini and Hudson 1989, Albon and Langvatn 1992, Kucera 1992, Pierce et al. 2004). Conversely, young females were risk-averse (sensu Stephens and Krebs 1986) and tended to arrive on winter range earlier in autumn (Fig. 10), ostensibly trading off risk of early winter storms on summer range against obtaining lower-quality, but predictable forage on winter range. Indeed, those age-specific patterns of migration support the terminal-investment hypothesis (Clutton-Brock 1984, Stearns 1992), where old females attempt to maximize nutritional gain in support of reproduction, in spite of increased risk of mortality.

The linear relationship between age and timing of autumn migration (Table 3), however, also supports an experiential explanation. Increased experience with age often is associated with enhanced reproductive performance in large herbivores (Cameron et al. 2000, Gaillard et al. 2000, Weladji et al. 2006; 2010), as well as the potential for improved knowledge of spatial and temporal patterns in the distribution and availability of forage (Mirza and Provenza 1992, Ortegareyes and Provenza 1993). Additional experience with weather patterns in autumn and distribution of forage may have allowed older females to enhance nutritional gain by delaying autumn migration (White 1983) without a detriment to survival, because older females may have better knowledge of the true risk associated with delayed migration. Although we failed to document mortality that was related to delaying autumn migration over 11 years (based on monitoring of collared individuals), late autumn migration can have fatal consequences (Berger 1986, Bleich and Pierce 2001). Despite the impending risk of mortality, older females delayed autumn migration, which could be explained by a combination of a more comprehensive knowledge of true risk, and differential strategies relative to residual reproductive value.

Body fat is the primary energy reserve of the body and is related to multiple demographic factors of large herbivores including timing of breeding (Cook et al. 2004), pregnancy and twinning rate (Keech et al. 2000, Stewart et al. 2005), gestation length (Garcia et al. 2006), birth mass (Keech et al. 2000, Lomas and Bender 2007), and survival (Cook et al. 2004, Bender et al. 2007). Although demographic factors may be directly affected by animal nutrition, we documented that behavioral decisions regarding when to migrate during autumn also had nutritional underpinnings for mule deer. Female mule deer that were nutritionally stressed (sensu Cook et al. 2007) exhibited risk-averse behavior by migrating to winter range early (Fig. 10), where forage resources were likely less palatable and diverse, but more predictable. In contrast, migratory patterns for birds reveal delayed migration for individuals in poor physical condition (Mitrus 2007, Pulido 2007). Energy expenditure and catabolism of somatic reserves associated with thermoregulation and locomotion in large herbivores, however, increases with reduced temperature, rising snow depth, and with the decline in availability and quality of forage (Mautz 1978). In response to those conditions, individuals use various physiological, morphological, and behavioral adaptations to conserve energy and promote survival (Moen 1976, Mautz 1978).

Parker et al. (2009) proposed that behavioral strategies for large herbivores are based on lessening the primary detriment to fitness and that the basis of the strategies is nutritional. Mule deer in the Sierra Nevada may be capable of sequestering better forage resources on summer range in autumn by delaying migration to winter range; however, the primary detriment to adult females in poor nutritional condition may be mortality if they encounter deep snow that increases energetic costs and nutritional loss. We hypothesize that the lower energetic buffer against the potential loss of forage and energetic costs of locomotion in deep snow were responsible for the negative relationship between the daily probability of autumn migration and nutritional condition in mule deer (Table 3; Fig. 10). Similarly, bison (*Bison bison*) arrived earlier to low-elevation winter range as population density increased in Yellowstone National Park, USA, likely in response to negative effects of density dependence on nutritional condition (Plumb et al. 2009).

For spring migration, Garrott et al. (1987) hypothesized that deer must improve their physiological condition prior to incurring the energetic costs associated with migration, which aligns with predictions based on the somatic control of avian migration (Mitrus 2007, Pulido 2007). Contrary to that hypothesis, we observed no relation between date of departure from winter range and nutritional condition, and documented the opposite pattern in autumn. Indeed, no life-history characteristic that we measured was strongly associated with the timing of spring migration (Table 4). Likewise, White et al. (2010) reported little support for effects of age or pregnancy status on timing of spring migration in North American elk. Winter foraging conditions for most large herbivores act as an equalizer by lowering the level and variability of nutritional condition of all deer by spring (Mautz 1978, Barboza et al. 2009, Parker et al. 2009), which likely reduces individual variability in timing of migration and lessens the flexibility in advantageous strategies between individuals during spring migration. Our results indicate that spring migration likely is caused by a direct response to seasonal stimuli of receding snow and new plant growth, and is equally advantageous for female mule deer regardless of age, destination (summer residency), fetal rate, or nutritional condition.

Climate

Phenological traits of both plants and animals are sensitive to climatic processes, with several characteristics advancing in chronology in response to climate change. For example, avian migration is related to plant and invertebrate phenology, with earlier spring migrations corresponding to earlier arrival of spring (Forchhammer et al. 2002, Sparks et al. 2005, Jonzén et al. 2006, Carey 2009). Indeed, the ability of species to advance or recess their timing of migration may have a direct effect on their ability to persist in the face of a changing climate (Walther et al. 2002, Møller et al. 2008, Carey 2009). Mule deer in our study adjusted their timing of seasonal migration to correspond with climatic conditions and plant phenology (Fig. 6, Fig. 8), which may enhance fitness when climate change alters seasonal dynamics of forage quality and availability, so long as that change is not too severe.

In some instances, timing of parturition by large herbivores may respond rapidly to effects of climatic warming on plant phenology (Rachlow and Bowyer 1991, Loe et al. 2005). Timing of migration and parturition by caribou in West Greenland, however, has failed to keep pace with the advancement of the plant-growing season; consequently, recruitment of young has declined fourfold during a single decade (Post and Forchhammer 2008). Plasticity in timing of migration may allow large herbivores to partially compensate for trophic mismatches between seasonal peaks in resource availability and peak energetic demands for reproduction, when phenological patterns of reproduction are less plastic (Post and Forchammer 2008). Plasticity in migration may be an adaptive trait (Gotthard and Nylin 1995), because it likely holds fitness consequences in a changing climate. For example, Møller et al. (2008) reported that populations of migratory birds that failed to exhibit a phenological response to climate change were declining. Species that coordinate life-history phenomena with patterns that remain unaffected by climate change, such as photoperiod, are more likely to encounter trophic mismatches because they fail to synchronize with food supplies that are affected by climate (Carey 2009). Our data indicate, however, that large herbivores may be capable of buffering negative effects of shifts in climate, because patterns of migration are flexible and individuals are responsive to environmental conditions.

Despite clear relationships between the phenological patterns of migration and local weather, timing of autumn migration by mule deer in the Sierra Nevada was influenced by life-history characteristics. Failure to consider effects of nutrition and other life-history traits on phenological patterns of mammals may confound relationships associated with outcomes expected from climate change. For example, progressive changes in nutritional condition or age within a particular population, as a result of density-dependent feedbacks (McCullough 1979, Kie et al. 2003), may yield directional shifts in the timing of migration, even in the absence of a shift in climate (e.g., Plumb et al. 2009). Even in a stochastic environment, fluctuations in population size with bottom-up underpinnings yield dramatic fluctuations in nutritional condition and age structure (Kie et al. 2003, Bowyer et al. 2005), both of which influenced phenological patterns of autumn migration for mule deer (Table 5, Fig. 10). Consequently, climatic change may affect phenological patterns of migration directly, through seasonal weather patterns (Table 1), and indirectly when climatic effects on migration are mediated through life-history characteristics (Fig. 10).

Recently, Barnett et al. (2008) provided evidence of anthropogenic effects on the changes in snow pack and the hydrological regime in the western United States. Between 1950 and 1999, precipitation in montane regions in the western US exhibited a general shift from snow to rain (Knowles et al. 2005), declining snow pack (Hamlet et al. 2005), and snowmelt occurred progressively earlier (Hamlet et al. 2005, Mote et al. 2005). If the occurrence of heavy snowfall wanes with the changing climatic regime, risk of delaying departure from summer range lessens and the nutritional benefits of remaining on summer range increase. Hence, individuals that exhibit risk-prone behavior by delaying departure from summer range will sequester more and higher-quality resources, likely yielding greater fitness than individuals arriving on winter range early. As a result, differences in nutritional condition among individuals within a population may inherently determine the direction of selection with respect to migratory strategies. Likewise, the relation between nutritional condition and the timing of migration, as well as the fitness consequences of that timing, are well documented in birds (Newton 2006, Pulido 2007). Although delayed arrival to and early departure from winter range could bear the cost of encountering inclement weather conditions, individuals employing such tactics may benefit from greater abundance and diversity of food (Albon and Langvatn 1992), yielding higher fitness in the face of a warming climate. Partial migration is common in some populations of large herbivores and, if a warming climate does not compel migration to winter range, we hypothesize that differential selection among individuals employing such strategies will favor the evolution and maintenance of partial migration with permanent residents on summer range (Kaitala et al. 1993).

Phenological relationships for autumn migration also are less conclusive in other taxa compared with spring migration (Walther et al. 2002, Adamik and Pietruszkova 2008, Carey 2009), perhaps because patterns of autumn migration are confounded by life-history characteristics. Thus, we recommend obtaining long-term data on the timing of spring migration to assess the effects of climate change on those phenological patterns because patterns of spring migration may be less confounded by individual life-history characteristics and provide more definitive patterns with respect to climate change. Furthermore, effects of nutritional condition on the timing of migration and how that timing, in turn, influences nutrition and selective pressures among various strategies, requires further investigation across other species of large herbivores.

Conclusions

The persistent movement of thousands of animals across large spatial scales on a seasonal basis is among the most spectacular and well-recognized phenomena of the natural world. Nevertheless, long-distance migrations are being altered by burgeoning human populations and ensuing disturbance and barriers to movement, including habitat loss (Berger 2004, Bolger et al. 2008). In addition, phenological patterns of seasonal migration are likely to be affected by climate change (Walther et al. 2002, Stenseth et al. 2003, Bolger et al. 2008). The need for effective conservation of animal migration warrants a more complete understanding of the biology of this complex behavior (Bolger et al. 2008, Wilcove 2008). We employed an extension of an analytical approach used for survival analyses (Dinsmore et al. 2002, Fieberg and DelGiudice 2008) to consider the distribution of migratory events among individuals and assess the effects of life-history characteristics on timing of migration, which has heretofore received little attention. This methodology should be useful for assessing questions related to timing in most migratory species. We documented that autumn migration of mule deer in the Sierra Nevada was highly variable and associated with patterns of winter weather (cold and snow), whereas spring migration was coincident with decreasing snow depth and advances in plant phenology (Table 5). Although we did not observe directional changes in chronology of spring or autumn migration during our 11-year study, the association between seasonal migration and environmental conditions provides convincing evidence that those migratory patterns may be altered by global climate change. Nevertheless, the close association of the phenology of seasonal migration with environmental conditions may reduce the potential for migratory patterns to be mismatched (sensu Post and Forschhammer 2008) with food availability as climate change alters seasonal patterns of plant growth.

The response of individual mule deer to environmental conditions during autumn was influenced by their life-history characteristics, which may conceal expected relationships with climate change. The risk-prone strategy of delaying autumn migration, which was exhibited by older females, lends support to both the terminal-investment hypothesis, and an experiential explanation (Fig. 10a), and the effects of summer residency on autumn migration indicate that individuals respond to fine-scale patterns of weather within their local environment (Fig. 10b). We demonstrated that unlike birds, mule deer did not accumulate a threshold of fat reserves prior to initiating migration during either season, but in contrast, delayed autumn migration when fat reserves were abundant (Table 3), and yet were unaffected by fat reserves in spring (Table 4). Clearly, our results illustrate the potential problems with extending models developed for avian taxa to large herbivorous mammals (sensu Ralls 1977). Nutritional underpinnings of the timing of autumn migration for mule deer support the hypothesis that behavioral decisions by large herbivores are based on lessening the primary detriment to fitness (Parker et al. 2009), and that those decisions may be underpinned by current nutritional state. We emphasize the importance of considering the influence of individual life-history characteristics on behavior of large herbivores and the underlying effects of nutrition on their life-history strategies. For large herbivores, failure to consider the effects of life-history characteristics when attempting to elucidate relationships between phenological patterns of life-history events and climate may, at best, lead to equivocal relationships or, at worst, be entirely misleading.

Acknowledgments

We thank fixed-wing pilots R. Anthes, T. Evans, and G. Schales of California Department of Fish and Game (CDFG), and G. Pope (Black Mountain Air Service), and R. Nixon for their dedication and interest in this project. Landells Aviation was largely responsible for the helicopter capture and survey work, especially, S. deJesus, and C. Pickrell, who worked closely with CDFG capture specialists R. Teagle and T. Glenner to ensure safe and efficient handling of hundreds of mule deer. We are also privileged to have worked with numerous dedicated field assistants including, P. McGrath, J. Augustine, D. Spitz, A. Howell, T. Swearingen, W. Allsup, A. Stephenson, M. Kiner, T. Branston, C. Schroeder, H. Johnson, M. Leonard-Cahn, K. Monteith, R. Long, S. Monteith, and especially P. Partridge who committed much of his own time and resources to maintain deer monitoring. We are indebted to volunteers C. Baker, R. Noles, N. Partridge, and D. deJesus for their selfless dedication to mule deer research in Round Valley. We thank D. German, L. Konde, and K. Knox, for their assistance with the Round Valley deer project. Support for capture work was provided by numerous individuals including, J. Villepique, J. McKeever, T. Taylor, B. Clark, and B. Adams. Additional capture support was provided by personnel from the CDFG Wildlife Investigations Lab including S. Torres, K. Jones, A. Hunter, B. Gonzales, P. Swift, J. Schultz, and H. Zurawka. We also are thankful to other CDFG employees and other volunteers who aided in the completion of this long-term research project. The bulk of the funding and logistical support for this long-term investigation was provided by the CDFG Deer Herd Management Plan Implementation Program through the efforts of E. Loft, S. Mastrup, K. Mayer, R. Mohr, and C. Stowers; additional funding was provided by the California Deer Association, Mule Deer Foundation, Granite Bay Chapter of Safari Club International, and Idaho State University. We dedicate this paper to the memory of our friends and colleagues Clu Cotter, Mike Donovan, Kevin O'Connor, and Tom Stolberg who died in a tragic helicopter accident while conducting an aerial survey on summer range used by mule deer from Round Valley. This is a contribution from the CDFG Deer Herd Management Plan Implementation Program, and is Professional Paper 084 from the Eastern Sierra Center for Applied Population Ecology. We thank R. Long, E. Andersen, M. Kauffman, J. Jenks, A. Mysterud, and an anonymous reviewer for their comments that improved previous versions of this manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the United States Government.

Literature Cited

Adamik, P., and J. Pietruszkova. 2008. Advances in spring but variable autumnal trends in timing of inland wader migration. Acta Ornithologica 43:119–128.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267–281 *in* B. N. Petran and F. Csaki, editors. International symposium on information theory. Second edition.

Akademiai Kiado, Budapest, Hungary.

Albon, S. D., and R. Langvatn. 1992. Plant phenology and the benefits of migration in a temperate ungulate. Oikos 65:502–513.

Alerstam, T., A. Hendenström, and S. Åkesson. 2003. Long-distance migration: evolution and determinants. Oikos 103:247–260.

Badeck, F.-W., A. Bondeau, K. Böttcher, D. Doktor, W. Lucht, J. Schaber, and S. Sitch. 2004. Responses of spring phenology to climate change. New Phytologist 162:295–309.

Baker, R. B. 1978. The evolutionary ecology of animal migration. Holmes and Meier Publishers, Inc. New York, New York, USA.

Barboza, P. S., K. L. Parker, and I. D. Hume. 2009. Integrative wildlife nutrition. Springer-Verlag, Berlin, Heidelberg, Germany.

Barnett, T. P. et al. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080–1083.

Bender, L. C., L. A. Lomas, and J. Browning. 2007. Condition, survival, and cause-specific mortality of adult female mule deer in north-central New Mexico. Journal of Wildlife Management 71:1118–1124.

Bercovitch, F. B., C. P. Loomis, and R. G. Rieches. 2009. Age-specific changes in reproductive effort and terminal investment in female Nile lechwe. Journal of Mammalogy 90:40–46.

Berger, J. 1986. Wild horses of the Great Basin: social competition and population size. University of Chicago Press, Chicago, USA.

Berger, J. 2004. The last mile: how to sustain long-distance migration in mammals. Conservation Biology 18:320–331.

Bleich, V. C., and B. M. Pierce. 2001. Accidental mass mortality of migrating mule deer. Western North American Naturalist 61:124–125.

Bleich, V. C., B. M. Pierce, J. L. Jones, and R. T. Bowyer. 2006. Variance in survival of young mule deer in the Sierra Nevada, California. California Fish and Game 92:24–38.

Bleich, V. C., T. R. Stephenson, N. J. Holste, I. C. Snyder, J. P. Marshal, P. W. McGrath, and B. M. Pierce. 2003. Effects of tooth extraction on body condition and reproduction of mule deer. Wildlife Society Bulletin 31:233–236.

Bolger, D. T., W. D. Newmark, T. A. Morrison, and D. F. Doak. 2008. The need for integrative approaches to understand and conserve migratory ungulates. Ecology Letters 11:63–77.

Bowyer, R. T., D. K. Person, and B. M. Pierce. 2005. Detecting top-down versus bottom-up regulation of ungulates by large carnivores: implications for biodiversity. Pages 342–361 *in* J. C. Ray, K. H. Redford, R. S. Steneck, and J. Berger, editors. Large carnivores and the conservation of biodiversity. Island Press, Washington, D.C., USA.

Boyce, M. S. 1991. Migratory behaviour and management of elk (*Cervus elaphus*). Animal Behaviour Science 29:249–250.

Brinkman, T. J., C. S. DePerno, J. A. Jenks, B. S. Haroldson, and R. G. Osborn. 2005. Movement of female white-tailed deer: effects of climate and intensive row-crop agriculture. Journal of Wildlife Management 69:1099–1111.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information theoretic approach. Second edition. Springer-Verlag, New York, USA.

Cameron, E. Z., W. L. Linklater, K. J. Stafford, and E. O. Minot. 2000. Aging and improving reproductive success in horses: declining residual reproductive value or just older and wiser? Behavioral Ecology and Sociobiology 47:243–249.

Carey, C. 2009. The impacts of climate change on the annual cycles of birds. Philosophical Transactions of the Royal Society of London B 364:3321–3330.

Chapin, F. S., III. 1983. Direct and indirect effects of temperature on arctic plants. Polar Biology 2:47–52.

Christianson, D., and S. Creel. 2009. Fecal chlorophyll describes the link between primary production and consumption in a terrestrial herbivore. Ecological Applications 19:1323–1335.

Ciuti, S., P. Bongi, S. Vassale, and M. Apollonio. 2006. Influence of fawning on the spatial behaviour and habitat selection of female fallow deer (*Dama dama*) during late pregnancy and early lactation. Journal of Zoology 268:97–107.

Clutton-Brock, T. H. 1984. Reproductive effort and terminal investment in iteroparous animals. American Naturalist 123:212–229.

Cook, J. C., B. K. Johnson, R. C. Cook, R. A. Riggs, T. Delcurto, L. D. Bryant, and L. L. Irwin. 2004. Effects of summer-autumn nutrition and parturition date on reproduction and survival of elk. Wildlife Monographs No 155.

Cook, R. C., T. R. Stephenson, W. L. Myers, J. G. Cook, and L. A. Shipley. 2007. Validating predictive models of nutritional condition for mule deer. Journal of Wildlife Management 71:1934–1943.

Dingle, H. 1985. Migration and life histories. Pages 27–42 *in* M. A. Rankin, editor. Migration: Mechanisms and Adaptive Significance. Contributions in Marine Science, Volume 27. University of Texas Marine Science Institute, Port Arkansas, Texas, USA.

Dingle, H. 2006. Animal migration: is there a common migratory syndrome? Journal of Ornithology 147:212–220.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476–3488.

Fancy, S. G., and R. G. White. 1985. Energy expenditures by caribou while cratering in snow. Journal of Wildlife Management 49:987–993.

Fieberg, J., and G. DelGiudice. 2008. Exploring migration data using interval-censored time-to-event models. Journal of Wildlife Management 72:1211–1219.

Fieberg, J., D. W. Kuehn, and G. D. DelGiudice. 2008. Understanding variation in autumn migration of northern white-tailed deer by long-term study. Journal of Mammalogy 89:1529–1539.

Forchhammer, M. C., and E. Post. 2004. Using large-scale climate indices in climate change ecology studies. Population Ecology 46:1–12.

Forchhammer, M. C., E. Post, and N. C. Stenseth. 2002. North Atlantic Oscillation timing of long- and short-distance migration. Journal of Animal Ecology 71:1002–1014.

Fryxell, J. M., and A. R. E. Sinclair. 1988. Causes and consequences of migration by large herbivores. Trends in Ecology and Evolution 3:237–241.

Fryxell, J. M., J. Greever, and A. R. E. Sinclair. 1988. Why are migratory ungulates so abundant? American Naturalist 131:781–798.

Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of Ecology and Systematics 31:367–393.

Gannon, W. L., R. S. Skies, and the Animal Care and Use Committee of the American Society of Mammalogists. 2007. Guidelines of the American Society Mammalogists for the use of wild mammals in research. Journal of Mammalogy 88:809–823.

Garcia, A. J., T. Landete-Castillejos, D. Carrion, E. Gaspar-Lopez, and L. Gallego. 2006. Compensatory extension of gestation length with advance of conception in red deer (*Cervus elaphus*). Journal of Experimental Biology 305A:55–61.

Garrott, R. A., G. C. White, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Movements of female mule deer in Northwest Colorado. Journal of Wildlife Management 51:634–643.

Garroway, C. J., and H. G. Broders. 2005. The quantitative effects of population density and winter weather on the body condition of white-tailed deer (*Odocoileus virginianus*) in Nova Scotia, Canada. Canadian Journal of Zoology 83:1246–1256.

Gochfeld, M. 1980. Mechanisms and adaptive value of reproductive synchrony in colonial seabirds. Pages 207–265 *in* J. Burger, B. L. Olla, and H. E. Winn, editors. Behavior of marine animals, Volume 4, Marine birds. Plenum Press, New York, New York, USA.

Gordo, O., and J. J. Sanz. 2005. Phenology and climate change: a long-term study in a Mediterranean locality. Oecologia 146:484–495.

Gotthard, K., and S. Nylin. 1995. Adaptive plasticity and plasticity as an adaptation: a selective review of plasticity in animal morphology and life history. Oikos 74:3–17.

Grovenburg, T. W., J. A. Jenks, R. W. Klaver, C. C. Swanson, C. N. Jacques, and D. Todey. 2009. Seasonal movements and home ranges of white-tailed deer in north-central South Dakota. Canadian Journal of Zoology 87:876–885.

Hamel, S., M. Garel, M. Festa-Bianchet, J.-M. Gaillard, and S. D. Côté. 2009. Spring Normalized Difference Vegetation Index (NDVI) predicts annual variation in timing of peak faecal crude protein in mountain ungulates. Journal of Applied Ecology 46:582–589.

Hamlet, A. F., P. W. Mote, M. P. Clark, and D. P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western United States. Journal of Climate 18:4545–4561.

Hebblewhite, M., E. Merrill, and G. McDermid. 2008. A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. Ecological Monographs 78:141–166.

Holdo, R. M., R. D. Holt, and J. M. Fryxell. 2009. Opposing rainfall and plant nutritional gradients best explain the wildebeest migration in the Serengeti. American Naturalist 173:431–445.

Johnson, D. S., R. P. Barry, and R. T. Bowyer. 2004. Estimating timing of life-history events with coarse data. Journal of Mammalogy 85:932–939.

Jönsson, P., and L. Eklundh. 2004. TIMESAT—a program for analyzing time-series of satellite sensor data. Computers and Geosciences 30:833–845.

Jonzén, N. et al. 2006. Rapid advance of spring arrival dates in long-distance migratory birds. Science 312:1959–1961.

Kaitala, A., V. Kaitala, and P. Lundberg. 1993. A theory of partial migration. American Naturalist 142:59–81.

Keech, M. A., R. T. Bowyer, J. M. Ver Hoef, R. D. Boertje, B. W. Dale, and T. R. Stephenson. 2000. Life history consequences of maternal condition in Alaskan moose. Journal of Wildlife Management 64:450–462.

Kie, J. G., R. T. Bowyer, and K. M. Stewart. 2003. Ungulates in western forests: habitat relationships, population dynamics, and ecosystem processes. Pages 296–340 *in* C. Zabel and R. Anthony, editors. Mammal community dynamics in western coniferous forests: management and conservation. The Johns Hopkins University Press, Baltimore, Maryland, USA.

Klein, D. R. 1965. Ecology of deer range in Alaska. Ecological Monographs 35:259–284.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2005. Trends in snowfall versus rainfall in the Western

United States. Journal of Climate 19:4545–4559.

Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1985. Capturing deer and mountain sheep with a net-gun. Wildlife Society Bulletin 13:71–73.

Kucera, T. E. 1988. Ecology and population dynamics of mule deer in the Eastern Sierra Nevada, California. Ph.D. Dissertation. University of California, Berkeley, California, USA.

Kucera, T. E. 1992. Influences of sex and weather on migration of mule deer in California. Great Basin Naturalist 52:122–130.

Kucera, T. E. 1997. Fecal indicators, diet, and population parameters in mule deer. Journal of Wildlife Management 61:550–560.

Loe, L. E., C. Bonenfant, A. Mysterud, J. M. Gaillard, R. Langvatn, F. Klein, C. Calenge, T. Ergon, N. Pettorelli, and N. C. Stenseth. 2005. Climate predictability and breeding phenology in red deer: timing and synchrony of rutting and calving in Norway and France. Journal of Animal Ecology 74:579–588.

Loft, E. R., R. C. Bertram, and D. L. Brown. 1989. Migration patterns of mule deer in the central Sierra Nevada. California Fish and Game 75:11–19.

Lomas, L. A., and L. C. Bender. 2007. Survival and cause-specific mortality of neonatal mule deer fawns, north-central New Mexico. Journal of Wildlife Management 71:884–894.

Marshal, J. P., P. R. Krausman, V. C. Bleich, W. B. Ballard, and J. S. McKeever. 2002. Rainfall, El Niño, and dynamics of mule deer in the Sonoran Desert, California. Journal of Wildlife Management 66:1283–1289.

Mautz, W. W. 1978. Sledding on a bushy hillside: the fat cycle in deer. Wildlife Society Bulletin 6:88–90.

McCullough, D. R. 1979. The George Reserve deer herd: population ecology of a *K*-selected species. The University of Michigan Press, Ann Arbor, Michigan, USA.

McCullough, D. R. 1985. Long range movements of large terrestrial mammals. Pages 444–465 *in* M. A. Rankin, editor. Migration: mechanisms and adaptive significance. Contributions in Marine Science, Volume 27. University of Texas Marine Science Institute, Port Arkansas, Texas, USA.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer, New York, USA.

Meunier, J., R. Song, R. S. Lutz, D. E. Anderson, K. E. Doherty, J. G. Bruggink, and E. Oppelt. 2008. Proximate cues for a short-distance migratory species: an application of survival analysis. Journal of Wildlife Management 72:440–448.

Miller, F. L. 1971. Behaviour of maternal black-tailed deer (*Odocoileus hemionus columbianus*). Zeitschrift für Tierpsychologie 28:527–533.

Mirza, S. N., and F. D. Provenza. 1992. Effects of age and conditions of exposure on maternally mediated food selection by lambs. Applied Animal Behavior Science 33:35–42.

Mitrus, C. 2007. Is the later arrival of young male red-breasted flycatchers (*Ficedula parva*) related to their physical condition? Journal of Ornithology 148:53–58.

Moen, A. N. 1976. Energy conservation in white-tailed deer in winter. Ecology 57:192–198.

Moen, A. N. 1978. Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. Journal of Wildlife Management 42:715–738.

Møller, A. P., D. Rubolini, and E. Lehikoinen. 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. Proceedings of the National Academy of Sciences, USA 105:16195–16200.

Monteith, K. L., L. E. Schmitz, J. A. Jenks, J. A. Delger, and R. T. Bowyer. 2009. Growth of male white-tailed deer: consequences of maternal effects. Journal of Mammalogy 90:651–660.

Morgantini, L. E., and R. J. Hudson. 1989. Nutritional significance of wapiti (*Cervus elaphus*) migrations to alpine ranges in western Alberta, Canada. Arctic and Alpine Research 21:288–295.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Mysterud, A. 1999. Seasonal migration patterns and home range of roe deer (*Capreolus capreolus*) in an altitudinal gradient in southern Norway. Journal of Zoology, London 247:479–486.

Mysterud, A., R. Langvatn, N. G. Yoccoz, and N. C. Stenseth. 2001. Plant phenology, migration and geographical variation in body weight of a large herbivore: the effect of a variable topography. Journal of Animal Ecology 2001:915–923.

Nelson, M. E. 1995. Winter range arrival and departure of white-tailed deer in northeastern Minnesota. Canadian Journal of Zoology 73:1069–1076.

Nelson, M. E., and L. D. Mech. 1981. Deer social organization and wolf predation in northeastern Minnesota. Wildlife Monographs No 77.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. Fourth edition. WCB McGraw-Hill, Boston, Massachusetts, USA.

Newton, I. 2006. Can conditions experienced during migration limit the population levels the population levels of birds? Journal of Ornithology 147:146–166.

Nicholson, M. C., R. T. Bowyer, and J. G. Kie. 1997. Habitat selection and survival of mule deer: tradeoffs associated with migration. Journal of Mammalogy 78:483–504.

Nicholson, M. C., R. T. Bowyer, and J. G. Kie. 2006. Forage selection by mule deer: does niche breadth increase with population density? Journal of Zoology 269:39–49.

Nussey, D. H., T. Coulson, M. Festa-Bianchet, and J.-M. Gaillard. 2008. Measuring senescence in wild animal populations: towards a longitudinal approach. Functional Ecology 22:393–406.

Ortegareyes, L., and F. D. Provenza. 1993. The amount of experience and age effect the development of foraging skills of goats browsing blackbrush (*Coleogyne ramosissima*). Journal of Animal Science 71:380–383.

Parker, K. L., P. S. Barboza, and M. P. Gillingham. 2009. Nutrition integrates environmental responses of ungulates. Functional Ecology 23:57–69.

Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474–488.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 420:168–171.

Patterson, B. R., and F. Messier. 2000. Factors influencing killing rates of white-tailed deer by coyotes in eastern Canada. Journal of Wildlife Management 64:721–732.

Pekins, P. J., K. S. Smith, and W. W. Mautz. 1998. The energy cost of gestation in white-tailed deer. Canadian Journal of Zoology 76:1091–1097.

Pettorelli, N., F. Pelletier, A. von Hardenberg, M. Festa-Bianchet, and S. D. Côté. 2007. Early onset of vegetation growth vs. rapid green-up: impact on juvenile mountain goats. Ecology 88:381–390.

Pettorelli, N., J. O. Vik, A. Mysterud, J.-M. Gaillard, C. J. Tucker, and N. C. Stenseth. 2005. Using satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20:503–510.

Pierce, B. M., V. C. Bleich, J. D. Wehausen, and R. T. Bowyer. 1999. Migratory patterns of mountain lions: implications for social regulation and conservation. Journal of Mammalogy 80:986–992.

Pierce, B. M., V. C. Bleich, and R. T. Bowyer. 2000. Selection of mule deer by mountain lions and coyotes: effects of hunting style, body size, and reproductive status. Journal of Mammalogy 81:462–472.

Pierce, B. M., R. T. Bowyer, and V. C. Bleich. 2004. Habitat selection by mule deer: forage benefits or risk of predation? Journal of Wildlife Management 68:533–541.

Plumb, G. E., P. J. White, M. B. Coughenour, and R. L. Wallen. 2009. Carrying capacity, migration, and dispersal in Yellowstone bison. Biological Conservation 142:2377–2387.

Post, E., and M. D. Forchhammer. 2008. Climate change reduces reproductive success of an arctic herbivore through trophic mismatch. Philosophical Transactions of the Royal Society B 363:2369–2375.

Post, E., C. Pederson, C. C. Wilmers, and M. C. Forchhammer. 2008. Warming, plant phenology and the spatial dimension of trophic mismatch for large herbivores. Proceedings of the Royal Society of London B 275:2005–213.

Pulido, F. 2007. Phenotypic changes in spring arrival: evolution, phenotypic plasticity, effects of weather and condition. Climate Research 35:5–23.

Rachlow, J. L., and R. T. Bowyer. 1991. Interannual variation in timing and synchrony of parturition in Dall's sheep. Journal of Mammalogy 72:487–492.

Ralls, K. 1977. Sexual dimorphism in mammals: avian models and unanswered questions. American Naturalist 111:917–938.

Reed, B. C., J. F. Brown, D. VanderZee, T. R. Loveland, J. W. Merchant, and D. O. Ohlen. 1994. Measuring phenological variability from satellite imagery. Journal of Vegetation Science 5:703–714.

Robbins, C. T., and B. L. Robbins. 1979. Fetal and neonatal growth patterns and maternal reproductive effort in ungulates and subungulates. American Naturalist 114:101–116.

Ruckstuhl, K. E., and M. Festa-Bianchet. 1998. Do reproductive status and lamb gender affect the foraging behavior of bighorn ewes? Ethology 104:941–954.

Sabine, D. L., S. F. Morrison, H. A. Whitlaw, W. B. Ballard, G. J. Forbes, and J. Bowman. 2002. Migration behavior of white-tailed deer under varying winter climate regimes in New Brunswick. Journal of Wildlife Management 66:718–728.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016–2025.

Sparks, T. H., F. Bairlein, J. G. Bojarinova, O. Hüppop, E. A. Lehikoinen, K. Rainio, L. V. Sokolov, and D. Walker. 2005. Examining the total arrival distribution of migratory birds. Global Change Biology 11:22–30.

Stearns, S. C. 1992. The evolution of life histories. Oxford University Press, Oxford, New York, USA.

Stenseth, N. C., A. Mysterud, G. Ottersen, J. W. Hurrell, K.-S. Chan, and M. Lima. 2002. Ecological effects of climate fluctuations. Science 297:1292–1296.

Stenseth, N. C., G. Ottersen, J. W. Hurrell, A. Mysterud, M. Lima, K.-S. Chan, N. G. Yoccoz, and J. Adlandsvik. 2003. Studying climate effects on ecology through the use of climate indices: the North Atlantic Oscillation, El Niño Southern Oscillation and beyond. Proceedings of the Royal Society of London B 270:2087–2096.

Stephens, D. W., and J. R. Krebs. 1986. Foraging theory.

Princeton University Press, Princeton, New Jersey, USA.

Stephenson, T. R., J. W. Testa, G. P. Adams, R. G. Sasser, C. C. Schwartz, and K. J. Hundertmark. 1995. Diagnosis of pregnancy and twinning in moose by ultrasonography and serum assay. Alces 31:167–172.

Stephenson, T. R., V. C. Bleich, B. M. Pierce, and G. P. Mulcahy. 2002. Validation of mule deer body composition using in vivo and post-mortem indices of nutritional condition. Wildlife Society Bulletin 30:557–564.

Stewart, K. M., R. T. Bowyer, B. L. Dick, B. K. Johnson, and J. G. Kie. 2005. Density-dependent effects on physical condition and reproduction in North American elk: an experimental test. Oecologia 143:85–93.

Stone, R. C., G. L. Hammer, and T. Marcussen. 1996. Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384:252–255.

Storer, T. I., R. L. Usinger, and D. Lukas. 2004. Sierra Nevada Natural History. University of California Press, Berkeley, California, USA.

Swets, D. L., B. C. Reed, J. D. Rowland, and S. E. Marko. 1999. A weighted least-squares approach to temporal NDVI smoothing. 1999 ASPRS Annual Conference: From Image to Information, Portland, Oregon, May 17–21. Proceedings. Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing.

Swift, P. K., V. C. Bleich, T. R. Stephenson, A. E. Adams, B. J. Gonzales, B. M. Pierce, and J. P. Marshal. 2002. Tooth extraction from live-captured mule deer in the absence of chemical immobilization. Wildlife Society Bulletin 30:253–255.

Swingland, I. R., and P. J. Greenwood. 1983. The ecology of animal movement. Oxford University Press, London, UK.

Telfer, E. S., and J. P. Kelsall. 1979. Studies of morphological parameters affecting ungulate locomotion in snow. Canadian Journal of Zoology 57:2153–2159.

Trenberth, K. E., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics 9:303–319.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant, Second edition. Cornell University Press, Ithaca, New York, USA.

Verme, L. J. 1965. Reproduction studies of penned white-tailed deer. Journal of Wildlife Management 29:74–79.

Voeten, M. M., C. A. D. M. van de Vijver, H. Olff, and F. van Langevelde. 2009. Possible causes of decreasing migratory ungulate populations in an East African savannah after restrictions in their seasonal movements. African Journal of Ecology 48:169–179.

Walther, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. M. Fromentin, O. Hoegh-Guldberg, and F. Barilein. 2002. Ecological responses to recent climate change. Nature 416:389–395.

Weladji, R. B., J.-M. Gaillard, N. G. Yoccoz, Ø. Holand, A. Mysterud, A. Loison, M. Nieminen, and N. C. Stenseth. 2006. Good reindeer mothers live longer and become better in raising offspring. Proceedings of the Royal Society of London B 273:1239–1244.

Weladji, R. B., Ø. Holand, J.-M. Gaillard, N. G. Yoccoz, A. Mysterud, M. Nieminen, and N. C. Stenseth. 2010. Age-specific changes in different components of reproductive output in female reindeer: terminal allocation or senescence? Oecologia 162:261–271.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120–139.

White, P. J., K. M. Proffitt, L. D. Mech, S. B. Evans, J. A. Cunningham, and K. L. Hamlin. 2010. Migration of northern Yellowstone elk: implications of spatial structuring. Journal of Mammalogy 91:827–837.

White, R. G. 1983. Foraging patterns and their multiplier effects on productivity of northern ungulates. Oikos 40:377–384.

Wilcove, D. S. 2008. No way home. Island Press, Washington, D.C., USA.

Williams, G. C. 1966. Adaptation and natural selection. Princeton University Press, Princeton, New Jersey, USA.

Zar, J. H. 1999. Biostatistical Analysis. Fourth Edition. Prentice Hall, Upper Saddle River, New Jersey, USA.

Zeng, Z.-G., P. S. A. Beck, T.-J. Wang, A. K. Skidmore, Y.-L. Song, H.-S. Gong, and H. H. T. Prins. 2010. Effects of plant phenology and solar radiation on seasonal movement of golden takin in the Qinling Mountains, China. Journal of Mammalogy 91:92–100.

APPENDIX

Table A1. Summary statistics for daily temperature, daily snow depth during winter (November–March), total annual snowfall and precipitation for Mammoth Lakes, California, USA, and annual mean of the southern oscillation index (SOI), 1999–2009.

Weather variable	Mean	SD	Range
Maximum temperature (°C)	13.6	9.2	−13.3–32.8
Average temperature (°C)	5.9	8.0	−20.0–23.3
Minimum temperature (°C)	−1.7	7.3	−26.7–16.7
Snow depth (cm)	39.4	39.1	0–167.6
Annual snowfall (cm)	469.4	163.1	152.4–714.2
Annual precipitation (cm)	49.5	14.9	13.6–66.5
SOI	0.08	0.6	−0.7–1.0

Table A2. Loadings for principle components (1–5) for daily weather variables included in principle components analysis. Weather variables are daily measurements and daily change (Δ) in weather relative to the mean for the previous 2 weeks, Mammoth Lakes, California, USA, 1999–2009.

	Principle component				
Weather variable	1	2	3	4	5
Maximum temperature (°C)	−0.180	−0.021	0.568	−0.083	0.183
Average temperature (°C)	−0.155	0.001	0.518	−0.004	0.198
Minimum temperature (°C)	−0.129	0.024	0.468	0.076	0.212
Snowfall (cm)	0.071	0.191	0.008	0.623	−0.007
Snow depth (cm)	0.945	−0.188	0.242	−0.012	0.110
Precipitation (cm)	0.005	0.015	0.000	0.051	0.000
ΔMaximum temperature (°C)	−0.013	−0.144	0.222	−0.012	−0.612
ΔAverage temperature (°C)	−0.011	−0.110	0.196	0.072	−0.520
ΔMinimum temperature (°C)	−0.010	−0.076	0.170	0.157	−0.429
ΔSnowfall (cm)	0.012	0.193	0.007	0.702	0.076
ΔSnow depth (cm)	0.171	0.922	0.119	−0.265	−0.187
ΔPrecipitation (cm)	0.005	0.015	0.001	0.058	0.007

Attachment B

Invited Article

Winter Habitat Selection of Mule Deer Before and During Development of a Natural Gas Field

HALL SAWYER,[1] *Western Ecosystems Technology, Inc., Cheyenne, WY 82001, USA*
RYAN M. NIELSON, *Western Ecosystems Technology, Inc., Cheyenne, WY 82001, USA*
FRED LINDZEY, *United States Geological Survey (USGS), Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY 82071, USA*
LYMAN L. McDONALD, *Western Ecosystems Technology, Inc., Cheyenne, WY 82001, USA*

Abstract

*Increased levels of natural gas exploration, development, and production across the Intermountain West have created a variety of concerns for mule deer (*Odocoileus hemionus*) populations, including direct habitat loss to road and well-pad construction and indirect habitat losses that may occur if deer use declines near roads or well pads. We examined winter habitat selection patterns of adult female mule deer before and during the first 3 years of development in a natural gas field in western Wyoming. We used global positioning system (GPS) locations collected from a sample of adult female mule deer to model relative frequency or probability of use as a function of habitat variables. Model coefficients and predictive maps suggested mule deer were less likely to occupy areas in close proximity to well pads than those farther away. Changes in habitat selection appeared to be immediate (i.e., year 1 of development), and no evidence of well-pad acclimation occurred through the course of the study; rather, mule deer selected areas farther from well pads as development progressed. Lower predicted probabilities of use within 2.7 to 3.7 km of well pads suggested indirect habitat losses may be substantially larger than direct habitat losses. Additionally, some areas classified as high probability of use by mule deer before gas field development changed to areas of low use following development, and others originally classified as low probability of use were used more frequently as the field developed. If areas with high probability of use before development were those preferred by the deer, observed shifts in their distribution as development progressed were toward less-preferred and presumably less-suitable habitats.* (JOURNAL OF WILDLIFE MANAGEMENT 70(2):396–403; 2006)

Key words

generalized linear model (GLM), Global Positioning System (GPS), habitat selection, mule deer, natural gas development, negative binomial, Odocoileus hemionus, *resource selection probability function (RSPF), Wyoming.*

Natural gas development on public lands in Wyoming has steadily increased since 1984 (Bureau of Land Management 2002) and created much concern over potential impacts to wildlife. Public lands with high gas potential often coincide with regions of Wyoming that support large mule deer (*Odocoileus hemionus*) populations, such as the Green River Basin (Bureau of Land Management 2000*a*), Great Divide Basin (Bureau of Land Management 2000*b*), and Powder River Basin (Bureau of Land Management 2003). Impacts of natural gas development on mule deer may include the direct loss (i.e., surface disturbance) of habitat to well pad, access road, and pipeline construction. Additional indirect habitat losses may occur if increased human activity (e.g., traffic, noise) associated with infrastructure cause mule deer to be displaced or alter their habitat use patterns. Although it is relatively easy to quantify the direct habitat losses that result from conversion of native vegetation to infrastructure, it is much more difficult to document indirect habitat losses. Nonetheless, because indirect impacts can affect a substantially larger area than direct impacts, understanding them may be a key component to maintaining mule deer seasonal ranges and populations in regions with high levels of natural gas development. Accordingly, there is a need among land management and wildlife agencies to better understand how natural gas development can lead to indirect habitat loss to ensure informed land-use decisions are made, reasonable and effective mitigation measures identified, and appropriate monitoring programs implemented. Our objective was to determine whether natural gas development affected the habitat selection patterns and, thus, distribution of wintering mule deer in western Wyoming.

Study Area

Beginning in 2000, the Bureau of Land Management (BLM) approved the construction of 700 producing well pads, 645 km of pipeline, and 444 km of roads to develop a natural gas field in the Pinedale Anticline Project Area (PAPA; Bureau of Land Management 2000*a*). The PAPA contains one of the largest and highest density (19 to 30 deer/km^2) mule deer winter ranges in Wyoming (S. Smith, Wyoming Game and Fish Department, Cheyenne, Wyo., USA, unpublished data). The PAPA is located in the upper Green River Basin of western Wyoming, approximately 5 km southwest of Pinedale. The PAPA consists primarily of federal lands (80%) and minerals administered by the BLM (83%). The state of Wyoming owns 5% (39 km^2) of the surface and another 15% (121 km^2) is private (Bureau of Land Management 2000*a*). The study area contains abundant deep gas reserves, supports a variety of agricultural uses, and provides winter range for 4,000 to 5,000 migratory mule deer that summer in portions of 4 different mountain ranges 80 to 200 km away (Sawyer and Lindzey 2001). Although the PAPA covers 799 km^2, most mule deer wintered in the northern one-third, an area locally known as the Mesa. The Mesa is 260 km^2 in size, bounded by the Green River on the west and the New Fork River on the north, south, and east, and vegetated primarily by Wyoming big sagebrush (*Artemisia tridentata*) and sagebrush–grassland communities. Elevation ranges from 2,070 to 2,400 m. Our study was restricted to the Mesa portion of the PAPA.

[1] *E-mail: hsawyer@west-inc.com*

Methods

Capture

We captured adult ($\geq$1 year) female mule deer using helicopter net-gunning in the northern portion of the PAPA where deer congregated in early winter before moving to their individual winter ranges throughout the Mesa (Sawyer and Lindzey 2001). We believed attempting to randomly capture deer in this area during early winter provided the best opportunity to achieve a representative sample from the wintering population. In years before development (winters 1998–1999 and 1999–2000), we fitted deer with standard, very high frequency (VHF) radio collars (Advanced Telemetry Systems, Isanti, Minnesota). We located radio-collared deer from the ground or air every 7 to 10 days during the 1998–1999 and 1999–2000 winters (1 Dec to 31 Mar). During years of gas field development (winters 2000–2001, 2001–2002, and 2002–2003), we fitted deer with store-on-board global positioning system (GPS) radio collars (Telonics, Inc., Mesa, Arizona) equipped with VHF transmitters and remote-release mechanisms programmed to release at specified dates and times. We fitted GPS radio collars to a sample of different deer each winter; however, 3 deer had collars that collected GPS locations for both the 2001–2002 and 2002–2003 winters. We programmed GPS radio collars to attempt location fixes every 1 or 2 hrs, depending on model type. We did not differentially correct GPS locations because 3-dimensional fixes typically have <20 m error (Di Orio et al. 2003), and previous work in the study area indicated 99% fix-rate success with 80% of successful fixes 3-dimensional locations (Sawyer et al. 2002). Potential fix-rate bias was not a concern because of the high fix-rate success of the GPS collars.

Modeling Procedures

Defining availability.—We defined the study area by mapping 39,641 locations from 77 mule deer over a 6-year period (1998 to 2003), creating a minimum convex polygon (MCP), and then clipping the MCP to the boundary of the PAPA. This was consistent with the McClean et al. (1998) recommendation that the study-area level of habitat availability should be based on the distribution of radio-collared animals.

Habitat variables.—We identified 5 variables as potentially important predictors of winter mule deer distribution, including elevation, slope, aspect, road density, and distance to well pad. We did not include vegetation as a variable because the sagebrush–grassland was relatively homogeneous across the study area and difficult to divide into finer vegetation classes. Further, we believed differences in sagebrush characteristics could be largely explained by elevation, slope, and aspect. We used the SPATIAL ANALYST extension for ArcView (Environmental Systems Research Institute, Redlands, California) to calculate slope and aspect from a 26 × 26-m digital elevation model (U.S. Geologic Survey 1999). Grid cells with slopes >2 degrees were assigned to 1 of 4 aspect categories: northeast, northwest, southeast, or southwest. Grid cells with slopes of $\leq$2 degrees were considered flat and assigned to a fifth category that was used as the reference (Neter et al. 1996) during habitat modeling. We obtained elevation, slope, and aspect values for each of the sampled units using the GET GRID extension for ArcView. The sample units consisted of approximately 4,500 circular units with 100-m radii distributed across the study area. We annually digitized roads and well pads from LANDSAT thematic satellite images acquired from the U.S. Geologic Survey and processed by SkyTruth (Sheperdstown, West Virginia). The LANDSAT images were obtained every fall, before snow accumulation, but after most annual development activities were complete. We calculated road density by placing a circular buffer with a 0.5-km radius on the center of the sample unit and measuring the length of road within the buffer. We used the NEAREST NEIGHBOR extension for ArcView to measure the distance from the center of each sampled unit to the edge of the nearest well pad. We did not distinguish between developing and producing well pads. We assumed habitat loss was similar among all well pads because development of the field was in its early stages (i.e., <5 years), and there was no evidence of successful shrub reclamation. Additionally, there was no evidence that suggested the type of well pad was an accurate indicator of the amount of human activity (e.g., traffic) that occurred at each site. Without an accurate measure of human activity, we believed it was inappropriate to distinguish between producing and developing well pads.

Statistical analyses.—Our approach to modeling winter habitat use consisted of 4 basic steps: 1) estimate the relative frequency of use (i.e., an empirical estimate of probability of use) for a large sample of habitat units for each radiocollared deer, during each winter; 2) use the relative frequency as the response variable in a multiple regression analysis to model the probability of use for each deer as a function of predictor variables; 3) develop a population-level model from the individual deer models, for each winter; and 4) map predictions of population-level models from each winter. Our analysis treated each winter period separately to allow mule deer habitat use and environmental characteristics (e.g., road density or number of well pads) to change through time. We treated radiocollared deer as the experimental unit to avoid pseudo-replication (i.e., spatial and temporal autocorrelation) and to accommodate population-level inference (Otis and White 1999, Johnson et al. 2000, Erickson et al. 2001).

We estimated relative frequency of use for each radio-collared deer using a simple technique that involved counting the number of deer locations in each of approximately 4,500 randomly sampled, circular habitat units across the study area. We took a simple random sample with replacement for each winter to ensure independence of the habitat units (Thompson 1992:51). We chose circular habitat units that had a 100-m radii; an area small enough to detect changes in animal movements but large enough to ensure multiple locations could occur in each unit. Previous analyses suggested model coefficients were similar across a variety of unit sizes, including 50, 75, and 150-m radii (R. Nielson, Western Ecosystems Technology, Inc., Cheyenne, Wyo., USA, unpublished data). We measured predictor variables on each of the sampled habitat units and conducted a Pearson's pairwise correlation analysis (PROC CORR; SAS 2000) before modeling to identify multicolinearities and to determine whether any variables should be excluded from the modeling ($|r| > 0.60$).

The relative frequency of locations from a radio-collared deer found in each habitat unit was an empirical estimate of the probability of use by that deer and was used as a continuous response variable in a generalized linear model (GLM). We used an offset term (McCullagh and Nelder 1989) in the GLM to estimate probability of use for each radiocollared deer as a function of a linear combination of predictor variables, plus or minus an error term assumed to have a negative binomial distribution (McCullagh and Nelder 1989, White and Bennetts 1996). We preferred the negative binomial distribution over the more commonly used Poisson because it allows for overdispersion (White and Bennetts 1996).

We obtained a population-level model for each winter by first estimating coefficients for each radiocollared deer. We used PROC GENMOD (SAS 2000) and the negative binomial distribution to fit the following GLM for each radiocollared deer during each winter period:

$$\ln[E(r_i)] = \ln(total) + \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \qquad (1)$$

which is equivalent to

$$\ln[E(r_i/total)] = \ln[E(\text{Relative frequency}_i)]$$
$$= \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p \qquad (2)$$

where r_i is the number of locations for a radio-collared deer within habitat unit i ($i = 1, 2, \ldots, 4{,}500$), *total* is the total number of locations for the deer within the study area, β_0 was an intercept term, $\beta_1, \ldots, \beta_p$ are unknown coefficients for habitat variables X_1, ..., X_p, and $E(.)$ denotes the expected value. We used the same offset term for all sampled habitat units of a given deer, thus the term ln(*total*) was absorbed into the estimate of β_0 and ensured we were modeling relative frequency of use (e.g., 0, 0.003, 0.0034, ...) instead of integer counts (e.g., 0, 1, 2, ...). Because some locations for each deer were not within a sampled habitat unit, inclusion of the offset term in Eq. (1) was not equivalent to conditioning on the total number of observed locations (i.e., multinomial distribution). In fact, one could drop the offset term and simply scale the resulting estimates of frequency of use by the total number of observed locations to obtain predictions of relative frequency identical to those obtained by Eq. (1). This approach to modeling resource selection estimates the relative frequency or absolute probability of use as a function of predictor variables, so we refer to it as a resource selection probability function (RSPF; Manly et al. 2002).

We assumed GLM coefficients for predictor variable k, for each deer, were a random sample from a normal distribution (Seber 1984, Littell et al. 1996), with the mean of the distribution representing the average or population-level effect of predictor variable k on probability of use. We estimated coefficients for the population-level RSPF for each winter using

$$\hat{\hat{\beta}}_k = \frac{1}{n} \sum_{j=1}^{n} \hat{\beta}_{kj}, \qquad (3)$$

Where $\hat{\beta}_{kj}$ was the estimate of coefficient k for individual j ($j = 1, \ldots, n$). We estimated the variance of each population-level model coefficient using the variation between radiocollared deer and the equation

$$\text{var}(\hat{\hat{\beta}}_k) = \frac{1}{n-1} \sum_{j=1}^{n} (\hat{\beta}_{kj} - \overline{\beta}_k)^2. \qquad (4)$$

This method of estimating population-level coefficients using Eqs. (3) and (4) was used by Marzluff et al. (2004) and Glenn et al. (2004) for evaluating habitat selection of Steller's jays (*Cyanocitta stelleri*) and northern spotted owls (*Strix occidentalis caurina*), respectively. Population-level inferences using Eqs. (3) and (4) are unaffected by potential autocorrelation because temporal autocorrelation between deer locations or spatial autocorrelation between habitat units do not bias model coefficients for the individual radiocollared deer models (McCullagh and Nelder 1989, Neter et al. 1996).

Standard criteria for model selection such as Akaike's Information Criterion (Burnham and Anderson 2002) might be appropriate for individual deer but do not apply for building a model for population-level effects because the same model (i.e., predictor variables) is required for each deer within a winter. Therefore, we used a forward-stepwise model-building procedure (Neter et al. 1996) to estimate population-level RSPFs for winters 2000–2001, 2001–2002, and 2002–2003. The forward-stepwise model-building process required fitting the same models to each deer within a winter and using Eqs. (3) and (4) to estimate population-level model coefficients. We used a t-statistic to determine variable entry ($\alpha \leq 0.15$) and exit ($\alpha > 0.20$; Hosmer and Lemeshow 2000). We considered quadratic terms for road density, distance to nearest well pad, and slope during the model-building process and following convention, the linear form of each variable was included if the model contained a quadratic form.

We conducted stepwise model building for all winters except for the predevelopment period that included winters 1998–1999 and 1999–2000. The limited number of locations recorded for radiocollared deer during that period precluded fitting individual models. Rather, we estimated a population-level model for the predevelopment period by pooling location data across 45 deer that had a minimum of 10 locations. We took simple random samples of 30 locations from deer with >30 locations to ensure that approximately equal weight was given to each deer in the analysis. We fit a model containing slope, elevation, distance to roads, and aspect for the predevelopment period. Distance to well pad was not included as a variable in the predevelopment model because there were only 11 existing well pads on the Mesa before development, and most were >10 years old, with little or no human activity associated with them. We used bootstrapping to estimate the standard errors and P values of the predevelopment population-level model coefficients.

We mapped predictions of population-level RSPFs for each winter on 104 × 104-m grids that covered the study area. We checked predictions to ensure all values were in the [0,1] interval, such that we were not extrapolating outside the range of the model data (Neter et al. 1996). The estimated probability of use for each grid cell was assigned a value of 1 to 4 based on the quartiles of the distribution of predictions for each map. We assigned grid cells with the highest 25% of predicted probabilities of use a value of 1 and classified them as high-use areas, assigned grid cells in the 51 to 75 percentiles a value of 2 and classified them as medium- to high-use areas, assigned grid cells in the 26 to 50 percentiles a value of 3 and classified them as medium- to low-use areas, and assigned grid cells in the 0 to 25 percentiles a values of 4 and classified them as low-use areas. We used contingency tables to identify changes in the 4 habitat-use categories across the 4 winter periods.

Results

Predevelopment: Winters 1998–1999 and 1999–2000

The population-level RSPF was estimated from 953 VHF deer locations collected from 45 adult female mule deer during the winters (1 Dec to 15 Apr) of 1998–1999 and 1999–2000 (Table 1). Units with the highest probability of use (Fig. 1) had an average elevation of 2,275 m, an average slope of 5 degrees, and an average road density of 0.14 km/km^2. Aspects with the highest probability of use were northwest and southwest.

Year 1 of Development: Winter 2000–2001

Individual models were estimated for 10 radiocollared deer during the winter (1 Jan to 15 Apr) of 2000–2001. Eight of the 10 deer had positive coefficients for elevation and negative coefficients for road density, indicating selection for higher elevations and low road densities. Based on the relationship between the linear and quadratic terms for slope and distance-to-well-pad variables, all 10 deer selected for moderate slopes, and 7 of 10 deer selected areas away from well pads.

The population-level RSPF was estimated from 18,706 GPS locations collected from 10 radiocollared deer during the winter of 2000–2001 (Table 1). The RSPF included elevation, slope, road density, and distance to well pad (Table 1). Deer selected for areas with higher elevations, moderate slopes, low road densities, and away from well pads. Habitat units with the highest probability of use (Fig. 2) had an average elevation of 2,266 m, slope of 5 degrees, road density of 0.16 km/km^2, and were 2.7 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well pads and access roads (Fig. 2). Shifts in deer distribution between predevelopment and year 1 of development were evident through the changes in the 4 deer use categories (Table 2). Of the habitat units classified as high deer use before development, only 60% were classified as high deer use during year 1 of development (Table 2). Of the areas classified as low deer use before development, 58% remained classified as low deer use during year 1 of development (Table 2).

Year 2 of Development: Winter 2001–2002

Individual models were developed for 15 radiocollared deer during the winter (4 Jan to 15 Apr) of 2001–2002. Fourteen of the 15 deer had positive coefficients for elevation, indicating selection of higher elevations. Based on the relationship between the linear and quadratic terms for slope and distance-to-well-pad variables, all 15 deer selected for moderate slopes, and 12 of 15 deer selected areas away from well pads.

The population-level RSPF was estimated from 14,851 GPS locations collected from 15 radiocollared deer during the winter of 2001–2002 (Table 1). The RSPF included elevation, slope, and distance to well pad (Table 1). Deer selected for areas with higher elevations, moderate slopes, and away from well pads. Habitat units with the highest probability of use (Fig. 3) had an average elevation of 2,255 m, slope of 5 degrees, and were 3.1 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well pads (Fig. 3). Shifts in deer distribution between predevelopment, year 1, and year 2 of development were evident through the changes in the 4 deer-use categories (Table 2). Of the habitat units classified as high deer use before development, only 49% were classified as high deer use during year 2 of development (Table 2). Of the areas classified as low deer use before development, 48% remained classified as low deer use during year 2 of development (Table 2).

Year 3 of Development: Winter 2002–2003

Individual models were developed for 7 radiocollared deer during the winter (20 Dec to 15 Apr) of 2002–2003. All 7 deer had positive coefficients for elevation, indicating selection of higher elevations. Based on the relationship between the linear and quadratic terms for slope and distance-to-well-pad variables, 6 of 7 deer selected for moderate slopes, and 6 of 7 deer selected areas away from well pads.

The population-level RSPF was estimated from 4,904 GPS locations collected from 7 radiocollared deer during the winter of 2002–2003 (Table 1). Our target sample of 10 marked animals was not met because 3 deer died early in the season. The RSPF included elevation, slope, and distance to well pad (Table 1). Deer selected areas with high elevations, moderate slopes, and away from well pads. Habitat units with the highest probability of use (Fig. 4) had an average elevation of 2,233 m, slope of 5 degrees, and were 3.7 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well

Table 1. Coefficients for population-level winter mule deer resource selection probability functions (RSPF) before and during 3 years of natural gas development in western Wyo., USA, 1998–2003.

	Predevelopment			Year 1			Year 2			Year 3		
	β	SE	P	β	SE	P	β	SE	P	β	SE	P
Intercept	−29.649	6.637	<0.001	−84.560	21.124	0.003	−75.712	12.931	<0.001	−104.295	11.316	<0.001
Elevation	0.009	0.001	<0.001	0.031	0.008	0.005	0.027	0.005	<0.001	0.036	0.004	<0.001
Slope	0.098	0.010	<0.001	0.391	0.073	<0.001	0.258	0.046	<0.001	0.342	0.128	0.036
Slope^2	−0.004	0.001	<0.001	−0.022	0.004	<0.001	−0.017	0.003	<0.001	−0.019	0.007	0.042
Well distance	na[a]			3.129	1.899	0.134	3.375	1.264	0.018	6.712	2.394	0.031
Well distance^2	na			−0.465	0.229	0.073	−0.416	0.156	0.019	−0.719	0.289	0.047
Road density	−0.249	0.027	<0.001	−0.827	0.387	0.061	ns[b]			ns		
Aspect = NE	0.012	0.051	0.818	ns			ns			ns		
Aspect = NW	0.399	0.025	<0.001	ns			ns			ns		
Aspect = SE	−0.301	0.022	<0.001	ns			ns			ns		
Aspect = SW	0.194	0.028	<0.001	ns			ns			ns		

[a] Not applicable.
[b] Not significant.

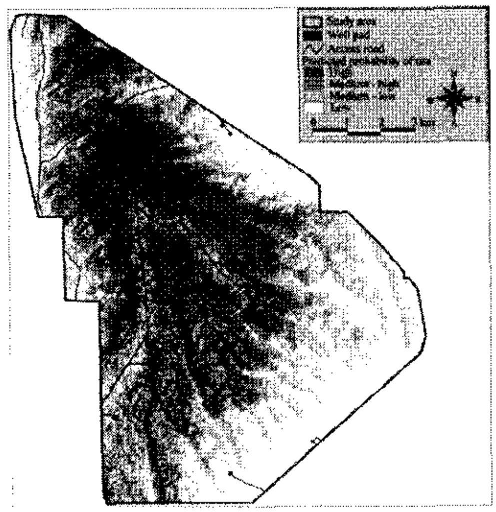


Figure 1. Predicted probabilities and associated categories of mule deer habitat use during 1998–1999 and 1999–2000 winters, before natural gas field development in western Wyo., USA.

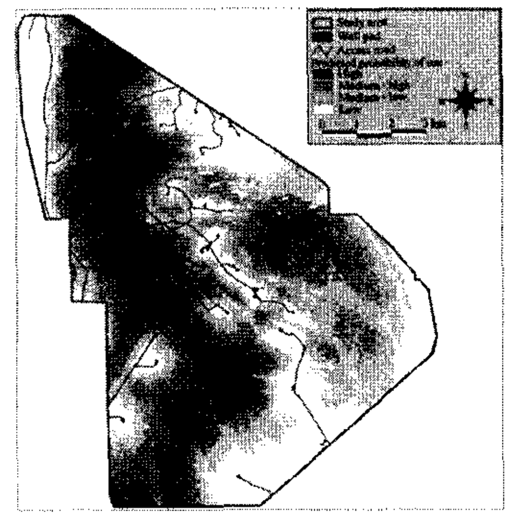


Figure 2. Predicted probabilities and associated categories of mule deer habitat use during year 1 (winter of 2000–2001) of natural gas development in western Wyo., USA.

pads (Fig. 4). Shifts in deer distribution between predevelopment, year 1, year 2, and year 3 of development were evident through the changes in the 4 deer-use categories (Table 2). Of the habitat units classified as high deer use before development, only 37% were classified as high deer use during year 3 of development (Table 2). Of the areas classified as low deer use before development, 41% remained classified as low deer use during year 3 of development (Table 2).

Discussion

Our statistical analysis differs from the typical methods used in the study of habitat selection (Manly et al. 2002) in several important ways. First, our sample size was the number of radiocollared deer during each winter, and our objective was to make statistical inferences to the corresponding population in the study area. Thus, we assumed that our radiocollared deer represented a simple random sample from the population each winter. Second, our response variable was an empirical estimate of the probability of use of a habitat unit, or the volume under an animal's utilization distribution surface. And third, we used a stepwise model-building procedure to develop a population-level model from individual deer models, where the average of the coefficients across deer comprised the population-level model for each winter period.

We recognize that other techniques may be used to estimate population-level models. Random-coefficients or hierarchical models (Littell et al. 1996) can estimate individual and population-level coefficients; however, model convergence can be problematic. To date, we believe the most appropriate method to obtain a population-level model is to fit a GLM with negative binomial errors to each radiocollared deer and average the coefficients. Seber (1984:486) describes this estimator and notes that identical population-level coefficients can be obtained if one averages the relative frequency of use in each of the sampled habitat units and fits a single model. We prefer to estimate individual models because the variation among individuals is often of biological interest.

We would have preferred the use of GPS radio collars during all years of this study because they can systematically collect thousands of accurate deer locations, regardless of weather conditions or time of day. Although the VHF radio collar locations used for the predevelopment model were collected at irregular intervals and during daylight hours, we believe the resulting model provides a reasonable comparison to models estimated during years of development with GPS radio collar locations. Hayes and Krausman (1993) suggested diurnal use of habitats by female mule deer were representative of overall patterns of habitat use, except in areas with high levels of human disturbance. Because human activity was exceptionally low on the Mesa before development, we believe the 953 VHF locations collected from 45 radiocollared deer accurately reflect overall deer use during that time period.

We view our resource selection analysis as an objective means to document mule deer response to natural gas development and quantify indirect habitat losses through time. Although indirect impacts associated with human activity or development have been documented in elk (*Cervus elaphus*; Lyon 1983, Morrison et al. 1995, Rowland et al. 2000), data that suggest similar behavior in mule deer (Rost and Bailey 1979, Yarmaloy et al. 1988, Merrill et al. 1994) are limited and largely observational in nature. Specific knowledge of how, or whether, mule deer respond to natural gas development does not exist in the literature. Our results suggest winter habitat selection and distribution patterns of mule deer were affected by well pad development. Changes in habitat selection by mule deer appeared to be immediate (i.e., year 1 of development), and through 3 years of development, we found no evidence they acclimated or habituated to well pads. Rather, mule deer had progressively higher probability of use in areas farther away from well pads as development progressed. The nonlinear relationship between probability of deer use and distance to well pad indicates deer selected areas away from well pads, but only up to a certain distance. We believe this reflects the ability of mule

Table 2. Percent change in the 4 predevelopment deer-use categories through 3 years (2001–2003) of natural gas development in western Wyo., USA.

Predevelopment category[a]	Year of development	Deer use category: High	Medium–high	Medium–low	Low
High	Year 1	60%	23%	13%	4%
	Year 2	49%	19%	23%	9%
	Year 3	37%	22%	27%	14%
Medium–high	Year 1	31%	36%	22%	11%
	Year 2	34%	23%	25%	18%
	Year 3	27%	22%	28%	22%
Medium–low	Year 1	9%	34%	31%	26%
	Year 2	16%	35%	25%	25%
	Year 3	25%	27%	25%	23%
Low	Year 1	0%	7%	34%	58%
	Year 2	1%	23%	27%	48%
	Year 3	11%	29%	20%	41%

[a] Category rows may not sum to exactly 100% because of rounding error.

deer to avoid localized disturbances and habitat perturbations without completely abandoning their home ranges.

Population-level RSPFs and associated predictive maps were useful tools for illustrating changes in habitat selection patterns through time. We recognize the 4 levels of habitat use were subjectively defined and could vary depending on study objectives or species information. Nonetheless, we believe RSPFs and associated predictive maps can provide a useful framework for quantifying indirect habitat losses by measuring the changes (e.g., percentage or area) in habitat use categories through time. Predictive maps suggest that some areas categorized as high use before development, changed to low use as development progressed, and other areas initially categorized as low use changed to high use. For example, following year 1 of development, 17% of units classified as high use before development had changed to medium–low or low use, and by year 3 of development, 41% of those areas classified as high use before development had changed to medium–low or low use. Conversely, by year 3 of development, 40% of low-use areas had changed to medium–high or high-use areas. Assuming habitats with high probability of use before development were more suitable than habitats with lower probability of use, these results suggest natural gas development on the Mesa displaced mule deer to less-suitable habitats.

Winter severity and forage availability can influence the distribution patterns of mule deer (Garrott et al. 1987, Brown 1992). However, winter conditions on the Mesa were considered relatively mild during the course of this study (1998–2003) and were unlikely to have precluded deer from using their entire winter range. Gilbert et al. (1970) reported snow depths >61 cm were required to preclude use of an area by mule deer. With the exception of isolated drifts, snow depths were <61 cm across the Mesa during all years of study. If the observed changes in deer distribution were due to severe winter conditions, we would expect deer use to shift to areas with lower elevations and south-facing slopes. Instead, deer always selected for high elevations, and aspect was never a significant predictor variable during years of development, further suggesting the observed shifts in deer distribution

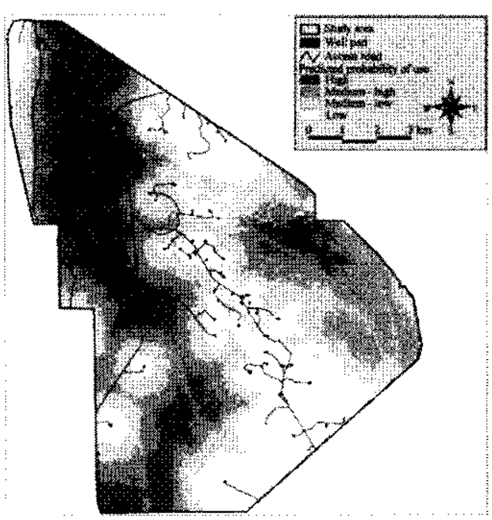


Figure 3. Predicted probabilities and associated categories of mule deer habitat use during year 2 (winter of 2001–2002) of natural gas development in western Wyo., USA.

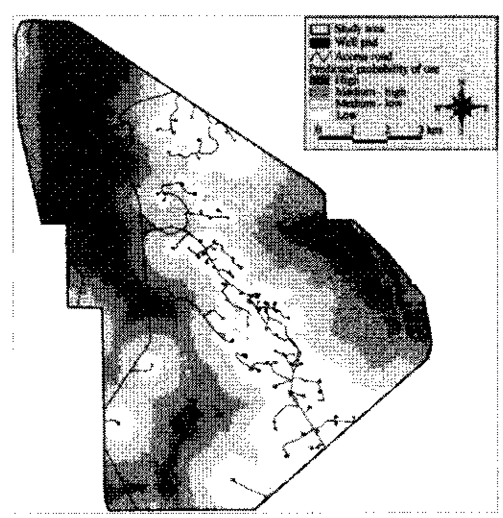


Figure 4. Predicted probabilities and associated categories of mule deer habitat use during year 3 (winter of 2002–2003) of natural gas development in western Wyo., USA.

were due to increased well-pad development and associated human activity rather than winter conditions.

A single well pad typically disturbs 3 to 4 acres of habitat; however, areas with the highest probability of deer use were 2.7, 3.1, and 3.7 km away from well pads during the first 3 years of development, respectively. There are 2 potential concerns with the apparent avoidance of well pads by mule deer. First, the avoidance or lower probability of use of areas near wells creates indirect habitat losses of winter range that are substantially larger in size than the direct habitat losses incurred when native vegetation is removed during construction of the well pad. Habitat losses, whether direct or indirect, have the potential to reduce carrying capacity of the range and result in population-level effects (i.e., survival or reproduction). Second, if deer do not respond by vacating winter ranges, distribution shifts will result in increased density in remaining portions of the winter range, exposing the population to greater risks of density-dependent effects. Consistent with Bartmann et al. (1992), we would expect fawn mortality to be the primary density-dependent population-regulation process because of their high susceptibility to overwinter mortality (White et al. 1987, Hobbs 1989).

Monitoring shifts in distribution or habitat use allows for mitigation measures aimed at reducing impacts to be evaluated and for timely, site-specific strategies to be developed. The current mitigation measure is focused on seasonal-timing restrictions, where drilling activity is limited to nonwinter months. This type of mitigation is common across federal lands and intended to reduce human activity and, presumably, the associated stress to big game during the winter months, typically 15 November to 30 April. Major shifts in the distribution of mule deer on the Mesa occurred even though drilling on federal lands was largely restricted to nonwinter months. Our findings suggest current mitigation measures may not be achieving desired results. Winter-timing restrictions are only imposed on leases that occur in areas designated as crucial winter range, and then, only through the development phase of the well. Consequently, variable levels of human activity may occur throughout the field during winter as producing wells are serviced, and despite the recognition of the uniqueness of crucial winter range, roads may cross or abut these areas, exposing them to human disturbances as well.

Management Implications

In deep-gas fields like the PAPA, where well densities range from 4 to 16 pads per section (2.58 km^2), the number of producing well pads and associated human activity may negate the potential effectiveness of timing restrictions on drilling activities as a means of reducing disturbance to wintering deer. Mitigation measures designed to minimize disturbance to wintering mule deer in natural gas fields should consider all human activity across the entire project area and not be restricted to the development of wells or to crucial winter ranges. Reducing disturbance to wintering mule deer may require restrictions or approaches that limit the level of human activity during both production and development phases of the wells. Directional-drilling technology offers promising new methods for reducing surface disturbance and human activity. Limiting public access and developing road management strategies may also be a necessary part of mitigation plans. Future research and monitoring efforts should evaluate how different levels of human activity (e.g., traffic or noise) at developing and producing well pads influence mule deer distribution. Understanding mule deer response to different levels of human activity and types of well pads would allow mitigation measures to be properly evaluated and improved.

Assuming there is some level of increased energy expenditure required for deer to alter their winter habitat-selection patterns (Parker et al. 1984, Freddy et al. 1986, Hobbs 1989), the apparent displacement of deer from high-use to low-use areas has the potential to influence survival and reproduction. This relationship, however, needs to be documented. Accordingly, we recommend appropriate population parameters (i.e., adult female survival, overwinter fawn survival, recruitment) be monitored in areas with large-scale gas development so that changes in reproduction or survival can be detected. The major shortcoming of efforts to evaluate the impacts of disturbances on wildlife populations is that they seldom are addressed in an experimental framework but, rather, tend to be short-term and observational. Brief, postdevelopment monitoring plans associated with regulatory work generally result in little or no information that allow agencies and industry to assess impacts on wildlife or to improve mitigation measures. We encourage long-term (>5 years) studies that identify habitat-selection patterns and that measure population characteristics in control and treatment areas before and during gas-development projects that occur in sensitive mule deer ranges.

Acknowledgments

We thank D. McWhirter, S. Smith, B. Holz, H. Haley, D. Almquist, B. Hovinga, S. Edberg, D. Clause, and S. Werbelow of the Wyoming Game and Fish Department (WGFD); S. Anderson of the Wyoming Cooperative Fish and Wildlife Research Unit; P. Guernsey of TRC Mariah Associates, Inc.; and S. Belinda of the BLM for providing field, office, and logistical support. Discussions with D. Thomas, J. Millspaugh, C. Nations, T. McDonald, and G. White helped refine the statistical methods. Comments from L. Carpenter, R. Sparrowe, and J. Brown improved the manuscript. Our research was funded by Ultra Petroleum, Questar Exploration and Production Company, the BLM, and the WGFD.

Literature Cited

Bartmann, R. M., G. C. White, and L. H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121.

Brown, C. B. 1992. Movement and migration patterns of mule deer in southeastern Idaho. Journal of Wildlife Management 56:246–253.

Bureau of Land Management. 2000*a*. Record of decision: environmental impact statement for the Pinedale Anticline natural gas field exploration and development project prepared for Pinedale field office, Wyoming. Pinedale, Wyoming, USA.

Bureau of Land Management. 2000*b*. Record of decision: environmental impact statement for Continental Divide/Wamsutter II natural gas project, Sweetwater and Carbon Counties, Wyoming. Rawlins and Rock Springs field offices. Rawlins, Wyoming, USA.

Bureau of Land Management. 2002. Oil and gas activity on public lands in the United States and Wyoming. USDI-BLM, Wyoming State Office, Cheyenne, USA.

Bureau of Land Management. 2003. Final environmental impact statement

and proposed plan amendment for the Powder River Basin oil and gas project. Buffalo field office. Buffalo, Wyoming, USA.
Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. Second edition. Springer, New York, New York, USA.
Di Orio, A. P., R. Callas, and R. J. Schaefer. 2003. Performance of two GPS telemetry collars under different habitat conditions. Wildlife Society Bulletin 31:372–379.
Erickson, W. P., T. L. McDonald, K. G. Gerow, S. Howlin, and J. W. Kern. 2001. Statistical issues in resource selection studies with radio-marked animals. Pages 209–242 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations, Academic, San Diego, California, USA.
Freddy, D. J., W. M. Bronaugh, and M. C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63–68.
Garrott, R. A., G. C. White, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Movements of female mule deer in northwest Colorado. Journal of Wildlife Management 51:634–643.
Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. Journal of Wildlife Management 34:15–23.
Glenn, E. M., M. C. Hansen, and R. G. Anthony. 2004. Spotted owl home-range and habitat use in young forests of western Oregon. Journal of Wildlife Management 68:33–50.
Hayes, C. L., and P. R. Krausman. 1993. Nocturnal activity of female desert mule deer. Journal of Wildlife Management 57:897–904.
Hobbs, N. T. 1989. Linking energy balance to survival in mule deer: development and test of a simulation model. Wildlife Monographs 101.
Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. Second edition. John Wiley and Sons, New York, New York, USA.
Johnson, B. K., J. W. Kern, M. J. Wisdom, S. L. Findholt, and J. G. Kie. 2000. Resource selection and spatial separation of mule deer and elk during spring. Journal of Wildlife Management 64:685–697.
Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, Cary, North Carolina, USA.
Lyon, J. L. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81:592–594.
Manly, B. F., L. McDonald, D. Thomas, T. McDonald, and W. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic, Boston, Massachusetts, USA.
Marzluff, J. M., J. J. Millspaugh, P. Hurvitz, and M. S. Handcock. 2004. Relating resources to a probabilistic measure of space use: forest fragments and Steller's jays. Ecology 85:1411–1427.
McClean, S. A., M. A. Rumble, R. M. King, and W. L. Baker. 1998. Evaluation of resource selection methods with different definitions of availability. Journal of Wildlife Management 62:793–801.
McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Second edition. Chapman and Hall, Boca Raton, Florida, USA.
Merrill, E. H., T. P. Hemker, K. P. Woodruff, and L. Kuck. 1994. Impacts of mining facilities on fall migration of mule deer. Wildlife Society Bulletin 22:68–73.
Morrison, J. R., W. J. Devergie, A. W. Alldredge, A. E. Byrne, and W. W. Andree. 1995. The effects of ski area expansion on elk. Wildlife Society Bulletin 23:481–489.
Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. Fourth edition. McGraw-Hill, Boston, Massachusetts, USA.
Otis, D. L., and G. C. White. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. Journal of Wildlife Management 63:1039–1044.
Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474–488.
Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634–641.
Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modeling in relation to roads. Journal of Wildlife Management 64:672–684.
SAS Institute. 2000. SAS/STAT user's guide: statistics. Version 8. SAS Institute, Cary, North Carolina, USA.
Sawyer, H., and F. Lindzey. 2001. The Sublette mule deer study. Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, USA.
Sawyer, H., D. Strickland, and L. McDonald. 2002. Summary of 2002 project results and scope of long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline project area. Western Ecosystems Technology, Cheyenne, Wyoming, USA.
Seber, G. A. F. 1984. Multivariate observations. John Wiley and Sons, New York, New York, USA.
Thompson, S. K. 1992. Sampling. John Wiley and Sons, New York, New York, USA.
U.S. Geological Survey. 1999. Thirty-meter national elevation data set (tiled for Wyoming): U.S. Geological Survey EROS data center, Sioux Falls, South Dakota, USA.
White, G. C., R. A. Garrott, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Management 51:852–859.
White, G. C., and R. E. Bennetts. 1996. Analysis of frequency count data using the negative binomial distribution. Ecology 77:2549–2557.
Yarmaloy, C., M. Bayer, and V. Geist. 1988. Behavior responses and reproduction of mule deer does following experimental harassment with all-terrain vehicle. Canadian Field-Naturalist 102:425–429.

Associate Editors: Strickland and McDonald.

Attachment C

Literature Review and Synthesis on the Effects of Residential Development on Ungulate Winter Range in the Rocky Mountain West

Jean Polfus

May 2011

REPORT PREPARED FOR MONTANA FISH, WILDLIFE AND PARKS

Acknowledgements

I wish to acknowledge John Vore and Doris Fischer from Montana Fish, Wildlife and Parks for supporting this project and providing essential advice, comments and enthusiastic encouragement during the duration of the work. Funding was also provided by the Montana Chapter of the Wildlife Society. Heidi Kretser of the Wildlife Conservation Society provided helpful feedback and suggestions as well as insightful knowledge of the human dimensions aspects of wildlife impact research. Sarah Reed generously shared her research and ideas on conservation and residential development. Background research for this report benefited from a thorough literature review on suburban and exurban influences on wildlife and fish by Paul Krausman, Sonja Smith, Jonathan Derbridge and Jerod Merkle of the University of Montana and a literature review on the effects of energy development on ungulates by Mark Hebblewhite. Paul Krausman also provided helpful advice, guidance and access to hard to find sources. I appreciate the Heb Lab at the University of Montana, especially Nick DeCesare, Scott Eggeman and Mark Hebblewhite for lending me innumerable books. Shawn Cleveland also provided revisions and advice. Photos in the report used with permission from Michel Kohl, Sonja Smith, Claire Polfus and the Wildlife Conservation Society. Finally, the report benefited from revisions by Claire Polfus.

Montana Fish, Wildlife & Parks

Montana Chapter

Please cite as:

Polfus, J. L. 2011. Literature review and synthesis on the effects of residential development on ungulate winter range in the Rocky Mountain West. Report prepared for Montana Fish, Wildlife and Parks. Helena, MT.

Cover artwork by J. Polfus

Updated March 2012

Table of Contents

List of Figures

List of Tables

Executive Summary

In the past 40 years rural residential development has increased dramatically in the valley bottoms and mountain foothills of the Rocky Mountain West. Development has diverse impacts on wildlife including altered ecological community composition and biotic interactions, fragmentation of natural landcover and the establishment of source sink dynamics. All of these mediators have been linked to modified species behavior, such as avoidance of areas near development and human activity, interrupted dispersal and movement patterns, restricted distributions and population declines. Wildlife persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive human development across the American West.

During winter ungulates must select resources to sustain a positive energy balance, minimize energetic costs and reduce predation risk across broad temporal and spatial scales. In general, ungulate winter range includes low-elevation valley bottoms and mountain foothills composed of a mixture of private and public lands that have low snow cover and high solar radiation. Typically, agricultural or ranch land is the first to be converted into residential spaces across the West. This focuses most new residential growth in productive regions that support high species biodiversity. Thus, high quality ungulate winter range and new developments are intersecting at increasing rates. Roads and subdivisions near and in winter range affect ungulate populations through multiple behavioral, physiological, population and ecological community processes.

I reviewed > 80 peer-reviewed articles, theses, dissertations, reports and professional papers on the effects of human disturbance and residential development on five ungulate species: white-tailed deer, mule deer, elk, American pronghorn and bighorn sheep. Unfortunately, very few studies have focused exclusively on the effects of residential development on ungulates (n=22), thus, I also emphasize key studies on the effects of human activity, roads and industrial development on ungulate populations. In each section I detail key characteristics of winter range and highlight various impacts of development from overt behavioral reactions to population-level responses. Problems associated with habituation, migration, disease and predation are also reviewed.

White-tailed deer populations have expanded in the last century and display high adaptability to human activity. Most studies on white-tailed deer response to residential development have occurred in the eastern or midwestern United States. These studies suggest that deer often select high quality forage near residential structures and benefit from reduced predation rates and a lack of hunting by humans in close proximity to developments. White-tailed deer may display greater avoidance of human disturbance during sensitive biological seasons. In some situations, white-tailed deer habitat use has declined with increasing housing densities. Habituated white-tailed deer impact humans through the spread of diseases, increased deer-vehicle collisions, attacks on humans and alterations to plant structure and community composition. Human attitudes and perceptions of white-tailed deer in urban environments can limit wildlife management options such as hunting. Care should be taken to fully understand the effects of development on local populations before critical habitat is lost.

Mule deer populations in the West have declined in recent decades. Though research has not isolated the confounding factors involved in the declines, it is probable that residential development has played a significant role. Mule deer are known to display behavioral escape responses such as avoidance, decreased flight initiation distances and other behavioral reactions to human activity and recreation. Studies indicate that mule deer often avoid roads and industrial infrastructure. In some cases, avoidance of human disturbance can increase energy expenditure and may impact individual survival during the winter. Because mule deer utilize flexible migration behaviors to maximize resources and decrease predation pressure, development in migration corridors can have significant consequences. Like white-tailed deer, mule deer can also become habituated to urban areas. Abundant deer populations pose a threat to human safety, cause property damage and can generate concerns for animal welfare. Future research is needed to determine how predation, disease and residential developments may interact to influence mule deer populations.

Elk initially respond to human disturbance with increased vigilance, flight responses and behavioral avoidance, all of which have the potential to increase winter energy expenditure. In northern climates, decreases in energy reserves during winter can lower survival. Therefore, development has the potential to lead to severe population level declines in elk. Unfortunately, very few studies have directly examined the population-level consequences of human development on elk. However, large developments, such as ski areas, can alter elk distributions during sensitive periods such as fawning, leading to decreased reproductive success. Without direct negative pressure from humans, elk can and will habituate to human activity. Habituated elk are associated with crop depredation, overgrazing, property damage, injury to humans, disease transmission and an eventual decline in migratory behavior. Elk also react to pressure from hunting by humans by moving to areas with hunting restrictions such as private lands. As hunter-friendly ranches are increasingly transformed into subdivisions, more land is available as a refuge for elk during the hunting season. This reduces the ability of managers to control elk populations, further escalating problems with habituation.

No studies have specifically examined the impact of residential development on American pronghorn behavior or demography. However, research on the impacts of human disturbance on pronghorn indicates that pronghorn increase vigilance, flight responses and behavioral avoidance near human activity. Pronghorn need large contiguous areas with relatively few physical barriers to complete seasonal migrations. Energy development, transportation infrastructure, fencing and rural residential development are all threats to pronghorn migration. Mitigating the effects of residential development in critical migration bottlenecks should receive priority conservation. Pronghorn can habituate to certain levels of disturbance, especially when not hunted or harassed. During severe winters pronghorn may select agricultural lands which can reduce or eliminate migratory behavior. Resident habituated pronghorn can deplete agricultural crops and may be at higher risk for vehicle collisions. In general, pronghorn persistence is dependent on large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.

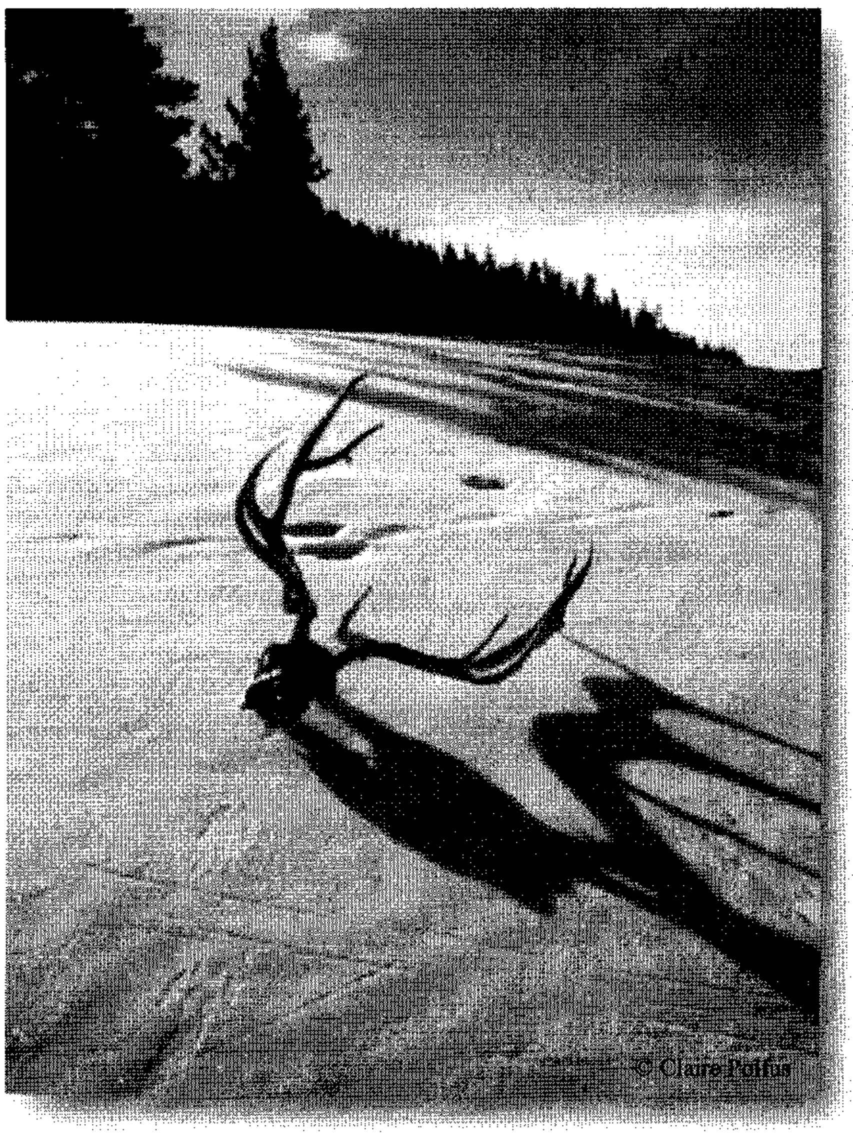
Similar to pronghorn, no specific research has been conducted on the effects of residential development on bighorn sheep behavior or demography. Historic declines in bighorn sheep are likely due to expansion of urban development, resource extraction, disease, competition with domestic livestock and habitat fragmentation; though no cause and effect studies documented the declines. Mountain sheep are highly vigilant and exhibit a number of overt behavioral reactions in response to human disturbance. Where human development intersects sheep range, roads may act as a barrier to movement, especially when highways bisect migration routes or corridors to important seasonal mineral lick sites. Aircraft overflights can increase movement rates, heart rates and interrupt foraging and resting behaviors. Disease and parasite levels have also increased following human disturbance. Evidence of habituation to temporally and spatially predictable human activity has been documented in certain situations. Protection and maintenance of mountain sheep habitat is essential to prevent extirpations similar to those observed in the past century.

In summary, most ungulates exhibit short-term behavioral reactions in response to human disturbance. However, very few studies have linked these responses to population-level consequences. These inferences are needed to evaluate the effectiveness of management strategies, understand and predict the impacts of development and monitor regulatory requirements. Several recent long term monitoring projects on the effects of energy development on ungulates suggest that demographic impacts may take many years to detect. Compensatory reproduction and resilience in adult age-cohorts create time lags between disturbance events and the eventual long-term impact on the population. Thus, there is a pressing need for long-term cumulative effects studies that can clarify the mechanisms driving changes in abundance and distribution.

Recently, 'conservation development' has been proposed as an alternative to traditional development patterns. By clustering homes in a small area, conservation development reduces the overall footprint by minimizing the influence of each house on the ecosystem. Thus, large-scale impacts on open spaces and agricultural lands can be mitigated. However, there is growing concern that these strategies may neglect important high quality wildlife habitat. New research indicates that the configuration of development (i.e., where clustered development occurs on the landscape) is at least as important, if not more important, than simply conserving open space.

Land use guidelines can help facilitate the development of policies and regulations needed to guide decisions on how to design developments and regulate their influence on wildlife. Guidelines are often specific to ecological and political scales. At the smaller site scale, guidelines suggest buffering development, reducing exotic species, reducing fencing and other barriers to movement, reducing noise and light disturbance, controlling domestic pets, maintaining connected patches of undeveloped land and assessing site level habitat conditions. At the larger landscape scale, collaboration between governments, local jurisdictions, NGOs and private interests are needed to maintain large intact patches of unfragmented habitat. To protect winter range development should be clustered in areas near existing development to leave as much high quality winter range undeveloped as possible.

As the West faces continuing pressure to develop ungulate winter range, policies and regulations that incorporate scientific research, ecological principles and land use planning guidelines are essential for successful conservation of important ungulate habitat and migration corridors. This requires ecologists and wildlife managers to engage with land use planners to ensure that pertinent research directs large-scale development patterns. To date, no studies have rigorously analyzed the population-level impacts of residential development on ungulates. Though this lack of definitive research can sometimes delay the implementation of policies and regulations, planners must proceed on the basis of the most pertinent scientific research as well as the professional opinion of planners and wildlife managers. As new information is acquired, policies should be modified accordingly. Adaptive management is one possible avenue towards evaluating the impact of residential development on ungulate winter range.



Introduction

Human influence on natural systems is drastically increasing as the world population grows and the pace of industrialization and consumption progress. The total land area impacted by human activities is projected to increase to 50-90% worldwide by 2050 (UNEP 2001). The accelerating rate of habitat loss is the primary cause of wildlife population decline and extinction (Fahrig 1997, Myers et al. 2000, Brooks et al. 2002). Human developments and activity can impact wildlife through changes in behavior to decreased survival or fecundity and large-scale regional extinctions (Ceballos and Ehrlich 2002). The term *effect* refers to the change in the environment caused by human activity, while the term *impact* represents the consequences of these changes on wildlife (Wathern 1990, Johnson and St-Laurent 2011). While most human development will have an effect on an ecosystem, the spatial and temporal impacts on wildlife may vary by season, disturbance type, species and a range of other environmental factors (Johnson and St-Laurent 2011). The expansion of the human population and, in particular, the associated demand for housing space, is and will continue to be a challenge to wildlife management and conservation with unpredictable and unprecedented impacts on natural systems (Liu et al. 2003).

Historically, settlement of the mountainous regions of the American West was constrained to valley bottoms by topography and water availability. As land was bought and sold in the early 1900s, a general pattern emerged with public lands at high elevations and private lands at lower elevations (Knight et al. 1995, Gude et al. 2006). Because of the extreme winter conditions associated with high elevations, valley bottoms and mountain foothills are important winter habitat for many species, including ungulates (Safford 2003). Many ungulates lose body mass over the winter due to increased energetic costs of gestation for females (Pekins et al. 1998), movement in snow (Parker et al. 1984, Fancy and White 1987), and starvation due to poor winter nutrition (Festa-Bianchet 1989, Post and Klein 1999, Creel and Creel 2009, Parker et al. 2009). Fine scale winter habitat preferences vary between species, but ungulates generally prefer low elevation areas composed of a mixture of large tract ranch land and low elevation public land that have low snow cover and high solar radiation (Anderson et al. 2005, D'Eon and Serrouya 2005, Christianson and Creel 2007, Klaver et al. 2008).

In the past 40 years the human population and rural residential development have increased dramatically in valley bottoms and low elevation foothills, especially in the highly scenic areas near national parks that contain the largest densities of ungulates (Gude et al. 2006). The rate of land conversion into residential development often exceeds the rate of human population growth (Fulton et al. 2001). Development that occurs along the urban-rural gradient beyond urban and suburban areas has been termed exurban (Table 2., Nelson 1992). It is characterized by low-density vehicle-dependent residential development, segregated land uses, poor pedestrian access to services and a lack of community-based shared spaces (Johnson 2001, Ewing et al. 2005). Exurban sprawl can be especially detrimental because it results in the loss of more land to accommodate fewer people. The conditions that make winter range preferable to ungulates, including relatively low snowfall, high solar radiation and proximity to summer range, are often also desirable to humans. The rising rate of exurban development in the Rocky Mountain West means that high quality ungulate winter range and new development will intersect at increasing rates. Roads and subdivisions near and in winter range affect ungulate herds through multiple behavioral and demographic responses and at the same time reduce management options. The high rate of land use change is projected to continue, making local land use management plans especially important to preserving important ungulate habitat (Gude et al. 2007).

The direct and indirect effects of exurban development on ungulate winter range vary by region, ungulate and predator species, specific habitat type and development structures. This review will explore the effects of land use change, especially residential development at exurban densities, on the following ungulates of the Rocky Mountain West: white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), American pronghorn (*Antilocapra antilocapra*) and bighorn sheep (*Ovis canadensis*). To support efforts by Montana Fish Wildlife and Parks to offer guidance to local governments and land developers on proposed subdivisions and future rural development, I will also review papers describing the integration of ecological principles into land use planning and how they can be applied to the development planning on or near ungulate winter range. In summary, the objectives of this literature review are to:

- Review the impacts of land use change, especially residential development, on ungulates in the Rocky Mountain West,
- Review the history and status of land use change in the Rocky Mountain West, and its implications to ungulate winter range,
- Summarize land use and growth management policies that affect ungulates,
- Review weaknesses and limitations in the current literature available, and
- Recommend guidelines for future research.

Methods and Scope

I conducted a literature review of the effects of residential development on five focal species using a variety of electronic resources including: ISI Web of Knowledge, Zoological Record, CSA Biological Sciences, CSA Illustrata: Natural Sciences, Google Scholar, and Biological Abstracts. I used a combination of the following keywords: ungulates, exurban development, residential development, mule deer, white-tailed deer, pronghorn, elk, bighorn sheep, energy development, roads, habitat degradation, human impact, habitat suitability, habitat quality, home range, survival, recruitment and resource selection. I focused on studies that incorporated specific responses of ungulates to human land use change including residential development, industrial development, roads and other impacts. I also included literature reviews, grey literature reports, theses and dissertations that explored the effects of human development on wildlife and land use policies in the West including suggested guidelines towards sustainable development. Articles were mined for references that were relevant and that did not show up in the search criteria.

To summarize the literature I recorded information on the following categories for each research article that was relevant to ungulates response to human development: peer review status, sample size, study area location, study area size (km^2), study duration (years study occurred), type of development, study design (review, modeling, experimental, observational, telemetry, comparative, survey, before/after), housing buffer, estimated minimum patch size, general methods, general results and conclusions and management recommendations. These summaries can be found at the end of each species summary section in this report. Other pertinent literature on ungulates is summarized in Appendix A. Though the list of articles is extensive, it is likely that some studies may have been overlooked because they were grey literature, rarely cited or did not match the search criteria. Not every article reviewed in the text is included in the summary tables.

Results

I reviewed over 100 articles on the impacts of residential development on wildlife. Not all studies reviewed were summarized in the tables at the end of each species section. Approximately 80 studies were directly related to the effects of human development on ungulates. Only 22 specifically examined residential development and its influences on the five focal species (Table 1). Most studies (n=55) were observational studies that inferred the impact of development by correlating behavioral responses to human developments. This is generally the weakest study design and makes determining cause and effect difficult (Hebblewhite 2008). Comparative studies (n=7), examined responses before and during/after development, or between control and treatment areas. Experimental designs (n=8) included controlled situations in which a treatment was applied to individuals or a population and results were compared to controls.

Table 1. Summary of pertinent literature reviewed by species and human disturbance type (some studies included more than one species and more than one development type).

Species	Total	Peer Review	Residential	Recreation	Energy Development	Roads	Other
White-tailed deer	14	10	14	-	-	-	-
Mule deer	19	14	5	3	5	3	3
Elk	17	12	4	5	-	5	3
Pronghorn	14	5	1	1	4	1	2
Mt. Sheep	16	12	-	6	3	-	5
Total	**80**	**53**	**24** (22 total)	**15**	**12**	**9**	**13**

Geographically, all but one study on the effects of residential development on white-tailed deer occurred in the midwestern and eastern United States (Figure 1). Studies on the effects of aircraft on bighorn sheep all occurred in the dessert southwest, where Department of Defense lands exist. Most elk studies occurred along the Rocky Mountains. Studies on energy development cluster in southwestern Wyoming and southern Alberta, Canada.

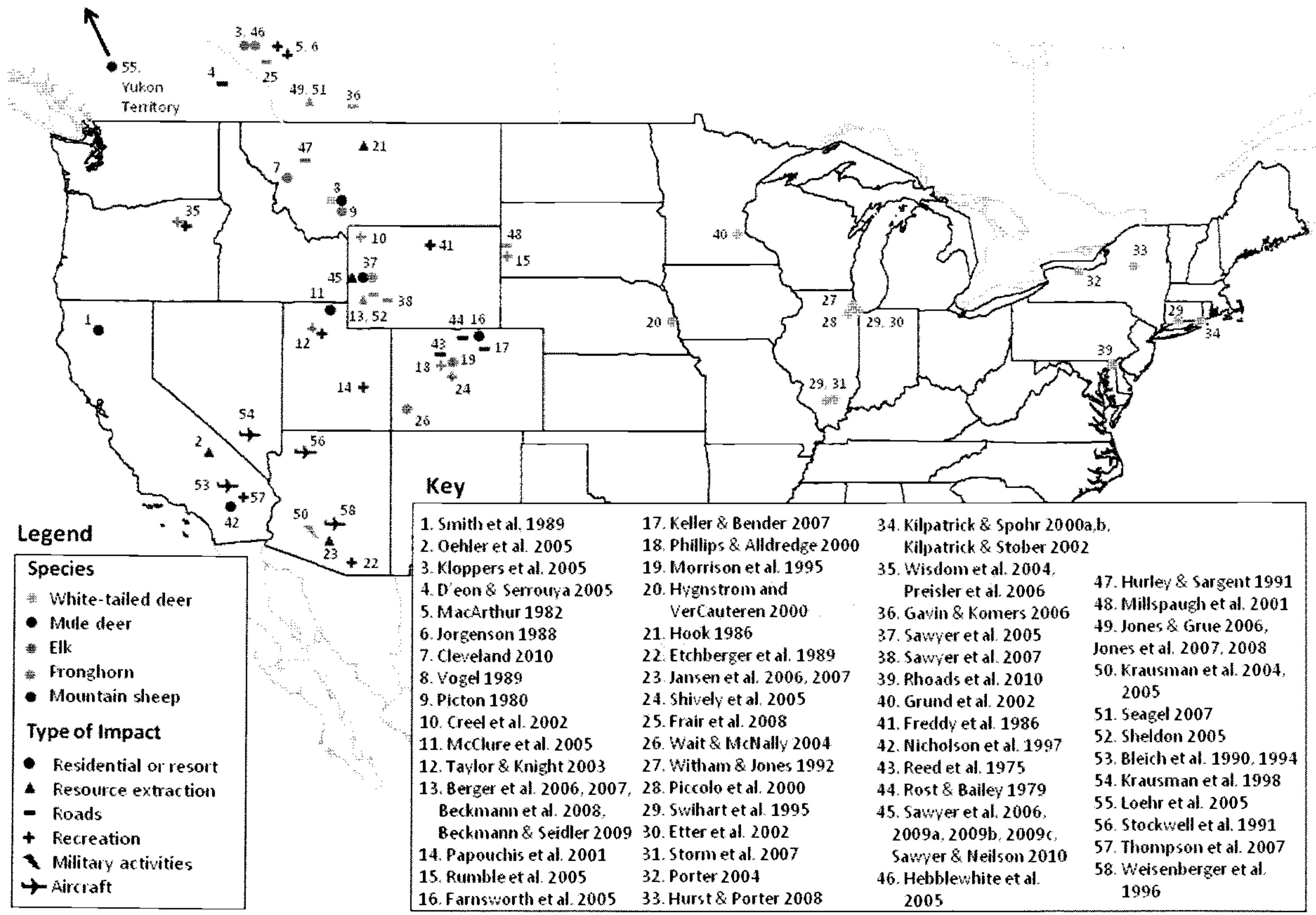


Figure 1. Location of studies on the effects of human development and activity on ungulates.

Land Use Change

The expansion of human development into intact ecosystems is inevitable as land is converted to accommodate the increasing human population (McKinney 2002, Foley et al. 2005). In 2010, the U.S. census indicated that the population of the Western U.S. grew dramatically, resulting in a 13.8% increase from 2000. Montana's population increased by 9.7%, while Idaho, Wyoming, Utah and Colorado increased by 21.1%, 13.1%, 23.8%, and 16.9% respectively, all well above the national average of 8.8% (Figure 2., http://2010.census.gov). The influx of humans in the West since 1910, mostly comprised of European settlers, has had diverse ecological and economic consequences, from the forced removal of Native American people from their traditional territories in the late 1800s to the current demand for increased energy consumption and natural resource extraction. Economic growth often competes with wildlife conservation because of the conflicting goals of sustainable management and production of consumption goods and services (Czech 2000). However, there is a growing appreciation for green infrastructure strategies that protect critical wildlife habitats while at the same time supporting education and healthcare services, recreation, tourism and sustainable local economies (Chambers et al. 2010). As the West faces future economic, ecological and demographic transitions collaboration between governments, local jurisdictions, NGOs and private interests will be required to promote sustainable development.

Globally, the increase in resource exploration, mines, power lines, pipelines, utilities, hydroelectric plants and dams has progressively altered the distribution and abundance of species. Extensive studies, books and reviews have documented the impact that conspicuous land use change as a result of resource extraction, logging and energy development has had on wildlife (UNEP 2001, Hebblewhite 2008, Vistnes and Nellemann 2008, Naugle 2011), and a comprehensive review of this topic is beyond the scope of this paper. Much less attention has been given to the impacts residential structures, offices and shopping centers have on the habitat and population dynamics of wildlife (but see Glennon and Kretser 2005, Hansen et al. 2005, Krausman et al. 2011). Growing evidence indicates that while houses may appear to have a smaller footprint than industrial infrastructure, the combination of the reckless pace of residential development and the lack of comprehensive and enforceable land use policies ensures that residential development in the West will have considerable impacts on wildlife (Hansen et al. 2005).

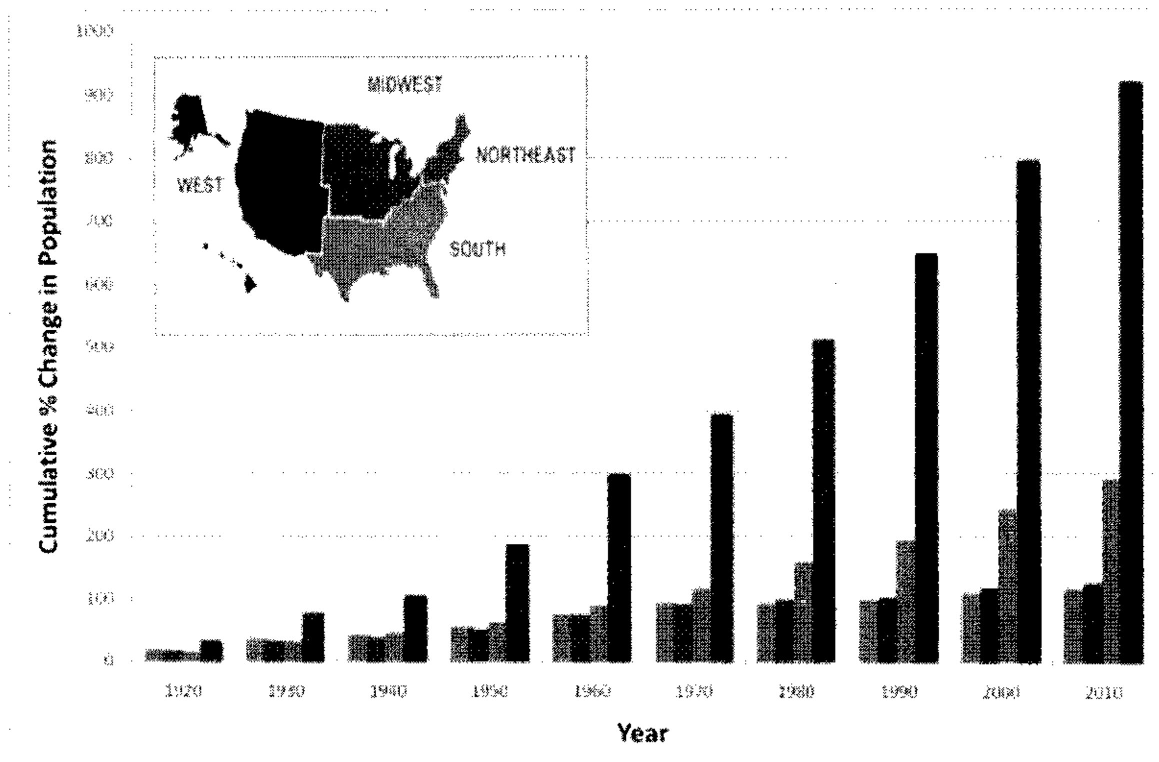


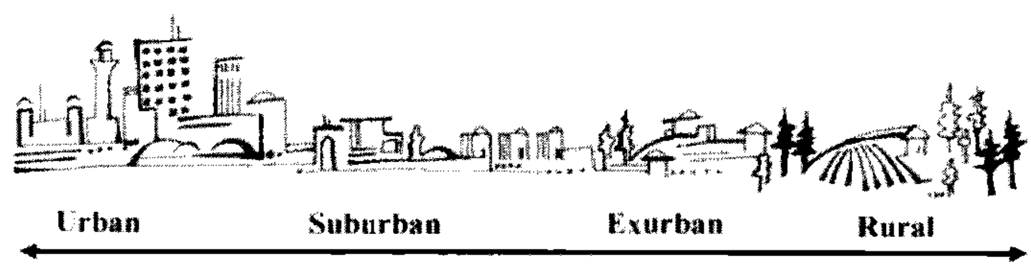
Figure 2. Cumulative change in U.S. population from census data by regions from 1910 to 2010. Red bars indicate that the West has consistently experienced the highest rates of population growth.

Exurban Development

For the purposes of this paper, the term exurban is used to describe development located in areas along the urban-rural gradient that are beyond the reach of urban public facilities and services. Beginning in the 1970s, growth of rural areas began to exceed growth of metropolitan regions. By 2000, over 25% (1.39 million km^2) of the conterminous U.S. was occupied at exurban densities (1 unit per 1 to 40 acres), resulting in extensive impacts on agricultural lands, forests and range lands (Brown et al. 2005). Some estimates suggest that exurbia is home to approximately 37% of the U.S. population (Travis 2007) and encompasses an area 7 times larger than urban and suburban areas combined (Theobald 2005). Generally, 'exurban' is characterized by large lot sizes, low overall housing densities and close proximity to rural or undeveloped lands (Table 2). Because exurban densities are so low, each new residential development has a disproportionately large effect on the surrounding area (Leinwand et al. 2010). Some authors include urban fringe development as exurban development, especially in areas where physical commuting can still occur, although telecommuting has increased the distance from major metropolitan areas (Nelson 1992, Hansen et al. 2005). Exurban development is unique because it is often the first major development on lands that were previously natural, undeveloped or agricultural (Radeloff et al. 2005). Thus, surrounding habitat patches remain connected and are often dominated by native vegetation complexes (Odell and Knight 2001, Brown et al. 2005).

Unfortunately, there is a lack of consensus in the literature on a consistent definition of exurban densities (Arendt 1997). Terminology varies between land use planners, local governments, developers, biologists and community members and descriptions range from the number of structures per square kilometer to density based on human population or the number of acres per housing unit. Because roads may influence habitat differently than residential units that include lawns, pavement and ranging domestic pets, there is a need to refine descriptions of developments by specific types or classes (Theobald et al. 2005). To further complicate the situation, available data on housing densities, road type, traffic volumes and human activity levels can vary between districts, counties, planning regions and states. This lack of consistency makes it challenging to compare management plans and development policies between regions. However, advances in remote sensing, mapping capabilities and GIS applications have the potential to bring consistency to the field (Travis et al. 2005). If the overall goal of management is to understand how heterogeneous resources affect wildlife population viability, then the functional properties of developments must be examined at multiple spatial and temporal scales (see section on Impacts of Human Development on Ungulates, Theobald et al. 2005). From a wildlife biology perspective, there is a need to understand the scale of ecological thresholds that define important demographic consequences to wildlife species. As McIntyre and Hobbs (1999) note, "how an organism experiences landscape alteration, is of more significance in conservation biology than the human perspective."

Table 2. Summary of number of acres per housing unit across the urban – rural gradient (diagram by J. Polfus).



Author		**number of acres per housing unit**		
Hansen et al. 2005			9.9-41.2 acres	
Brown et al. 2005	1 acre		1-40 acres	> 40 acres
Theobald 2004	1 acre	1 to 10 acres	10-40 acres	> 41 acres
Clark et al. 2005			1.65-16.5 acres (medium exurbia)	> 165 acres
Glennon & Kretser 2005			5-40 acres	
Lenth et al 2006			39.5 acres	
Daniels 1999			5-10 acres	

Spatial Distribution of Private and Public Lands

The recent drivers of exurban development are nested within a complex history of land use change in the Western U.S. Understanding the factors that influence land use change is necessary to make informed decisions about future trends and the appropriateness of various management techniques (Brown et al. 2005). Well before colonial influence, the American landscape was modified by Native American people to ensure essential resources remained present (Czech 1995, Krech 1999). Thus, it is important to understand the idealistic perspective of the term "natural" or "wild" when referring to conditions prior to European settlement (Krech 2005). In the early 1900s, the boom-bust markets for metal, timber and cattle defined the political, social and ecological geography of the American West (Limerick et al. 2002). In addition to the inherently unstable natural resource-based economies in the region, land speculation was a significant market that created a land use regime based on private property (Travis 2007).

Almost half the land base in the Western U.S. is federally owned and will not be modified by extensive agricultural, residential and commercial uses (Figure 3). While roads, mines, energy development, forestry, campgrounds and lodges can occur on federal lands, the sprawl of metropolitan areas and exurban development will be limited to private lands. This, more than any other factor, makes the dynamics of land use in the West unique when compared to the rest of the country (Travis 2007). Travis (2007) points out that the "relationships between developed and undeveloped land, and between development and topography, play an important role in shaping sense of place in the American West." Public lands, largely composed of Forest Service (USFS) and Bureau of Land Management (BLM) lands (but also including state lands) occur largely at higher elevations and desert basins while private lands dominate fertile river valley bottoms and mountain foothills with the most productive soils, the greatest species diversity (Scott et al. 2001, Ewing et al. 2005) and much of the West's ungulate winter range. The interactions between private and public lands influence the spatial pattern of land use change, and can have consequences on species, such as ungulates, that utilize essential seasonal ranges.

Of the private lands available in the West, almost one fifth have been developed for residential, industrial or commercial use (Travis 2007). While population growth may be the ultimate driver of the increasing rate of exurban development, a complex suite of factors determine where and why exurban growth occurs. Some researchers have suggested that the settlement of the West has been shaped by three stages of growth: natural resource constraints, transportation expansion and the pursuit of natural amenities (Huston 2005, Gude et al. 2006). Currently, the resource-based economies of ranching, farming, mining and logging are being replaced by private sector jobs that support tourism, recreation, retirement and second homes (Shumway and Otterstrom 2001). This economic transition is being fueled by amenity migrants who value environmental quality more than economic opportunities (Nelson 2003). The attraction of small town life, areas of high social and scenic amenities, recreational activities and safe communities are hastening the growth of exurban regions in the West by attracting highly skilled professionals and entrepreneurs as well as retirees and tourists (McGranahan 1999, Rudzitis 1999, Rasker and Hansen 2000). Interestingly, these new residents are driving employment opportunities and economic activity in rural areas rather than the other way around, further perpetuating the evolution of the "New West" (Shumway and Otterstrom 2001). The changing demographic makeup also brings about disparate perceptions of wildlife and the environmental attitudes which can lead to new conflicts over the fate of the New West (Peterson et al. 2008).

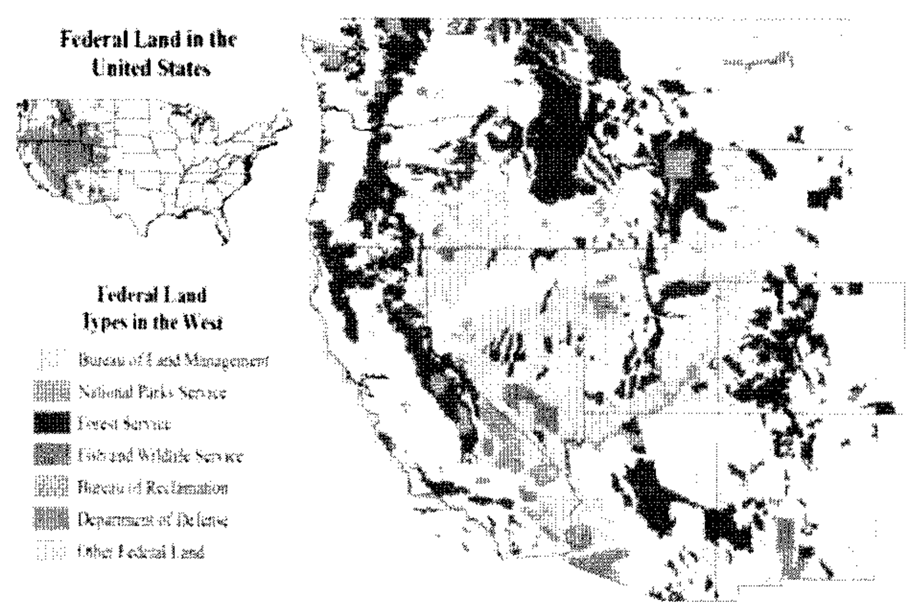


Figure 3. Distribution of public and private (white areas) lands in the West (data from the National Atlas of the United States 2006).

Typically, agricultural or ranch land is the first to be converted to exurban residential spaces. This focuses most new growth in low elevation valley bottoms (Knight et al. 1995, Gude et al. 2006). Further, the proximity of private land to national parks or other wilderness lands, biologically diverse riparian areas, lakes and productive farmlands increases the probability of development (Gude et al. 2006, Jarvis 2008). The transfer of ranches from traditional owners to amenity buyers has altered management models and goals. Some large lots are fragmented into many small private parcels which complicates issues related to access, rights of way, water rights, liability and public relations (Knight et al. 1995). Other land is sold intact to non-traditional owners who manage not for livestock, but a variety of amenity-related pursuits or conservation initiatives (Gosnell et al. 2006, Travis 2007). Tension can arise between new migrants and long-time locals on issues such as land use regulations, predator abundance and irrigation practices. Complicating the situation, in some areas private lands are used by ungulates as a refuge during hunting seasons (Burcham et al. 1999). Traditional agreements with private landowners to manage these herds have become more complicated (Haggerty and Travis 2006). Hunting has become less of a viable management tool due to increased restricted areas surrounding new exurban development (Harden et al. 2005, Haggerty and Travis 2006). The diverse range of economic backgrounds, beliefs, values and motivations pose increasing challenges to managers tasked with finding solutions to wildlife conflicts. This discord is likely to become more difficult in the future if people become more and more detached from nature and ignorant about wildlife and conservation. Management solutions will be dependent on finding a precarious balance between the rights of individuals, monetary losses and the preservation of the environment for future generations.

Impacts on Wildlife

Though loss of habitat is the primary cause of species decline (Ehrlich and Wilson 1991, Soulé 1991, Pimm and Raven 2000), there is a growing consensus that the proximate mechanisms for the accelerating loss of terrestrial biodiversity and species extinctions are often indirect and asymmetrical (DeCesare et al. 2010). Conservationists are beginning to recognize the importance of indirect and complex (nonlinear) interactions in driving population dynamics (Polis and Strong 1996, Sinclair and Byrom 2006). Indirect effects of development include altered animal and plant community composition and biotic interactions, fragmentation of natural land cover, avoidance of areas near development or human activity, as well as the establishment of source-sink dynamics. All of these mediators have been linked to modified species behavior, interrupted dispersal and movement patterns, and habitat alterations which can impact population dynamics, distributions and decrease biodiversity (Odell and Knight 2001, McKinney 2002, Miller et al. 2003, Glennon and Kretser 2005, Hansen et al. 2005, McKinney 2008).

In general, increased housing densities result in a decrease in native species sensitive to human disturbance and an increase in generalist human adapted species (Schneider and Wasel 2000, Maestas et al. 2003, Fraterrigo and Wiens 2005, Hansen et al. 2005, Lenth et al. 2006, Gude et al. 2007, Blair and Johnson 2008). This results in biotic homogenization as urban-adaptable species such as coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), European starlings (*Sturnus vulgaris*), house sparrows (*Passer domesticus*) and early successional plant species become increasingly abundant (Hayden 1975, McKinney 2002, Fraterrigo and Wiens 2005, McKinney 2006, Kretser et al. 2008). Development can also lead to a loss of native species richness through competition with invasive exotic species (Radeloff et al. 2005). Humans physically transport and introduce invasive species into new areas as well as provide disturbed habitat that can be utilized by competitive non-native species (D'Antonio and Meyerson 2002, McKinney 2006). Predators and large mammals are often the first species to decrease near human development due to active persecution, low reproductive rates and extensive resource needs (Ray et al. 2005). The loss of both vertebrate and invertebrate predators can lead to overabundant prey species in some areas or increase the competitive ability of non-native species (Shochat et al. 2004). Extreme consequences of altered species abundance and distribution can impact ecological community dynamics through trophic cascades that are mediated by human activity (Crooks and Soule 1999, Hebblewhite et al. 2005, Berger and Conner 2008, Berger et al. 2008).

In certain cases, predators can benefit from human modified landscapes when resource availability is altered. Subsidized predators occur when humans directly or indirectly create resource subsidies that allow predators to maintain population levels above what would occur without additional resources (Gompper and Vanak 2008). Common Ravens (*Corvus corax*) receiving subsidies from garbage dumps near human developments have been shown to hunt threatened desert tortoises (*Gopherus agassizii*) in the Mojave Desert (Boarman 2003, Kristan and Boarman 2003, Boarman et al. 2006). Similarly, generalist coccinellid beetles subsidized in croplands displayed increased predation pressure on native aphid herbivores in natural habitat remnants (Rand and Louda 2006) and red fox subsidized by human farmlands had behavioral effects on gerbil (*Gerbillus spp.*) foraging levels in the desert of Jordan (Shapira et al. 2008). Thus, subsidies can have a strong impact on population interactions and the structure of the ecological community (Polis et al. 1997).

Fragmentation of intact landscapes has diverse effects on different species. In general, development often reduces habitat from its original extent to a series of disconnected small patches (see review by Saunders et al. 1991). This results in decreased connectivity between patches, overall loss of habitat and an increase in edge habitat, all of which can decrease the ability of an area to support individuals and populations (Glennon and Kretser 2005). For example, the human population in an area of exurban growth near Seattle, WA increased by 193% between 1974 and 1998. This resulted in increased forest fragmentation and reduced interior forests > 200 m from an edge by 60% (Hansen et al. 2005, Robinson et al. 2005). Other studies have found that the loss of mature forests can decrease native forest bird abundance (Hansen et al. 2005). In Ontario, an increase in the number of houses near forest patches (irrespective of the size of the patch) decreased the diversity and abundance of Neotropical migrant songbirds, suggesting that any external residential development had a large impact on forest communities (Friesen et al. 1995). An increase in edge habitats as a result of fragmentation can alter disturbance regimes and biotic interactions and lead to invasion of non-native species as described above (Dale et al. 2005).

Fragmentation is a result of the conspicuous alterations to the environment through exurban development. These changes include the construction of linear features such as roads, fences, power lines as well as buildings. The associated human disturbance is often difficult to quantify but can include increased recreation in surrounding areas, traffic levels, noise, human presence, security lights and domestic pets (Knight et al. 1995). Avoidance of human development and disturbance can lead to an extensive loss of habitat effectiveness. Avoidance can be defined as a reduction in use of areas near human activity compared to areas farther from development. Various species have been shown to alter behavior and habitat use near human activity (Theobald et al. 1997, Odell and Knight 2001, Vistnes and Nellemann 2008, Polfus et al. *in review*). Patterns of avoidance vary with respect to species, sex, age, season, density dependence, size of the area affected and development type. Furthermore, roads can act as barriers to movement, encourage new residential development, increase soil erosion and sedimentation and promote foreign chemical transport, all of which cause further habitat degradation to the local system (Forman and Alexander 1998, Trombulak and Frissell 2000, Hawbaker et al. 2006).

Some species may be sensitive to the associated increase in human activity around development. Roads and residential developments facilitate additional human activities such as hunting, resource extraction and recreation. Areas surrounding residential developments also experience increased authorized and unauthorized use (Henderson and O'Herren 1992). Domestic pets can be efficient and effective predators and can impact the distribution and abundance of native species. Studies have shown that domestic dogs impact the behavior of white-tailed deer and mule deer but demographic impacts were not tested (Hayden 1975, Sime and Schmidt 1999, Miller et al. 2001). However, other studies have shown direct mortality of fawns due to dog predation in New Brunswick (Ballard et al. 1999). There is substantial evidence indicating that domestic cats can have severe impacts on songbird, small mammal and reptile populations and are an increasing threat to biodiversity (Coleman and Temple 1996, Crooks and Soule 1999).

There is growing concern that areas near roads and human developments may be attractive population sinks for a number of species. In these situations, individuals select risky habitats (most likely due to high quality forage, for example; near roadsides) which decrease survival through increased mortality rates (Nielsen et al. 2006). These habitats are often called attractive sinks (Pulliam 1988) or ecological traps (Gates and Gysel 1978) where individuals experience high mortality, but populations are maintained by immigration from source areas with positive reproduction and recruitment. Attractive sinks are common in habitats that have been altered by humans because species are unable to recognize or adapt to mortality risks that were not present in their evolutionary history (Delibes et al. 2001, Donovan and Thompson 2001, Schlaepfer et al. 2002). The interactive effects between public and private lands in the West can produce complex population dynamics. Hansen and Rotella (2002) found that undeveloped productive low-elevation private lands act as a source for native bird species in the Greater Yellowstone Ecosystem. However, when residential development occurred in these areas, nest success declined due to brood parasitism by cowbirds. These dynamics suggest that ranchlands and other private lands should be an important focus of conservation efforts (Maestas et al. 2003).

Understanding the interactions of multiple development types across large temporal and spatial scales is important for predicting how future developments may impact populations. Different types of human disturbance, such as roads or houses, are likely to have varying degrees of influence on the strength of avoidance and have the potential to interact in a cumulative manner with habitat quality and local population dynamics (Polfus 2010). In this way, a single road may be individually inconsequential, but the combined impact of multiple roads and development complexes can be significant over time (Spalding 1994, Jeffrey and Duinker 2000, Scott 2007). Current management policy, which often attempts to mitigate impacts by restricting development through timing or seasonal restrictions, is unlikely to mitigate environmental degradation from the increasing exurbanization. Wildlife persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive development across the United States. The scale and measured process of piecemeal development in exurbia further confounds the ability of land planners to address cumulative effects. Single development permits, authorized over the span of years can make it difficult for review boards and planners to decline building permits when an area already contains multiple houses (Travis 2007). Thus, the cumulative impact of multiple low-density residential developments can produce significant ecological effects over time.

Impacts on Society

The spread of residential development into rural and undeveloped areas not only threatens wildlife habitats, but also has many negative social impacts that are often overlooked. For example, rural sprawl puts increasing pressure on public facilities and services such as hospitals, libraries, schools, fire stations and law enforcement. Often these services are not supported by revenue from exurban tax dollars and deplete local government budgets (Gude et al. 2006). Rural sprawl also decreases the efficiency of power lines and roads, increases the costs of transportation, separates low income families from jobs and disrupts community cohesion (Ewing et al. 2005, McElfish 2007). These hidden costs have been linked to increased traffic fatalities (Ewing et al. 2003a), increased pollution, obesity (Ewing et al. 2003b) and disturbance to aquatic ecosystems and water quality (Wear et al. 1998, Nassauer et al. 2004).

Land use change in areas where undeveloped land meets development poses serious threats to human quality of life and safety as well as the environment. This abutment zone has been termed the wildland-urban interface (WUI), and some estimates suggest that it occupies close to 9% of the U.S. (Radeloff et al. 2005). A host of environmental problems are associated with the WUI including alteration of ecological process, energy flows and natural disturbance regimes such as the frequency of pest outbreaks, fires, floods and blowdown events (Dale et al. 2005). The increase in exurban development has made managing wildfires challenging, costly and dangerous (Radeloff et al. 2005, Travis 2007, Gude et al. 2008). In Western states, 50% of new homes are built in areas classified as severe fire zones, increasing the exposure of people and structures to wildfire (Theobald and Romme 2007). Exurban development can also influence the stability of sensitive riparian areas and increase the risks of floods that can impact both ecological systems and in some cases human communities (Johnson 2001, Hansen et al. 2005).

Where residential units are adjacent to undeveloped areas, there is generally an increase in human-wildlife interactions and conflicts (Wolch et al. 1995, Woodroffe et al. 2005). Conflicts can result from direct experiences such as deer-vehicle collisions, crop-depredations, scorpion stings or direct attacks on humans by predators (Lacey et al. 1993, Baker and Timm 1998, McIntyre 1999, Riley and Decker 2000). Development patterns can have a significant impact on the rate and severity of human-wildlife interactions. McIntyre (1999) found that the number of reported scorpion stings around Phoenix, Arizona, increased in areas of low-density residential housing (<5 units per acre) and that the proximity to undeveloped land was also a good predictor of the frequency of stings. In northern New York near Adirondack Park, Kretser et al. (2008) modeled the spatial distribution of species-specific human-wildlife interactions across a range of housing densities. Interaction reports were clustered in the center of the urban-rural gradient with more conflicts reported in low-density suburban and exurban areas compared to urban areas and wildlands.

Threats to property and human safety can impact people's perceptions of wildlife and set back local conservation efforts (Conover 1998). Societal characteristics influence the beliefs, attitudes, and behaviors humans have towards wildlife. Studies have found that tolerance towards wildlife tends to decrease as the number of interactions increases (Lacey et al. 1993, Kretser et al. 2009, Thornton and Quinn 2009). In New York state, negative outlooks towards wildlife were associated with older, lower income residents who had less experience with wildlife (Kretser et al. 2009). However, risk perception is also a function of historic cultural attitudes and media coverage of serious conflicts (Wolch et al. 1995, Riley and Decker 2000, Hudenko et al. 2008). Supporting projects that increase positive interactions between people and wildlife, such as bird watching, is an important consideration since people with positive interactions with wildlife are more willing to support local wildlife management programs (Kretser et al. 2009). The management of human-wildlife conflict is undoubtedly dependent on managing human behavior. Wildlife managers must be able to respond to issues with appropriate methods to decrease risks to human welfare while at the same time promoting wildlife and habitat conservation.

Unfortunately, the amenities that draw people to the West, such as scenic beauty, wildlife and open spaces are being destroyed by houses owned by the very people who value these qualities in the first place. The propensity for well educated, environmentally oriented people to live in natural areas is a troubling pattern for conservation (Peterson et al. 2008). There is a need for people concerned about the environment to change ingrained behaviors, such as choice of household location, that are threatening wildlife habitat (Peterson et al. 2008). Altering established societal systems will be exceedingly difficult, but conservation biologists will be forced to tackle these issues in the face of growing residential development across the Western U.S.

> "The biggest problem is the loss of winter range (for mule deer and elk), and I've now become part of it because my wife won't live in town."
>
> – Retired Idaho Fish and Game biologist quoted in Peterson et al. (2008)

Ungulates

Ungulate Winter Range

Habitat represents the resources and environmental conditions in an area that determine the survival and reproduction of a given organism (Hall et al. 1997, Sinclair et al. 2006). Ungulates must select resources to sustain a positive energy balance, minimize energetic costs and reduce predation risk across broad temporal and spatial scales (Altendorf et al. 2001, Lind and Cresswell 2005). In the northern hemisphere, digestible nutrients and protein decline during the winter and snow accumulation increases energy loss during movement (Ungulate Winter Range Technical Advisory Team 2005). Thus, ungulate winter range must provide security and thermal cover and allow ungulates to maximize forage intake and minimize energy loss through movement (Figure 4., Armleder et al. 1994). However, many ungulates still experience a negative energy balance during winter as a result of increased energetic costs of gestation for females (Pekins et al. 1998), deep snow events (Parker et al. 1984, Fancy and White 1987) and loss of fat and protein due to low quality winter nutrition (Torbit et al. 1985, Festa-Bianchet 1989, Parker et al. 2009).

Winter range is highly variable between regions and species due to the exogenous effects of climate, topography, landcover, predation and the influence of human development (Figure 4., Sweeney and Sweeney 1984, Safford 2003). Because of these differences, specific requirements of winter range for mule deer, white tailed deer, elk, American pronghorn and bighorn sheep will be described in more detail in the following sections. However, it is possible to make a few general observations about ungulate winter range. Snow is likely the single most important aspect of winter range in climates that experience extreme weather events (Poole and Mowat 2005). Snow depth, density and hardness determine the amount of forage that can be reached (Harestad 1985), ability of ungulates to avoid predators and the timing of fine scale daily habitat selection movements and migration (Parker et al. 1984). Ungulate response to various snow depths (or more correctly sinking depths) is well documented in the literature for a number of species (Pruitt 1959, Kelsall 1969, LaPerriere and Lent 1977, Parker et al. 1984, Sweeney and Sweeney 1984, Pauley et al. 1993). Because of the implications snow depth has on ungulate energetics, forested habitats where canopy cover reduces snow on the ground can be an essential component of winter range. Old growth closed-canopy forests are used by ungulates as movement corridors and can also provide arboreal lichen as forage (Armleder et al. 1994), moderate temperatures and hiding and escape cover (Toweill and Thomas 2002). In mountainous regions during periods of heavy snow, ungulates use low elevations and west and south facing slopes where snow is more likely to melt (Kelsall 1969, Henderson and O'Herren 1992, Pauley et al. 1993). Because digestible forage is generally more abundant in open areas ungulates must make trade-offs between the benefits and costs of forest cover, snow depth and forage availability (Pauley et al. 1993, Serrouya and D'Eon 2008).

Determining the amount of winter range required to sustain an ungulate population is difficult because nutritional value of forage, snow accumulation, density and quality, climate, predation and proximity to human development all influence the quality of winter range. Ungulates generally require smaller areas when quality is high and larger areas when quality is low (Anderson 2005), though there are exceptions to this rule (Hoskinson and Tester 1980). Most ungulates exhibit high fidelity to winter range, but habitat preference can change in response to development, winter severity, or predation pressure (Nelson 1998, Hebblewhite et al. 2005, Sawyer et al. 2006, Hurst and Porter 2008). Migration pathways to and from winter range also contribute to habitat quality (Sawyer et al. 2009b).

Because most private land occurs in valley bottoms and mountain foothills, ranches are often an important component of ungulate winter range. In fact, it is likely that over 50% of the wild ungulates in Montana spend a large portion of time on private agricultural lands (Irby et al. 1997). As private lands are converted to residential development it is probable that high quality ungulate winter range will be lost. Furthermore, though little research has focused on the variation in quality of winter range habitat, it can be assumed that residential development in an area of critical habitat, such as essential escape terrain or thermal cover, has the potential to reduce the overall carrying capacity even if the development footprint is small (Krausman et al. 2011). Some areas of winter range may be important only during some winter conditions, such as icing events, and development on these areas could have large impacts during specific years.

Recent work has also shown summer habitat to be critical because of the importance of summer nutrition to ungulate population dynamics (Cook et al. 2004; Parker 2003). Spring green-up has a large effect on fetal growth and reproduction success (Henderson and O'Herren 1992). Thus, the proximity of summer ranges to wintering areas and the quality of important migration corridors also have important implications for ungulate population viability. Mule deer, white-tailed deer, elk, pronghorn and bighorn sheep commonly migrate between 50 and 100 km in spring and fall (Hoekman et al. 2006, Sawyer et al. 2009b, Williams et al. *In prep*). Unfortunately, these migration routes are increasingly threatened by energy development, tourism, exurban development and highway mortality especially in bottlenecks where options for avoiding development pressure are limited (Berger 2004, Gude et al. 2007).

Conserving undeveloped areas of important seasonal ungulate habitat is a key conservation priority for Montana Fish, Wildlife and Parks. As more and more winter range is converted to residential areas, ungulates are increasingly forced into developed areas during the winter. These animals can become habituated to high levels of human activity resulting in conflicts with humans. Problem animals in urban areas stress the financial capacity and oversight of managers. These animals are not only a threat to human safety through increased vehicle collisions but also cause property damage, spread diseases, alter plant community composition and compromise the human perception of wildlife as natural and free-roaming. Further, by decreasing hunting opportunities, habituated wildlife can reduce revenue from the sale of hunting tags, diminish the flexibility of managers to control ungulate populations and weaken public enjoyment of wildlife. Thus, Montana Fish, Wildlife and Parks defines functional ungulate winter ranges as large unfragmented landscapes of suitable habitat where ungulates occur in a natural wild state during the winter. The characteristics of functional winter range include (Vore 2010):

1. Wildlife can use the habitat undisturbed
2. Animals can move easily to and from summer range
3. There are no conflicts with people and domesticated pets
4. Traditional human use and enjoyment of the animals is maintained
5. All options for effective wildlife management, including hunting with rifles, can be employed if desired

Differentiating between 'functional' and 'non-functional' winter range can help direct conservation priorities.

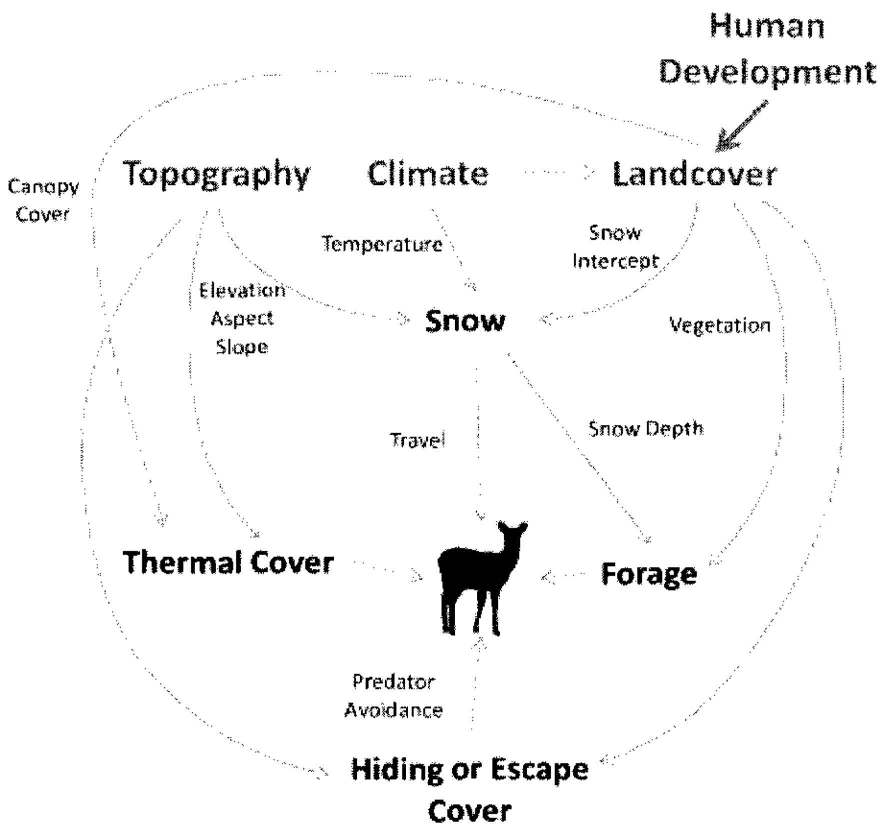


Figure 4. Factors affecting the energy balance of ungulates during the winter. Dashed lines represent factors that influence the condition of ungulates and solid arrows represent factors that influence attributes of winter range habitat. Adapted from Safford (2003).

Impacts of Human Development on Ungulates

As discussed earlier, recent evidence suggests that the effects of human activity and development on wildlife can have non-linear asymmetrical impacts on individuals and populations. Making comparisons across studies of species responses to development can be difficult due to differences in methodology, techniques, regulatory measures, and the scale of the impact examined (Johnson and St-Laurent 2011). In general, the lack of unifying theory has made it challenging to identify universal principles of wildlife-development interactions across studies, taxonomy and development types. Johnson and St-Laurent (2011) have recently proposed a typology for wildlife impact research that sets up a framework for classifying and predicting the impacts of human-wildlife interactions and can serve as a starting point for comparing divergent studies. This framework highlights three broad categories of effects (the spatiotemporal dimensions of the effect, the magnitude of the effect and the regulation and mitigation of the effect) that interact hierarchically to alter the scale of the biological impact on the species. In this way, the range of impacts and effects can be unified by examining the spatial and temporal scale of the response.

Studies that examine avoidance of human development often vary greatly in methodology, with techniques ranging from aerial and ground surveys, pellet counts, movement rates and analyses of telemetry data (Picton 1980, Vistnes and Nellemann 2001, Weir et al. 2007, Cleveland 2010). Notably, recent research suggests that the scale of assessment has a strong influence on the probability of detecting impacts (Hebblewhite 2008, Vistnes and Nellemann 2008) . For example, research on caribou and reindeer (*Rangifer spp*) shifted from local to regional scales in the 1990s. Data that included wider temporal and spatial scales revealed *Rangifer* avoid industrial development, where earlier local behavioral studies had found negligible or indecisive effects (Vistnes and Nellemann 2008). Similar patterns have been detected in other species (Johnson et al. 2005, Nielsen et al. 2008).

Disparate techniques have lead to political and scientific controversy regarding the effect of human activity on ungulates, especially when stakeholders have a vested interest in the interpretation of avoidance distances (Wolfe et al. 2000). Many regulatory processes identify a zone of influence (ZOI) around developments where species experience impacts. The width of a ZOI buffer (the distance of avoidance) is often based on expert opinion or published literature (Anderson et al. 2002, Gallagher et al. 2004, Johnson et al. 2005, Florkiewicz et al. 2006).

However, the ZOI is dependent on biological scale being investigated, the season, the type of development, type of response measured and other biologic factors which can make measuring significance difficult (Gunn et al. 2011). In northern British Columbia, biologically relevant ZOI were developed based on locations from GPS collared woodland caribou (*Rangifer tarandus caribou*) to determine the avoidance of multiple types of human developments (Polfus et al. *in review*). Avoidance of each development type (cabins, town, mines, high use roads and low use roads) varied between seasons and scales, highlighting the importance of cumulative effect studies, which require wider temporal and spatial scales in order to describe population level effects (Krausman 2011).

Many studies and reviews have focused on comparing biophysical-behavioral forces such as home range size, movement rates, annual survival and fertility rates between studies of ungulates along the urban-rural gradient (Kilpatrick and Spohr 2000b, Krausman et al. 2011). While these comparisons may shed light on some general responses to human disturbance, specific environmental conditions in each study area as well as significant differences in methods makes this type of comparison difficult. For example, many studies have shown that estimates of home range size vary due to the estimation techniques especially with the increased reliance on GPS collars (Getz and Wilmers 2004, Getz et al. 2007, Johnson and Gillingham 2008, Kie et al. 2010). Clearly, understanding home ranges, and more importantly, the underlying behavioral mechanisms that explain how and why animals use space, go far beyond the absolute size of the estimated area. Further, the validity of the home range size depends on the scale of the biological question being asked.

The magnitude of the effect also influences the consequences of development on ungulates. Direct habitat loss is easily measured and simply calculates the amount of area converted to human structures. These structures will decrease available habitat in some cases and may also act as barriers to movement and alter metapopulation dynamics (Dyer et al. 2002). The total magnitude of the effect depends both on the total area converted as well as the temporal scale of the exposure to development activity (Johnson and St-Laurent 2011). Single isolated activities may have a trivial impact on ungulate behavior or demography (Oehler et al. 2005), while effects that are large-scale and accumulate over time generally have a larger impact on populations (Nellemann and Cameron 1998). Again, different research designs and metrics used to assess the effect will alter the detection of impacts. Finally, Johnson and St-Laurent (2011) argue that the eventual outcome of development on wildlife is also a result of the types and effectiveness of regulatory frameworks. The importance of policies that effectively provide restrictions and guidelines on the location, size and appropriateness of new developments cannot be over-stated. When the management process becomes self-regulatory the resulting impact on species is more likely to have population or community-level consequences.

Biological Scale of Impact

Individual Behavioral Responses

The framework for identifying the biological scale of the impact developed by Johnson and St-Laurent (2011) provides a hierarchical structure for understanding how various effects of human development influence ungulates. The incremental increase in the severity of the observed biological impact likely does not follow a completely linear relationship, but does reflect a general continuum from individual behavioral responses and physiological changes to population and community-level impacts that have broad implications for population viability (see Table 3., Johnson and St-Laurent 2011). Short-term behavioral changes such as movement away from disturbance, flight response, increased vigilance, altered foraging rates and changes in maternal activities are often the first response ungulates exhibit when their environment is modified (see reviews by Frid and Dill 2002, Stankowich 2008). These changes can be monitored through observational studies, analysis of distributions, indirect measures of habitat use or radio-telemetry. Behavioral changes are a result of multiple non-additive factors (life history, disturbance level, group size, season, etc.) that influence ungulate decisions to flee or stay in an area (Stankowich 2008). In general ungulates assign different levels of risk to different stimuli. Response can vary from minor increased vigilance to panicked flight depending on numerous variables such as prior disturbance and habituation, season, quality of cover, distance from stressor, visibility and other environmental factors (Webster 1997). Often loud noises, aircraft or vehicular stimuli have less of an impact on ungulate responses than pedestrian approach (MacArthur et al. 1982, Andersen et al. 1996, Harrington 2003, Stankowich 2008).

Both direct and indirect impacts can result from increased human development, activity and infrastructure. Anthropogenic mediated mortality of ungulates can occur through hunting, poaching, collisions with vehicles, domestic animal predation, and injuries from building structures and toxins (Burton and Doblar 2004, Krausman et al. 2011). Avoidance and displacement from optimal habitat can be considered a form of indirect habitat loss. For example, studies have documented that caribou and reindeer avoid areas near roads, seismic lines, oil well sites, human settlements, tourist resorts and cabins, power lines, hydroelectric developments, mine sites, logging clearcuts, and snowmobile activity (Dyer et al. 2001, Nellemann et al. 2003, Schaefer and Mahoney 2007, Seip et al. 2007). Displacement from optimal foraging grounds could lead to less suitable habitats and cause crowding and overgrazing (Nellemann et al. 2003). Avoidance may influence individuals' ability to circumvent harsh snow conditions and local habitat variables. Displacement also has the potential to alter predation risk by making ungulate locations more predictable and thus more vulnerable to hunting by animal predators and humans (Stuart-Smith et al. 1997, James and Stuart-Smith 2000, Dyer et al. 2001). However, while disturbance may produce similar effects, the impacts are almost always species-specific. This highlights the need for long term studies that examine the impacts of different development types on a range of species.

When disturbance frequency is regular or constant, ungulates have been shown to become habituated to human activity, though levels of habituation vary among individuals and populations (Stankowich 2008). Moose (*Alces alces*), white-tailed deer and elk populations have all shown high adaptation to human habitation (Thompson and Henderson 1998, Kilpatrick and Spohr 2000a, Kloppers et al. 2005, Walter et al. 2010). For example, in Anchorage, Alaska, moose numbers in the city can increase to over 1,000 individuals in the winter and moose are becoming an escalating hazard to drivers (Rozell 1999). Hunting has been shown to decrease habituation towards humans, but in some cases seasonal hunting may not provide enough constant negative stimuli to override other forms of recreation (Colman et al. 2001).

Individual Physiological Responses

Responses to human activity may also include altered physiological, energetic or nutritional states (Johnson and St-Laurent 2011). In ungulates these responses include increased heart rate, respiration and stress hormone concentration (Macarthur et al. 1979, Creel et al. 2009). In some cases, heart rate may increase during disturbance but quickly decrease to pre-disturbance levels with little impact on behavior or habitat use (Krausman et al. 1998). However, prolonged disturbance events may cause increased vigilance, reduced feeding time and lower nutrient intake which have been shown to reduce reproductive rates (Nellemann and Cameron

1996, Cameron et al. 2005). Energetically, flight responses may also increase movement costs and have the potential to reduce body condition and mass and possibly survival (Johnson et al. 2002). Because of the high energy requirements for gestating and lactating females, body condition has direct consequences on the timing of parturition, birth mass and early survival of offspring (Parker et al. 2009). Energetic models for caribou suggest that the energy costs associated with multiple noise disturbance events over the winter could result in a loss of 15% body mass (Bradshaw et al. 1998). Females with calves are especially sensitive to disturbance and may select low quality forage to avoid predation risk (Festa-Bianchet 1988, Poole et al. 2007). Non-invasive techniques have the potential to increase our understanding of physiological status through analysis of parasite loads to examine fitness (Hughes et al. 2009), monitoring of stable isotopes to measure nutritional quality (Parker et al. 2005) or fecal glucocorticoid hormones to measure physiological stress responses (Creel et al. 2002). Unfortunately, most management and regulatory efforts are reactionary and focus on attempting to reverse declines that are already severe (Ludwig et al. 1993). Therefore, understanding key nutritional, physiological and behavioral changes in individuals may provide managers with the opportunity to mitigate the impacts of human disturbance before large-scale population declines occur (Creel et al. 2002).

Population Responses

Behavioral and physiological responses by ungulates to disturbance are by far the most studied impact due to the ease of monitoring and detecting changes. However, disturbance is only important if it decreases vital rates such as reproduction or survival and leads to a population decline (Gill et al. 2001). This information is crucial for managers who must recognize and predict how future developments will influence population dynamics. Few studies have been able to link short or long-term behavioral or physiological responses to changes in abundance, distribution or demography (Hebblewhite 2011, Johnson and St-Laurent 2011). However, when disturbance is severe, physiological or behavioral changes will alter vital rates and be detected at higher biological scales. These inferences are needed to evaluate the effectiveness of management strategies, understand and predict the effects of development and monitor regulatory requirements (Stankowich 2008, Johnson and St-Laurent 2011). Unfortunately, few firm conclusions exist about the population level impacts of human development on ungulates (Hebblewhite 2011). Because ungulates are generally long-lived, the effects of development on sensitive vital rates, such as adult female survival, are extremely difficult to measure in 2-3 year studies. Compensatory reproduction and resilience in adult age-cohorts create time lags between the effects of development and the eventual impact on the species. Without detailed demographic data, the mechanisms driving changes in abundance and distribution are impossible to determine with confidence (Hebblewhite 2011).

However, some studies have documented large scale range abandonment in response to development. The construction of a large hydroelectric reservoir (and associated power lines and roads) in southwestern Norway, resulted in a 92% decline in reindeer density within 4 km of infrastructure over a 10 year period. Areas more that 4 km from roads and power lines experienced a 217% increase in reindeer use. Cow:calf ratios declined as habitat was lost, most likely due to loss of high quality summer range (Nellemann et al. 2003). In south-eastern British Columbia, Seip et al. (2007) used resource selection functions to demonstrate caribou displacement from preferred winter habitat by snowmobiles. Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality.

Finally, human development can result in large scale range contractions and local extirpations. Laliberte and Ripple (2004) examined historic range contractions for North American ungulates and found that many were less likely to persist in areas of high human influence. Specifically, range contractions resulted in 74% loss of historic range for elk, 64% loss for pronghorn, 25% loss for bighorn sheep, 24% loss for caribou, 11% loss for moose and 8% loss for mule deer. Alternatively, white-tailed deer range expanded by 6%. These contractions are important to keep in mind when examining the response to development of remaining populations that have persisted. It is likely that many areas now occupied by residential developments, towns and cities were once critical ranges for elk, pronghorn, bighorn sheep and mule deer.

Ecological Community Responses

Proximity to human development may also alter interspecific relationships such as predation and competition and thus influence the ecological community composition and distribution (Johnson and St-Laurent 2011). For example, evidence suggests that high white-tailed deer densities have extirpated black bears (*Ursus americanus*) on Anticosti Island in Québec (Cote 2005) and black-tailed deer populations (*Odocoileus hemionus*) alteration of native vegetation negatively impacts songbird populations on the Gulf and San Juan Island archipelagos of western Canada and the United States (Martin et al. 2011). Predators have a major impact on prey species and in some cases contribute to species declines and extinctions (Sinclair et al. 1998). These impacts can result from direct effects of predation or be mediated through indirect effects that may cascade through a community (Ripple et al. 2001, Hebblewhite et al. 2005, Berger et al. 2008). Human-altered landscapes can disrupt natural predator-prey relationships since apex predators are more susceptible to extirpation due to conflict with humans (Ray et al. 2005). Because of this, human developments can be attractive to ungulates due to the inherent avoidance of human infrastructure by predators such as wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*). In Anchorage, moose exploit the city for protection from nearby wolf packs in the winter (Garrett and Conway 1999). In the Greater Yellowstone Ecosystem, Berger (2007) found that female moose chose sites closer to roads to give birth, likely as a shield against predation by grizzly bears. In southeastern British Columbia, Kunkel and Pletscher (2000) compared sites where moose were killed by wolves to random locations from radio collared moose. Their results suggest that moose were less likely to be killed by wolves in areas of high road density. Though wolves use roads to enhance travel and searching speeds, the risk of encountering humans on roads may have offset any hunting efficiency benefits.

Conversely, some predators may be drawn into exurban areas by abundant prey species and anthropogenic foods resulting in increasing conflict with humans (Baker and Timm 1998). For example, mountain lion (*Puma concolor*) -human interactions are increasing in the West (Riley and Decker 2000), and coyote populations have increased in residential areas (Grinder and Krausman 2001). As a consequence, a favorable public perception of wildlife may decline due to perceived risks to property and personal safety (Riley and Decker 2000, Hudenko et al. 2008). However, human dimensions research has revealed that the duration and quality of experience with carnivores can interact to influence risk perceptions. For example, resident attitudes towards mountain lions were positive near Calgary, Alberta, and the residents with the most experience with mountain lions were more accepting of management actions and hunting (Thornton and

Quinn 2009). Education of the public about the actual risks associated with wildlife can improve public relations and increase management options.

In circumstances where predator populations are subsidized by an alternative prey species, natural predator-prey dynamics can become decoupled and increased predation can drive the native prey to extinction (DeCesare et al. 2010). For example, in Alberta, human development has altered predator-prey relationships by providing young seral forests that are preferred by moose and white-tailed deer and subsequently, predators such as wolves. High wolf densities consequently increase the vulnerability of woodland caribou to predation (James et al. 2004, Latham et al. 2011). Linear developments such as roads and seismic lines may also increase the mobility of wolves. In northeastern Alberta, James and Stuart-Smith (2000) found that caribou have higher risk of predation from wolves near linear corridors. Seismic lines, which have low human use, may be preferentially used by wolves, increasing their travel efficiency and the ease of caribou detection. Even a small increase in predation through altered spatial relationships between ungulates, predators, and alternate prey could lead to population level effects in herds with low growth rates.

Table 3. Ungulate response to development along the continuum of the biological scale of impacts as described by Johnson and St-Laurent (2011).

Biological Scale of impact	**General Ungulate Response**	**Monitoring Methods**	**Key Research**
Individual Behavioral Responses	Movement away from disturbance, flight response, $\uparrow$ vigilance, altered foraging rates, changes in maternal activities, avoidance of development and habituation. Loud noise, aircraft & vehicular stimuli < impact than humans on foot.	Observational studies, analysis of distributions, indirect measures of habitat use or radio-telemetry.	Reviews by Frid & Dill 2002 and Stankowich 2008
Individual Physiological Responses	$\uparrow$heart rate, respiration and stress hormone concentration. Prolonged disturbance events may cause $\uparrow$ vigilance, reduced feeding time and $\downarrow$ nutrient intake $\rightarrow$ $\downarrow$ reproductive rates. Body condition influences the timing of parturition, birth mass and early survival of offspring.	Analysis of parasite loads, monitoring of stable isotopes and fecal glucocorticoid hormones.	Review by Parker et al. 2009, research by Creel et al. 2002, 2009 and Millspaugh et al. 2003
Population Responses	Prolonged and severe physiological or behavioral changes can alter vital rates and be detected at higher biological scales. Few firm conclusions exist about the population-level impacts of human development on ungulates, but large scale range abandonment has been recorded.	Long-term cumulative effects studies.	Reviews by Hebblewhite 2008, 2011 and Laliberte & Ripple 2004, research by Nellemann et al. 2003 and Seip et al. 2007
Ecological Community Responses	Altered interspecific relationships $\rightarrow$ community composition and distribution. Indirect effects may cascade through a community. Ungulates may use development as a shield against predators or alternately predators may be drawn to development by abundant prey. Subsidized predators $\downarrow$ prey populations.	Large-temporal and spatial scale, multi-level, cumulative effect studies.	Research by Ripple et al. 2001, Hebblewhite et al. 2005, Berger et al. 2008, and Latham et al. 2011

White-tailed Deer

Key characteristics of winter range

White-tailed deer are ubiquitous throughout North and Central America and display a wide range of regional variation in behavior, physiology and demographics (Geist 1998). Defining specific habitat requirements for white-tailed deer is difficult because they are opportunistic generalists. In fact, the diversity of food choices by white-tailed deer makes any attempt to characterize resource selection problematic. As Geist (1998) writes, "to classify deer as browsers obscures more than it enlightens." However, consistent with all northern ungulates, white-tailed deer must balance metabolic costs of movement and predator avoidance with forage availability. In areas without severe seasonal weather conditions, white-tailed deer will occupy the same range year round (Alexander 1968, Sparrowe and Springer 1970, Larson et al. 1978). However, snow depth has a significant influence on white-tailed deer body condition and behavior in the northern part of their range (Telfer 1978, Garroway and Broders 2007). In eastern North America, white-tailed deer often congregate in low-elevation winter yards in response to increasing snow depths (Tierson et al. 1985, Lesage et al. 2000, Hurst and Porter 2008). Extensive use of these areas can severely deplete available browse and can occasionally lead to starvation (Potvin et al. 1981). While some studies suggest that site fidelity to winter range is likely highly plastic, allowing deer to respond to variable browse quality, winter severity or the influence of human disturbance such as fire, timber harvest or bait sites (Tierson et al. 1985, Lesage et al. 2000, Grund et al. 2002, Kilpatrick and Stober 2002, Hurst and Porter 2008), other research points to high fidelity to winter ranges (Woodward 2000, Porter et al. 2004, Hoekman et al. 2006, Klaver et al. 2008).

In the Rocky Mountain West, white-tailed deer are often migratory, moving 20 – 30 km between distinct seasonal ranges (Hoekman et al. 2006). When snow is minimal, deer use open low-elevation habitats to maximize forage on forbs and woody browse (Smith 1977, Telfer 1978). Deer are known to select agricultural land, shrub land, aspen forests, riparian zones and areas near humans that provide high quality forage in suburban lawns (Safford 2003, Krausman et al. 2011). Studies in Montana, Idaho and British Columbia suggest that white-tailed deer adopt an energy conservation strategy when snow depths exceed 30 – 40 cm (Smith 1977, Pauley et al. 1993, Hoekman et al. 2006). To increase efficiency white-tailed deer become dependent on mature conifer stands with > 80% canopy cover that intercept snow and mitigate movement costs. Tree species important to white-tailed deer winter range vary widely between regions and can include ponderosa pine, Douglas fir, Engelmann spruce, western red cedar and western hemlock (Jenkins and Wright 1988, Pauley et al. 1993, Sabine et al. 2002, Hoekman et al. 2006, Klaver et al. 2008). Southwestern aspects are also selected for increased insulation and snow melt rates. Thus, in the Rocky Mountains ideal winter range is characterized by a mix of open habitats with diverse forage and browse that are in close proximity to mature forest stands.

Response to Development

Observational studies have recorded short-term behavioral responses of white-tailed deer subjected to various human stimuli (Kucera 1976, Hirth and McCullough 1977, Lagory 1987, Caro et al. 1995, Lingle and Wilson 2001). In general, white-tailed deer display a variety of predator-avoidance behaviors and physiological responses to disturbance events such as alerting and orienting to the approaching human, tail-flagging, flight (Lingle and Wilson 2001) and increased heart-rates (Moen et al. 1982). Deer are more likely to respond to approach from humans on foot (average flushing distance 122 m), then to humans on horseback or in a truck in Manitoba (Kucera 1976). These reactions may cause deer to use areas farther from human developments if they perceive human activity as a threat. However, white-tailed deer populations have increased steadily since the early 1900s and have expanded into urban and suburban areas where they have adapted remarkably well to human activity (Swihart et al. 1995).

Research on white-tailed deer biology and ecology is substantial and includes numerous studies specific to population dynamics and behavior in residential areas (Table 4). White-tailed deer rapidly reach high densities in suburban and urban landscapes (see comparison of densities in Krausman et al. 2011:169) in part due to decreased movements and dispersal, decreased mortality from hunting, lack of large mammalian predators and increased availability of ornamental plants, shrubs, fertilized yards and supplemental feeding areas (Swihart et al. 1995). Many studies suggest that survival is generally higher and home ranges are smaller in urban areas compared to rural areas, though diverse monitoring methods and estimation techniques make comparisons between studies difficult (Swihart et al. 1995, Hygnstrom and VerCauteren 2000, Piccolo et al. 2000, Etter et al. 2002, Grund et al. 2002, Porter et al. 2004, Krausman et al. 2011).

In a review of several studies in Illinois and analysis of unpublished data from Connecticut, Swihart et al. (1995) concluded that white-tailed deer commonly habituate to human presence in suburban areas. Snow tracking indicated that deer browsed close to houses in winter where forage species richness was two times greater < 50 m from structures. Deer avoided highly developed areas with > 80 houses/km^2, but survival was approximately equal between rural and urban areas. Kilpatrick and Spohr (2000a,b) monitored VHF collared deer in an affluent residential area of Groton, Connecticut. They found that deer did not avoid development and the number of houses within home ranges was greatest in the winter. In suburban areas the minimum space required during the winter/spring transition was 9 ha of undeveloped land associated with 7 ha of residential development. Bird feeders provided significant food resources for deer and likely drew deer close to houses in March when food availability was limited in forest patches. However, the study area was highly fragmented with very little habitat available far from residential areas, thus the availability of undeveloped areas for deer to select was likely limited. The study did suggest that during the fawning period, the number of houses in the core use area was lowest (Kilpatrick and Spohr 2000b). Sensitivity to human disturbance was also strongest during the spring in Carbondale, Illinois, where white-tailed deer in an exurban landscape tended to avoid human structures during fawning, though the result was not statistically significant (Storm et al. 2007b). Contrary to other studies, Storm et al. (2007) also documented higher survival for deer in exurban areas compared to nearby suburban and rural environments. This could be a result of reduced hunting efficiency and lower vehicle collisions in exurban landscapes (Storm et al. 2007a). Grund et al. (2002) monitored deer in a suburb of Minneapolis, Minnesota. Deer generally avoided areas of high human activity in early summer, but shifted habitat selection to residential areas during a severe winter. The authors suggest that anthropogenic food sources and sheltered areas near buildings may have benefited deer during deep snow events and cold temperatures.

Other research in more rural areas has documented white-tailed deer avoidance of residential areas. In a frequently cited study on the effects of housing on white-tailed deer and mule deer populations, Vogel (1989) documented avoidance of existing development in Gallatin Valley, Montana. White-tailed deer home ranges became smaller and more linear with increasing development. Avoidance of houses increased linearly with housing density. Farmhouses were avoided at distances of < 400 m but beyond 1600 m there was no effect. Deer were less likely to be active when there were >11 houses within 800 m and also shifted to more nocturnal behavior. However, several caveats should be explored. This study was conducted from 1981 – 1983 at the advent of VHF collar technology and thus sample sizes were very low (12 white-tailed deer and 4 mule deer radio collared and monitored for a short time) and the number of locations collected was not reported. Further, because many of the locations were observed from driving routes and in defined study plots there is likely to be sample bias associated with deer locations. Other studies of deer response to exurban growth in the West are needed to confirm the relationships described in this study. Comparatively, in southern Illinois, white-tailed deer in a suburban landscape avoided development and selected for wooded areas (Cornicelli et al. 1996).

Habituation

High densities of white-tailed deer in close proximity to human habitation (sometimes > 70 deer/km^2) can exceed human tolerance levels (Swihart et al. 1995, Siemer et al. 2007, Krausman et al. 2011). The inherent problems associated with habituated white-tailed deer at high densities include the spread disease, increased deer-vehicle collisions, attacks on humans and damage to native and ornamental vegetation and crops (DeNicola et al. 2000, DeVault et al. 2007, Hubbard and Nielsen 2009). Managing habituated white-tailed deer is a human perception issue and generally depends more on conflicting social attitudes about wildlife than deer ecology. Management options include birth control measures, fencing, bans on deer feeding, frightening devices, repellents, trapping, translocation, sharpshooting and managed hunts (DeNicola et al.

2000, Beringer et al. 2002). However, public support for lethal control methods is generally low in suburban or urban areas (Decker and Gavin 1987, Cornicelli et al. 1993, Stout et al. 1997), making the task of minimizing deer-human conflicts difficult.


© Jean Polfus

Deer may use areas near human development and activity as a refuge to reduce predation risk from both native predators and human hunters (Harden et al. 2005, Storm et al. 2007a). Exclusion zones that prevent firearm discharge or hunting in proximity to structures can reduce the proportion of land available for hunting, especially at exurban densities where housing is more spread out and each structure has a disproportionate influence on the landscape (Storm et al. 2007a). In the West, ungulate use of private lands as a refuge has caused increasing controversies and can cost landowners up to $6,353 per year (Lacey et al. 1993). In a survey of agricultural producer attitudes towards wild ungulates in Montana, Irby et al. (1997) found that while white-tailed deer occurred most frequently on private land they received higher tolerance from residents than pronghorn and elk. Several cities in Montana have large suburban deer populations. Management agencies like Montana Fish, Wildlife and Parks must respond to complaints and problems associated with habituated deer. This results in an ineffective and costly use of resources that can anger hunters whose license fees provide the majority of funding for urban deer management where hunting is not possible.

Migration

White-tailed deer have adapted several different migration strategies that are likely dependent on local habitat characteristics (Rhoads et al. 2010). In some situations deer will maintain year-long residency in one area (Hygnstrom and VerCauteren 2000), while in other areas deer may shift home ranges in response to severe weather (Nelson 1998, Sabine et al. 2002, Rhoads et al. 2010). In the northern extent of their range, snow depth often forces deer to migrate 20 – 30 km seasonally between distinct ranges (Hoekman et al. 2006). However, other research suggest that snow might not always be a factor in initiating migrations (Grovenburg et al. 2009).

Studies indicate that migration behavior is learned by fawns following their mothers (Nelson 1998). Evidence of individuals switching strategies between years, however, indicates that migration behavior is likely not obligatory and is flexible enough to respond to winter severity or human development (Nelson 1998, Hurst and Porter 2008). Because white-tailed deer are able to adapt to human activity, it is unlikely that residential development will severely disrupt migrations.

Disease

A range of parasites and diseases are known to infect deer of the genus *Odocoileus*. Chronic wasting disease (CWD), is a fatal infectious prion disease that has recently spread through ungulates in North America (Habib 2010). Because CWD can be spread to uninfected deer through contact with live diseased deer, as well as through ingestion of prions in the environment (shed through feces and saliva) there is an increased potential for transmission where deer are concentrated or habitat is limited (Habib 2010). Residential development that limits available winter range could increase deer congregations and facilitate the spread of disease. In the eastern and midwestern U.S., white-tailed deer are also known to carry ticks which serve as the primary vector for the bacteria *Borrelia burgdorferi* (Lyme disease). Human infections of Lyme disease in these areas have increased 25-fold since 1982 (DeNicola et al. 2000). Thus, high densities of deer pose a very real risk to human health, especially in the east and midwest where Lyme disease is prevalent.

Predation

Deer-vehicle collisions are the main source of white-tailed deer mortality in urban and suburban areas (Witham and Jones 1992, Etter et al. 2002, Porter et al. 2004). This problem has significant consequences, both in economic terms and with regards to human injuries (for more thorough review see Krausman et al. 2011). In rural areas hunter harvest is generally the primary source of deer mortality (Harden et al. 2005). In some situations, abundant white-tailed deer populations may draw large predators such as mountain lions into close proximity to human development. This can influence public perception of wildlife through perceived risk (Riley and Decker 2000, Hudenko et al. 2008).

Summary

White-tailed deer populations have expanded their range with the growth of suburban areas. Across their distribution, deer have proven highly adaptable to human activity. White-tailed deer often select high quality forage near residential structures and benefit from reduced predation rates and a lack of hunting in close proximity to human development. While white-tailed deer will respond to perceived threats with overt behavioral reactions and physiological changes, these behaviors do not appear to negatively impact demographics. In fact, white-tailed deer often have higher survival rates in urban environments (Swihart et al. 1995). However, evidence suggests that during sensitive periods of the year, such as during fawning, white-tailed deer tend to avoid human disturbance. In some situations, selection for areas near houses in winter may occur because no alternate undeveloped habitat exists in the region (Gill et al. 2001). In Montana, during the early stages of development, white-tailed deer use declined with increasing housing densities (Vogel 1989). This work suggests the need for more studies that examine how white-tailed deer respond to incremental development in high quality undeveloped habitat. Further, there are likely large behavioral differences between highly habituated white-tailed deer in the eastern United States and deer in the West, where large undeveloped spaces still exist. This highlights the need for future research that will increase our understanding of the impacts of residential development on western white-tailed deer winter range.

Although some people appreciate seeing deer in their neighborhoods, habituated white-tailed deer almost always create problems. White-tailed deer can have cascading and pervasive impact on residential communities through the spread of diseases, increased deer-vehicle collisions, attacks on humans and alterations to plant structure and plant community composition. Human attitudes and perceptions of white-tailed deer in urban environment can limit wildlife management options. Successful white-tailed deer management must include input from various stakeholders because management actions have the potential to take place in peoples' backyards. Thus, to maintain public confidence, managers must request input from the community (Cornicelli et al. 1993, Lauber 2010). White-tailed deer in the West are an important species both economically and culturally. Care should be taken to fully understand the effects of development on local populations before critical habitat is lost.

Table 4. Review of scientific literature on the effects of human disturbance on white-tailed deer, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffer, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Development Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Housing Buffer**	**Min patch size**	**Conclusions & Management Recommendations**
Etter et al. 2002: *1995-1998*	yes	n = 200 ET, 140 VHF	Chicago, IL; 3349 km^2	resid.	Obs.	VHF	Monitored VHF-collared and ear-tagged deer twice weekly, analyzed movement, home ranges and survival.	Survival was high compared to rural populations, the majority of deaths were caused by DVC, dispersal was ↓, HRs were ~= to other suburban populations.	na	na	Suburban deer have high survival rates which can cause ↑ populations. Management should take movements into consideration. DVC should be addressed.
Grund et al. 2002: *1996-1999*	yes	n = 31	Blooming-ton, MN; 30 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, analyzed movements and home range use.	HRs varied according to season, especially during a severe winter, HRs were smaller than those of rural deer.	na	na	Deer use habitat in and near residential areas especially during severe winters. Exurban deer can move seasonally and management should take the season of deer-human conflict into account.
Hurst & Porter 2008: *1960-70 & 2003-2004*	yes	na	Adiron-dacks, NY; na	resid.	Obs.	VHF	Monitored VHF-collared deer 3+x/week, compared historic to present winter yard locations, analyzed winter yard fidelity and migration patterns.	9 of 16 winter yards were relocated from historical to contemporary, 8 of 9 moved closer to residential area, 1 of 9 contracted yard around feeder. Deer migrated to same winter yards, but changed area a little.	na	na	Deer can change winter yards as migration is learned, not innate. Feeding deer (now illegal in NY) will bring deer closer to residential areas. Managers still need to work on limiting shrubs.
Hygn-strom & VerCauteren 2000: *1995-1997*	no	n = 59	Sarpy County, NE, na	resid.	Obs.	VHF	Monitored VHF-collared deer 4x/week, noted habitat and location.	Average HR was 276 ha, but almost half had much smaller, exhibited high fidelity to home range with little emigration even with high densities and hunting pressure.	na	na	Deer have ↑ densities and small HRs when living near suburban development, since emigration rates are ↓, deer effectively managed with hunting.
Kilpatrick & Spohr 2000a: *1995-1997*	yes	n = 25	Groton, CT; 1.9 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer 1x/week for movements around suburban area.	No difference in HR during year, deer moved closer to resid. during bowhunting, average HR was smaller in developed than undeveloped, deer ≠ avoid development.	na	< 0.01 km^2	Deer are using residential area. Late season bow hunt should be implemented. Sharpshooting program should put out bait piles every 40-50 ha to ensure access to entire population.
Kilpatrick & Spohr 2000b: *1995-1997*	yes	n = 39	Groton, CT; 186.8 km^2	resid.	Obs.	VHF	Monitored VHF collared deer every 4 hours 1 day/week, found HR and CA size and number of houses in each during different seasons.	HR and CA size did not differ between seasons. More houses were in HR during winter than fawning season. Bird feeders provided food. Highest use near houses was in March.	na	0.09 undevel., 0.07 km^2 res. devel.	Local management is necessary. Remove birdfeeders. Management action most efficient during March when HR smallest and closest to houses.
Kilpatrick & Stober 2002: *1995-1997*	yes	n = 44	Groton, CT; 1.9 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, placed temporary bait piles, analyzed proximity to bait piles	Deer retained CA if bait site was placed within CA, shifted CA toward bait site if the site was within HR, but outside of core area, and abandoned CAs far from bait sites.	na	na	Baiting with hunting could affect deer within a 30-60 ha area since deer used the bait sites if they were within HR. Bait sites shouldn't affect deer whose HR do not include bait site.

Table 4 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Min patch size	Conclusions & Management Recommendations
Piccolo et al. 2000: *1998-1999*	no	n = 21 (10 in Des Plaines and 11 in Palos)	Des Plaines and Palos Forest Preserves near Chicago, IL; na	resid.	Obs.	VHF	Monitored VHF collared deer day and night, but only collected ~14 locations. Used MCP to generate HR.	Des Plaines deer had smaller, more linear HR that stretched into urban areas outside the reserve. Palos deer remained within the preserve boundaries and had smaller more centralized HRs.	na	na	Des Plaines deer were forced into residential areas. Palos deer had smaller HR because food was more abundant. HR may expand when deer reach carrying capacity. Control might be necessary to preserve local plant communities and min deer human conflicts.
Porter 2004: *1997-1999*	yes	n = 22	Monroe County, NY; 43 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer, modeled HR and fidelity, tracked survival, modeled population.	Most deer moved some seasonally, had 6-10% dispersal rates, small HRs compared to rural areas, main causes of death were DVC, hunting and accidents during culling.	na	na	Localized control though contraception and/or culling can work, but dispersal makes it complicated. Managers should consider removing deer from problem areas only.
Rhoads et al. 2010: *2004-2006*	yes	n = 66	Cecil County, MD: 23 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer in all seasons, analyzed movements, HR, habitat use.	HR varied according to season, including hunting season, deer moved most in dusk, HR sizes approx same as other midwestern exurban populations.	na	na	Exurban deer populations exhibit tendencies between urban/suburban and rural populations, since they didn't exhibit a lot of movement, management strategies should be effective.
Storm et al. 2007a: *2003-2005*	yes	n = 43	Carbon-dale, IL; 18 km^2	resid.	Obs.	GPS, VHF	Monitored VHF and GPS-collared deer 2+x/week and every 1-2 hours, analyzed movements within landcover and distance to structures, mortality analysis.	HR size between rural and suburban ranges, tended (not statistically) to avoid structures during fawning. In winter, grassland outside of ZOI was preferred over grassland inside, but forested cover was preferred over entire site.	100m	na	Habitat use is generally in between suburban and rural. Main problem may be lack of hunting. Alternatives to hunting will be needed to manage deer herds if exurban development continues
Swihart et al. 1995: *varied between sites*	no	varied betwee n sites	Carbon-dale, IL; 47 km^2, Chicago; 5900 km^2, Bethel-Newton, CT; 25 km^2, Bridge-port CT; 1.8 km^2	resid.	Obs.		Summarized Cornicelli 1992, Witham and Jones 1992, and analyzed unpublished data from Bethel-Newton CT and Bridgeport CT.	Deer avoided developed areas (> 80 houses/ km^2) and had smaller HR in urban areas. Activity was more concentrated in urban areas. Survival was approx. = between rural and urban areas. Deer browsed close to houses where spp richness was 2 x greater <50 m from houses.	none	na	Deer can habituate to urban areas. There are high densities of deer in urban areas because 1) low movement dispersal, 2) decreased human and non-human predation, 3) increased feeding by people. Need to find way to manage urban deer where hunting is difficult.

Table 4 Cont.

Author: *Study Duration*	**Peer Review**	**Sample Size**	**Location, Study area size**	**Devel-opment Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Hous-ing Buffer**	**Min patch size**	**Conclusions & Management Recommendations**
Vogel 1989: *1981-1983*	yes	n = 12 VHF, n = 25 colored neckband	Gallatin Valley, MT; 1000 km^2	resid.	Obs.	VHF	Monitored VHF-collared deer every 1-2 weeks, analyzed movements and habitat use.	Deer used developed land less than undeveloped (80% deer observed white-tails). Closer to development HRs became smaller and more linear, and deer became more nocturnal. Housing was more detrimental when evenly distributed.	400m	na	Deer were less likely to be active when there were >11 houses within 800 m. Managers should cluster developments because the first houses in an area have the greatest effect.
Witham & Jones 1992: *1983-1989*	no	n = 103 live captures	Cook, DuPage, Kane, and Lake counties IL; 5,900 km^2	resid.	Obs.		Monitored deer population, reduced deer with sharpshooting, Measured vegetation pre and post deer removal, surveyed DVC.	Deer body condition varied between sites that were relatively close to each other. Some plant species seemed to regenerate after reduction in deer density.	na	na	Deer survival, age distribution, reproduction were similar to other studies on WT deer. Deer affected the plant community at high density. Lethal methods are needed to reduce deer abundance.

Notes: Abbreviations are ET, ear-tagged; DVC, deer-vehicle-collision; HR, home range; CA, core area; Obs., observational; resid., residential.

Mule Deer

Key Characteristics of winter range

Mule deer are important species both economically and socially in the American West (Geist 1998). Unlike white-tailed deer, mule deer do not occur in humid climates of eastern North America. However, their western range extends from the boreal forests of Canada to the arid deserts of Baja Mexico (Wallmo 1981). Winter habitat preferences, therefore, vary according to ecoregion, presence of trees or cover and snow depth (Watkins et al. 2007). In the Rocky Mountains, mule deer, like white-tails, are often migratory, moving from alpine environments in the summer to low-elevation valley bottoms in the winter, though some mule deer remain resident year-round (Nicholson et al. 1997). As with other ungulates, mule deer prefer areas with low snow depths (< 40 cm) and high solar duration in winter (D'Eon and Serrouya 2005, Poole and Mowat 2005). When snow depths increase they tend to prefer mature forests with high crown closures which intercept snow, provide thermal and security cover as well as important winter forage (Pac et al. 1991, Armleder et al. 1994, Baty 1995, Safford 2003, D'Eon and Serrouya 2005, Poole and Mowat 2005, Serrouya and D'Eon 2008, Proulx 2010). In open arid regions mule deer will often find cover in rugged topographic features such as coulees (Wood 1989, Fox et al. 2009). Areas of winter range that provide a diverse cover and browse when conditions are severe are considered critical as deer tend to congregate in them in high densities at certain times (Pac et al. 1991).

Mule deer are also opportunistic feeders and select similar forage to white-tailed deer, however, preferences vary regionally (Wallmo 1981). Studies indicate that the two deer species avoid competition through minimal spatial overlap (Baty 1995). In open habitat, shrubs such as sage brush are considered important browse when other forage is unavailable (Carpenter et al. 1979, Fox et al. 2009) while in forested habitats mule deer select many woody species (Hayden et al. 2008). Naturally cured forbs are also important winter browse (Geist 1998). Throughout the year, mule deer prefer diverse habitats with a range of species and cover types. Thus, invasive plants that create single-species vegetative cover, such as cheat grass (*Bromus tectorum*), decrease habitat quality for mule deer (Watkins et al. 2007). However, mule deer are also known to winter near irrigated agricultural areas and can cause extensive damage to hayfields, stackyards and orchards (Reed 1981). Because winter forage has low digestibility, mule deer often enter a negative energy balance in the winter, making fat and protein stores important determinates in overwinter survival (Torbit et al. 1985). In general, mule deer display high fidelity to home ranges and individual migration routes, but can shift distribution to accommodate changing environmental conditions (Pac et al. 1991, Nicholson et al. 1997, Sawyer et al. 2009b).

Response to Development

Mule deer exhibit a number of short-term overt behaviors in response to human activity. Mule deer alert to approaching humans at longer distances (70-1000 m) than white-tailed deer, likely a result of their adaptation to more open habitats (Lingle and Wilson 2001). Like other ungulates, mule deer display stronger responses to humans on foot than to vehicles. In Colorado, mule deer initially responded to snowmobiles at longer distances than hikers, but fled from hikers more frequently and for longer distances (191 m for hikers and 133 m for snowmobiles). However, disturbance trails did not have an impact on mule deer reproduction or survival though the authors estimated that each disturbance event cost between 0.2-5% of daily metabolic requirements (Freddy et al. 1986). In Antelope Island State Park, Utah, mule deer responded to hikers and mountain bikers with a 70% probability of flushing when within 100 m of trails. When recreationists were located off-trails their probability of flushing increased to 96% and did not drop to 70% until perpendicular distance from humans reached 390 m (Taylor and Knight 2003). However, Wisdom et al. (2004) found that radio-collared mule deer did not display an increased probability of flight in response to hikers, mountain bikers, horseback riders and ATVs in the Starkey Experimental Forest and Range in northeastern Oregon, where vegetation and hiding cover were likely higher than on Antelope Island. Movement rates did increase slightly to recreationist's presence, but not to ATVs (Wisdom et al. 2004).

Mule deer have been shown to avoid human development and roads in certain cases (Nicholson et al. 1997, D'Eon and Serrouya 2005). In north-central Colorado, winter pellet transects indicated that mule deer used habitat within 200 m of roads significantly less than areas farther from roads. This relationship was stronger in shrublands than in forested habitat (Rost and Bailey 1979). As with other ungulates, roads can produce a significant source of mortality through deer-vehicle collisions. Roads may also fragment populations and can alter migratory behaviors (Reed 1981, Hayden et al. 2008). In Colorado, Reed et al. (1975) video recorded mule deer attempting to cross an I-70 underpass not specifically designed for wildlife crossings. They found that mule deer had a 40% group success rate and 61% of individuals were eventually successful. This study was one of the first examinations of wildlife-highway mitigation efforts (Hebblewhite 2008).

Several studies have examined mule deer behavior and distribution in relation to residential development. As described in the white-tailed deer section, Vogel (1989) monitored deer response to development in the Gallatin Valley near Bozeman, Montana. During a period of rapid residential growth in the valley (53.4% increase in residents from 1970-80) residents reported that white-tailed deer populations had encroached on historic mule deer ranges. The study monitored both deer species (though 80% were white-tailed) and found that deer avoided houses and increased nocturnal behavior near subdivisions. Fewer houses were present within 800 m of mule deer observations than within 800 m of white-tailed deer observations, alluding to an increased avoidance of human disturbance by mule deer compared to white-tailed deer. As discussed earlier, future studies with larger sample sizes are needed to confirm the results of this research. In Shasta County, California, winter pellet transects around 15 houses in a residential subdivision indicated that deer use was lower within 22.8-45.7 m of houses compared to areas > 68.6 m from houses. The authors suggest that deer habitat use was influenced up to 82.3 m from houses during the winter (Smith et al. 1989). McClure et al. (2005) monitored VHF-collared mule deer on two different winter ranges in the Cache Valley of northern Utah. They found that deer that wintered in an urban area (15-800 houses/km^2) were more likely to be migratory, and migrated earlier in the spring, than deer on a rural winter range. Urban deer also exhibited lower fawn recruitment (measured through fawn:doe ratios) even though migratory animals from the two herds intermixed on a common, high-elevation summer range. Urban deer had smaller home ranges and selected concealment vegetation, which may have limited forage opportunities and account for the difference in fawn survival, though the mechanisms driving the differences between urban and rural deer were not specifically tested (McClure et al. 2005).

A series of studies on mule deer response to energy development in the Jonah and Pinedale Anticline natural gas formations in southwest Wyoming demonstrate that mule deer avoid a wide range of human developments including roads and infrastructure associated with oil and gas development. Hebblewhite (2008) summarized the Sublette mule deer studies in an extensive review of the effects of energy development on ungulates. Early publications indicated that mule deer exhibited strong behavioral avoidance of well pads and roads (avoidance up to 2700-3700 m of well pads; Sawyer et al. 2006, Sawyer et al. 2009a). However, the two final reports of the study: Sawyer et al. (2009c) and Sawyer and Neilson (2010), that monitored mule deer response over 10 years of energy development, were the first to document population-level declines. Though the results continue to be preliminary, the 9-year trend in abundance suggests a 36% decline since 2001. Further, four years of population surveys of a nearby herd outside the energy development area have displayed increasing abundance during the same time-frame. These results are some of the first, from long-term monitoring projects, that imply development pressure can have negative population impacts on mule deer.

Habituation

Similar to white-tailed deer, mule deer populations can exceed human tolerance in suburban and urban areas. In some areas mule deer browsing at high densities can cause substantial damage to crops, orchards and ornamental vegetation near homes (Reed 1981). Some evidence suggests that mule deer do not adapt as well as white-tailed deer to residential areas (Vogel 1989, McClure et al. 2005), but high densities of mule deer have been documented in urban areas, such as Helena, Montana (Hickman 2007). As with white-tailed deer, managing urban populations of mule deer requires education and outreach to the public as well as input from various stakeholders on management and control options.

Migration

In the Rocky Mountains, a large percentage of mule deer are migratory, moving 20-158 km between seasonal ranges (Brown 1992, Sawyer et al. 2005). However, many populations contain both resident and migratory deer, suggesting that migration strategies are adaptive and can vary depending on environmental stochasticity, predation pressure and individual costs associated with migration (Kufeld et al. 1989, Pac et al. 1991, Brown 1992, Nicholson et al. 1997). In southern California, migratory female mule deer tended to avoid human development more than non-migratory deer and exhibited high plasticity in migratory patterns (Nicholson et al. 1997). Other studies have also found high life-long fidelity to migration behaviors and traditional routes, and suggest that early learning by fawns form perpetual movement patterns (Pac et al. 1991, Sawyer et al. 2009b). Thus the protection of migration routes is essential for the maintenance of many ungulate populations (Berger 2004).

Unfortunately, migration corridors can be negatively impacted by even small amounts of development. Between 2,500–3,500 mule deer moved through the Trappers Point bottleneck, a natural topographic feature in Wyoming that funnels ungulate movements between summer range in the Yellowstone and Jackson Hole regions and winter range in the Green River valley. Threats such as residential development, roads and fences have reduced the passage by almost half its original width.

Any increase in development has the potential to significantly affect mule deer migrations. In southwest Wyoming, Sawyer et al. (2009b) and Sawyer and Kauffman (2011) used statistical movement models to identify stop-over sites along mule deer migration routes. Mule deer spend 95% of their time at stop-over sites during migrations to forage and amass additional energy reserves. The authors found that these sites had higher quality forage than migration corridors and suggest that stop-over sites should have high conservation priority because of their importance to maintaining migratory behavior (Sawyer and Kauffman 2011). They also found that while individual mule deer displayed strong fidelity to migration routes, the subpopulation used a network of migration corridors between seasonal ranges. Managers should consider prioritizing routes that are used by a larger proportion of the population over routes used by only a few individuals (Sawyer et al. 2009b).

Disease

Mule deer can contract multiple rapidly spreading diseases such as tuberculosis, hemorrhagic disease and CWD (Mule Deer Working Group 2003). Chronic wasting disease is especially pertinent to mule deer populations because studies have shown that rates of infection are higher in mule deer than in white-tailed deer and other ungulates (Habib 2010). Symptoms of CWD include weight loss, loss of fear of humans, and ultimately degradation of brain matter. It is of special concern for its similarity to livestock diseases and potential for cross-species infection (Mule Deer Working Group 2003). A study in Colorado found that CWD infection increased with proximity to developed areas; potentially due to the high densities and more sedentary nature of deer in urban areas (Farnsworth et al. 2005). Further, urban areas may have lower predation rates from natural and human hunters allowing infected deer to live longer and shed more infectious agent into the environment. A recent study modeled CWD disease transmission and found that selective predation on diseased prey (mimicking wolf predation on deer) reduced disease prevalence much more rapidly than nonselective mortality (Wild et al. 2011). Thus, predators may be an important management tool in reducing the risk of CWD in deer.

Predation

The influence of predation by coyotes, mountain lions, and wolves on mule deer populations depends on many interacting factors such as habitat quality, the influence of human development, climate, competition with other ungulates and a range of other environmental dynamics (Ballard et al. 2001). Few studies have determined clear consequences of predation on mule deer populations (Gill 1999). In some areas hunting can play a large role in regulating populations. However, more studies are needed to determine how human development, especially exurban residential development, interacts with predation rates to influence mule deer populations in the West.

Summary

Mule deer population levels are well below historic highs recorded in the 1940's, likely due to synergistic factors such as loss of high quality habitat as a result of increased human development, competition with other ungulates and livestock, predation, over-hunting in some areas and disease (Gill 1999). While studies that isolate these confounding and interacting influences are lacking, it is probable that human development has played a large role in mule deer declines in the West. Mule deer are known to react behaviorally to human activity and recreation. In some cases, avoidance of human disturbance increases energy expenditure and could impact individual survival during the winter when travel is difficult. However, other studies have shown that mule deer may not always flee from approaching humans and more research is needed to elucidate these discrepancies.

In general, mule deer avoid human developments. Habitat use has been shown to be lower around roads and other industrial infrastructure such as well sites. Residential development probably has a serious impact on mule deer winter range, especially when it impacts undeveloped areas. Pellet transects indicate that mule deer use areas near houses less than areas farther from houses in winter. Further, urban areas may affect migration strategies and have been shown to decrease fawn recruitment, thought the mechanisms driving these differences require further study. A series of long-term studies (>10 years of monitoring) on the effects of oil and gas development have indicated that mule deer populations are declining in response to large scale energy development in southwest Wyoming. These studies are the first of their kind to begin to shed light on large-scale ungulate responses to development and suggest that demographic impacts may take many years to detect (Sawyer and Neilson 2010).

Because mule deer utilize flexible migration behaviors to maximize resources and possibly decrease predation pressure, protecting migration corridors should be a high conservation priority. Important stop-over sites along corridors also merit protection. Like white-tailed deer, mule deer can also become habituated to urban areas. Deer populations can pose a threat to human safety, cause property damage and high densities of deer can generate concerns for animal welfare (Hickman 2007). Other indirect effects of development include an increase in the transmission rate of CWD. Future research is needed to determine how predation, disease and residential developments may interact to influence mule deer populations.

Table 5. Review of scientific literature on the effects of human disturbance on mule deer, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffer, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Conclusions & Management Recommendations
D'Eon & Serrouya 2005: *1999-2003*	yes	n = 12	Selkirk Mountains, BC; 219.24 km2	roads	Obs.	GPS	Monitored GPS-collared mule deer every 4-6 hours, created RSF for winter and summer at 2nd order scale.	In winter deer preferred ↓ elevations, ↑ solar duration, mature fir-pine forest, ↑ crown closures, avoided cedar, hemlock and early seral. Some deer avoided roads (6 of 12 used locations farther from roads than random).		Elevation and solar duration are best determinates of winter range. Protect mature forest in winter range and keep roads out of winter range.
Farns-worth et al. 2005: *1997-2002*	yes	na	Larimer County, CO; 1200 km2	resid.	Obs., Model-ing		Tested deer for CWD in urban and rural areas, modeled results.	Males had almost double the infection rate of females, urban deer had almost double the infection rate of rural deer, different sites had varying levels of infection.		Prevalence may be ↑ in urban areas because of increased sedentary behavior, fewer predators (infected deer lived longer) and concentration due to habitat loss. Urban deer need to be managed when trying to control CWD.
Freddy et al. 1986: *1979-1980*	yes	n = 17 collared (VHF or neck-band), 67 trials	North-central CO; 3 km2	recreat.	Obs., Compar.	VHF	Compared flight responses of mule deer to approach trials by snowmobiles and hikers.	Responses by deer to hikers were longer in duration, involved running more frequently, and were greater in estimated energy expenditure. Each disturbance event cost 0.2-5% of the daily metabolic requirements.		Minimizing all levels of response by deer would require persons afoot and snowmobiles to remain >334 m and >470 m from deer, respectively. Human activity restrictions required on winter ranges.
Gill et al. 1999: *na*	no	na	Colorado; na	all	Review		Reviewed literature and historical trends. Evaluated different hypotheses for mule deer declines in Colorado.	Declines could be caused by; 1) competition with increasing elk populations, 2) density dependence, 3) long-term declines in habitat quality, 4) overharvest in some key areas, 5) increasing predator populations, and 6) diseases.		Recommended large-scale adaptive management experiments designed to test the main hypotheses of predation and habitat change. Long-term (6-8 year), large-scale (WMU scale, 1000 km^2) will be required to rigorously assess mule deer declines.
Kufeld 1989: *1982-1984*	yes	n = 27	Rocky Mountain Front, CO; 14.5 km2	Hunting	Obs.	VHF	Monitored VHF-collared deer 1x/10 days, noted location.	25/27 deer were resident and exhibited high fidelity to home range, even when hunted.		Mule deer in CO can be migratory or non-migratory, especially in areas with high quality winter and summer habitat. Resident and migratory deer herds should be managed in sub-units.
McClure et al. 2005: *1994-1995*	yes	n = 17 urban, 14 rural	Cache Valley of northern UT; 32 km2 urban, 42 km2 rural	resid.	Obs., Compar.	VHF	Monitored VHF-collared deer 2-3x/week, monitored migratory status and number of fawns for both rural and urban deer.	15 of 17 urban deer were migratory, opposed to 8 of 14. Deer in urban areas travelled an average 31.5 km and deer in rural areas travelled an average 14.5 km between winter and a shared summer range. Urban deer had lower fawn recruitment than rural deer.		Available forage was similar between rural and urban. However, risk differed and urban deer had smaller home ranges. Urban deer behavior to avoid risk may have limited forage opportunities and may account for the difference in fawn survival.

Table 5 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Conclusions & Management Recommendations
Nicholson et al. 1997: *1989-1991*	yes	n = 23	San Bernard-ino Mnts, CA; 320 km2	develop.	Obs.	VHF	Monitored VHF-collared deer every 10 days, analyzed results for habitat selection and survival.	14 migrated, 4 switched, 5 were resident, all exhibited high fidelity to home range. Avoided development in all seasons. Migratory animals used ↑ quality habitat and were farther than expected from development. During low precip. years migratory had ↑ mortality.		Deer exhibit behavioral plasticity, dual strategies probably exist because of higher predation risk during migration.
Reed et al. 1975: *1972-1973*	yes	n = 4450 video approaches	Eagle County, CO; na	roads	Obs.		Video-taped mule deer responses to a concrete box underpass under I-70 in Colorado.	Mule deer groups had a 40% success rate, 60% overall individual success.		Underpasses can be useful to mitigate negative effects of habitat fragmentation and mortality caused by roads – first study of its kind.
Rost & Bailey 1979: *1973-1974*	yes	n = 66 sites	Roosevelt and White River NFs, CO; na	roads	Obs.		Transects for abundance and density of fecal pellets at sites along roads.	Deer and elk avoided roads, particularly areas within 200 m of a road.		Expanding road systems will effect distribution of elk and deer. Range improvement projects would benefit deer and elk more if they were located away from roads.
Sawyer et al. 2005: *1998-2001*	yes	n = 171 (27 GPS, 144 VHF)	Western WY, 15000 km2	energy extraction, resid.	Obs.	VHF, GPS	Monitored VHF and GPS-collared mule deer along migration routes. VHF collared animals were monitored every 7-10 days during migration.	Mule deer migrated 20-158 km between seasonal ranges. A number of significant bottlenecks were observed. Estimate 2,500–3,500 mule deer moved through the bottleneck twice a year.		Housing developments have narrowed effective bottleneck to <0.8 km. Fences, roads, and ↑ human disturbance influences the effectiveness of mule deer migration routes. Special attention should be paid to migration routes especially where bottlenecks occur.
Sawyer et al. 2006: *1998-2003*	yes	n=77 (45 VHF '98-00, 7-15 GPS/yr '00-03)	Pinedale Anticline Project Area, southwest WY, ~800 km2	energy extraction	Obs., Compar.	VHF, GPS	Monitored VHF collared deer every 7-10 days 1998-2000, GPS deer monitored every 1-2 hrs 2000-2003. Modeled habitat selection before and during development.	Mule deer avoided areas in close proximity to well pads. Changes were immediate (i.e., year 1 of development), and no evidence of well-pad acclimation. Lower predicted probabilities of use within 2.7 to 3.7 km of well pads.		Indirect habitat losses larger than direct habitat losses. Some areas classified as high probability of use before development changed to areas of low use after development and vice versa. Higher densities of well pads will negate the potential effectiveness of timing restrictions on drilling activities.
Sawyer et al. 2009a: *2005-2007*	yes	n = 31	Pinedale Anticline Project Area, southwest WY; ~800 km2	energy extraction	Obs.	GPS	Monitored GPS collared mule deer every 2 hrs. Examined mule deer response to 3 types of well pads and modeled resource selection.	Mule deer avoided 2.61 km from LGS well pads, 4.30 km from non-LGS well pads, and 7.49 km from active drill pads and selected areas further from well pads with high levels of traffic in winter.		Impacts could be reduced through technology and planning that min. the number of well pads and human activity. LGS pipelines ↓ long-term indirect habitat loss, whereas drilling in crucial winter range created a short-term ↑ in deer disturbance and indirect habitat loss.

Table 5 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Conclusions & Management Recommendations
Sawyer et al. 2009b: *2005-2006*	yes	n = 44 GPS, 80 migrations	South-west WY; winter ranges; 40 & 141 km2	energy extraction	Obs.	GPS	Monitored GPS-collared deer every 2.5 hrs, created a movement model to find migration corridors and stopover site, >10% use = corridor.	3 main migration corridors for Wild Horse range and 1 for Dad range. Individual mule deer displayed strong fidelity to migration routes, the subpopulation used a network of migration corridors.		Important to conserve migration routes in area with impending development. Suggest stop-over sites should have high conservation priority. Prioritizing routes that are used by a larger proportion of the population over routes used by only a few individuals
Sawyer et al. 2009c and **Sawyer & Neilson 2010:** *1998-2010*	no	n > 360 GPS and VHF	Pinedale Anticline Project Area, southwest WY; ~800 km2	energy extraction	Obs., Compar.	VHF, GPS	Monitored GPS and VHF collared mule deer in treatment and reference areas pre-development and during development of oil and gas infrastructure.	9-year trend during development suggests a 36% decline since 2001. 4 years of population surveys of a nearby reference herd displayed increasing abundance during the same time-frame.		Mule deer continued to avoid areas close to well pads in years 8, 9 and 10 of development. Recommend abundance be measured directly, rather than estimated from survival rates. Use of LGS can reduce traffic levels and the amount of indirect habitat loss, which may minimize the potential negative effects on survival.
Smith et al. 1989: *4 months 1983*	no	n = 114 transects	Shasta County, CA; 132 km2	resid.	Obs.		Counted pellets along transects near 15 houses.	Deer use was less 22.8-45.7 m from houses than > 68.6 m. Deer use was influences up to 82.3 m from houses during winter.	82.3 m	Deer avoided houses. There appeared to be a tendency for deer to avoid houses with dogs more. Deer also tended to use areas closer to homes that were surrounded by dense cover.
Taylor & Knight 2003: *2000-2001*	yes	n= 110 obs.of on-trail mule deer, 60 off-trail	Antelope Island, UT; 104 km2	recreat.	Obs., Survey		Observed ungulate response to humans, surveyed recreationists.	Mule deer exhibited a 70% probability of flushing from on-trail recreationists within 100 m from trails and 96% probability of flushing within 100 m of recreationists located off trails. Probability of flushing did not drop to 70% until perpendicular distance reached 390 m.		Wildlife is being affected by recreation more than people realize. Need to ↑ public education, limit off-trail use and trail use during calving/fawning. Enforce buffer zones around wildlife.
Vogel 1989: *1981-1983*	yes	n = 4 VHF, 5 colored collar	Gallatin County, MT; 1000 km2	resid.	Obs.	VHF	Monitored VHF-collared deer every 1-2 weeks, analyzed movements and habitat use.	Fewer houses were present within 800 m of mule deer obs. than within 800 m of white-tails. Deer use decreased curvilinearly as development increased - the first few houses had the greatest effect. Shift in spp composition from mule deer to white-tailed deer.	400 m	Potential increased avoidance of human disturbance by mule deer compared to white-tailed deer. Deer were less likely to be active when there were >11 houses within 800 m. Managers should cluster developments because the first houses in an area have the greatest effect.
Wisdom et al. 2004: *2002-2004*	no	n = 12	Starkey, OR; 14.53 km2	recreat.	Exper., Compar.	VHF	Monitored VHF-collared deer every 10 minutes during treatments of off-road ATV, horseback riding, mountain biking and hiking.	Deer did not react as strongly as elk, slightly higher movement rates in response to all but ATVs.		Deer did not respond as strongly as elk to off road recreational activities. Deer might have changed fine scale behavior, such as moving short distances to dense cover. Suggest limiting off-road recreation.

Notes: Abbreviations are LGS, liquids gathering systems; CWD, chronic wasting disease; Exper., experimental; Obs., observational; Compar., comparative; recreate., recreation; resid., residential.

Elk


© Michel Kohl

Key Characteristics of winter range

Elk once ranged across North America, but hunting and habitat loss resulted in their extirpation from the eastern portions of their range (Laliberte and Ripple 2004). In the West, elk occur in a large variety of habitats from open, desert valleys to the dense coastal, coniferous rainforests of the Pacific Northwest as well as a wide range of shrub, forest and prairie habitats. Adaptations to specific regions make winter range an inherently diverse and at times incongruous concept that requires site specific research to define (Toweill and Thomas 2002). Elk are often migratory in the Rocky Mountains, initiating movement to areas with less snow when snow depth reaches ~ 40 cm and utilizing low elevation south-facing slopes with low snow depths in winter (Poole and Mowat 2005). Snow depth exceeding 70 cm requires plowing or bounding and restricts elk movement (Sweeney and Sweeney 1984). Determining the exact space requirements of winter range for elk is difficult because quality of forage, snow accumulation and other factors such as predation, wind and competition with other ungulates and cattle all affect the area and location of winter range. For example, elk require smaller winter range in areas with lower snow depth and high quality forage biomass than in areas with low quality habitat (Anderson et al. 2005).

In the Rocky Mountain West, elk tend to prefer edge habitats where both browse and protective cover are available (Safford 2003). They are, however, highly adaptable and can use a wide variety of habitats including mesic meadows, xeric shrublands and forests and wet shrub meadows (Hobbs et al. 1982). Elk winter diet is flexible and will change according to the severity of winter and availability of forage (Hobbs et al. 1981). In less severe winters elk strongly prefer grazing to browsing but will paw through the snow for graminoids when they are sticking through the snow (Sweeney and Sweeney 1984, Baty 1995, Christianson and Creel 2007). When snow depth is high, or when graminoids are not available, elk will utilize high-protein shrub browse (Hobbs et al. 1981, Hobbs et al. 1982). Elk will also forage on hay bales in agricultural areas during periods of deep snow (Safford 2004). During periods of severe weather elk may opt for energy conservation over forage intake. Therefore, thermal cover is often necessary in high quality elk winter range (Christensen et al. 1993). In areas without forest cover, elk utilize low-elevation south-facing slopes with a high diversity of vegetation types and species (Sawyer et al. 2007). Despite generalist foraging habits, elk in the Greater Yellowstone Ecosystem steadily lose body mass and fat through the winter, which can affect pregnancy rates (Cook et al. 2001, Cook et al. 2004).

Response to Development

Elk response to development can be measured on a continuum from individual behavioral responses to population-level impacts. Many studies have demonstrated short-term behavioral changes as a result of human activity. In a controlled study within the Starkey Experimental Forest and Range in northeastern Oregon, elk were subjected to disturbance from off-road recreationalists. Radio collared elk responded most strongly to all-terrain vehicles (ATVs) and initiated flight at relatively far distances (> 1000 m, Preisler et al. 2006). Elk movement rates were also higher following disturbance by mountain bikers, horseback riders and hikers than during control periods of no human activity (Wisdom et al. 2004). Increased human recreation, both motorized and non-motorized, in elk winter range has been shown to increase the levels of stress hormones, especially when the recreation is sporadic (Cassirer et al. 1992, Creel et al. 2002). Vehicle use on roads also induced a physiological stress response in elk but was highest during the summer (Millspaugh et al. 2001).

More permanent development initially causes more drastic changes in elk behavior than sporadic recreation. The response of elk to roads and infrastructure was not extensively reviewed here, but some inferences relevant to residential development can be made about the impacts of industrial infrastructure on elk behavior and populations. Many studies have examined the various effects of roads on elk (Lyon 1979, Rost and Bailey 1979, Lyon 1983, Cole et al. 1997, Rowland et al. 2000, Cole et al. 2004, Ayotte et al. 2006, St. Clair and Forrest 2009). In general, avoidance of roads is greater in areas that experience hunting activity (Hillis et al. 1991, Hurley and Sargent 1991, Leptich and Zager 1991, Rumble et al. 2005), however these impacts can be mediated by many factors including habitat quality, topography and the spatial design of road networks (Edge and Les Marcum 1991). For example in heavily developed areas of Alberta, elk were more likely to occur in areas ≤ 0.5 km of road/km^2. With increasing road densities, elk tended to use areas near roads more often, most likely due to the decreasing availability of areas without roads. However, when road densities reached >1.08 km of road/km^2, elk displayed strong avoidance of roads and the design of the road network accounted for differences in risk of mortality (Frair et al. 2008). The avoidance of roads was likely due to risk associated with hunting in the region, as other studies have found that elk use areas with > 2 km of road/km^2 in areas where human activity is non-lethal and highly predictable such as Banff National Park (Hebblewhite et al. 2005).

In a thorough review of the effects of energy development on ungulates, Hebblewhite (2008) found that while the literature is lacking rigorous studies that examine population level responses to development, in general elk tend to avoid roads by 200 – 2000 m and active gas and well sites by 500 – 2000 m (Hebblewhite 2008:86). In Wyoming, avoidance distances around well sites was lowest in winter (500 m), but increased to up to 2000 m during the summer (Powell 2003). Similarly in southwestern Wyoming, Sawyer et al. (2007) found that during winter elk habitat use shifted closer to roads than in summer, likely a result of the lower levels of traffic during winter. Finally, the 2008 review also synthesized a series of long-term studies as part of the Montana Cooperative Elk-Logging study on the responses of elk to logging, human recreational disturbance and climate. This research, as well as more recent work conducted at the Starkey Experimental Forest and Range, suggests that elk avoid active logging, recent burns and roads (Hebblewhite 2008). However, without direct negative pressure from humans, elk can and will habituate to high levels of human disturbance and infrastructure (Thompson and Henderson 1998).

Population-level impacts of human development are expressed through altered distribution, abundance and vital rates. In Colorado, the expansion of the Vail ski area initially caused dramatic decrease in the number of elk observed in the area, especially where a chairlift was built (Morrison et al. 1995). By the end of the study, elk began to habituate to the development, but elk use remained low in areas where human activity was highest indicating that long term impacts may exist. To test the impacts of spring and summer recreational pressure in and around calving grounds, Phillips and Alldredge (2000) monitored 71-85 elk/area/year near the Vail ski area. Their results indicated that reproductive success and calf survival decreased during years of disturbance suggesting a significant impact on population growth. A follow-up study indicated that the herd was able to rebound after the disturbance pressure was lifted, though productivity did not exceed pre-disturbance levels (Shively et al. 2005).

Few studies have specifically examined the effects of residential development on elk. Subdivision development generally results in new infrastructure such as buildings and roads that directly reduce available habitat. Residential development also leads to greater human recreational use which can increase stress and vigilance in elk. In Colorado, habitat fragmentation as a result of housing developments and associated road and infrastructure construction caused elk to avoid patches of habitat less than 0.04 km^2. Elk prefered habitat patches greater than 0.24 km^2 with available hiding cover (Wait and McNally 2004). Housing development also affects elk movement patterns. In a residentially developing area north of Missoula, Montana, elk started moving faster 750 m from houses and trails and preferred habitat 1600 m from any human development (Cleveland 2010).

Habituation

Elk are a generalist species with the ability to adapt to a wide-range of habitats, including areas of human development. The degree of habituation varies according to habitat-type, the presence of predators and type of development (Stankowich 2008). According to Thompson and Henderson (1998), the risk of habituation is highest in winter and in areas with constant human pressure such as near town sites and housing developments. High elk population densities can also cause dispersal toward development which can lead to reduction or loss of migratory behavior, which may result in overgrazing of winter ranges by resident elk during summer (Thompson and Henderson 1998, Hebblewhite et al. 2006). A lack of hunting


© Michel Kohl

pressure is one of the key factors influencing the habituation of elk. Human development and activity can act as a "human shield" by reducing the risk of predation from both native predators and human hunters in areas close to development or in National Parks (Berger 2007). For example, in Alberta, near Banff National Park, elk that occurred within the townsite of Banff had significantly higher survival and recruitment than elk in the surrounding area. Elk density was also higher indicating that use of developed areas can be highly profitable for elk (Hebblewhite et al. 2005). Similarly, in Rocky Mountain National Park of Colorado, human disturbance had little effect on the distribution, abundance or behavior of elk. In fact, elk were frequently seen feeding during crepuscular periods in residential areas in the National Park and throughout suburban lawns and gardens of nearby Estes Park, Colorado (Schultz and Bailey 1978).

Urban elk populations are associated with a range of ecological and management problems such as crop depredation, overgrazing, property damage, injury to humans and increased risk of elk-vehicle collisions (Walter et al. 2010). However, human perception of the risks associated with habituated elk can be contradictory and in some cases can limit management options. In Flagstaff, Arizona, the majority of residents surveyed enjoyed seeing elk and were not concerned about safety issues. They did, however, express concern about lethal management methods (Lee and Miller 2003). Sporadic human activity and hunting pressure can reduce habituation (Thompson and Henderson 1998), but is not always possible due to societal values. In Banff, predator-resembling aversive conditioning with herding dogs and with humans with fire-crackers reduced habituation behavior. However, more effort is needed when predators are present outside of the developed area (Kloppers et al. 2005). Multiple non-lethal management strategies for limiting elk herds in and around developed areas exist, but many are under-examined, costly and energy-intensive (Walter et al. 2010).

Migration

Migratory behavior of ungulates is likely in decline worldwide as a result of habitat loss and fragmentation (Berger 2004). Elk are generally migratory in areas with large topographic relief and where snow depths influence forage availability in winter. Winter range enhancement, including feeding grounds and hunting restrictions, combined with predator relief can alter elk behavior from migratory to residential. In Alberta, near Banff National Park, the Ya Ha Tinda elk herd has decreased migratory behavior by 75% between 1970 and 2004. Further, the timing of migration has also shifted with elk returning to winter range almost a month earlier (Hebblewhite et al. 2006). Behavioral shifts in seasonal migration patterns have the potential to alter traditional predator-prey relationships, density-dependent population dynamics and jurisdictional management policies.

Disease

When elk congregate in large groups, as is common on winter range, they are more likely to contract diseases such as brucellosis and CWD (Olsen 2010). Rates of disease are generally higher in elk that congregate in areas with artificial feed, which is also where spread of the disease to cattle is most likely (Olsen 2010). Cross et al. (2010) found that although rates of brucellosis were initially higher in elk that utilized artificial feeding areas, the rates increased to elk that did not use feeding areas as well, potentially due to large group size rather than overall density. Development infringement on winter range could cause greater congregations of elk on remaining intact habitat or increase the density of urban elk habituated to the developed area.

Predation

As a prey species, elk react behaviorally to hunting pressure from both natural predators and from humans. Predators, such as wolves, tend to avoid areas of high human activity, therefore human developments can become a refuge for elk. In fact, in Banff National Park predation rate by wolves on elk was reduced by 60% where human activity was highest (Hebblewhite et al. 2005). Since humans do not hunt elk in national parks, resident elk could minimize predation risk by utilizing habitat near human settlements (Hebblewhite and Merrill 2009).

As discussed earlier, hunting also has profound impacts on elk behavior. Elk regularly hunted by humans exhibited more vigilance behavior than non-hunted elk and vigilance decreased after hunting season (Cleveland 2010). In areas of low road density and therefore less hunter access, bull elk survival doubled compared to areas with high road density (Christensen et al. 1993). Elk, will use areas with higher density roads in non-hunted areas than in areas with hunting (Frair et al. 2008). Elk also react to hunting pressure by moving to areas with hunting restrictions, including private lands (Burcham et al. 1999). With the increasing transfer of valley bottom lands from hunter-friendly ranches to seasonal hobby mini-ranches and exurban subdivisions, more land is available as a refuge for elk during the fall. This reduces the ability of managers to control elk populations further escalating problems with habituation (Haggerty and Travis 2006).

Summary

The main requirement for elk winter range is sufficient forage to provide a positive energy balance. European settlers initially used elk winter range as grazing range for domestic livestock and altered the natural vegetation structure (Toweill and Thomas 2002). Today, developers are creating exurban subdivisions on elk winter range. Because of the settlement patterns in the West, very little low-elevation land is designated as wilderness and therefore, there is a growing need to develop protocols to protect winter range. Because elk winter range varies from rarely grazed allotments to developed residential areas, the threshold between 'wild' and 'non-wild' range may be somewhat indistinct.

More studies are needed to determine the difference between functional and non-functional winter range. Determining how elk responses to development vary across a gradient that includes initial road construction to permanent infrastructure and the increase in human recreation that follows, can help augment our understanding of the impacts of residential development on elk. Initially, elk react to human disturbance with increased vigilance, flight and behavioral avoidance, all of which have the potential to increase energy expenditures. In northern climates, decreases in energy reserves can lower survival for both calves and adults. Therefore, development has the potential to lead to severe population level declines in elk. Unfortunately, very few studies have directly examined the population-level consequences of any form of human development on elk. Further, the overall influence of development depends on placement and spatial pattern of new residences across a gradient of habitat quality. The proximity to forests and escape and hiding cover, as well as landcover type, can all modify the effect of development. Other factors such as the presence of predators, the occurrence of hunting by humans and competition with other ungulate populations also have a significant impact on observed responses (Baty 1995, Jenkins et al. 2007). The minimum patch size of winter range in which elk can both avoid risks associated with human development and maximize fitness also depends on these same factors. Development that maintains open space by clustering structures in one part of a parcel is likely a first step towards minimizing conflicts with wildlife (Wait and McNally 2004).

Since much development itself is not actually lethal to elk, habituation is likely to continue to occur across the West. Elk are generalists and can subsist on a varied diet which includes graminoids and shrubs found in and around human development. Habituated elk are often found at greater densities than elk outside of development which can lead to faster spread of disease. Higher quality forage and an absence of predators can also lead to an elimination of migratory behavior. Resident habituated elk herds can create multiple problems in human communities. Because natural predators do not generally habituate as often as prey species and hunting by humans is often discouraged around development, management options are reduced. Habituated elk populations can create human-wildlife problems akin to white-tailed deer in the eastern United States.

Table 6. Review of scientific literature on the effects of human disturbance on elk, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, housing buffers and conclusions and management recommendations.

Author: *Study Duration*	**Peer Re-view**	**Sample Size**	**Location; Study area size**	**Devel-opment Type**	**Study Design**	**Collar Type**	**General Methods**	**General Results**	**Hous-ing Buffer**	**Conclusions & Management Recommendations**
Cleveland 2010; Chpt 2: *2008-2009*	no	n = 363 (obs.)	MT and WY; na	hunting	Obs.		Surveyed vigilance at 4 sites with varying levels of predation risk from human and non-human predators.	Vigilance ↑ with predation risk, ↓ vigilance in non-hunted herd (Mammoth, WY). Humans > impact on vigilance than non-humans (wolves), movement didn't ↓ after hunting season but vigilance did ↓	na	Humans influence vigilance. Elk have measured spatial and temporal response to hunting. Hunting, or non-lethal aversive tactics, can ↓ habituation. Managers should restructure hunting seasons to alter vigilance/movement.
Cleveland 2010; Chpt 3: *2007-2009*	no	n = 9	North Hills, Missoula, MT; na	resid.	Obs.	GPS	Monitored GPS-collared elk every 6 hours, modeled movement, first passage time (FPT) and habitat selection (RSF).	Hunting ↓ movement, but did not affect selection. Elk moved faster 750 m from houses and trails, selected habitat 1600 m from human development.	1600 m	Hunting effects habituation if elk perceive humans as risk, movement was related to human predation risk. Hunting is important to maintain a 'wild' elk herd and avoid habituation.
Creel et al. 2002: *1998-1999*	yes	n = 125 (elk scat)	Yellow-stone, Isle Royale, Voyageurs NPs; varied	recreat.	Obs.		Tested fecal GC levels in elk in Yellowstone and in wolves in Isle Royale, Yellowstone and Voyageurs.	GC levels increased in both species when snowmobile use increased, more than for wheeled vehicles.	na	Snowmobile season causes GC levels to increase, but did not cause a measurable effect on population. The impact could be more subtle and long term. Stress levels can indicate problems before demographic impacts occur.
Frair et al. 2008: *2001-2004*	yes	n = 23	AB, Canada; 2800 km^2	roads	Obs.	GPS	Monitored GPS-collared elk every 2 hours, created a random walk framework model	Elk were more common in areas ≤ 0.5 km of road/ km^2. With ↑ road densities, elk use areas near roads more. Elk avoid >1.08 km of road/ km^2. In areas with no hunting pressure, elk used higher densities of roads.	na	Road placement away from large patches with high quality forage would help to keep elk on the landscape.
Hebblewhite et al. 2005: *1997-1999*	yes	n = 45	Banff, AB and Banff National Park; 6641 km^2	resid.	Obs. Compar.	VHF	Monitored VHF-collared elk 1x/week, monitored mortality in 2 treatments, high wolf and low wolf. Pellet counts to monitor use.	Elk density was significantly ↑ around Banff, where predation was low. Survival ↑ in Banff. Recruitment ↑around Banff. Elk pellet density 3.2 x ↑ in the central no-wolf area.	na	Recolonization of wolves had substantial direct effects on elk demography in BNP, ↓ elk density, survival, and recruitment. Predator exclusion as a result of ☒ human activity ↓ predation rates by wolves by 60%. Management must account for trophic cascades of predators.
Hurley & Sargent 1991: *1984-1990*	no	n = 88 VHF,	Bob Marshall Wilderness, MT; 1300 km^2	roads	Obs.	VHF	Monitored VHF-collared elk and survival of 43 male elk (1987-1990).	Elk used dense cover during hunting, no change in non-hunted areas. Move away from roads with ↑ hunting pressure. 94% of male mortality = hunting.	na	43% of hunting occurs in areas with roads. Dense cover important during hunting season for security.

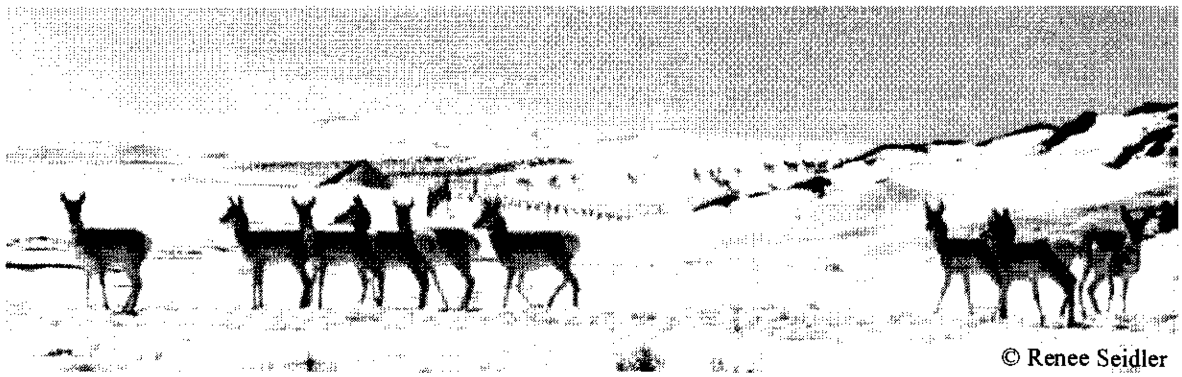
Table 6 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location; Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Hous-ing Buffer	Conclusions & Management Recommendations
Kloppers et al. 2005: *2001-2002*	yes	n = 24	Banff, AB; 4.66 km^2	resid.	Obs., Exper.	VHF	Monitored VHF-collared elk before/during/after treatment. Measured flight distance, vigilance and proximity to town. Treatments human, human and dog and control.	Human and human+dog increased flight distance, human increased distance from town, vigilance decreased in all groups. All effects were tempered by abundance of wolves (the more wolves, the shorter flight distance and distance to town).	na	Predator-resembling aversive conditioning works with humans and humans and dogs. More effort needed in areas with wolves. Dogs more expensive, but quieter. Humans loud w/ firecrackers, but a quieter human chase may also work.
Millspaugh et al. 2001: *1995-1997*	yes	n = 30 elk, n = 558 fecal samples	Custer State Park, SD; 291.5 km^2	roads	Obs.		Quantified fecal glucocorticoid concentrations among free-ranging elk in relation to human activities.	Fecal glucocorticoid measures were least in winter and greatest in summer.	na	Vehicle use on roads also induced a physiological stress response in elk but was highest during the summer.
Morrison et al. 1995: *1985-1992*	yes	na	near Vail, CO; na	resort	Obs., Compar.		Observations two areas before and after ski area expansion, Vail- physical development, Beaver Creek - ↑ human use.	Elk use ↓ significantly in Vail after expansion, especially in China bowl which had more human use and a chairlift. In Beaver Creek overall no effect from development.	na	Hunted elk are affected by ski area expansion, but # of elk ↑ linearly each year after development, especially in open areas with physical development. Habitat variables and amount of human activity important.
Phillips & Alldredge 2000: *1995-1997*	yes	n = 71-85 elk/area /year	Summit County, CO; 500 km^2	recreat.	Obs.	VHF	Monitored VHF-collared female elk 2x/week before and during treatment years. Elk disturbed by hikers in spring, tracked calf success.	Calf:cow ratios ↓incrementally in treatment area each year, 0.225 calves/cow lower in treatment area. Modeling indicates >10 disturbances/cow = population ↓	na	Human disturbance during spring and summer can seriously impact calf success. More studies on actual recreation should be done, restrictions on calving areas should continue.
Picton 1980: *1971-1975*	yes	na	Big Sky, MT; na	resort	Obs.		Pellet transects on $mile^2$ sections; compared as development increased.	Elk present in most areas, generally avoided roads and human activity, but used resort area.	na	Elk affected by development, resort development not following original plan.
Preisler et al. 2006: *2002*	yes	n = 12	Starkey, OR; 14.53 km^2	recreat.	Exper., Compar.	VHF	Monitored VHF-collared elk 1x/30 min, monitored movements before and after ATV use.	Elk responded to ATVs up to 1000 m, probability of flight higher when elk were closer to the ATV routes.	na	Elk perceive roads or trails as predictable sources of human disturbance. Over successive days of treatment, elk appear to adjust their distributions so that they are located in areas not visible from roads.
Rumble et al. 2005: *2000-2001*	yes	n = 8	Black Hills, SD; 1133 km^2	roads	Obs.	GPS	Monitored GPS-collared elk every 2 hours, analyzed habitat preference in response to roads and human-use.	Elk ↑ movement during the 3 hunting seasons (elk-archery, elk-rifle, deer-rifle) corresponding with ↑ human activity. During the middle of the hunting seasons ≠ move more. Avoided grasslands during daytime hours during the hunting seasons.	na	Movement rates may ↑ energetic demands. Need areas of reduced disturbance (road closures) for elk.

Author: *Study Duration*	Peer Re-view	Sample Size	Location; Study area size	Devel-opment Type	Study Desig n	Collar Type	General Methods	General Results	Hous-ing Buffer	Conclusions & Management Recommendations
Sawyer et al. 2007: *1999-2004*	yes	n = 55 VHF, 33 GPS	Southwest WY; 2517 km^2	roads	Obs.	GPS, VHF	monitored VHF-collared elk 1x/month 1999-2002 and GPS-collared elk every 4 hours 2003-2004, habitat model for summer and winter habitat.	Elk used higher elevations in summer, close to shrub cover and away from roads. Shifted to areas with lower elevations and southerly aspects in winter.	na	Elk respond to roads especially in summer during high-use. In non-forested areas, managers should recognize the importance of diverse vegetation and not rely on forage to cover ratios.
Shively et **al. 2005**: *1998-1999*	yes	n = 170	Summit County, CO; 500 km^2	recreat.	Obs.	VHF	Monitored VHF-collared females, monitored calf success, compared to results from Phillips & Alldredge.	Elk reproductive success rebounded after recreation pressure was lifted, back to pretreatment levels, no overcompensation.	na	Elk recovered from recreational disturbance but there may be a threshold beyond which they can't recover. Selective closures needed to prevent disturbance in certain important calving areas.
Wait & McNally 2004: *1996-1998*	no	n= 30	La Plata County, CO; 660 km^2	resid.	Obs.	VHF	monitored VHF collared deer 1x/month and measured selection of use vs availability with a chi2 test	Elk show significant preference towards grass/forb rangelands, sagebrush, and pinyon-juniper habitats, and avoid ponderosa pine and mixed conifer habitats. Elk avoid parcels < 4 ha, and prefer parcels > 24 ha.	na	Elk impacted by development, habituation may be occurring. Need > 24 ha area for hiding cover. Elk avoided agricultural areas. Should cluster homes in larger parcel, maintain open spaces while reducing per-unit cost.
Wisdom et al. 2004: *2002-2004*	no	n = 12	Starkey, OR; na	recreat.	Exper. , Comp ar.	VHF	Monitored VHF-collared deer and elk every 10 minutes during treatments of off-road ATV, horseback riding, mountain biking and hiking	Movement rates were higher in morning and highest for > ATV > mountain bike > hiking > horseback riding. Elk had a high probability of flight response at <1500m from ATV and bikers, <750m from horseback riders and <500 from hikers.	na	Elk demonstrated higher levels of movement during all treatments than during no-treatment. Elk respond to off-road recreation with increased energy expenditure. Limit off road recreation.

Notes: Abbreviations are Exper., experimental; Obs., observational; Compar., comparative; resid., residential; recreate., recreation; Chpt., chapter.

American Pronghorn


© Renee Seidler

Key Characteristics of Winter Range

Historically 40 – 100 million American pronghorn inhabited summer and winter ranges in the western half of the United States. After a sharp decline in the early 1900s followed by a recovery due to hunting bans mid-century, population estimates today total between 400,000 and 800,000 (Yoakum 2004a). Pronghorn are an obligate grassland species and the historic cultivation of land for agriculture as well as other human disturbance has reduced their range by as much as 64% (Laliberte and Ripple 2004). Snow depth has been found to be the most important factor influencing pronghorn winter range selection (Bruns 1977, Berger et al. 2006). Pronghorn will move to avoid the greatest snow depths, making travel corridors within winter range very important (Yoakum 2004c). Generally, low snow depths < 30 cm are selected while snow > 45 cm can restrict mobility (Yoakum 2004c, Berger et al. 2006, Berger et al. 2007). Some studies have reported pronghorn use of topographic relief, as well as shrubs and trees to avoid high winds (Bruns 1977, Wood 1989, Yoakum 2004c). However, slopes greater than 20%, rock cliffs, steep terrain, and dense woody vegetation are generally avoided (Yoakum 2004c, Autenrieth et al. 2006).

Because pronghorn occupy three different biomes – prairie, shrub-steppe and desert – winter forage is varied (Yoakum 2004d). Annually, pronghorn prefer forbs over shrubs and grasses (Mitchell and Smoliak 1971, Autenrieth et al. 2006). In winter, pronghorn occupy open habitat dominated by sagebrush (Berger et al. 2007) or bunchgrass prairie (Wood 1989). When snow accumulates, shrubby browse is generally the most important vegetation available to pronghorn (Mitchell and Smoliak 1971, Yoakum 2004d). In a low sagebrush area, pronghorn selected for greasewood and rabbitbrush (Boccadori 2002). Pronghorn prefer varied native vegetation over a single vegetation type (Yoakum 2004d). Due to the small relative size of their rumen compared to other ungulates, pronghorn are very selective regarding the parts of shrubs on which they browse and are considered 'dainty' eaters (O'Gara 2004c). Pronghorn will browse on agricultural fields and have caused considerable damage to winter wheat crops and alfalfa in some areas (Yoakum 2004b, Autenrieth et al. 2006, Jones et al. 2008a).

In winter pronghorn congregate in herds of approximately 30 – 100 individuals (though herds up to 1000 individuals have been reported, Bruns 1997) with a large amount of mixing between groups (Sawyer and Lindzey 2000). In response to severe weather and snowfall they will travel in single-file lines, develop hierarchies at cratering sites and lie down in groups (Bruns 1969). Pronghorn generally exhibit high fidelity to winter range (Sawyer and Lindzey 2000, Sheldon 2005, Berger et al. 2007), but may also occupy multiple ranges between years in response to weather severity (Amstrup 1978). The size of seasonal home ranges likely depends on local habitat quality and various studies have found contradictory results with winter home ranges being larger than summer ranges in some regions (Hoskinson and Tester 1980, Sheldon 2005) and smaller in others (Boccadori 2002, Jones et al. 2007).

Response to Development

Similar to other ungulates, pronghorn exhibit brief overt reactions in response to human disturbance. The adaptation by pronghorn to arid open-habitats may predispose them to rapid flight from perceived danger. In Antelope Island State Park, Utah, pronghorn exhibited a 70% probability of flushing from recreationists within 100 m from trails. Pronghorn tended to flush more often and flee further than bison or mule deer (Taylor and Knight 2003). Pronghorn also displayed increased vigilance in response to high levels of vehicular traffic associated with

resource extraction (Berger et al. 1983). However, other studies have determined that military activities including overflights, sonic booms and ground activities had little impact on the behavior or habitat use of endangered Sonoran pronghorn (*A. a. sonoriensis*) in Arizona (Krausman et al. 2004, Krausman et al. 2005). Pronghorn exposed to military activity traveled more, stood alert more and foraged less than the closest population (different subspecies) without military activity. However, differences were more likely due to the distribution of resources than reactions to human activity. Further, Sonoran pronghorn tended to use areas closer to disturbed sites, presumably as a result of increased forage production, visibility and ease of movement (Krausman et al. 2005).

Most studies regarding pronghorn response to development concern the changes in habitat selection, migration routes and population-level impacts of the effects of oil and gas extraction (see Hebblewhite 2008). No studies specifically examined the impact of residential development on pronghorn, though houses have been implicated as a major factor in blocking migration corridors (Sawyer et al. 2005). However, other research on linear features such as fences and roads (structures inherently associated with residential areas) demonstrate the negative effects of development on pronghorn. Roads are a major concern to pronghorn and can create barriers to movement (Yoakum 2004b) as well as direct mortality consequences through vehicle collisions (O'Gara 2004b, Gavin and Komers 2006). Recent studies demonstrate that pronghorn exhibit increased levels of vigilance near roads, especially when young are present and group size is small (Gavin and Komers 2006). Other studies, however, have shown that pronghorn will use plowed roads as movement corridors (Bruns 1977). Unfortunately, this tendency to use snow free areas has lead to the death of 800 pronghorn on railroad tracks in Montana during the winter of 2010-2011 where especially deep snows hindered pronghorn movements (Whittle 2011). Pronghorn have been known to use roads to avoid the fences and gain access to the Bridger-Teton National Forest in Wyoming (Sawyer and Lindzey 2000), suggesting that habitat fragmentation is a result of right-of-way fences rather than roads.

The negative effects of fences on pronghorn populations have been well-documented. Unlike deer and elk, pronghorn rarely jump fences and require approximately 40 cm of space below to lowest wire in a fence to crawl underneath (Yoakum 2004b). Few fences are built to facilitate pronghorn movements, and consequently, fencing is a major source of habitat fragmentation (Sawyer and Rudd 2005, Paige 2008). Snow accumulation in winter can decrease the available crawling space and severely impede movement (Autenrieth et al. 2006). Other studies have found foraging rates declined in the proximity to fences, suggesting that pronghorns may perceive security differently near fences (Berger et al. 2007, Beckmann and Seidler 2009). Further, in southwestern Wyoming, pronghorn selected seasonal home ranges in areas with the lowest density of fences (Sheldon 2005).

Several studies have documented the response of pronghorn to the development of the Jonah and Pinedale Anticline natural gas formations in the Upper Green River basin in southwest Wyoming (Sawyer and Lindzey 2000, Berger et al. 2006, Berger et al. 2007, Beckmann et al. 2008, Beckmann and Seidler 2009). In a five year study to determine the impacts of progressive oil and gas development on wintering pronghorn, Joel Berger and colleagues monitored collared individuals in both control and experimental areas based on *a priori* proximity to energy development. Preliminary findings did not detect a significant response to development in survival rates, body mass, stress levels and progesterone levels. However, even in year one, results indicated that pronghorn generally avoided habitat fragments less than 600 acres and the most heavily developed areas (Berger et al. 2006). In the second year of the study, strong avoidance of development was detected for certain individuals, though vital rates remained similar between control and experimental areas (Berger et al. 2007). By the third year of the study, Beckmann et al. (2008) began to detect population-level avoidance of gas fields with the highest activity levels. Further data revealed that pronghorn reduced use of developed areas in previously highly-used area as compared to more intact parcels. While these behavioral responses suggest some impact from increased development, the preliminary results do not indicate a decline in survival for pronghorn wintering in gas field areas compared to those utilizing areas away from human activity (Beckmann and Seidler 2009).

Another large-scale study in southern Alberta also examined the response of pronghorn to anthropogenic disturbance. Preliminary results indicate pronghorn tend to select native prairie cover and avoid agricultural land, pipelines, gravel roads, and active well sites at the stand level (Jones and Grue 2006, Sheriff 2006, Jones et al. 2008b). The distribution of monitored individuals within a large military training base in Alberta was negatively related to well pad density in the summer, but not in the winter (Seagel 2007). Similarly in the Rattlesnake Hills of Wyoming, Easterly et al. (1991) found that pronghorn densities were substantially lower closer to energy development and radio-collared pronghorn avoided well sites during disturbance.

However, this study lacked predevelopment distribution data, making inferences about the effects of energy development less robust than the Pinedale study (Hebblewhite 2011).

Habituation

The thresholds that determine habituation in pronghorn have not been well studied though it is generally recognized that pronghorn can habituate to chronic human activity (Krausman et al. 2004, Krausman et al. 2005). Some pronghorn will freely use areas near development while others will not (Berger et al 2007). However, their main response to any disturbance is flight and they generally run longer and sooner than other ungulates (Taylor and Knight 2003). Even when raised in captivity, pronghorn tend to be flighty and react strongly to new disturbances (Grandin 2007).

Migration

Pronghorn undergo one of the greatest long-distance over-land migrations of the world travelling up to 550 km annually from winter to summer range and back (Berger 2004). Extreme migrations of 445 km one-way have even been recorded (Jones et al. 2007). Most (approximately 70 – 100%) pronghorn migrate although some plasticity exists (White et al. 2007). Pronghorn exhibit high fidelity to migration routes. In fact, in Wyoming, archaeological data confirms that one migration corridor has been in use for at least 6000 years (Sawyer et al. 2005, Berger et al. 2006). The timing of migration is flexible, as pronghorn often follow the snowline back to higher elevation summer ranges in spring (Sawyer et al. 2005). Fall migration is thought to be induced by the amount of moisture in vegetation or temperature rather than snowfall (Hoskinson and Tester 1980, Sheldon 2005). Pronghorn also use staging areas where they gather before further pursuing migration (Sawyer and Lindzey 2000).

Unfortunately, approximately 78% of migratory behavior by pronghorn has been lost in the Greater Yellowstone Ecosystem (Berger 2004).The main problems regarding development and pronghorn migration are corridor bottlenecks or "pinch points" and fences. Bottlenecks are topographic features through which pronghorn are funneled during their migration. Because of the small size and high use of these areas, minimal development can have a disproportionate affect on a pronghorn population. One well-studied example of this is the Trappers Point bottleneck in Wyoming. Pronghorn use this route during migration from the Green River basin to the Jackson Hole region. Historically, the bottleneck measured approximately 1.6 km across. Today, due to roads and residential development, the bottleneck is half that length. Almost all of the pronghorn and half the mule deer (1000 pronghorn and up to 3500 mule deer) in the Sawyer et al. (2005) study, travel through the Trappers Point bottleneck to reach summer range in Jackson Hole. Any increase in development has the potential to significantly affect pronghorn migration (Berger 2004, Sawyer et al. 2005, Berger et al. 2006, White et al. 2007). Fences crossing migration pathways can cause similar problems. As addressed in the development section, pronghorn have difficulty crossing fence lines. Fencing of private lands can directly impede migration or create new migration bottlenecks (Yoakum 2004b). Since bottlenecks occur in many migration routes, it is important to identify where they occur and conserve the land around them to ensure the integrity of pronghorn migration (White et al. 2007).

Disease

Pronghorn are generally less susceptible to disease than other ungulates, likely because they live on arid range. Bluetongue virus is often considered the most serious disease for pronghorn. It causes mass die-offs due to malnutrition and hemorrhage. Cattle can pass the disease to pronghorn as they are carriers, but do not develop symptoms (O'Gara 2004a). Pronghorn can also contract parasites from livestock (O'Gara 2004b). They are susceptible to severe weather and environmental stochasticity which can cause mass winter mortality and reduce genetic variation in small isolated populations (Dunn and Byers 2008).

Predation

Adult pronghorn generally have high survival rates, but fawns are vulnerable to predation. Research has suggested that fawn survival is positively correlated with wolf density and birth weight. This is likely because the presence of wolves lowers the density of transient coyotes (significant predators of pronghorn fawns), although resident coyote densities were similar with or without wolves (Berger et al. 2008). Since large predators tend to avoid development more than mesopredators, pronghorn fawn survival could be negatively impacted by increased development that facilitates coyote predation through indirect trophic interactions.

Summary

Pronghorn are highly adapted to native grass prairie habitats of the West (Sheriff 2006). Unfortunately, the historic conversion of grasslands to agriculture have severely reduced available habitat (Seagel 2007). Further, diverse native forbs selected by pronghorn are often greatly reduced near development (Wood 1989, Hansen et al 2005). Because pronghorn need large contiguous areas with relatively few physical barriers to complete large seasonal migrations, the increase in leasing of public lands for energy development, transportation infrastructure, fencing and rural residential development are all future threats to pronghorn persistence. Various environmental variables such as snow accumulation, habitat quality, barriers to movement and predation all influence the minimum patch size of functional winter range. There is a growing need to protect important winter range and migration corridors. Fencing is likely one of the greatest threats to pronghorn movement, and will occur more frequently with increased residential development. Modifying the bottom wire of fences to allow pronghorn to crawl underneath is one management solution (Paige 2008). Other options to facilitate movements include opened gates (Bruns 1977) or highway underpasses (Sawyer and Rudd 2005). Mitigating the effects of residential development that occurs in critical migration bottlenecks should receive the high conservation priority.

No studies have specifically examined the impact of residential development on pronghorn behavior or demography. However, research on the impacts of human disturbance on pronghorn indicates that pronghorn increase vigilance, flight and behavioral avoidance which can increase energy expenditure and decrease the ability of pronghorn to respond to other environmental stressors. Recent large scale projects in Wyoming and Alberta have the potential to shed light on the population-level consequences of human development on pronghorn. Results of these studies will help facilitate our understanding of how future exurban development will influence pronghorn populations.

The ability of pronghorn to habituate to certain levels of disturbance, especially when not hunted or harassed, makes defining a threshold between 'wild' and 'non-wild' winter range difficult. During severe winters pronghorn may use agricultural lands to maintain positive energy budgets and the high quality forage in these areas has the potential to eliminate migratory behavior (Jones et al. 2008a). Resident habituated pronghorn can deplete agricultural crops and may be at higher risk of vehicle collisions. High pronghorn population densities have been shown to decrease population growth and fawn survival (Sheriff 2006). In general, pronghorn persistence is dependent on large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.

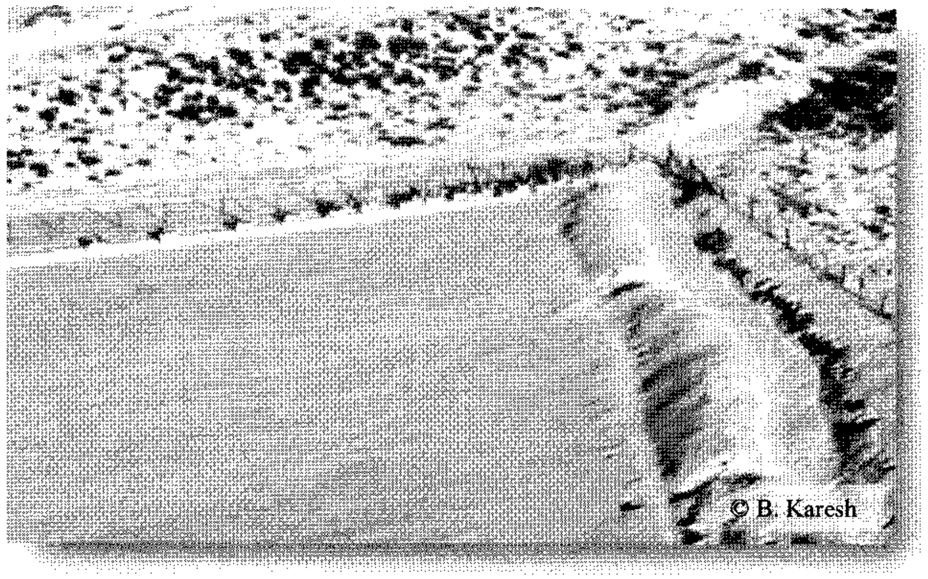


Table 7. Review of scientific literature on the effects of human disturbance on American pronghorn, summarizing study authors, study duration, whether the study was peer reviewed or not, sample size, location, study area size, development type, study design, collar type, general methods and results, minimum patch size requirements and conclusions and management recommendations.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Min patch size	Conclusions & Management Recommendations
Berger et al. 2006, 2007, Beckmann et al. 2008, Beckmann & Seidler 2009: *2005-2008*	no	n = 150/yr	Upper Green River Basin, WY; 4000 km^2	resource extraction	Obs., Compar.	GPS	Multi-year study. Monitored GPS-collared pronghorn every 3 hours, monitored survival rates, body mass, stress levels, and progesterone levels.	Pronghorn avoid fragments < 600 acres, individuals avoided densest development. Vital rates remained similar between control and experimental areas. Some population-level avoidance of gas fields with the highest activity levels.	2.428 km^2	Pronghorn reduced use of developed areas in previously highly-used area as compared to more intact parcels. Majority of locations (>94%) in winter 07-08 were in the lowest disturbance level quartile. No corresponding impact on pronghorn demography. Survival rates of pronghorn wintering in gas field areas were similar to those utilizing areas away from human activity.
Gavin & Komers 2006: *na*	yes	n = 112 observations 16 hrs	Southeast AB; na	roads	Obs.		Observed pronghorn response to roads with different numbers of vehicles.	Pronghorns < 300 m from roads ↑ vigilance and ↓ feeding. Vigilance ↑ when fawns present. Larger groups ↓ vigilance.	na	Pronghorn are more risk-adverse near roads. Road traffic level and placement should be considered by managers.
Jones & Grue 2006, Jones et al. 2007, 2008: *2005-2006*	no	n = 25/yr	Southern AB; 63,000 km^2	resource extraction	Obs.	GPS	Monitored GPS-collared pronghorn every 4 hours. Modeled habitat selection.	% of native prairie in winter ranges was significantly greater than the available winter ranges. Locations were further from collector roads and well sites than available points in 2006.	na	Preliminary results suggesting that pronghorn selection patterns may be influenced by energy development.
Krausman et al. 2004, 2005: *1999-2002*	yes	n > 265 days of observations	Barry M. Gold-water Range; 5,739 km^2, Buenos Aires NWR, AZ; 455 km^2	military activities	Obs.		Observed Sonoran pronghorn behaviors and locations with spotting scopes on military base and in non-disturbed National Wildlife Refuge.	Pronghorn exposed to military activity foraged less and stood and traveled more than pronghorn not exposed to military activity. Other behaviors were similar between two populations. 2nd study: 73% of locations occurred in proximity to disturbed sites and roads.	na	The military activity had only marginal influence on Sonoran pronghorn. Pronghorn behavior exposed to military activity was similar to behaviors of pronghorn not exposed. Disturbed landscapes may attract Sonoran pronghorn by creating favorable forage.
Sawyer et al. 2005: *1998-2001*	yes	n = 34	Western WY; 15000 km^2	resource extraction, resid.	Obs.	VHF	Monitored VHF-collared pronghorn along migration routes ever 7-10 days during migration.	Pronghorn migrated 116-258 km. A number of significant bottlenecks were observed. Housing developments narrowed width of the bottleneck to < 800 m. All 1,500–2,000 pronghorn moved through the bottleneck twice a year.	na	Fences, road networks, and increased human disturbance associated with energy and housing developments influence the effectiveness of pronghorn migration routes. Special attention should be paid to migration routes especially where bottlenecks occur.

Table 7 Cont.

Author: *Study Duration*	Peer Re-view	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Min patch size	Conclusions & Management Recommendations
Seagel 2007: *2003-2005*	no	n = 49	Canadian Forces Base Suffield, AB; 2690 km^2	resource extraction, roads	Obs.	GPS	Monitored GPS-collared pronghorn and flew aerial surveys. Modeled habitat selection.	Pronghorn avoided burned areas in winter. Distribution was negatively related to well density in summer, but not in winter. Weak negative response by pronghorn to major roads in summer and winter.	na	Pronghorn responded to biophysical and anthropogenic features on the landscape differently in the summer and winter. Need more data on military activities and oil and gas development to make stronger conclusions.
Sheldon 2005: *2002-2003*	no	n=72	Southwestern, WY; 2,800 km^2	fences	obs.	GPS	Monitored GPS-collared pronghorn 1-3x/day. Modeled HR.	Fence density was lower in HRs than in the study area. Fence density was greater within the periphery of HR. Most pronghorn (64%, n=28) were migratory and routes encountered fewer fences than random travel.	na	Pronghorn choose areas with lowest fence densities. Fences influenced distribution and movement patterns. Known movement corridors must be maintained. Obstacles to pronghorn movement, including fences, roads, and development should be limited.
Taylor & Knight 2003: *2000-2001*	yes	n = 88 observations	Antelope Island, UT; 104 km^2	recreat.	Obs., Survey		Observed pronghorn response to humans, surveyed recreationists.	Pronghorn exhibited 70% probability of flushing from on-trail recreationists < 100 m from trails. Flight occurred when 230 m from trail and distance moved was 150 m.	na	Animals were between 50 m and 200 m from trails. Need to ↑ public education, limit off-trail use and trail use during calving/fawning. Enforce buffer zones around wildlife.

Notes: Abbreviations are HR, home range; NWR, National Wildlife Refuge; Obs., observational; Compar., comparative; resid., residential.

Bighorn Sheep

Key Characteristics of Winter Range

Mountain sheep were once distributed continuously throughout the mountains of western North America. Human encroachment, competition with domestic livestock and diseases have all contributed to the current fragmentation of local populations (Armentrout and Boyd 1994, Beecham et al. 2007). Rocky Mountain bighorn sheep (*O. canadensis canadensis*) are distributed from central British Columbia and Alberta to New Mexico (Demarchi et al. 2000). Two subspecies, the endangered Sierra Nevada bighorn (*O. c. sierrae*) and the desert bighorn (*O. c. nelsoni*) occur throughout the desert southwest of the U.S. and in the central Sierra Nevada range. Thinhorn sheep (*O. dalli*) occur primarily in Alaska, the Yukon Territory, western Northwest Territories, and north of 56° latitude in British Columbia (Demarchi and Hartwig 2004). Among thinhorn sheep there are two subspecies classified by coat color: the white Dall's sheep (*O. d. dalli*) and the darker Stone's sheep (*O. d. stonei*) which only occur in the Yukon and northern British Columbia (Worley et al. 2004).

In the Rocky Mountains, bighorn sheep often occupy distinct seasonal ranges though some herds may stay in the same area year-round (Geist 1971). Winter ranges are commonly at lower elevations on south, southwestern or southeastern slopes. These aspects facilitate solar radiation and provide exposed grassy slopes where winds reduce snow cover (Shackleton et al. 1999). Sheep may also move to high-elevation, wind-swept ridges when snow accumulation increases at lower elevations (Geist 1971). Mountain sheep are a highly vigilant species and spend a large portion of time in open habitats in order to watch for potential predators (Hutchins and Geist 1987, Valdez and Krausman 1999). Thus, winter range is often associated with steep escape terrain (usually > 27°) and use of forested habitats is rare (Shackleton et al. 1999, Dicus 2002, DeCesare and Pletscher 2006, Dekker 2009). In fact, bighorn sheep heart rate has been shown to increases with increasing distance from escape terrain (Stemp 1982).

Some researchers describe mountain sheep as opportunistic feeders, sampling any forage available (Shackleton et al. 1999), while others suggest that bighorns are specialized grazers adapted to a diet of coarse graminoids (Geist 1971). Differences in diet descriptions are likely a result of the vastly different habitats, elevations and aridity occupied by different subspecies. Bighorn sheep are known to forage on shrubs, forbs and grasses in the winter (Wagner and Peek 2006). Burns can play an important role in the quality of winter range and can increase crude protein, visibility, timing of spring green-up and may increase overall habitat carrying capacity (Holl et al. 2004, Greene 2010). Bighorn populations often segregate into age and sex groups to reduce competition during much of the year. Females are known to display high fidelity to seasonal home ranges, while males are more likely to disperse (DeCesare and Pletscher 2006). Because no studies have examined the impacts of residential development on Rocky Mountain bighorn sheep, I will review effects of all types of human disturbance on all subspecies of wild mountain sheep in North America.

Response to Development

Similar to other ungulates, approach by humans on foot tends to illicit a greater response in mountain sheep than that of vehicular stimuli. In Utah, bighorn sheep fled three times more often in response to hikers than to vehicles (Papouchis et al. 2001). Even when sheep do not demonstrate overt behavioral reactions, they may still be under physiological stress. MacArthur et al. (1982) found that in southwestern Alberta, cardiac and behavioral responses of bighorn sheep were greatest when humans approach with a dog or approached from over a ridge. Loehr et al. (2005) studied the response of Dall's sheep to human presence in the Yukon Territory. They found that female sheep were more sensitive than males and decreased bedding and increased foraging when humans were present, whereas rams had no behavioral changes. Similarly, in Joshua Tree National Park, California, female sheep moved more often, used steeper slopes and areas farther from trails during high levels of human activity resulting in temporarily displacement from habitat (Thompson et al. 2007). Further, winter recreation has been shown alter bighorn sheep behavior possibly leading to increased energy expenditure, reduced reproduction, starvation, and lower resistance to disease and predation (see reviews by Legg 1998, Canfield et al. 1999, Olliff et al. 1999).

Human disturbance due to aircraft overflights is especially detrimental to wild sheep which are often found on exposed mountain slopes where cover is scarce. In California, Bleich et al. (1990, 1994) monitored the distribution and movements of bighorn sheep following disturbance by helicopter surveys. Their results indicated adult sheep moved 2.5 times farther during surveys and in the days following surveys than on non-survey days. The authors suggest that increased movement may lead to altered foraging rates, increased susceptibility to predators and increased stress. Bighorn sheep in western Arizona also demonstrated increased movements 19% of the time when exposed to low-level overflights from fixed wing aircraft. When aircraft approached within 50 m of the ground sheep left the area (Krausman and Hervert 1983). In Grand Canyon National Park, Stockwell et al. (1991) found that desert bighorns responded to helicopter disturbance within 250-450 m during the winter. Disturbance resulted in a 43% reduction in foraging efficiency.

Direct mortality due to vehicle collisions probably does not have large demographic consequences, but there are incidental reports of groups of bighorn sheep hit on roads across the West and into Canada along the Alaska highway (Gunther et al. 1998, British Columbia Ministry of Environment 2000). For example, eight bighorn sheep, including two trophy rams, were killed on Highway 1, west of Anaconda, Montana, in 2010 (Plaven 2010). This problem may be especially apparent where residual salt remains on roads due to the importance of mineral licks to bighorn sheep health (Tankersley 1984).

The indirect effects of roads likely have greater demographic consequences as a result of avoidance and displacement from key habitats. Roads can act as barriers to movement and may fragment habitat between important seasonal sites such as mineral licks. In Colorado, Keller and Bender (2007) observed attempts of bighorn sheep to cross a road to access an essential mineral site. They found that when traffic was high and people were present at the site, bighorn sheep made more attempts and took longer to cross the road. Furthermore, the number of bighorn sheep utilizing the mineral lick declined from nearly 800 sheep in 1996 to only 243 during the summer of 2003. In Denali National Park, unsuccessful road crossings by Dall's sheep have also been observed (Dalle-Molle and Van Horn 1991). Papouchis et al. (2001) studied desert bighorns response to roads and vehicles in Canyonlands National Park, Utah. They found that bighorns fled from vehicles in 17% of encounters. Heavy traffic caused greater avoidance and sheep fled most often when within 200 m of the road and did not respond if they were more than 800m from the road. In general, most bighorn sheep avoided roads and were on average 39% farther from roads than other areas. This avoidance produced a 20-36% decrease in the use of suitable habitat along the road corridor within the study area.

Human development may also influence bighorn sheep population dynamics and persistence. On the Rocky Mountain Front in Montana, seismic lines caused a significant decline in home range size of bighorn sheep. In the year following four large-scale cutlines, bighorns were excluded from 28% of their traditional fall range (Hook 1986). The 1988 Winter Olympics in Calgary, Alberta, caused local bighorn sheep populations to abandon parts of their range adjacent to the downhill skiing venue on Mt. Allan. After the ski area was opened in 1986, Jorgenson (1988) observed an 18% decline in the population due to decreased lamb survival and hunting pressure. A study by Epps et al. (2005) indicated that roads and anthropogenic features such as canals and fences have reduced genetic diversity for desert bighorn sheep populations in the Mojave and Sonoran deserts of California. Forest encroachment as a result of fire suppression may also block migration corridors and lower dispersal movements (Beecham et al. 2007), and may result in range abandonment (Etchberger et al. 1989). Because many sheep populations are inherently small (< 50 individuals) a significant decrease in genetic diversity due to barriers to movement may cause habitat fragmentation, impact metapopulation stability and have large implications on extinction risk (Berger 1990, Armentrout and Boyd 1994).

The effects of human infrastructure and mining development on mountain sheep behavior, abundance and habitat selection have been studied in the Mojave Desert of California, where a heap-leach gold mine was placed near a critically important spring used by bighorn sheep in the summer. Oehler et al. (2005) measured the influence of mining activity on habitat selection, home-range dynamics and foraging ecology of two subpopulations of bighorn sheep; one that occupied an area within the vicinity of the mine, and a control population in a non-mined area. They recorded few changes in sheep activity that could be directly correlated with mining. Their results did suggest that female sheep near the mine spent more time vigilant during the summer and fall and consequently spent less time foraging. Oehler et al. (2005) proposes that even a small decrease in forage intake could affect survival in populations of desert bighorns that must persist in marginal environments. Bighorn sheep within the perimeter of an active copper mine associated with vehicles and blasting in Arizona foraged up to 6% less than sheep in non-mined areas but did not appear to be more vigilant (Jansen et al. 2006,2007). The authors conclude that bighorn sheep may be able to habituate to predictable disturbance when subjected to years of mining activity.

Habituation

There is evidence that in certain conditions bighorn sheep may habituate to temporally and spatially predictable human activity such as low levels of recreation or mining activity (Horesji 1976, Wehausen et al. 1977, Jansen et al. 2007). Habituation to jet overflights has been observed in two studies that monitored bighorn sheep heart rate and behavior before, during and after being disturbed by loud noise associated with F-16 fighters. Krausman et al. (1998) found that in Nevada, the heart rate of bighorn sheep in a large enclosure flown over by jets only increased in 21 of 149 overflights and returned to preflight levels within 120 seconds. In a lab setting, Weisenberger et al. (1996) observed that bighorn sheep and mule deer were able to habituate rapidly to noise from a simulated jet overflight. They recorded 34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 seconds. These results suggest that bighorn sheep do not view overflights by jet aircraft as a threat. The level of bighorn sheep habituation to human activity likely varies between regions and the impact of development should be examined on a case-by-case basis (Beecham et al. 2007).

Migration

Mountain sheep are known to migrate between seasonal ranges. Typical migrations can range between 5 – 51 km (Hengel et al. 1992, Shackleton et al. 1999) but can also include shorter elevational migrations (Beecham et al. 2007). Sheep likely learn traditional migration routes from their mothers and fidelity to theses established corridors is relatively high (Geist 1971). As discussed earlier, changes in forest composition as a result of fire suppression and anthropogenic barriers such as canals, roads and fences may fragment populations of bighorn sheep (Epps et al.

2005, Beecham et al. 2007). Thus, maintaining routes between mountain ranges is important to prevent genetic isolation and extinction risk.

Disease

Disease plays a significant role in bighorn sheep natural history. With the arrival of European settlers to the West in the early 1900s came dramatic declines in bighorn sheep populations. These declines were likely the result of transmission of diseases and parasites from domestic livestock, particularly domestic goats and sheep (Beecham et al. 2007). Many different diseases affect bighorn sheep including: psoroptic scabies, sheep nasal botfly, chronic sinusitis, gastrointestinal parasites, bluetongue, paratuberculosis, verminous pneumonia, contagious ecthyma, mandibular osteomyelitis and lungworms (Bunch et al. 1999, George et al. 2009). However, bacterial pneumonia (caused by bacteria in the *Pasteurellaceae* family) is likely responsible for most of the declines and large-scale (> 50% of individuals) die-offs of bighorn sheep. Generally a combination of stress related factors such as harassment by humans, poor nutrition, severe weather or high density dependence trigger die-offs (Bunch et al. 1999). Low lamb recruitment can persist for years following a die-off and in some situations survivors can continue to infect other herds leading to even larger population-level consequences (George et al. 2009). Overgrazing and competition with domestic animals can also contribute to further declines. These epidemics can be exacerbated by other diseases, parasites or environmental stress such as human disturbance and increased residential development near bighorn sheep winter range could increase bighorn sheep susceptibility to disease (Beecham et al. 2007).

Predation

The large historic declines in bighorn sheep populations have likely altered predator-prey dynamics across their range (Beecham et al. 2007). While predators can influence bighorn sheep populations in some situations, predation likely has less of an impact on population dynamics than disease or habitat fragmentation. Bighorn sheep have adopted a successful anti-predator strategy by using open areas near escape terrain which allows them to detect and flee from cursorial predators such as wolves (Geist 1971, Dekker 2009). However, in some situations ambush predators, like mountain lions, have negatively impacted sheep populations (Hayes et al.

2000, Beecham et al. 2007, Greene 2010). Some researchers have speculated that mountain lion predation on bighorn sheep increased following a decline in mule deer numbers in California (Holl et al. 2004). Alternately, research by Rominger et al. (2004) indicates that mountain lion populations in central New Mexico were subsidized by cattle and thus maintained higher population numbers and had a significant negative impact on bighorn sheep populations.

Summary

Unfortunately, no specific research has been conducted on the effects of residential development on bighorn sheep behavior or demography, likely because of the general lack of overlap between current bighorn habitat and residential development. Historic reports suggest that bighorn sheep once ranged far from rugged mountain terrain now considered preferred habitat (Cowan 1940, Valdez and Krausman 1999). The overwhelming expansion of urban development, resource extraction, disease, competition with domestic livestock and habitat fragmentation have reduced historic ranges by 40% (Laliberte and Ripple 2004). The large-scale declines and extirpations of bighorn sheep populations near western cities like Tucson are likely a result of human encroachment, though no cause and effect studies documented the declines (Krausman et al. 2001). Further, successful translocation projects across the West have made identifying the underlying impacts of residential development difficult.

Mountain sheep are highly vigilant and exhibit a number of overt behavioral reactions in response to human disturbance. In general, approach by humans on foot elicits a stronger behavioral reaction than vehicle traffic. Where human development intersects sheep range roads may act as a barrier to movement, especially when highways bisect migration routes or corridors to important seasonal mineral lick sites. Other research suggests that mountain sheep avoid roads with high traffic volumes and in some cases may even abandon habitat following disturbance events (Armentrout and Boyd 1994). Aircraft overflights can increase movement rates, heart rates, and interrupt foraging and resting behaviors. Industrial mining can disrupt foraging efficiency by increasing time spent vigilant in the proximity of the mine, though few studies have linked behavioral changes to long term demographic consequences. Disease and parasite levels have also increased following human disturbance. Evidence for habituation temporally and spatially predictable human activity and to jet overflights has been proposed in certain situations. Other human mediated impacts such as an increase in invasive species that decrease native forage (Dekker 2009) and competition with domestic livestock also threaten bighorn sheep populations (Beecham et al. 2007). The situation face by bighorn sheep is eloquently embodied by Kruasman et al. (2001:226), who write, "society is faced with a difficult choice: either restrict suburban expansion and control human activities within sheep habitat or accept the reality that sheep and expanding developments are simply not compatible." Protection and maintenance of mountain sheep habitat is essential to prevent extirpations similar to those observed in the past century.

Table 8. Review of scientific literature on the effects of human disturbance on mountain sheep, summarizing study authors, study duration, whether the study was peer reviewed or not, species: (***Oc****–Ovis canadensis,* ***Ocn****–O. c. nelson,* ***Ocm****–O. c. mexicana,* ***Odd*** *–O. dalli dalli*), sample size, location, study area size, development type, study design, collar type, general methods and results, and conclusions and management recommendations.

Author: *Study Duration*	Peer Re-view	Spp.	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Conclusions & Management Recommendations
Bleich et al. 1990, 1994: *1988-1990*	yes	*Oc*	n =36	San Bernard-ino County, CA; 225 km^2	helicopter	Obs.	VHF	Monitored VHF-collared sheep 1x/week. Monitored response to low flying helicopters and compared to non-disturbed sheep.	Sheep moved 2.5x further the day following a heli survey than the previous day, some left the study area after surveys. Even low intensity heli surveys had a substantial effect on mountain sheep movement/distribution.	Movement by mountain sheep during helicopter survey may produce biased estimates of population size. Helis and fixed-wing aircraft may reduce foraging efficiency, alter use of habitat, increase susceptibility to predation, increase nutritional stress.
Etchberger et al. 1989: *1987-1988*	yes	*Ocm*	n ≈ 11	Coronado National Forest, AZ; 78 km^2	recreat.	Obs.	VHF	Monitored VHF-collared sheep to find current HR, compared habitat characteristics in abandoned vs used home range.	Habitats used by bighorn sheep have less human disturbance and higher forage biomass.	Human disturbance seems to be key factor in change of habitat. Fire is important and restoration fire could enhance sheep habitat. Reducing human activity in abandoned areas could enhance restoration.
Hook 1986: *1982-1984*	no	*Oc*	n = 8	Rocky Mountain Front, MT; na	resource extraction	Obs.	VHF	Monitored VHF-collared sheep approx 2x/week, noted habitat type along with location.	The average annual home range size significantly declined (28%) from average following seismic line disturbance.	sheep were affected by the placement of seismic lines, especially in the fall, which may have population-level effects. Oil and gas activities are detrimental to bighorn range.
Jansen et al. 2006, 2007: *2003-2005*	yes	*Oc*	n = 21, n = 12	Silver Bell Mountain s, AZ; 73 km^2, 58 k km^2	resource extraction	Obs.	VHF	Monitored VHF-collared sheep 1x/day and recorded habitat type. Recorded behavior of focal animal in each group.	Sheep used areas within the mine site. Sheep fed less (6%) while inside the mine perimeter. Other behaviors (e.g., bedding, standing, alert, and interacting) were similar inside/outside mine perimeter.	Minor differences in sheep behavior inside and outside the mining area. Sheep appeared to habituate to mining activity. Emphasis placed on restoration, especially in desert or semi-desert environments.
Jorgenson 1988: *1986-1987*	no	*Oc*	na	Alberta, Canada; na	resort	Obs.		Observed sheep from ground and air, measured variables to model population.	18% decline in population, including lower lamb survival, range abandonment, and more lungworm larvae.	First year negative effect of ski resort, but population rebounded in subsequent years. Continue to monitor herd vital rates and use mitigation measures to avoid unnecessary harassment.
Keller & Bender 2007: *2002-2003*	yes	*Oc*	n = 357 obs. in 02 and n = 159 obs. in 03	Rocky Mountain National Park, CO; 1076 km^2	recreat.	Obs.		Observed sheep crossing attempts and number of vehicles.	Number of groups visiting key mineral lick adjacent to a road declined as human disturbance increased. The time and number of attempts required by bighorn to reach Sheep Lakes was positively related to the number of vehicles and people present.	Negative effects of road and human avoidance may affect population dynamics. Recommended seasonal human use restrictions to maintain sheep populations. Also moving the interpretive site, moving the road or constructing an overpass.

Table 8 Cont.

Author: *Study Duration*	Peer Re-view	Spp.	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Conclusions & Management Recommendations
Krausman et al. 1998: *1990-1992*	yes	*Ocn*	n=22 in enclose-ure n=5 HRM	Desert National Wildlife Refuge, NV; 3.2 km^2	Jet aircraft	Exper.	Heart Rate	Monitored sheep behavior and habitats use in enclosure subjected to 149, F-16 overflights. Recorded heart rate and behavior of sheep 15 min pre-overflight, during the overflight, and postoverflight.	Heart rate increased above preflight levels in 21 of 149 overflights but returned to preflight levels within 120 sec. Noise level created did not alter behavior or use of habitat or increase heart rates to the detriment of the sheep.	Heart rate and behavior data suggest sheep habituate to aircraft and the noise they create.
Loehr et al. 2005: *1 month 2001*	yes	*Odd*	n=35 sheep observed	Faro, Yukon Territory; na	recreat.	Obs., Exper.		Thinhorn sheep were observed and subjected to human disturbance trials by hikers.	Females rested less and foraged more under human disturbance and were more vigilant, but not males.	With proper precautions and continued monitoring (to assess whether disturbance becomes more frequent or reactions of individuals change), disturbance of this type can be tolerated by thinhorn sheep.
MacArthur et al. 1982: *na*	yes	*Oc*	n = 5 HRM	Alberta, Canada; na	recreat.	Obs.	Heart Rate	Observed heart-rate-monitored sheep and noted corresponding causes of heart rate elevation.	Cardiac and behavioral responses were ↑ when humans and humans w/ dogs approached from over a ridge. Reactions to road traffic were minimal, no reactions to helicopters or fixed-wing aircraft at distances exceeding 400 m.	Responses to disturbance were detected using HR telemetry that were not evident from behavioral cues alone.
Oehler et al. 2005: *1995-1997*	no	*Oc*	n = 19 radio collared	Inyo County, CA; 23.5 km^2	resource extraction	Compar.	VHF	Monitored VHF-collared sheep 1x/week, noted habitat quality at locations, tested pellets for diet quality, surveyed for carnivore scat.	Size of annual HR, composition of diet, and ratios of young to adult females did not differ between sheep inhabiting mined and nonmined areas. Nonmined areas had higher forage biomass than mined sites. In spring sheep near mine had lower forage quality.	Greatest impacts were observed in the summer, recommended either providing alternate water sources away from the mine to mitigate negative impacts or ceasing mining activities during the summer.
Papouchis et al. 2001: *1993-1994*	yes	*Ocn*	n = 42	Canyon-lands National Park, UT; 8341 km^2	recreat.	Obs.	VHF	Monitored VHF collared animals and observed non-collared animals along 3km of road and monitored human activities in a high use area and a low use area.	Hikers caused severe responses in sheep (61% fled), vehicles (17%) and mountain bikers (6%). In spring, females in the high-use area fled from hikers >3x farther than females in the low-use area. Alerted up to 363 m from roads. Some sheep habituated to roads.	Hiking has the biggest impact likely because the greater unpredictability of hiker locations. Managers should confine hikers to designated trails during spring lambing and the autumn rut in desert bighorn sheep habitat.
Stockwell et al. 1991: *1985-1986*	yes	*Ocn*	na	Grand Canyon National Park, AZ; na	aircraft	Obs.		Observed desert bighorn sheep from a distance when helicopters were present and absent and recorded behaviors.	Bighorn were sensitive to disturbance during winter (43% reduction in foraging efficiency) but not during spring (no significant effect). Further analyses indicated a disturbance distance threshold of 250-450 m.	Helicopters alter foraging behavior which is most severe in winter. Impacts would be minimized if helicopters were to fly no nearer to bighorn habitat than 500m.

Table 8 Cont.

Author: *Study Duration*	Peer Re-view	Spp.	Sample Size	Location, Study area size	Devel-opment Type	Study Design	Collar Type	General Methods	General Results	Conclusions & Management Recommendations
Thompson et al. 2007: *2002-2004*	no	*Ocn*	n = 10	Joshua Tree National Park, CA; 300 km^2	recreat.	Obs.	GPS	Monitored GPS-collared desert bighorn sheep 3x/day. Recreation activity monitored.	Female sheep moved more often, used steeper slopes and areas farther from trails during high levels of human activity resulting in temporarily displacement from habitat.	Access to water and habitat may be temporarily constrained by human activities. Placement of new water sources should mimic historic areas and must support connectivity with other populations. Maintain probable routes between mountain ranges to help prevent isolation.
Weisen-berger et al. 1996: *3 months 1990-1991*	yes	*Ocm*	n = 5 HRM	University of Arizona, Tucson, AZ; small pens	aircraft	Exper.	Heart Rate	Measured heart rate and behavior responses to simulated overflights per day (range = 1-7) and noise levels (range = 92-112 decibels).	34 incidents of increased heart rate in bighorns during 112 overflights and heart rate returned to normal within 60-180 sec.	Sheep were able to habituate rapidly to noise from a simulated jet overflight. Results suggest that bighorn sheep do not view overflights by jet aircraft as a threat.

Notes: Abbreviations are HR, home range; HRM, heart rate monitor; Obs., observational; Exper., experimental; Compar., comparative; recreat., recreation.

Land Use Policies

Patterns of Development

As discussed earlier, almost half the land in the West is public. This limits where and how new exurban residences can be developed. Rather than the classic European pattern of clustered, mixed-use villages (similar to towns commonly found in New England), exurban development has evolved through advances in transportation, amenity migrations and high consumption lifestyles into specific-use, disconnected subdivisions, shopping centers and office parks (Newman 2009). Recent research has indicated that the pattern and rate of growth matter as much or more than the total development footprint (Travis et al. 2005). This is a critical issue as the rate of private land development is over twice the rate of private land protection in the U.S. In Montana, the Subdivision and Platting Act of 1973 was the first law to provide some criteria and a formal process for the division of land (Henderson and O'Herren 1992). However, subdivision growth in areas beyond established communities and in ungulate winter range has continued to occur at sometimes rapid rates, due to weak, fractured and uncoordinated state subdivision laws and local subdivision regulations (Travis 2007). Zoning to manage growth in Montana is an additional local government regulatory tool authorized by state law, but its use is not widespread outside of the larger municipalities. Consequently, a good deal of exurban development and human encroachment into ungulate winter range has occurred with few guidelines and standards regarding suitable location and design (D. Fischer, personal communication).

Recently, 'conservation development' has been proposed as an alternative to conventional sprawl development patterns. It is a tool that allows local governments to protect open spaces, agricultural lands and wildlife habitat from encroachment, while at the same time promoting economic growth (Apel 2011). Conservation development is composed of a variety of site design strategies, including; (1) conservation buyer projects such as conservation easements, (2) conservation and limited development projects which use revenue from limited development to finance land conservation, (3) conservation subdivisions that set aside a major portion of a site for open space and (4) conservation oriented planned development projects which aggregate conservation and development areas at larger scales (Milder 2007). All conservation developments attempt to cluster homes in a small area of a development. This helps to reduce the site-scale impact of a subdivision by minimizing the ZOI around each house (Figure 5). Many handbooks are available in the planning design literature that provide guidelines for developers (for example: Arendt 1996, American Society of Landscape Architects 2009, Washington Department of Fish and Wildlife 2009). However, recent concern over the ability of open space designs to protect important wildlife habitat suggests a need for improved communication between wildlife biologists, landscape architects and planners (Carter 2009, Hostetler and Drake 2009).

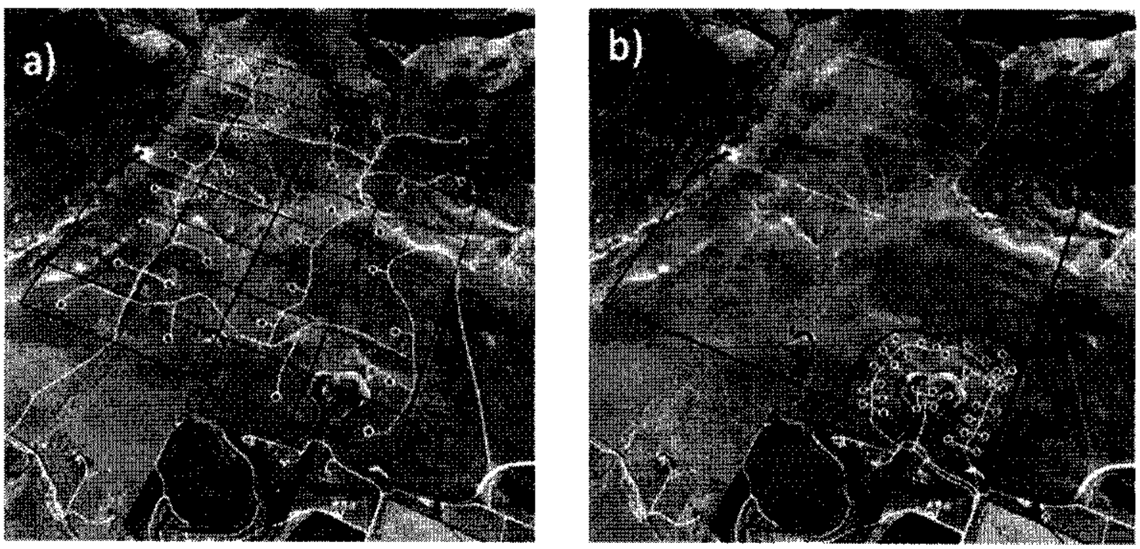


Figure 5. Examples of traditional development of thirty-two 20-acre lots spread across 640 acres of winter range (a), and a "clustered" design (b) of the same 32 houses on 2-acre lots which constitute 10% of the property (64 acres) and are situated in a corner near existing development (J. Vore, figure).

Hostetler and Drake (2009) point out a number of key problems with traditional conservation subdivision designs that bring up new research questions. First, though many development projects inventory species diversity before project implementation, few monitor species during multiple seasons. This is essential to mitigate the effects of development on critical migration stop-over sites, corridors or seasonal habitats such as ungulate winter range. More research is needed to determine how different corridor widths impact ungulate migration patterns at regional and site specific scales (i.e., migration bottlenecks). The potential for wildlife-friendly fencing and road crossing infrastructure to facilitate ungulate migrations also requires more research.

Second, there is a need to regulate habitat configuration, rather than the percent of open space in a development. Protecting a number of small undeveloped units in a parcel increases the amount of fragmentation and edge habitat. Work on songbirds suggests that negative effects of edges can extend into patches up to 200 m and be detrimental to nest success (Maestas et al. 2003, Lenth et al. 2006). On the other hand, protecting large areas adjacent to undeveloped land would provide functional habitat for sensitive species that are often displaced by habitat generalists near developments (Hansen et al. 2005). No research has examined how the design of residential development affects ungulates.

Third, while considerable effort is often put into the design phase of conservation development, less attention has been paid to the physical development and post-development stages. Proper implementation of a conservation plan by contractors is necessary to the success of a project (Hostetler and Drake 2009). Some studies on ungulates have indicated that construction can have a stronger influence on species distributions than post-development (Morrison et al. 1995). However, to date, no studies have specifically examined the influence of residential area construction on ungulates. Questions remain about the ability of ungulates to habituate to physical structures after construction is complete. Further, after development takes place, homeowners must be educated about the importance of open space and made aware that pets, invasive ornamental plant species and recreational use can decrease any remaining wildlife benefits in even the best designed conservation subdivisions. Patterns of residency (i.e., year-round vs. part-time) also likely influence the success of a conservation development projects. Studies on ungulates suggest that both physical development structures and the associated increase in human activity can cause avoidance behavior (Nellemann et al. 2001). Thus, research on the response of specific species to multiple stressors is needed to determine what anthropogenic factor affects ungulates the most.

Currently, most conservation development standards are included in regulations as options which a landowner may choose (e.g., a planned unit development). Such standards are typically not compulsory for development proposals located in wildlife-rich areas. Consequently development frequently occurs outside of zoned areas under the purview of county comprehensive plans, which are advisory only (Travis 2007). Incentives are often used to encourage developers to implement conservation development standards. These commonly include a density bonus that increases the number of units allowed on the property in return for development on a smaller area. Unfortunately, while this type of incentive might decrease the overall human footprint, the intensity and associated human activity in development is greater (S. Reed, personal communication). Another problem with such conservation development standards is that very few require input from ecological experts or plans. Finally, most of these standards last for a set amount of time. This allows development to take place in the conservation area once the project duration is over (for example; only 40 years in Colorado, and 65 years in Wyoming, S. Reed, personal communication). Thus, conservation development standards as currently designed may not be effectively preserving important habitat as well as might be expected at first glance.

Land Use Planning Guidelines

Human encroachment on undeveloped habitat has many negative consequences for wildlife and society. We must be willing to implement sometimes expensive, time consuming and controversial plans to mitigate impacts. As Krausman et al. (2011:189) write, "planning with enforcement has to be a key ingredient or the unplanned, random, and chaotic urban development scheme will continue to alter habitats." Land use policies are an important tool that can help guide decisions on where to place residential development, how to design developments, and how people can best live in those places. Policies and regulations that incorporate scientific research, ecological principles and land use planning guidelines are essential for successful conservation of important ungulate habitat and migration corridors. Many studies suggest guidelines for monitoring and managing the potential effects of residential development. While most of these guidelines are not specifically directed at ungulate winter range, they are pertinent to maintaining wildlife populations and habitats.

The lack of definitive research on the effects of residential development on ungulates can be frustrating to planners charged with developing effective policies and regulations. Facilitating a direct link between scientific research, ecological principles and land use planning is essential. This requires ecologists and wildlife managers to engage with land use planners to ensure that pertinent research guides large scale development patterns. Planners must proceed on the basis of the most pertinent scientific research as well as the professional opinion of the scientific community. Further, as new information is acquired, guidelines, policies and regulations should be modified accordingly (Duerksen et al. 1996, Environmental Law Institute 2003). It is likely that local governments, neighborhood groups and individual landowners will conceptualize guidelines in very specific ways. Thus, conservation planning needs to be a collaborative and flexible process, and guidelines should represent a starting point that can be modified in response to local variables. In this way land use guidelines can help facilitate the development of policies and regulations needed to guide decisions on how to design developments and regulate their influence on wildlife.

The spatial and temporal scales of the effect of development and the regulation and mitigation of the effect are important to consider when managing wildlife (Johnson and St-Laurent 2011) because land use planning can take place at multiple levels (e.g., individual landowner, local community, county, state, and federal). Mismatches between the scale of ecological processes and land use planning can challenge both scientists and managers (Theobald et al. 2005). Many studies stress the importance of local monitoring because of the complexity inherent to managing individual species that occur in very discrete habitats. Planning at the local or site-level must integrate specific guidelines to promote compatibility between humans and wildlife. A number of specific guidelines can help reduce human-wildlife conflict, support wildlife habitat and reduce habituation at the local scale (Dale et al. 2005, Washington Department of Fish and Wildlife 2009, Estes Valley Planning Commission 2010):

1. Buffer development by the largest area possible
2. Reduce non-native vegetation and the spread of exotic species
3. Reduce fencing or promote wildlife friendly fences
4. Reduce excessive lighting
5. Provide animal proof garbage disposal
6. Control or restrict free ranging domestic pets
7. Focus human impact on resilient areas
8. Maintain large connected patches of undeveloped land
9. Keep zoning densities low within and immediately surrounding high value habitat
10. Manage road systems to minimize the number of new roads and new barriers to important animal movement corridors
11. Include a site level habitat assessment to inform project conditions and management actions

However, because ungulates require large seasonal home ranges and depend on sensitive migration corridors that connect these areas, the best opportunity for conservation of ungulate habitat is at the landscape scale. As research on human impacts accumulates, there is growing focus on ecosystem approaches to monitoring cumulative effects. Ecosystem analysis focuses on ecological resources within natural boundaries and addresses issues of biodiversity and sustainability (Krausman 2011). More importantly, ecosystem analysis considers large landscapes, complex biotic interactions and addresses large temporal and spatial scales; all of which are crucial to understanding the influences of residential development on long-lived, highly mobile ungulate populations. To protect functional winter range, as defined by Montana Fish, Wildlife and Parks, there is a need for collaboration between stakeholders from federal, state, and local government, and private organizations, groups and individuals (Theobald et al. 2005). New innovations in spatial modeling and remote sensing have made conveying alternative land use scenarios to stakeholders across various planning scales possible. This can help determine how incremental development will impact a landscape, an important consideration in cumulative effects assessments. The following principles are useful for protecting habitat in rapidly developing areas at large landscape scales (Duerksen et al. 1996, Krausman 2011):

1. Maintain large, intact patches of native vegetation by preventing fragmentation
2. Establish priorities for species protection and protect habitats that constrain the distribution and abundance of those species
3. Protect rare landscape elements. Guide development toward areas of landscape containing "common" features
4. Use natural boundaries
5. Maintain connections among wildlife habitats by identifying and protecting corridors for movement
6. Maintain significant ecological processes in protected areas
7. Contribute to the regional persistence of rare species by protecting some of their habitat locally
8. Balance the opportunity for recreation by the public with the habitat needs of wildlife
9. Look beyond the life of the project

Table 9. Review of selected scientific literature on exurban development, summarizing study authors, short title, whether the study was peer reviewed or not, study area location, study design, general results and conclusions and management recommendations.

Author: Short Title	Peer Re-view	Study Area location and size	Study Design	General Results	Conclusions & Management Recommendations
Arendt 1997: Basing cluster techniques on development densities appropriate to area	yes	na	Review	When planning new development, regulations must take into account density of houses. After an appropriate density has been chosen, then housing should be clustered to reduce impact on farmland and conserve habitat.	Guidelines for land conservation include: indentifying conservation areas, special features, locate house sites at a respectful distance from resource lands, align streets and footpaths and set in lot lines.
Beier et al. 2008: Best management for wildlife corridors	no	Arizona	Review	Series of recommendations regarding roads, streams, development and canals in 'linkage' corridors between habitat.	Planners should follow guidelines when developing in corridor areas.
Ben-Ami & Ramp 2005: Modelling the effects of roads and other disturbances on wildlife	no	Australia	Review	Reviewed 4 case studies to find patterns in response to roads and found each population is unique.	Solutions must be location specific. Managers must examine population viability models because road crossings may or may not improve population viability.
Compas 2007: Measuring exurban change in the American West	yes	Gallatin County, MT	Review, Modeling	Major subdivisions have moved closer to service areas, are more clustered and leave more open space. Minor subdivisions are spreading out and taking up more space, thus negating the positive effects of the major subdivision changes. Both types are moving toward riparian areas.	The less consumptive trends of the major subdivisions are cancelled out by the minor subdivisions. Need to initiate more rules on minor subdivisions, more studies on ecological impacts.
Czech 2000: Economic growth limiting factor for wildlife conservation	yes	na	Review	Theoretical paper on why TWS and wildlife professionals should understand economic theory and growth.	Economic development is the limiting factor of wildlife conservation. Wildlife professionals should understand economic growth and take a position.
Dale et al. 2000: Ecological principles and guidelines for managing use of land	yes	na	Review	Land use change can affect 1) species demography and diversity, 2) land cover juxtaposition, 3) disturbance regimes, 4) biological cycles.	Proactive mitigation of land use changes are needed to retain ecological function.
Environmental Law Institute 2003: Conservation thresholds for land use planners	no	na	Review	Patches should be at least 55 ha and some patches should be 2500 ha. 20-50% should be suitable habitat, edge buffers should be 230-300 m, riparian buffers should be at least 100m, a network of corridors should exist. Site specific assessments are always best due to species, topography etc.	More studies need on reptiles, invertebrates and plants in relation to fragmentation. Studies should supply land planners with more concrete guidelines. Land planners should communicate with scientists about what they need.
Estes Valley Planning Commission 2010: Development Review for wildlife protection	no	Colorado	Review	Developers must submit plan, plan is reviewed by division of wildlife for effects on endangered species, calving/lambing/fawning ground, bighorn sheep, raptor nest site and riparian areas. If it does effect these things, developers must have mitigation plan.	Standards should include as large a buffer as possible, no non-native vegetation, no fencing, no excess lighting, animal proof garbage disposal and control of domestic animals.
Glennon & Kretser 2005: Impacts to wildlife from low-density exurban development	no	na	Review	Majority of articles on high density development. Fragmentation has varying effects on species but almost always a negative effect on biodiversity. Maintain up to 6 km buffer for some nesting bird spp.	Clustered and conservation subdivisions may mitigate some impacts but aren't a catchall. More studies need to be done on exurban development specifically, seasonal homes, and people's perception of wildlife.

Table 9 Cont.

Author: Short Title	Peer Re-view	Study Area location and size	Study Design	General Results	Conclusions & Management Recommendations
Gude et al. 2006: Rates and drivers of rural residential development in the Greater Yellowstone	yes	GYE; 145635 km2	Review	Private lands are generally in valley bottoms close to water and have been since 1900. Proximity to national parks raises chance of development. Towns with higher educated population had higher rates of development.	Private lands are generally found in winter ranges and areas important to wildlife for migration in the GYE. Counties need stricter land use regulations in order to control development and steer it in an ecologically sound direction.
Gude et al. 2007: Biodiversity consequences of alternative land-use scenarios in Greater Yellowstone	yes	GYE; 145635 km2	Modeling	Riparian habitat, elk winter range, migration corridors are likely to undergo substantial conversion (between 5% and 40%) to exurban development by 2020. Future exurban development outside the region's nature reserves is likely to impact wildlife populations within the reserves.	Most habitats are likely to experience 10-40% change in next 10 years, but growth management can influence pattern. Counties should implement zoning plans for conservation, conservation easements and apply incentives for growth near towns.
Hansen et al. 2005: Effects of exurban development on biodiversity	yes	the West	Review	Urban fringe development and rural residential development effect biodiversity in multiple ways, not always linear. Usually an increase of non-native species and decrease of non-adaptable native species. Decrease in biodiversity due to habitat alteration, ecological process alteration, biotic interaction alteration and human disturbance.	Need to study the patterns and mechanisms of exurban development so mitigation is more effective.
Hawbaker et al. 2006: Road development, housing growth and landscape fragmentation	yes	Northern WI; 1564 km2	Modeling	From 1939-1960 road density more than doubled, area affected by roads doubled, max roadless patch decreased by 1/2, mean and median patch sizes decreased 4 fold. First roads in area contributed more to habitat fragmentation than later roads.	Road density has increased and has changed the ecological landscape and probably the behavioral patterns of wildlife in the landscape. Limit early road construction. Construct under and overpasses to reduce fragmentation, remove unused roads.
Jarvis 2008: Residential development patterns in Flathead County, MT	no	Flathead County, MT; 13603 km2	Review, Modeling	The number of new residential parcels has increased. Distance to roads and home density are significant predictors of residential development.	Flathead county has a lot of exurban development. Almost everywhere is scenic so amenities were not significant in predicting development.
Knight et al. 1995: Ranching the view: subdivisions vs agriculture	yes	the West	Review	Patterns of land use in West show that subdivisions occur in valley bottoms, which are important habitat for many animals. Problems include roads, buildings, fences, noise, human presence, lights, exotic species, domestic predators.	Subdivisions are affecting biodiversity and ecosystems to a high degree in the West.
Kretser et al. 2008: Housing density as an indicator of spatial patterns of reported human-wildlife interactions	yes	Northern NY near Adirondack Park; 46000 km2	Modeling	Housing causes decline in biotic integrity. Human-wildlife interactions cluster in areas dominated by suburban and exurban housing densities compared to urban and wildlands. Low density developments have higher reported human-wildlife interactions. Reports of black bears increased within the wildland areas.	Suburban and exurban densities are the primary locations where interactions between humans and wildlife are reported. Developments should be clustered to minimize the influence of each house. More densely settled areas would reduce human-wildlife interactions. Focus outreach on specific human wildlife issues within particular land use densities.
Kretser et al. 2009: Factors affecting perceptions of human–wildlife interactions	yes	Northern NY near Adirondack Park; 24000 km2	Survey	People with a negative outlook on wildlife were older, lower income, lower knowledge of wildlife, and had fewer interactions with wildlife. People from urban backgrounds were more likely to have positive experiences with wildlife compared to rural backgrounds. People were more likely to support programs protecting wildlife and land if they had a positive experience with wildlife.	People with negative experiences were more likely to return the survey, but less likely to contact professionals about wildlife issues, thus reporting appears inconsistent with negative perceptions. Moose and deer had more positive perceptions than smaller "pest" species. Managers should focus on ways to increase positive interactions with people and wildlife (bird watching or photography). Need species specific policies for better communication with public.

Table 9 Cont.

Author: Short Title	Peer Re-view	Study Area location and size	Study Design	General Results	Conclusions & Management Recommendations
Lenth et al. 2006: Conservation value of clustered housing developments	yes	Boulder, CO	Observati onal	Clustered development was more similar to dispersed development than to undeveloped lands in species composition of both wildlife and plants.	Outlots were not large enough to compensate for development. Half of land was within buffer. Need to make outlots larger, cluster homes closer together and far from sensitive areas. Promote native landscaping and manage outlots for native species (ie control pets/people onto trails, promote native veg).
Maestas et al. 2001, 2003: Biodiversity across a rural land use gradient in the American West	yes	Larimer County, CO	Compar-itive	Biodiversity was higher on ranches and protected areas than in exurban areas. Non-native plants and human-adapted spp were highest in exurban development, some, including noxious weeds and nest predators seen only in exurban.	Exurban development could be eco-sink for wildlife and source for noxious spp and nest predators. Exurban development has profound effects on biodiversity. Conservation easements should be continued on ranches since private lands can have higher spp richness than protected areas.
Peterson et al. 2008: Household location choices: Implications for biodiversity conservation	yes	Teton Valley, ID/WY	Survey	Large differences in environmental attitude and reasons for household location between immigrants and natives. Older, more educated, more environmental and richer people were living in natural areas.	Environmentally friendly attitudes may lead to more exurban development. Need to educate people on the effects of their household choices.
Radeloff et al. 2005: The wildland-urban interface in the United States	yes	United States	Modeling	WUI is greatest in the east and in California. In Montana it is a high percentage of all houses but not a high percentage of land.	Fires are a growing problem with WUI houses as well as habitat fragmentation and degradation. Need to take ecology into consideration when developing.
Theobald 2005: Landscape patterns of exurban growth in the USA	yes	United States	Modeling	Exurban development is increasing faster than any other kind. 10-15% growth/year. Exurban development has a larger ecological footprint than urban and suburban development.	Ecologists need to know thresholds in each ecosystem for how much development can occur.
Theobald et al. 1997: Estimating the cumulative effects of development on wildlife habitat	yes	the West	Modeling	Clustered development had the lowest ZOI, but linear clusters could create a lot of fragmentation.	Well designed clustered development should be used to mitigate effects of development on wildlife.

Notes: Abbreviations are GYE, Greater Yellowstone Ecosystem.

Conclusions

> They come from all over, modern-day migrants fleeing freeways, smog and crime, yearning for their own little piece of the West. And with each new arrival, there is that much less of the wide open space they all crave. The American West is torn between two visions of one place. Although many cling desperately to the Old West ethos of a hardworking people who came to tame the land and tap its wealth, other are just as determined to bring on a New West, where nature is no longer ravaged, but restored. Yet, before the West can choose between Old and New, this stream of new settlers could doom them both. . . . Amid all the clamor over mining and grazing, grizzlies and wolves, [there is] something more troubling. . . . ***The single most dramatic resource issue we face, and I mean really immediately, is people.***
>
> (Diringer 1994, quoted in Shumway and Otterstrom 2001)

This review attempts to draw attention to the potential impacts the conversion of undeveloped land into residential structures has on habitat, behavior, population dynamics and management of ungulates. Only 22 papers reviewed specifically examined the effects of residential development on ungulates. Not one of the studies was a replicated experiment that rigorously analyzed the population-level impacts of development on ungulates species. This is a concerning result since the demand for new residential spaces is likely to increase in the coming decades in response to a growing human population in the West (Theobald 2005, Compas 2007, Gude et al. 2007).

The threat of unplanned, unregulated development on ungulate winter range should be a real concern to managers, policy-makers and the general public who appreciate and value native ungulates in the West. The effects of exurban development on wildlife may even exceed those of energy and resource extraction activities in some areas in part due to the lack of regulatory oversight and enforceable policies relating to new housing developments. Although no cause and effect studies documented the early influence of residential development on ungulate winter range during the past century, it is probable that this encroachment played a fundamental role in historic mule deer, elk, pronghorn and bighorn sheep declines in the West. Certainly, the low-elevation valleys and mountain foothills that are now occupied by western cities and towns were once vital winter ranges to a variety of ungulate species. **Though we cannot return these areas to pre-European settlement conditions, we can manage new growth to ensure that ungulates remain a significant part of the western landscape.**

Most ungulates exhibit short-term behavioral reactions in response to human disturbance. Many of these responses have been summarized in previous literature reviews (Canfield et al. 1999, Frid and Dill 2002, Hebblewhite 2008, Stankowich 2008, Parker et al. 2009). However, very few studies link short-term behavioral reactions to population-level consequences. This is unfortunate, because these inferences are needed to evaluate the effectiveness of management strategies, understand and predict the effects of development and monitor regulatory requirements. Evaluating the potential population-level responses of ungulates to residential development is further confounded by historic broad-scale population declines that make isolating the interacting influences of a range of synergistic factors difficult. Several recent long-term monitoring projects on the effects of energy development on ungulates suggest that demographic impacts may take many years to detect (Beckmann and Seidler 2009, Sawyer and Neilson 2010). As discussed by Hebblewhite (2008), short (2-5 year) studies simply do not have the statistical power to detect changes in vital rates. Compensatory reproduction and resilience in adult age-cohorts can create time lags between the effects of development and the eventual impact on the population. Further, ungulates are large, highly mobile species. They can, and will, adapt to predictable human disturbance through behavioral adaptations that can mitigate negative consequences on vital rates, at least in the short-term and within theoretical development thresholds. Thus, there is a pressing need for long term cumulative effects studies that can clarify the mechanisms driving changes in abundance and distribution.

Both direct and indirect impacts can result from increased human development, activity and infrastructure. Avoidance is defined as a reduction in use compared to what would be expected based on availability. Thus, it is important to note that avoidance does not indicate that ungulates never occur near developments, but rather, areas near developments are used less than expected. In general, for mule deer, elk, pronghorn and bighorn sheep, the avoidance ZOI extends well beyond human developments, though responses vary between species, development types and seasons (Tables 4, 5, 6, 7, and 8). In general, ungulates tend to avoid roads when human activity is highest, which is often during the summer (Hebblewhite 2008). Regardless of the actual percent decrease in use around developments, even a modest ZOI can result in large amounts of habitat becoming functionally lost due to indirect avoidance (Polfus 2010). The increase in GIS remote mapping capabilities and numbers of GPS collared animals will make determining how ungulates avoid various anthropogenic disturbances easier in the future. A large-scale habitat analysis of GPS location data from 581 radio-collared boreal woodland caribou (179,022 locations from 2000-2010) distributed across Canada indicated that caribou consistently avoided high road density and recent burns (Polfus and Hebblewhite 2010). Similar assessments that utilize GPS location data from published studies of elk, pronghorn, mule deer and bighorn sheep across a gradient of human land use densities could improve our understanding of the large-scale response of ungulates to residential development.

Making comparisons across studies of species responses to development can be difficult due to differences in methodology, techniques, regulatory measures, and the scale of the impact examined (Johnson and St-Laurent 2011). Specifically, defining minimum patch sizes and buffers around residential structures is difficult due to extensive variation in habitat quality, the proximity to forests and escape and hiding cover, the presence of predators, the occurrence of hunting by humans and competition with other ungulate populations. Perhaps most importantly, different research designs and metrics used to assess an effect will alter the detection of impacts. This discrepancy has lead to political and scientific controversy regarding the effect of human activity on ungulates, especially when stakeholders have a vested interest in the interpretation of avoidance distances (Wolfe et al. 2000). Further, results are also sensitive to the criteria used to define a metric. For example, the minimum patch size might relate to the area required to maintain species as measured by occurrence, population densities, survival or reproductive success. More space would likely be needed to maintain a large population that could tolerate environmental stochasticity while a smaller area could support a population during only one season. A literature review conducted by the Environmental Law Institute (2003) found only 20 papers that provided enough information to determine minimum patch area requirements for all wildlife species and none were specific to ungulates. Few studies have examined how much area is required to maintain species diversity or ecological community dynamics.

Of the studies reviewed on the effects of residential development on ungulates, the majority focused on white-tailed deer. These studies almost all occurred in the midwestern and eastern United States and, in general, concluded that white-tailed deer commonly habituate to human presence in suburban areas. There are likely large behavioral differences between highly habituated white-tailed deer in the eastern United States where available undeveloped habitat is a limited resource, and deer in the West that use large expanses of undeveloped land (Hoekman et al. 2006). However, even in western cities, white-tailed deer abundance can exceed human tolerance, threaten human safety through deer-vehicle collisions and conflict with personal property.

Only 5 studies on mule deer and 4 studies on elk analyzed populations in relation to residential development. Results of these papers are inconclusive. In general, mule deer show some avoidance of residential areas, but studies were based on indexes of distribution and all had low samples sizes (Smith et al. 1989, Vogel 1989, McClure et al. 2005). However, high densities of sedentary mule deer and elk in urban areas have been linked to increased rates of disease (Farnsworth et al. 2005, Olsen 2010). Two studies on elk found behavioral avoidance of residential development (Wait and McNally 2004, Cleveland 2010), while alternatively Hebblewhite et al. (2005) and Kloppers et al. (2005) studied a habituated elk herd that was adapted to the urban area of Banff, Alberta. However, many studies indicate that mule deer and elk avoid roads, industrial infrastructure and recreation. While behavioral avoidance behaviors have not been specifically tied to population-level responses in most cases (exception being the long term study by Sawyer and colleagues in southwest Wyoming), increased vigilance, flight and behavioral avoidance, have the potential to increase energy expenditures and could result in population declines, especially during severe winters. Migratory behavior in elk and mule deer also make protecting migration corridors important.

No studies have specifically examined the impact of residential development on American pronghorn or bighorn sheep. However, historic declines in both species are likely due to expansion of residential development, resource extraction, competition with domestic livestock and habitat fragmentation. Like other ungulates, both pronghorn and bighorn sheep exhibit a number of overt behavioral reactions in response to human disturbance which can increase energy expenditure. Barriers to movement, especially in pronghorn migration corridors, are a crucial threat to population persistence (Sawyer et al. 2005). Mitigating the effects of residential development that occur in critical migration bottlenecks should receive the highest conservation priority. Bighorn sheep continue to be subject to disease transfer from domestic livestock where habitat overlaps rangeland (George et al. 2009). In general, bighorn sheep and pronghorn populations require large-scale, multi-jurisdictional initiatives to protect critical migration corridors and winter ranges.

Ungulates can habituate to temporally and spatially predictable human activity especially when not hunted or harassed. These problem animals reduce the flexibility of managers to control ungulate populations through hunting quotas and weaken public enjoyment of wildlife. Further, negative interactions between problem wildlife and humans in residential areas can undermine public support for management agencies and conservation initiatives (Kretser et al. 2009). Habituated ungulates may display a decrease in migratory behavior, overgraze winter ranges and move to private lands or urban areas where hunting is not allowed. As more valley bottom lands are transferred from hunter-friendly ranches to subdivisions, the amount of land used as refuge by ungulates during the hunting season is likely to increase. This results in an ineffective and costly use of resources and reduces the ability of management agencies to control ungulate populations.

Finally, unregulated exurban development also poses a threat to human health, safety and public wellbeing. Subdivisions built in highly scenic areas, far from towns, stress public services and facilities, decrease the efficiency of roads and utility lines and increase the tax burden on county residents (Gude et al. 2006). Rural residential areas disrupt natural disturbance regimes and are at high risk for wildfire damage. Development trends suggest that new residential areas will continue to be built in high quality ungulate winter range. **As a society we walk a delicate line between enjoying the numerous traits of the wild places we value and destroying them with our presence.**

Management Implications

Understanding human expectations is critical to managing wildlife in proximity to human developments. As has been discussed before, successful management of wildlife depends on effective management of people (Krausman et al. 2011). The problems that face managers today are too complex to be solved by biologists or managers alone. Thus, it is important to acknowledge the limitations and biases associated with scientific research and recognize the importance of ethics and social justice in environmental problems. Specific to ungulates responses to development, this review suggests similar management recommendations to Hebblewhite (2008):

1) Short-term and small-scale behavioral impact studies on the effects of human development on ungulates are pervasive in the literature. Most studies are observational and infer the impact of development by correlating behavioral responses to human developments. This is generally the weakest study design and makes determining cause and effect difficult (Hebblewhite 2008). In general, mule deer and elk tend to avoid human activity near residential developments. Pronghorn and bighorn sheep display avoidance of other forms of human development and recreation. White-tailed deer are able to adapt to high levels of human activity near residential areas in the midwestern and eastern United States. Large scale multi-jurisdictional studies that utilize all available GPS location data from the published literature may help improve our understanding of the response of ungulates to residential development.

2) There is a need for long-term cumulative effect studies that monitor population level responses to the increasing growth of residential areas in the West. Ungulate persistence is unmistakably dependent on available habitat – habitat which is quickly being compromised by extensive development across the American West. The scale and incremental process of piecemeal development further confounds the ability of land planners to address cumulative effects. Single development permits, authorized over the span of years can make it difficult for review boards and planners to decline building permits when an area already contains multiple houses (Travis 2007). It is unlikely, especially when considering the historic large-scale declines in ungulates in the last century, that populations will be able to withstand this type of persistent gradual development. Thus, the cumulative impact of multiple low-density residential developments can be expected to produce significant ecological effects over time.

3) No studies have rigorously analyzed the population-level impacts of residential development on ungulates species. This is unfortunate, because the demand for new residential developments in the West is likely to increase in the coming decades in response to a growing human population. However, two long-term studies on the effects of energy development on pronghorn and mule deer suggest > 5 years of monitoring is needed to detect population level responses (Beckmann and Seidler 2009, Sawyer and Neilson 2010). The methods described in these studies can provide a framework for new research on the effects of cumulative residential development across the Rocky Mountain West. Because information is currently lacking on specific guidelines, managers should use **adaptive management** to test how new residential developments affect ungulate winter range.

4) Wildlife managers, ecologists and science providers or academics should be encouraged to engage in the land use planning process to ensure that pertinent research is integrated into regulations and policies. For example, wildlife biology students should be required to take classes in applied conservation biology that cover topics such as communication skills, stakeholder partnerships and local land use planning initiatives (Cleveland et al. 2009). Managers and academics should be encouraged to work with local communities, understand the desires of stakeholder groups and allow alternative management scenarios to be discussed (Lee and Miller 2003). Educating and including the people affected by management actions in the decision-making process will result in better implementation of plans on the ground.

Appendix A

Table A-1. Additional studies on the effects of human disturbance on ungulates, summarizing study authors, short title, species (Rtt-*Rangifer tarandus tarandus*, Rtc-*R. t. caribou*, Rtg-*R. t. granti*, Oa-*Oreamnos americanus* (mountain goat), Aa-*Alces alces*, Ov-*Odocoileus virginianus*, Ovc-*O. v. clavium* (Florida Key deer), Od-*O. hemionus*, Oc-*Ovis canadensis*, Ce-*Cervus elaphus*, Ua-*Ursus arctos*), whether the study was peer reviewed or not, study area location and size, development type, study design, study size, general results and conclusions and management recommendations.

Author: Short Title	*Spp*	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Andersen et al. 1996: Short term behavioural and physiological response of moose to military disturbance	*Aa*	Yes	Norway; 1,600 km^2	Human disturbance	Before/after, n=4 heart rate monitors and n=12 radio collared	Sources of disturbance which can be identified as human trigger flight responses at greater distances, and elevate heart rate for longer periods, than those recognized as mechanical.	Military activity of the type studied here is not especially detrimental to moose, and that the effects of their activity should not differ from comparable civilian harassment.
Berger 2007: Fear, human shields and the redistribution of prey and predators in protected areas	*Ao, Ua*	Yes	GYE; 500 km^2	Roads and human activities	Comparative, n=192 radio collared	Moose selected to be closer to human activity as grizzly bear predation increased. Grizzly bears avoided human activity, providing a human-caused refugia from predation.	Effects of human activities on wildlife can be counter-intuitive in the presence of human-caused refugia from predation. Considering indirect effects of trophic interactions to gauge development impacts key.
Bradsaw et al. 1997: effects of petroleum exploration on woodland caribou	*Rtt*	Yes	Northeastern AB; 20,000 km^2	Simulated Seismic explosions	Experimental, n=23	Exposed animals showed higher mean movement rate; no effect of distance from animal to canon vs. movement; exposed animals showed higher habitat patch change; exposure to sound reduced feeding time.	Total avoidance of winter petroleum exploration rather than shorter activity restrictions
Burcham et al. 1999: Elk use of private land refuges	*Ce*	Yes	Western Montana; na	na	Observational, n = 66 (1st period), 39 (second period)	Almost all of one herd used private land refuge during hunting and at least 75% of the other, use of private land is increasing, use is mainly during hunting season.	Try to implement special hunts on private lands, work with landowners to prevent overabundance.
Canfield et al. 1999: Effects of recreation on Rocky Mountain wildlife: ungulates	*ungu lotes*	No	the West	na	Review	Erratic behavior is more distressing than constant, snow is deciding factor for winter range, lower metabolic rates in winter. Bighorn are most vulnerable to humans, elevated heart rates = metabolic increase even without flight.	Managers should project winter range from recreation, more studies should be done on spring migration routes for regaining weight lost during the winter.
Christianson & Creel 2007: A review of environmental factors affecting elk winter diets	*Ce*	Yes	Western North America; na	na	Review	Elk prefer graminoids even when they are less abundant. Elk use open range less in hard winters, use more browse when hunted. Graminoids may not be the most nutritious but elk across North America prefer them.	Important to understand what elk will prefer especially when other environmental factors might affect winter range.
Colescott & Gillingham 1998: reaction of moose to snowmobiles	*Aa*	Yes	Wyoming; 0.04 km^2	Snowmobiles	Observational, observations from blinds	Snowmobile traffic did not appear to alter moose activity significantly though it did influence the behavior of moose within 300m of the trail and displaced moose to less favorable habitats.	Restrict the timing of snowmobile use to mid day when moose are resting.

Table A-1 Cont.

Author: Short Title	*Spp*	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Cote 1996: mountain goat responses to helicopter disturbance	*Oa*	Yes	Alberta; 21 km^2	helicopter (energy exploration)	Observational, n=14 radio collared n=98 marked	Goats showed overt responses to 58% of helicopter flights within 2 km. When helicopters flew within 500 m, 85% of flights caused the goats to move >100 m or to be alert for >10 min.	Recommended avoiding helicopter flights within 2 km of mountain goat habitat.
Dahle et al. 2008: reindeer avoidance of highways	*Rtt*	Yes	Norway; 8,200 km^2	highways and cabins	Observational, lichen sampling	Lichen height decreased 35% over an 8km distance from the highway and cabin indicating avoidance of highway.	Wild reindeer tolerance towards human infrastructure varies spatially and is influenced by herd traditions and/or motivation to follow established migration corridors.
DeCesare & Pletscher 2006: Movements, connectivity and resource selection of bighorn sheep	*Oc*	Yes	Western Montana, na	na	Observational, n = 21	Females had high fidelity to home range, but males moved more, including over highway/river, escape terrain is consistently important, but variation in habitat made other factors inconsistent (including roads).	Movement suggests more genetic and disease connectivity between populations than previously thought. Managers need to use local models.
DeNicola et al. 2000: Managing white-tailed deer in a suburban environment	*Ov*	No	na	na	Review	Management can occur at small group level because deer have high fidelity to matrilineal groups/ranges and wont colonize very quickly. New management strategies need to be community wide programs with a lot of information passed between parties.	There are a number of options for management in high density development areas, some lethal, some non-lethal. Need to make local plans to manage deer keep good relationships around the community.
Dyer et al. 2002: barrier effects of roads and seismic lines of woodland caribou	*Rtc*	Yes	Northern AB; 6000 km^2	roads and seismic lines	Observational, n=36	Roads were barriers to movement especially in late winter and seismic lines were not barriers. Functional habitat loss through avoidance.	Approach useful in quantifying animal movements.
Dyer et al. 2001: Avoidance of industrial development by woodland caribou	*Rtc*	Yes	Northern AB; 6000 km^2	roads, seismic lines, pipelines	Observational, n=36	Seismic lines were semi-permeable barriers to caribou movements, roads were barriers with high traffic. Caribou avoided human development by 250 – 1000 meters (seismic vs wells). 22% - 48% of study area impacted by roads.	Semi-permeable barrier effects may exacerbate functional habitat loss through avoidance behavior. Effects great year round.
Foster & Rahs 1985: canyon-dwelling mountain goats in relation to a proposed hydroelectric develop.	*Oa*	Yes	Northwest BC; n/a	Hydro-electric exploration activities	Observational, observed goats and n=56 marked with dye and neck collars	Mountain goats shifted their distribution 1 km - 3 km when subjected to drilling disturbances fully visible from escape terrain, but they returned when the disturbance was removed.	Recommended a 2km buffer to prevent an overt disturbance response to human activity
Garrett & Conway 1999: Characteristics of moose-vehicle collisions	*Aa*	Yes	Anchorage, Alaska	Vehicle collisions	Observational, data from moose collisions	Collision rate increased during the study period from 40 to 52 MVCs per 100,000 registered vehicles in Anchorage. Collisions were 2.6 times more likely to have occurred in the dark	Reduce speed limits around greenbelt areas, brighter vehicle headlights, placement of street lights in known moose areas, underpasses at known crossings, and snow removal to reduce berm height in areas of high moose concentrations.
Haggerty & Travis 2005: Out of administrative control: Absentee owners, resident elk	*Ce*	Yes	Paradise Valley, MT; 971.25 km^2	ranches	Survey, Modeling	Attitudes toward elk and hunting as a management tool have changed and resulted in an increasing elk population.	Elk are benefiting from a change of landownership from full time ranchers to part time nature enthusiasts. Hunting is no longer an effective strategy to manage the herd as a whole since they are spending so much time on private lands.

Table A-1 Cont.

Author: Short Title	*Spp*	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Harveson 2005: Impacts of urbanization on endangered Florida key deer	*Ovc*	No	Florida Keys, FL; 98.36 km2	urban	Observational	Key deer are more urbanized now than 30 years ago, positive relationship between spending time in urban areas and survival, deer now prefer urban areas, as urban use increases, flight response distance decreases.	Key deer have adapted to urban environment. There is probably a threshold of urbanization that key deer cannot withstand, roads should be protected to lower the mortality from cars.
Hebblewhite et al. 2006: Is the migratory behavior of montane elk herds in peril?	*Ce*	Yes	Alberta; 6000 km^2	na	Observational, n = 81 VHF, 20 GPS	Ratio of migratory to residential elk has declined. Change in migration is most likely due to winter range enhancements, habituation to hay feeding and wolf protection in Banff NP.	Managers should be alert to changes in migration since it's so important to ecosystem, need to work to provide better transboundary management schemes.
Hebblewhite et al. 2009: Trade-offs between predation risk and forage differ between migrant strategies	*Ce, Cl*	Yes	Banff National Park; 7000 km^2	ranches	Observational, n = 109 adult female elk	Migration reduced exposure to wolf predation risk by 70% compared to residents. Migrants had 6% higher digestible forage. Residents reduced predation at fine scales by using areas near humans.	Resident elk maximized forage by feeding on high quality forage near humans to reduce predation risk. Predator exclusion because of high human activity reduced predation rates by wolves by 60%. Human activity can disrupt predator-prey dynamics.
Henderson & O'Harren 1992: Winter ranges for elk and deer: un-controlled subdivisions?	*Ov, Oh, Ce*	No	Montana	na	Review	Winter range is quickly being developed to the detriment of MT's natural resources and wildlife.	Subdivision laws are not strict enough, too many exemptions. Conservation easements are a good way to protect habitat. Local government must get involved.
James & Stuart-Smith 2000: Distribution of caribou and wolves in relation to linear corridors	*Rtt*	Yes	Northeastern AB; 20,000 km^2	roads, trails, seismic lines, pipelines	Observational, n=98	Caribou mortalities attributed to wolf predation were closer to linear corridors.	Development of new corridors within caribou habitat should be minimized. Existing corridors should be made unsuitable as travel routes to reduce impacts.
James et al. 2004: spatial separation of caribou from moose and its relation to wolves	*Rtt*	Yes	Northeastern AB; 20,000 km^2	Oil and gas, seismic lines	Observational	Caribou avoided habitats selected by wolves and moose, but moose preferred habitats impacted by forestry.	Limit overlap of energy and forestry development with spatial refuge areas for caribou.
Johnson et al. 2005: Cumulative effects of human developments on arctic wildlife	*Rtg*	Yes	Northwest Territories; 190,000 km^2	Energy exploration, hunting, mines.	Observational, n=28	Mines had the largest negative effect on species. During post-calving caribou had a 37% reduction in the area of the highest quality habitats and an 84% increase in the area of the lowest quality habitats.	Regional cumulative effects analyses serve as the coarsest framework for understanding the impacts of human developments on wide-ranging animals.
Joslin 1986: mountain goat population changes in relation to energy exploration	*Oa*	No	Montana; 823 km^2	Energy exploration, Seismic lines	Observational, n=24 radio collared, n=8 neckbanded	Significant decline in numbers of adult females, kids, and productivity that coincided with a peak in seismic/exploration activities by energy industry.	Efforts should be made to reduce human activities in the Teton-Dupuyer segment in order to allow goat populations to recover.
Kunkel & Pletscher 2000: Habitat factors affecting vulnerability of moose to predation by wolves in BC	*Aa*	Yes	Southeastern BC; na	logging and wolf predation	Observational, n=29 radio collared	Moose density was greater and hiding-cover levels were lower at kill sites than at control sites. Forest harvest practices in this study area apparently did not increase the vulnerability of moose to wolf predation.	Moose are less likely to be killed by wolves at higher elevations, farther from trails, away from other moose, nearer to or within areas sheltered by large trees, and in areas with higher road density.

Table A-1 Cont.

Author: Short Title	Spp	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Lauber 2010: Community-based deer management	*Ov*	No	New York	na	Survey	3 barriers to deer management: inadequate stakeholder engagement, a decision-making process that was ineffective at promoting information exchange and dialogue, and lack of leadership.	Used 3 terms: power, legitimacy, and urgency to describe the situation in each town. When these 3 things work with stakeholders as well as good leadership, it is easier to come to conclusions.
Lee & Miller 2003: Managing elk in the wildland-urban interface	*Ce*	Yes	Flagstaff, AZ	na	Survey	People like seeing elk, concerned about vehicle collisions, not concerned about property damage. Very concerned about hunting b/c of human safety, increased oversight of urban hunt could allay fears.	People could be convinced of urban hunting with the right controls. Find out what the population wants for urban wildlife, make sure to address their concerns.
Mahoney et al. 2001: Caribou reactions to provocation by snowmachines	*Rtc*	Yes	Newfoundland; 1,805 km^2	snowmobiles	Observational, approached groups	Snowmobiles displaced caribou from resting activities and initiated avoidance reactions that interrupted feed bouts and increased locomotion rates. Displaced 60-237m from initial locations.	Variation in response by individuals and across years must be taken into account.
Nellemann et al. 2001: Winter distribution of wild reindeer in relation to power lines, roads and resorts	*Rtt*	Yes	Norway; 2900 km^2	Roads, railroads, power lines	Observational, n=2500	Density of reindeer was 79% lower within 2.5 km from power lines compared with background areas. Areas within 5km of development were avoided in all years.	Construction of roads, power lines and cabin resorts endanger the available winter ranges of reindeer in southern Norway.
Nellemann et al. 2003: Progressive impact of piecemeal infrastructure development on wild reindeer	*Rtt*	Yes	Norway; 1350 km^2	Hydroelectric development	Comparative, before, during, after development n=>2000	Reindeer densities within a 4km radius to infrastructure declined during winter and summer with a 217% increase in use of the few remaining sites located >4km from infrastructure.	Controlling piecemeal development in infrastructure is critical for the survival of the remaining European populations of wild mountain reindeer.
Nelson 1998: migratory behavior in northern white-tailed deer	*Ov*	Yes	Superior NF, MN; 2500 km^2	na	Observational	Fawns generally followed the migratory pattern of their mothers, but could and did change.	Migratory deer is a learned social pattern and not genetic.
Pedevillano & Wright 1987: The influence of visitors on mountain goat activities	*Oa*	Yes	Glacier NP, MT; na	human disturbance	Observational	Park visitors did not disturb goats enough to stop them from using licks but people on overpasses and traffic did scare goats away from crossing highways.	All crossings were eventually successful. Before underpass made goats ran back 44% of the time, after underpass only 24% of the time
Polfus et al. *in review*: Identifying indirect habitat loss and avoidance of human infrastructure by caribou	*Rtc*	*in review*	Atlin, northern BC; 11594 km^2	human development	Observational, n = 10	Caribou avoided 2 km around high use roads and 1 km for low use roads. In winter, caribou avoided town by 9 km compared to 3 km in summer. In winter avoidance of mines (250 m) and no avoidance of cabins. In summer caribou avoided mines by 2 km and cabins by 1.5 km.	Seasonal habitat models indicated that high quality habitat in the vicinity of human development was used by caribou less than expected. Conservation efforts should prioritize protecting areas of high quality habitat within human zone of influence.
Reimers et al. 2003: Behavior responses of wild reindeer to snowmobile or skier	*Rtt*	Yes	Norway; 5700 km^2	snowmobiles and skiers	Observational	Reindeer responded to snowmobile disturbance on average 164m further away than skiers. Mean flight distances were 281m from skiers and 264m from snowmobiles.	Restrict recreational use of snowmobiles.
Reimers et al. 2006: flight by reindeer in response to approach on foot or skis.	*Rtt*	Yes	Norway; 2,000 km^2	Human approach	Observational, approach reindeer groups	The farther away the person was when first sighted, the greater the distance of flight. This response was greatest in July and least in September-October during rut.	Humans stay 350m away from reindeer from March-July and 200m in September-October. Human approach did not appear to cause substantial energy costs to reindeer in this system.

Table A-1 Cont.

Author: Short Title	Spp	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Schneider & Wasel 2000: The effects of human settlement on moose density	*Aa*	Yes	Northern AB;3 76,224 km^2	Human settlement	Observational, aerial surveys	At the regional scale the density of moose was positively associated with the density of roads. The regions with the greatest moose densities also had the greatest intensity of licensed hunting.	↑ densities of moose were observed in association with a highly fragmented landscape with substantial agricultural, implying that moose requirements for cover may be quite flexible, at least in regions where snow fall is not extreme.
Seip et al. 2007: Displacement of mountain caribou From winter habitat by snowmobiles	*Rtc*	Yes	Southeastern BC, na	snowmobiles use	Observational, n=28 radio collared	Caribou were not found in areas of high snowmobile use over several years in mountain blocks. Habitat modeling indicated that significantly lower numbers of caribou were using snowmobile habitat than expected based on habitat quality.	Snowmobiling should be restricted from high-quality mountain caribou winter habitat, or at least limited to a small proportion of the total high-quality habitat for each herd.
Siemer et al. 2007: perspectives of residents in communities near Fire Island National Seashore	*Ov*	No	Fire Island National Seashore, NY	na	Survey	Residents closer to the park had more interest in deer issues. Mostly concerned with deer eating trash and disease.	Year-round residents and adjacent community members were more concerned about impacts from deer and more interested in providing input. Need to educate residents.
Singer 1978: Behavior of mountain goats in relation to U.S. highway	*Oa*	Yes	Glacier NP, MT; na	roads	Observational, n=117 days of observations	A total of 87 successful crossings (692 goats) and 31 unsuccessful attempts (101 goats) were observed in 197S.	Create an underpass so that goats can move to mineral lick without traffic.
Sorensen et al. 2008: Determining sustainable levels of cumulative effects for boreal caribou	*Rtt*	Yes	Alberta; 50,000 km^2	Oil and gas development, forestry	Comparative, n=6 caribou herds	Compared the cumulative amount of all industrial development and natural disturbance (fire) against caribou population growth rates (Lambda) in 6 different herds. Lambda well predicted by % industrial development.	S of 6 caribou herds declining in study because industrial development exceeded thresholds of a maximum of about 40-60% of the range impacted by industrial development. Recommend planning at the range level (~8,000km2) scale.
Stankowich 2008: Ungulate flight responses to human disturbance	*ungu lates*	Yes	na	na	Review	Large amounts of heterogeneity between species and populations, generally humans on foot were perceived as most dangerous, ungulates can habituate to human activity, open habitats result in more flight.	Humans influence ungulates and are important in their flight response. Interactions may not be additive but interactive and multiplicative. Specific information is need on populations to ensure flight response is addressed.
Stewart et al. 2002: Temporospatial distributions of elk, mule deer, and cattle	*Ce, Oh*	Yes	northeast OR, southeast WA; 14.S3 km^2	na	Observational, n = 14 cattle, 18 mule deer, 25 elk	Mule deer and elk selected for habitat but cattle did not, elk preferred mesic and logged forest, mule deer avoided xeric grassland, mesic forest. Mule deer and elk were more apt to use higher elevations and steeper slopes.	There is resource partitioning occurring between 3 species, competition as well. Acknowledge competition and get to know it better in site specific areas.
Thompson & Henderson 1998: Elk habituation as a credibility challenge for wildlife professionals	*Ce*	Yes	the West	na	Review	Hunting can stop habituation, risk of habituation is highest in winter, if human activity is constant (near development) it is feared less than sporadic (skiers and snowmobilers). Predation is limited near development; high population density causes dispersal toward development.	Keep elk populations down so dispersal doesn't occur, try to prevent habituation.
Varley 1998: Winter recreation and human disturbance on mountain goats	*Oa*	No	review	Human recreation and disturbance	Review	Conflict between goats and most recreation types are rare because of spatial segregation. Helicopters may pose a threat.	Helicopters should avoid areas within 2-2.Skm of areas where goats are known to winter to avoid disturbance.

Table A-1 Cont.

Author: Short Title	*Spp*	Peer Re-view	Study Area location and size	Development Type	Study Design	General Results	Conclusions & Management Recommendations
Vistnes & Nellemann 2001: avoidance of cabins, roads and power lines by reindeer	*Rtt*	Yes	Norway; 213 km^2	resorts, power lines and roads	Observational, n= 776 and 678 caribou in each season	Reindeer density was 78% lower within 4km of a tourist resort complex and 73% lower within 4km from high voltage power lines. Forage availability also decreased significantly with increasing distance from human impacts.	Reindeer avoid human disturbance even at low levels of human traffic. Cumulative effects increase fragmentation and may reduce body condition and calf survival.
Vistnes & Nellemann 2008: a review of reindeer and caribou response to human development	*Rtt*	Yes	review	human activity	Review	Rangifer tarandus will reduce use of areas within S km of infrastructure and human activity by S0-9S%.	Mitigation must regulate human impacts in caribou habitat.
Weclaw & Hudson 2004: simulation of conservation and management of woodland caribou	*Rtt*	Yes	Alberta; 20,000 km^2	roads, infrastructure	Modeling	The most detrimental factor is the loss of habitat due to avoidance of good habitat in proximity of industrial infrastructure.	Wolf control is not a practical solution. Development thresholds to maintain habitat required.
Yost & Wright 2001: Moose, caribou, and grizzly bear distribution in relation to road traffic	*Aa, Ua, Rtt*	Yes	Denali NP, AK; 130 km road	Roads	Observational, observed animals in backcountry and along roads	Moose sightings were lower than expected within 300 m of the road. more moose than expected occurred between 900 and 1200 m from the road.	The distribution of moose sightings suggests traffic avoidance, but the spatial pattern of preferred forage may have had more of an influence.

Notes: Abbreviations are NP, national park; NF, national forest.

Literature Cited

Alexander, B. G. 1968. Movements of deer in northeast Texas. Journal of Wildlife Management 32:618-620.

Altendorf, K. B., J. W. Laundre, C. A. L. Gonzalez, and J. S. Brown. 2001. Assessing effects of predation risk on foraging behavior of mule deer. Journal of Mammalogy 82:430-439.

American Society of Landscape Architects. 2009. The sustainable sites initiative: guidelines and performance benchmarks. Lady Bird Johnson Wildflower Center at the University of Texas at Austin. United States Botanic Garden. [Available online: http://www.sustainablesites.org/].

Amstrup, S. C. 1978. Activities and habitat use patterns of pronghorns on Montana-Wyoming coal lands. Proceedings of the Pronghorn Antelope Workshop 8:270-304.

Andersen, R., J. D. C. Linnell, and R. Langvatn. 1996. Short term behavioural and physiological response of moose Alces alces to military disturbance in Norway. Biological Conservation 77:169-176.

Anderson, D. P., J. D. Forester, M. G. Turner, J. L. Frair, E. H. Merrill, D. Fortin, J. S. Mao, and M. S. Boyce. 2005. Factors influencing female home range sizes in elk (Cervus elaphus) in North American landscapes. Landscape Ecology 20:257-271.

Anderson, R. B., S. J. Dyer, S. R. Francis, and E. M. Anderson. 2002. Development of a Threshold Approach for Assessing Industrial Impacts on Woodland Caribou in Yukon. Report prepared for Environment Directorate, Northern Affairs Program. Whitehourse, Yukon.

Apel, M. B. 2011. Conservation subdivisions - an alternative to western ranchettes. Western Planner January/February:10-13.

Arendt, R. 1997. Basing cluster techniques on development densities appropriate to the area. Journal of the American Planning Association 63:137-145.

Arendt, R. G. 1996. Conservation design for subdivisions: a practical guide to creating open space networks. Island Press, Washington, DC.

Armentrout, D. J., and R. J. Boyd. 1994. Consequences of habitat fragmentation on wild sheep metapopulation management within USA. Pages 149-158 *in* Proceedings of Biennial Symposium Northern Wild Sheep and Goat Council. 9. Cranbrook, BC.

Armleder, H. M., M. J. Waterhouse, D. G. Keisker, and R. J. Dawson. 1994. Winter habitat use by mule deer in the central interior of British Columbia. Canadian Journal of Zoology 72:1721-1725.

Autenrieth, R. E., D. E. Brown, J. Cancino, R. M. Lee, R. A. Ockenfels, B. W. O'Gara, T. M. Pojar, and J. D. Yoakum, editors. 2006. Pronghorn Management Guides: Fourth Edition. Pronghorn Workshop and North Dakota Game and Fish Department, Bismarck, North Dakota. 158 pp.

Ayotte, J. B., K. L. Parker, J. M. Arocena, and M. P. Gillingham. 2006. Chemical composition of lick soils: Functions of soil ingestion by four ungulate species. Journal of Mammalogy 87:878-888.

Baker, R. O., and R. M. Timm. 1998. Management of conflicts between urban coyotes and humans in southern California. Pages 299-312 *in* Proceedings of The Vertebrate Pest Conference. 18. University of California, Davis, CA.

Ballard, W. B., H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-579.

Ballard, W. B., D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. Devos. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

Baty, G. R. 1995. Resource partitioning and browse use by sympatric elk, mule deer and white-tailed deer on a winter range in western Montana. MS Thesis. University of Montana, Missoula, MT. 252 pp.

Beckmann, J., K. M. Berger, J. K. Young, and J. Berger. 2008. Wildlife and energy development: pronghorn of the Upper Green River Basin – year 3 summary. Wildlife Conservation Society, Bronx, NY.

Beckmann, J., and R. G. Seidler. 2009. Wildlife and energy development: pronghorn of the Upper Green River Basin – year 4 summary. Wildlife Conservation Society, Bronx, New York, USA.

Beecham, J. J. J., C. P. Collins, and T. D. Reynolds. 2007. Rocky Mountain Bighorn Sheep (Ovis canadensis): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf [accessed 25 March 2011].

Beier, P., D. Majka, S. Newell, and E. Garding. 2008. Best management practices for wildlife corridors. Northern Arizona University. 14 pp.

Ben-Ami, D., and D. Ramp. 2005. Modeling the effect of roads and other disturbances on wildlife populations in the peri-urban environment to facilitate long-term viability. *in* UC Davis: Road Ecology Center. Retrieved from: http://escholarship.org/uc/item/8hh225z3

Berger, J., D. Daneke, J. Johnson, and S. H. Berwick. 1983. Pronghorn foraging economy and predator avoidance in a desert ecosystem: Implications for the conservation of large mammalian herbivores. Biological Conservation 25:193-208.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91-98.

Berger, J. 2004. The last mile: How to sustain long-distance migration in mammals. Conservation Biology 18:320-331.

Berger, J., K. M. Berger, and J. Beckmann. 2006. Wildlife and energy development: pronghorn of the Upper Green River Basin – year 1 summary. Wildlife Conservation Society, Bronx, NY.

Berger, J. 2007. Fear, human shields and the redistribution of prey and predators in protected areas. Biology Letters 3:620-623.

Berger, K. M., J. Beckmann, and J. Berger. 2007. Wildlife and energy development: pronghorn of the Upper Green River Basin – year 2 summary. Wildlife Conservation Society, Bronx, NY.

Berger, K. M., and M. M. Conner. 2008. Recolonizing wolves and mesopredator suppression of coyotes: impacts on pronghorn population dynamics. Ecological Applications 18:599-612.

Berger, K. M., E. M. Gese, and J. Berger. 2008. Indirect effects and traditional trophic cascades: A test involving wolves, coyotes, and pronghorn. Ecology 89:818-828.

Beringer, J., L. P. Hansen, J. A. Demand, J. Sartwell, M. Wallendorf, and R. Mange. 2002. Efficacy of translocation to control urban deer in Missouri: costs, efficiency, and outcome. Wildlife Society Bulletin 30:767-774.

Blair, R. B., and E. M. Johnson. 2008. Suburban habitats and their role for birds in the urban-rural habitat network: points of local invasion and extinction? Landscape Ecology 23:1157-1169.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, R. L. Vernoy, and R. W. Anthes. 1990. Responses of mountain sheep to helicopter surveys. California Fish and Game 76:197-204.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, M. C. Nicholson, and R. W. Anthes. 1994. Mountain sheep ovis canadensis and helicopter surveys: ramifications for the conservation of large mammals Biological Conservation 70:1-7.

Boarman, W. I. 2003. Managing a subsidized predator population: Reducing common raven predation on desert tortoises. Environmental Management 32:205-217.

Boarman, W. I., M. A. Patten, R. J. Camp, and S. J. Collis. 2006. Ecology of a population of subsidized predators: Common ravens in the central Mojave Desert, California. Journal of Arid Environments 67:248-261.

Boccadori, S. J. 2002. Effects of winter range on a pronghorn population in Yellowstone National Park. MS Thesis. Montana State University, Bozeman, MT. 79 pp.

Bradshaw, C. J. A., S. Boutin, and D. M. Hebert. 1997. Effects of petroleum exploration on woodland caribou in northeastern Alberta. Journal of Wildlife Management 61:1127-1133.

Bradshaw, C. J. A., S. Boutin, and D. M. Hebert. 1998. Energetic implications of disturbance caused by petroleum exploration to woodland caribou. Canadian Journal of Zoology 76:1319-1324.

British Columbia Ministry of Environment. 2000. Thinhorn Sheep in British Columbia: Ecology, Conservation and Management. Province of British Columbia.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16:909-923.

Brown, C. G. 1992. Movement and migration patters of mule deer in southeastern Idaho. Journal of Wildlife Management 56:246-253.

Brown, D. G., K. M. Johnson, T. R. Loveland, and D. M. Theobald. 2005. Rural land-use trends in the conterminous United States, 1950-2000. Ecological Applications 15:1851-1863.

Bruns, E. H. 1969. A preliminary study of behavioral adaptations of wintering pronghorn antelope. MS Thesis. University Calgary, Calgary, Alberta, Canada.

Bruns, E. H. 1977. Winter behvaior of pronghorns in relation to habitat. Journal of Wildlife Management 41:560-571.

Bunch, T. D., W. M. Boyce, C. P. Hibler, W. R. Lance, T. R. Spraker, and E. S. Williams. 1999. Diseases of North American wild sheep. *in* R. Valdez, andP. R. Krausman, editors. Mountain Sheep of North America. University of Arizona Press, Tucson, AZ.

Burcham, M., W. D. Edge, and C. L. Marcum. 1999. Elk use of private land refuges. Wildlife Society Bulletin 27:833-839.

Burton, D. L., and K. A. Doblar. 2004. Morbidity and mortality of urban wildlife in the Midwestern United States. W. W. Shaw, L. K. Harris, andL. VanDruff, editors. Pages 171-181 *in* Proceedings of Fourth international symposium on urban wildlife conservation. Tucson, Arizona, USA.

Canfield, J. E., L. J. Lyon, J. M. Hillis, and M. J. Thompson. 1999. Ungulates. Pages 6.1-6.25 *in* G. Joslin, andH. Youmans, editors. Effects of recreation on Rocky Mountain wildlife: A Review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society. 307pp.

Caro, T. M., L. Lombardo, A. W. Goldizen, and M. Kelly. 1995. Tail-flagging and other antipredator signals in white-tailed deer: New data and synthesis. Behavioral Ecology 6:442-450.

Carpenter, L. H., O. C. Wallmo, and R. B. Gill. 1979. Forage diversity and dietary selection by wintering mule deer. Journal of Range Management 32:226-229.

Carter, T. 2009. Developing conservation subdivisions: Ecological constraints, regulatory barriers, and market incentives. Landscape and Urban Planning 92:117-124.

Cassirer, E. F., D. J. Freddy, and E. D. Ables. 1992. Elk responses to disturbance by cross-country skiers in Yellowstone National Park. Wildlife Society Bulletin 20:375-381.

Ceballos, G., and P. R. Ehrlich. 2002. Mammal population losses and the extinction crisis. Science 296:904-907.

Chambers, N., S. Johnson, M. McKinney, and G. Tabor. 2010. Remarkable beyond borders: People and Landscapes in the Crown of the Continent. Center for Natural Resources and Environmental Policy: The University of Montana, Sonoran Institute, and the Lincoln Institute of Land Policy.

Christensen, A. G., L. J. Lyon, and J. W. Unsworth. 1993. Elk management in the Northern Region: considerations in forest plan updates or revisions. U S Forest Service General Technical Report INT 303:1-10.

Christianson, D. A., and S. Creel. 2007. A review of environmental factors affecting elk winter diets. Journal of Wildlife Management 71:164-176.

Cleveland, S., J. Merkle, R. Stutzman, G. Neudecker, J. Stone, and D. Naugle. 2009. Lessons from the field: a hands-on crash course in landscape conservation. The Wildlife Professional, Winter 2009.

Cleveland, S. M. 2010. Human predation risk and elk behavior in heterogeneous landscapes. Thesis. University of Montana, Missoula, Montana, USA.

Cole, E. K., M. D. Pope, and R. G. Anthony. 1997. Effects of road management on movement and survival of Roosevelt elk. Journal of Wildlife Management 61:1115-1126.

Cole, E. K., M. D. Pope, and R. G. Anthony. 2004. Influence of road management on diurnal habitat use of Roosevelt elk. Northwest Science 78:313-321.
Coleman, J. S., and S. A. Temple. 1996. On the prowl. Wisconsin Natural Resources 20:4-8.
Colescott, J. H., and M. P. Gillingham. 1998. Reaction of moose (Alces alces) to snowmobile traffic in the Greys River Valley, Wyoming. Alces 34:329-338.
Colman, J. E., B. W. Jacobsen, and E. Reimers. 2001. Summer response distances of Svalbard reindeer Rangifer tarandus platyrhynchus to provocation by humans on foot. Wildlife Biology 7:275-283.
Compas, E. 2007. Measuring exurban change in the American West: a case study in Gallatin County, Montana, 1973-2004. Landscape and Urban Planning 82:56-65.
Conover, M. R. 1998. Perceptions of American agricultural producers about wildlife on their farms and ranches. Wildlife Society Bulletin 26:597-604.
Cook, R. C., D. L. Murray, J. G. Cook, P. Zager, and S. L. Monfort. 2001. Nutritional influences on breeding dynamics in elk. Canadian Journal of Zoology 79:845-853.
Cook, R. C., J. G. Cook, and L. D. Mech. 2004. Nutritional condition of northern Yellowstone elk. Journal of Mammalogy 85:714-722.
Cornicelli, L., A. Woolf, and J. L. Roseberry. 1993. Residential attitudes and perceptions toward a suburban deer population in southern Illinois. Transactions of the illinois State Academy of Science 86:23-32.
Cornicelli, L., A. Woolf, and J. L. Roseberry. 1996. White-tailed deer use of a suburban environment in southern Illinois. Transactions of the illinois State Academy of Science 89:93-103.
Cote, S. D. 2005. Extirpation of a large black bear population by introduced white-tailed deer. Conservation Biology 19:1668-1671.
Cowan, I. M. 1940. Distribution and variation in the native sheep of North America. American Midland Naturalist 24:505-580.
Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. Conservation Biology 16:809-814.
Creel, S., and M. Creel. 2009. Density dependence and climate effects in Rocky Mountain elk: an application of regression with instrumental variables for population time series with sampling error. Journal of Animal Ecology 78:1291-1297.
Creel, S., J. A. Winnie, and D. Christianson. 2009. Glucocorticoid stress hormones and the effect of predation risk on elk reproduction. Proceedings of the National Academy of Sciences of the United States of America 106:12388-12393.
Crooks, K. R., and M. E. Soule. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563-566.
Cross, P. C., E. K. Cole, A. P. Dobson, W. H. Edwards, K. L. Hamlin, G. Luikart, A. D. Middleton, B. M. Scurlock, and P. J. White. 2010. Probable causes of increasing brucellosis in free-ranging elk of the Greater Yellowstone Ecosystem. Ecological Applications 20:278-288.
Czech, B. 1995. American Indians and wildlife conservation. Wildlife Society Bulletin 23:568-573.
Czech, B. 2000. Economic growth as the limiting factor for wildlife conservation. Wildlife Society Bulletin 28:4-15.
D'Antonio, C., and L. A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: A synthesis. Restoration Ecology 10:703-713.
D'Eon, R. G., and R. Serrouya. 2005. Mule deer seasonal movements and multiscale resource selection using global positioning system radiotelemetry. Journal of Mammalogy 86:736-744.
Dahle, B., E. Reimers, and J. E. Colman. 2008. Reindeer (Rangifer tarandus) avoidance of a highway as revealed by lichen measurements. European Journal of Wildlife Research 54:27-35.
Dale, V., S. Archer, M. Chang, and D. Ojima. 2005. Ecological impacts and mitigation strategies for rural land management. Ecological Applications 15:1879-1892.
Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. Ecological Applications 10:639-670.

Dalle-Molle, J., and Van Horn. 1991. Observations of vehicle traffic interfering with migration of Dall's Sheep, Ovis dalli dalli, in Denali National Park, Alaska. Canadian Field-Naturalist 105:409-411.
DeCesare, N. J., and D. H. Pletscher. 2006. Movements, connectivity, and resource selection of Rocky Mountain bighorn sheep. Journal of Mammalogy 87:531-538.
DeCesare, N. J., M. Hebblewhite, H. S. Robinson, and M. Musiani. 2010. Endangered, apparently: the role of apparent competition in endangered species conservation. Animal Conservation 13:353-362.
Decker, D. J., and T. A. Gavin. 1987. Public attitudes toward a suburban deer herd. Wildlife Society Bulletin 15:173-180.
Dekker, D. 2009. Declines of bighorn sheep, Ovis canadensis, on deteriorating winter range in Jasper National Park, Alberta, 1981-2010. Canadian Field-Naturalist 123:157-164.
Delibes, M., P. Gaona, and P. Ferreras. 2001. Effects of an attractive sink leading into maladaptive habitat selection. American Naturalist 158:277-285.
Demarchi, R. A., C. L. Hartwig, and D. A. Demarchi. 2000. Status of the Rocky Mountain bighorn sheep in British Columbia. BC Minist. Environ., Lands and Parks, Wildl. Branch, Victoria, BC. Wildlife Bulletin No. B-99.
Demarchi, R. A., and C. L. Hartwig. 2004. Status of Thinhorn Sheep in British Columbia. Wildlife Bulletin. B.C. Ministry of Water, Land and Air Protection No. B-119.
DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments: a technical guide. Cornell Cooperative Extension, Ithaca, New York, USA.
DeVault, T. L., J. C. Beasley, L. A. Humberg, B. J. MacGowan, M. I. Retamosa, and O. E. Rhodes Jr. 2007. Intrafield patterns of wildlife damage to corn and soybeans in northern Indiana. Human-Wildlife Conflicts 1:205-213.
Dicus, G. H. 2002. An evaluation of GIS-based habitat models for bighorn sheep winter range in Glacier National Park, Montana, USA. MS Thesis. University of Montana, Missoula, MT. 89 pp.
Diringer, E. 1994. Remaking the West: The Cody saga. The San Francisco Chronicle December 15: A1–3.
Donovan, T. M., and F. R. Thompson. 2001. Modeling the ecological trap hypothesis: A habitat and demographic analysis for migrant songbirds. Ecological Applications 11:871-882.
Duerksen, C. J., N. T. Hobbs, D. L. Elliot, E. Johnson, and J. R. Miller. 1996. Managing development for people and wildlife: A handbook for habitat protection by local governments The Great Outdoors Colorado Trust Fund, Clarion Associates, Colorado Division of Wildlife. [Available online: http://ndis.nrel.colostate.edu/handbook/handbook.html], Denver Colorado. 122 pp.
Dunn, S. J., and J. A. Byers. 2008. Determinants of survival and fecundity through a population bottleneck in pronghorn (Antilocapra americana). Journal of Mammalogy 89:1124-1129.
Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65:531-542.
Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80:839-845.
Easterly, T. E., A. W. Wood, and T. Litchfield. 1991. Responses of pronghorn and mule deer to petroleum development on crucial winter range in the Rattlesnake Hills. Wyoming Game and Fish Department. Cheyenne, WY.
Edge, W. D., and C. Les Marcum. 1991. Topography ameliorates the effects of roads and human disturbance on elk. A. G. Christensen, L. J. Lyon, andT. N. Lonner, editors. Pages 94-98 *in* Proceedings of Elk vulnerability symposium. Montana State University, Bozeman, MT.
Ehrlich, P. R., and E. O. Wilson. 1991. Biodiversity studies - science and policy. Science 253:758-762.
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Environmental Law Institute, Washington D.C., USA.

Epps, C. W., P. J. Palsboll, J. D. Wehausen, G. K. Roderick, R. R. Ramey, and D. R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8:1029-1038.

Estes Valley Planning Commission. 2010. Estes Valley development code: wildlife and habitat protection. [Available online: http://www.estesnet.com/comdev/Wildlife%20HabitatProtection.aspx].

Etchberger, R. C., P. R. Krausman, and R. Mazaika. 1989. Mountain sheep habitat characteristics in the Pusch Ridge Wilderness, Arizona. Journal of Wildlife Management 53:902-907.

Etter, D. R., K. M. Hollis, T. R. Van Deelen, D. R. Ludwig, J. E. Chelsvig, C. L. Anchor, and R. E. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Ewing, R., R. A. Schieber, and C. V. Zegeer. 2003a. Urban sprawl as a risk factor in motor vehicle occupant and pedestrian fatalities. American Journal of Public Health 93:1541-1545.

Ewing, R., T. Schmid, R. Killingsworth, A. Zlot, and S. Raudenbush. 2003b. Relationship between urban sprawl and physical activity, obesity, and morbidity. American Journal of Health Promotion 18:47-57.

Ewing, R., J. Kostyack, D. Chen, B. Stein, and M. Ernst. 2005. Endangered by sprawl: How runaway development threatens America's wildlife. National Wildlife Federation, Smart Growth America, and NatureServe. Washington, D.C., USA.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61:603-610.

Fancy, S. G., and R. G. White. 1987. Energy expenditures for locomotion by barren-ground caribou. Canadian Journal of Zoology 65:122-128.

Farnsworth, M. L., L. L. Wolfe, N. T. Hobbs, K. P. Burnham, E. S. Williams, D. M. Theobald, M. M. Conner, and M. W. Miller. 2005. Human land use influences chronic wasting disease prevalence in mule deer. Ecological Applications 15:119-126.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity, and predator avoidance. Oecologia 75:580–586.

Festa-Bianchet, M. 1989. Survival of male bighorn sheep in southwestern Alberta. Journal of Wildlife Management 53:259-263.

Florkiewicz, R., R. Maraj, T. Hegel, and M. Waterreus. 2006. The effects of human land use on the winter habitat of the recovering Carcross woodland caribou herd in suburban Yukon Territory, Canada. *in* Proceedings of The Eleventh North American Caribou Workshop. Jasper, Alberta, Canada.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. Science 309:570-574.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Foster, B. R., and E. Y. Rahs. 1985. A Study of Canyon-Dwelling Mountain Goats in Relation to Proposed Hydroelectric Development in Northwestern British-Columbia, Canada. Biological Conservation 33:209-228.

Fox, L. B., A. A. Arsenault, C. E. Brewer, L. H. Carpenter, B. Jellison, J. A. Jenks, W. F. Jensen, T. W. Keegan, D. J. Kraft, D. W. Lutz, C. L. Richardson, B. D. Trindle, A. P. Schmidt, and T. S. Stivers. 2009. Habitat guidelines for mule deer: Great plains ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

Frair, J. L., E. H. Merrill, H. L. Beyer, and J. M. Morales. 2008. Thresholds in landscape connectivity and mortality risks in response to growing road networks. Journal of Applied Ecology 45:1504-1513.

Fraterrigo, J. M., and J. A. Wiens. 2005. Bird communities of the Colorado Rocky Mountains along a gradient of exurban development. Landscape and Urban Planning 71:263-275.

Freddy, D. J., W. M. Bronaugh, and M. C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63-68.

Frid, A., and L. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6:11.

Friesen, L. E., P. F. J. Eagles, and R. J. MacKay. 1995. Effects of residential development on forest dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.

Fulton, W., R. Pendall, M. Nguyen, and A. Harrison. 2001. Who Sprawls the Most? How Growth Patterns Differ Across the U.S. Washington, DC: The Brookings Institution.

Gallagher, M., R. Anderson, and C. Lambert. 2004. Carcross woodland caribou herd winter range cumulative effects assessment. YTG Department of Community Services Community Development Branch and YTG Department of Environment Fish and Wildlife Branch. Whitehorse, Yukon.

Garrett, L. C., and G. A. Conway. 1999. Characteristics of moose-vehicle collisions in Anchorage, Alaska, 1991-1995. Journal of Safety Research 30:219-223.

Garroway, C. J., and H. G. Broders. 2007. Adjustment of reproductive investment and offspring sex ratio in white-tailed deer (Odocoileus virginianus) in relation to winter severity. Journal of Mammalogy 88:1305-1311.

Gates, J. E., and L. W. Gysel. 1978. Avian nest dispersion and fledging success in field-forest ecotones Ecology 59:871-883.

Gavin, S. D., and P. E. Komers. 2006. Do pronghorn (Antilocapra americana) perceive roads as a predation risk? Canadian Journal of Zoology 84:1775-1780.

Geist, V. 1971. Mountain Sheep: A study in behavior and evolution. The University of Chicago Press, Chicago and London.

Geist, V. 1998. Deer of the world: their evolution, behaviour, and ecology. Stackpole Books, Mechanicsburg, PA.

George, J. L., R. Kahn, M. W. Miller, and B. Watkins, editors. 2009. Colorado bighorn sheep management plan 2009–2019. Colorado Division of Wildlife, Special Report No. 81.

Getz, W. M., and C. C. Wihners. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: Nonparameteric Kernel Methods for Constructing Home Ranges and Utilization Distributions. Plos One 2.

Gill, J. A., K. Norris, and W. J. Sutherland. 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97:265-268.

Gill, R. B. 1999. Declining mule deer populations in Colorado: reasons and responses. A report to the Colorado legislature. Colorado Division of Wildlife. Denver, CO.

Glennon, M., and H. E. Kretser. 2005. Impacts to wildlife from low density, exurban development: information and considerations for the Adirondack Park. Wildlife Conservation Society Adirondack Communities and Conservation Program. Technical paper No. 3. Saranac Lake, New York, USA.

Gompper, M. E., and A. T. Vanak. 2008. Subsidized predators, landscapes of fear and disarticulated carnivore communities. Animal Conservation 11:13-14.

Gosnell, H., J. H. Haggerty, and W. R. Travis. 2006. Ranchland Ownership Change in the Greater Yellowstone Ecosystem: Implications for Conservation. Society and Natural Resources 19:743-758.

Grandin, T. 2007. Behavioural principles of handling cattle and other grazing animals under extensive conditions. Pages 44-64 *in* T. Grandin, editor. Livestock handling and transport. CABI International, Cambridge, MA.

Greene, L. 2010. Short-term effects of wildfire on Sierra Nevada bighorn sheep habitat ecology. MS Thesis. University of Montana, Missoula, MT. 96 pp.

Grinder, M. I., and P. R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management 65:887-898.

Grovenburg, T. W., J. A. Jenks, R. W. Klaver, C. C. Swanson, C. N. Jacques, and D. Todey. 2009. Seasonal movements and home ranges of white-tailed deer in north-central South Dakota. Canadian Journal of Zoology-Revue Canadienne De Zoologie 87:876-885.

Grund, M. D., J. B. McAninch, and E. P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. Journal of Wildlife Management 66:123-130.

Gude, P., R. Rasker, and J. van den Noort. 2008. Potential for future development on fire-prone lands. Journal of Forestry 106:198-205.

Gude, P. H., A. J. Hansen, R. Rasker, and B. Maxwell. 2006. Rates and drivers of rural residential development in the Greater Yellowstone. Landscape and Urban Planning 77:131-151.

Gude, P. H., A. J. Hansen, and D. A. Jones. 2007. Biodiversity consequences of alternative future land use scenarios in Greater Yellowstone. Ecological Applications 17:1004-1018.

Gunn, A., C. J. Johnson, J. S. Nishi, C. J. Daniel, D. E. Russell, M. Carlson, and J. Z. Adamczewski. 2011. Understanding the cumulative effects of human activities on barren-ground caribou. Pages 113-134 *in* P. R. Krausman, andL. K. Harris, editors. Cumulative effects in wildlife management: impact mitigation. CRC Press, Boca Raton, Florida, USA.

Gunther, K. A., M. J. Biel, and H. L. Robison. 1998. Factors influencing the frequency of road-killed wildlife in Yellowstone National Park. Pages 32-42 *in* Proceedings of International Conference on Wildlife Ecology and Transportation. Fort Myers, FL.

Habib, T. J. 2010. Ecology and Management of White-tailed Deer (Odocoileus virginianus) and Mule Deer (O. hemionus) of East-Central Alberta in Relation to Chronic Wasting Disease. MS Thesis. University of Alberta, Edmonton, AB. 126 pp.

Haggerty, J. H., and W. R. Travis. 2006. Out of administrative control: Absentee owners, resident elk and the shifting nature of wildlife management in southwestern Montana. Geoforum 37:816-830.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173-182.

Hansen, A. J., and J. J. Rotella. 2002. Biophysical factors, land use, and species viability in and around nature reserves. Conservation Biology 16:1112-1122.

Hansen, A. J., R. L. Knight, J. M. Marzluff, S. Powell, K. Brown, P. H. Gude, and A. Jones. 2005. Effects of exurban development on biodiversity: Patterns, mechanisms, and research needs. Ecological Applications 15:1893-1905.

Harden, C. D., A. Woolf, and J. Roseberry. 2005. Influence of exurban development on hunting opportunity, hunter distribution, and harvest efficiency of white-tailed deer. Wildlife Society Bulletin 33:233-242.

Harestad, A. S. 1985. Habitat use by black-tailed deer on northern Vancouver Island Journal of Wildlife Management 49:946-950.

Harrington, F. H. 2003. Caribou, military jets and noise: The interplay of behavioural ecology and evolutionary psychology. Rangifer Special Issue 14:73-80.

Harveson, P. M. 2005. The impacts of urbanization on endangered Florida key deer. PhD Dissertation. Texas A&M University, College Station, TX. 117 pp

Hawbaker, T. J., V. C. Radeloff, M. K. Clayton, R. B. Hammer, and C. E. Gonzalez-Abraham. 2006. Road development, housing growth, and landscape fragmentation in northern Wisconsin: 1937-1999. Ecological Applications 16:1222-1237.

Hayden, B. 1975. Some effects of rural subdivisions on wildlife and wildlife habitat around Lolo, Montana. MS Thesis. University of Montana, Missoula, MT. 121 pp.

Hayden, J., G. Ardt, M. Fleming, T. W. Keegan, J. Peek, T. O. Smith, and A. Wood. 2008. Habitat guidelines for mule deer: Northern forest ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

Hayes, C. L., E. S. Rubin, M. C. Jorgensen, R. A. Botta, and W. M. Boyce. 2000. Mountain lion predation of bighorn sheep in the Peninsular Ranges, California. Journal of Wildlife Management 64:954-959.

Hebblewhite, M., C. A. White, C. G. Nietvelt, J. A. McKenzie, T. E. Hurd, J. M. Fryxell, S. E. Bayley, and P. C. Paquet. 2005. Human activity mediates a trophic cascade caused by wolves. Ecology 86:2135-2144.

Hebblewhite, M., E. H. Merrill, L. E. Morgantini, C. A. White, J. R. Allen, E. Bruns, L. Thurston, and T. E. Hurd. 2006. Is the migratory behavior of montane elk herds in peril? The case of Alberta's Ya Ha Tinda elk herd. Wildlife Society Bulletin 34:1280-1294.

Hebblewhite, M. 2008. A literature review of the effects of energy development on ungulates: Implications for central and eastern Montana. Montana Fish, Wildlife and Parks. Miles City, MT.

Hebblewhite, M., and E. H. Merrill. 2009. Trade-offs between predation risk and forage differ between migrant strategies in a migratory ungulate. Ecology 90:3445-3454.

Hebblewhite, M. 2011. Effects of energy development on ungulates. *in* E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA.

Henderson, R. E., and A. O'Herren. 1992. Winter ranges for elk and deer: victims of uncontrolled subdivisions? Western Wildlands 18:20-25.

Hengel, D. A., S. H. Anderson, and W. G. Hepworth. 1992. Population dynamics, seasonal distribution and movement patterns of the Laramie Peak bighorn sheep herd. J. Emmerich, andW. G. Hepworth, editors. Pages 83-96 *in* Proceedings of Northern Wild Sheep and Goat Council. 8. Cody, Wyoming.

Hickman, G. 2007. Helena urban deer inventory 2006-2007. Findings and Recommendations of the Helena Urban Wildlife Task Force. Helena, MT.

Hillis, J. M., M. J. Thompson, J. E. Canfield, L. J. Lyon, C. L. Marcum, P. M. Dolan, and D. W. McCleery. 1991. Defining elk security: the Hillis paradigm. A. G. Christensen, L. J. Lyon, andT. N. Lonner, editors. Pages 38-43 *in* Proceedings of Elk vulnerability symposium. Montana State University, Bozeman, MT.

Hirth, D. H., and D. R. McCullough. 1977. Evolution of alarm signals in ungulates with special reference to white-tailed deer. The American Naturalist 111:31-42.

Hobbs, N. T., D. L. Baker, J. E. Ellis, and D. M. Swift. 1981. Composition and quality of elk winter diets in Colorado. Journal of Wildlife Management 45:156-171.

Hobbs, N. T., D. L. Baker, J. E. Ellis, D. M. Swift, and R. A. Green. 1982. Energy-based and nitrogen-based estimates of elk winter-range carrying-capacity. Journal of Wildlife Management 46:12-21.

Hoekman, S. T., G. L. Dusek, and A. K. Wood. 2006. Spatial relationships and resource selection. *in* White-tailed deer studies in the Salish Mountains, northwest Montana. Federal Aid in Wildlife Restoration Project W-120-R. Montana Fish, Wildlife & Parks, Wildlife Division, Helena, Montana, USA.

Holl, S. A., V. A. Bleich, and S. G. Torres. 2004. Population dynamics of bighorn sheep in the San Gabriel Mountains, California, 1967-2002. Wildlife Society Bulletin 32:412-426.

Hook, D. L. 1986. Impacts of seismic activity on bighorn movements and habitat use. *in* Proceedings of the Fifth Biennial Symposium of Northern Wild Sheep and Goat Council Missoula, MT.

Horesji, B. 1976. Some thoughts and observations on harassment and bighorn sheep. T. Thorne, editor. Pages 149-155 *in* Proceedings of the Biennial Symposium of North American Bighorn Sheep Council. Jackson, WY.

Hoskinson, R. L., and J. R. Tester. 1980. Migration behavior of pronghorn in southeastern Idaho. Journal of Wildlife Management 44:132-144.

Hostetler, M., and D. Drake. 2009. Conservation subdivisions: A wildlife perspective. Landscape and Urban Planning 90:95-101.

Hubbard, R. D., and C. K. Nielsen. 2009. White-tailed deer attacking humans during the fawning season: a unique human-wildlife conflict on a university campus. Human-Wildlife Conflicts 3:129-135.

Hudenko, H. W., W. F. Siemer, and D. J. Decker. 2008. Humans and coyotes in suburbia: can experience lead to sustainable coexistence? Human Dimensions Research Unit, Cornell University. Series No. 08-9. Ithaca, New York, USA.

Hughes, J., S. D. Albon, R. J. Irvine, and S. Woodin. 2009. Is there a cost of parasites to caribou? Parasitology 136:253-265.

Hurley, M. A., and G. A. Sargent. 1991. Effects of hunting and land management on elk habitat use, movement patterns and mortality in western Montana. A. G. Christensen, L. J. Lyon, andT. N. Lonner, editors. Pages 94-98 *in* Proceedings of Elk vulnerability symposium. Montana State University, Bozeman, MT.

Hurst, J. E., and W. F. Porter. 2008. Evaluation of shifts in white-tailed deer winter yards in the Adirondack region of New York. Journal of Wildlife Management 72:367-375.

Huston, M. A. 2005. The three phases of land-use change: Implications for biodiversity. Ecological Applications 15:1864-1878.

Hutchins, M., and V. Geist. 1987. Behavioral considerations in the management of mountain-dwelling ungnlates. Mountain Research and Development 7:135-144.

Hygnstrom, S. E., and K. C. VerCauteren. 2000. Home ranges and habitat selection of white-tailed deer in a suburban nature area in eastern Nebraska. Proceedings of the Vertebrate Pest Conference 19:84-87.

Irby, L. R., J. Saltiel, W. E. Zidack, and J. B. Johnson. 1997. Wild ungnlate damage: perceptions of farmers and ranchers in Montana. Wildlife Society Bulletin 25:320-329.

James, A. R. C., and A. K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154-159.

James, A. R. C., S. Boutin, D. M. Hebert, and A. B. Rippin. 2004. Spatial separation of caribou from moose and its relation to predation by wolves. Journal of Wildlife Management 68:799-809.

Jansen, B. D., P. R. Krausman, J. R. Heffelfinger, and J. C. de Vos. 2006. Bighorn sheep selection of landscape features in an active copper mine. Wildlife Society Bulletin 34:1121-1126.

Jansen, B. D., P. R. Krausman, J. R. Heffelfinger, and J. C. de Vos. 2007. Influence of mining on behavior of bighorn sheep. Southwestern Naturalist 52:418-423.

Jarvis, L. A. 2008. Residential development patterns in Flathead County, Montana. MS Thesis. University of Montana, Missoula, MT. 88 pp.

Jeffrey, B., and P. N. Duinker. 2000. A comparative analysis of cumulative impact assessments involving mining developments and species at risk. Pages 77-96 *in* A. J. Kennedy, editor. Cumulative environmental effects management: Tools and approaches. Alberta Society of Professional Biologists, Calgary, Alberta, Canada.

Jenkins, D. A., J. A. Schaefer, R. Rosatte, T. Bellhouse, J. Hamr, and F. F. Mallory. 2007. Winter resource selection of reintroduced elk and sympatric white-tailed deer at multiple spatial scales. Journal of Mammalogy 88:614-624.

Jenkins, K. J., and R. G. Wright. 1988. Resource partitioning and competition among cervids in the northern Rocky Mountains. Journal of Applied Ecology 25:11-24.

Johnson, C. J., K. L. Parker, D. C. Heard, and M. P. Gillingham. 2002. Movement parameters of ungnlates and scale-specific responses to the environment. Journal of Animal Ecology 71:225-235.

Johnson, C. J., M. S. Boyce, R. L. Case, H. D. Cluff, R. J. Gau, A. Gunn, and R. Mulders. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monographs 160:1-36.

Johnson, C. J., and M. P. Gillingham. 2008. Sensitivity of species-distribution models to error, bias, and model design: An application to resource selection functions for woodland caribou. Ecological Modelling 213:143-155.

Johnson, C. J., and M. H. St-Laurent. 2011. Unifying framework for understanding impacts of human developments on wildlife. *in* E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA.

Johnson, M. P. 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A 33:717–735.

Jones, P. F., and M. Grue. 2006. Resource selection by pronghorn antelope in the Grassland Natural Region of Alberta: Progress Report #2. Alberta Conservation Association. Lethbridge, Alberta. 39 pp.

Jones, P. F., M. Grue, J. Landry-DeBoer, and M. Suitor. 2007. Resource selection by pronghorn antelope in the Grassland Natural Region of Alberta: Progress Report #3. Alberta Conservation Association. Lethhridge, Alberta. 33pp.

Jones, P. F., M. Grue, and J. Landry-DeBoer. 2008a. Landowner knows best: local ecological knowledge of pronghorn habitat use in Southern Alberta. Pages 29-38 *in* Proceedings of the 23rd Biennial Pronghorn Workshop. Canmore, Alberta. Canada.

Jones, P. F., M. Grue, J. Landry-DeBoer, M. Suitor, C. Gates, D. Eslinger, and K. F. Morton. 2008b. Winter habitat selection by pronghorn at multiple scales in Southern Alberta. Pages 67-78 *in* Proceedings of the 23rd Biennial Pronghorn Workshop. Canmore, Alberta. Canada.

Jorgenson, J. T. 1988. Environmental impact of the 1988 Winter Olympics on bighorn sheep of Mt. Allan. Pages 121-134 *in* Proceedings of Biennial Symposium of Northern Wild Sheep and Goat Council. 6. Banff, Alberta.

Joslin, G. 1986. Mountain goat population changes in relation to energy exploration along Montana's Rocky Mountain front. *in* Proceedings of Biennial Symposium of the Northern Wild Sheep and Goat Council. Missoula, Montana.

Keller, B. J., and L. C. Bender. 2007. Bighorn sheep response to road-related disturbances in Rocky Mountain National Park, Colorado. Journal of Wildlife Management 71:2329-2337.

Kelsall, J. P. 1969. Structural adaptations of moose and deer for snow. Journal of Mammalogy 50:302-&.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R. A. Powell, F. Cagnacci, M. S. Mitchell, J. M. Gaillard, and P. R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society B-Biological Sciences 365:2221-2231.

Kilpatrick, H. J., and S. M. Spohr. 2000a. Movements of female white-tailed deer in a suburban landscape: a management perspective. Wildlife Society Bulletin 28:1038-1045.

Kilpatrick, H. J., and S. M. Spohr. 2000b. Spatial and temporal use of a suburban landscape by female white-tailed deer. Wildlife Society Bulletin 28:1023-1029.

Kilpatrick, H. J., and W. A. Stober. 2002. Effects of temporary bait sites on movements of suburban white-tailed deer. Wildlife Society Bulletin 30:760-766.

Klaver, R. W., J. A. Jenks, C. S. Deperno, and S. L. Griffin. 2008. Associating seasonal range characteristics with survival of female white-tailed deer. Journal of Wildlife Management 72:343-353.

Kloppers, E. L., C. C. St Clair, and T. E. Hurd. 2005. Predator-resembling aversive conditioning for managing habituated wildlife. Ecology and Society 10.

Knight, R. L., G. N. Wallace, and W. E. Riebsame. 1995. Ranching the view - subdivisions versus agriculture. Conservation Biology 9:459-461.

Krausman, P. R., and J. J. Hervert. 1983. Mountain sheep responses to aerial surveys. Wildlife Society Bulletin 11:372-375.

Krausman, P. R., M. C. Wallace, C. L. Hayes, and D. W. DeYoung. 1998. Effects of jet aircraft on mountain sheep. Journal of Wildlife Management 62:1246-1254.

Krausman, P. R., W. C. Dunn, L. K. Harris, W. W. Shaw, and W. M. Boyce. 2001. Can mountain sheep and humans coexist? R. Field, R. J. Warren, H. O'Korma, andP. R. Sievert, editors. Pages 224-227 *in* Proceedings of the Second International Wildlife Management Congress.Wildlife, land and people: priorities for the 21st century. Bethesda, Maryland, USA.

Krausman, P. R., L. K. Harris, C. L. Blasch, K. K. G. Koenen, and J. Francine. 2004. Effects of military operations on behavior and hearing of endangered Sonoran pronghorn. Wildlife Monographs:1-41.

Krausman, P. R., L. K. Harris, S. K. Haas, K. K. G. Koenen, P. Devers, D. Bunting, and M. Barb. 2005. Sonoran pronghorn habitat use on landscapes disturbed by military activities. Wildlife Society Bulletin 33:16-23.

Krausman, P. R. 2011. Quantifying cumulative effects. Pages 47-64 *in* P. R. Krausman, andL. K. Harris, editors. Cumulative effects in wildlife management: impact mitigation. CRC Press, Boca Raton, FL.

Krausman, P. R., S. M. Smith, J. Derbridge, and J. Merkle. 2011. The cumulative effects of suburban and exurban influences on wildlife. Pages 135-192 *in* P. R. Krausman, andL. K. Harris, editors. Cumulative effects in wildlife management: impact mitigation. CRC Press, Boca Raton, Florida, USA.

Krech, S. 1999. The ecological Indian: myth and history. W. W. Norton & Company, Inc., New York, NY.

Krech, S. 2005. Reflections on conservation, sustainability, and environmentalism in indigenous North America. American Anthropologist 107:78-86.

Kretser, H. E., P. J. Sullivan, and B. A. Knuth. 2008. Housing density as an indicator of spatial patterns of reported human-wildlife interactions in Northern New York. Landscape and Urban Planning 84:282-292.

Kretser, H. E., P. D. Curtis, J. D. Francis, R. J. Pendall, and B. A. Knuth. 2009. Factors affecting perceptions of human-wildlife interactions in residential areas of northern New York and implications for conservation. Human Dimensions of Wildlife 14:102-118.

Kristan, W. B., and W. I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84:2432-2443.

Kucera, E. 1976. Deer flushing distance as related to observers mode of travel. Wildlife Society Bulletin 4:128-129.

Kufeld, R. C., D. C. Bowden, and D. L. Schrupp. 1989. Distribution and movements of female mule deer in the Rocky-Mountain foothills. Journal of Wildlife Management 53:871-877.

Kunkel, K. E., and D. H. Pletscher. 2000. Habitat factors affecting vulnerability of moose to predation by wolves in southeastern British Columbia. Canadian Journal of Zoology 78:150-157.

Lacey, J. R., K. Jamtgaard, L. Riggle, and T. Hayes. 1993. Impacts of big game on private land in south-western Montana - landowner perceptions. Journal of Range Management 46:31-37.

Lagory, K. E. 1987. The influence of habitat and group characteristics on the alarm and flight response of white-tailed deer. Animal Behaviour 35:20-25.

Laliberte, A. S., and W. J. Ripple. 2004. Range contractions of North American carnivores and ungulates. Bioscience 54:123-138.

LaPerriere, A. J., and P. C. Lent. 1977. Caribou feeding sites in relation to snow characteristics in North-eastern Alaska. Arctic 30:101-108.

Larson, T. J., O. J. Rongstad, and F. W. Terbilcox. 1978. Movement and habitat use of white-tailed deer in southcentral Wisconsin. Journal of Wildlife Management 42:113-117.

Latham, A. D. M., M. C. Latham, and N. A. McCutchen. 2011. Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. Journal of Wildlife Management 75:204-212.

Lauber, T. B. 2010. Community-based deer management: learning and community capacity. Human Dimensions Research Unit Publ. 10-1. Deptment of Natural Resources, Cornell University. Ithaca, NY. 34 pp.

Lee, M. E., and R. Miller. 2003. Managing elk in the wildland-urban interface: attitudes of Flagstaff, Arizona residents. Wildlife Society Bulletin 31:185-191.

Legg, K. L. 1998. A review of the potential effects of winter recreation on bighorn sheep. Pages 14–19 *in* Proceedings of Biennial Symposium of the Northern Wild Sheep and Goat Council. Whitefish, Montana.

Leinwand, I. I. F., D. M. Theobald, J. Mitchell, and R. L. Knight. 2010. Landscape dynamics at the public-private interface: A case study in Colorado. Landscape and Urban Planning 97:182-193.

Lenth, B. A., R. L. Knight, and W. C. Gilgert. 2006. Conservation value of clustered housing developments. Conservation Biology 20:1445-1456.

Leptich, D. J., and P. Zager. 1991. Road access management effects on elk mortality and population dynamics. A. G. Christensen, L. J. Lyon, andT. N. Lonner, editors. Pages 94-98 *in* Proceedings of Elk vulnerability symposium. Montana State University, Bozeman, MT.

Lesage, L., M. Crete, J. Huot, A. Dumont, and J. P. Ouellet. 2000. Seasonal home range size and philopatry in two northern white-tailed deer populations. Canadian Journal of Zoology-Revue Canadienne De Zoologie 78:1930-1940.

Limerick, P. N., W. Travis, and T. Scoggin. 2002. Boom and bust in the American west. A report compiled from the presentations and comments of workshop participants. *in* Proceedings.

Lind, J., and W. Cresswell. 2005. Determining the fitness consequences of antipredation behavior. Behavioral Ecology 16:945-956.

Lingle, S., and W. F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (Odocoileus virginianus) and mule deer (O-hemionus). Ethology 107:125-147.

Liu, J. G., G. C. Daily, P. R. Ehrlich, and G. W. Luck. 2003. Effects of household dynamics on resource consumption and biodiversity. Nature 421:530-533.

Loehr, J., M. Kovanen, J. Carey, H. Hogmander, C. Jurasz, S. Karkkainen, J. Suhonen, and H. Ylonen. 2005. Gender- and age-class-specific reactions to human disturbance in a sexually dimorphic ungulate. Canadian Journal of Zoology 83:1602-1607.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation - lessons from history. Science 260:17 & 36.

Lyon, L. J. 1979. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry 77:658-660.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81:592-595, 613.

Macarthur, R. A., R. H. Johnston, and V. Geist. 1979. Factors influencing heart-rate in free-ranging bighorn sheep - physiological approach to the study of wildlife harassment. Canadian Journal of Zoology 57:2010-2021.

MacArthur, R. A., V. Geist, and R. H. Johnston. 1982. Cardiac and behavioral-responses of mountain sheep to human disturbance. Journal of Wildlife Management 46:351-358.

Maestas, J. D., R. L. Knight, and W. C. Gilgert. 2003. Biodiversity across a rural land-use gradient. Conservation Biology 17:1425-1434.

Mahoney, S. P., K. Mawhinney, C. McCarthy, D. Anions, and S. Taylor. 2001. Caribou reactions to provocation by snowmachines in Newfoundland. Rangifer 21:35-43.

Martin, T. G., P. Arcese, and N. Scheerder. 2011. Browsing down our natural heritage: deer impacts on vegetation structure and songbird populations across an island archipelago. Biological Conservation 144:459-469.

McClure, M. F., J. A. Bissonette, and M. R. Conover. 2005. Migratory strategies, fawn recruitment, and winter habitat use by urban and rural mule deer (Odocoileus hemionus). European Journal of Wildlife Research 51:170-177.

McElfish, J. M. 2007. Ten things wrong with sprawl. Environmental Law Institute. Washington, DC.

McGranahan, D. A. 1999. Natural amenities drive rural population change. US Department of Agriculture, Economic Research Service. Agricultural Economic Report Number 781. Washington, DC.

McIntyre, N. E. 1999. Influences of urban land use on the frequency of scorpion stings in the Phoenix, Arizona, metropolitan area. Landscape and Urban Planning 45:47-55.

McIntyre, S., and R. Hobbs. 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology 13:1282-1292.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. Bioscience 52:883-890.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127:247-260.

McKinney, M. L. 2008. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosystems 11:161-176.
Milder, J. C. 2007. A framework for understanding conservation development and its ecological implications. Bioscience 57:757-768.
Miller, J. R., J. A. Wiens, N. T. Hobbs, and D. M. Theobald. 2003. Effects of human settlement on bird communities in lowland riparian areas of Colorado (USA). Ecological Applications 13:1041-1059.
Miller, S. G., R. L. Knight, and C. K. Miller. 2001. Wildlife responses to pedestrians and dogs. Wildlife Society Bulletin 29:124-132.
Millspaugh, J. J., R. J. Woods, K. E. Hunt, K. J. Raedeke, G. C. Brundige, B. E. Washburn, and S. K. Wasser. 2001. Fecal glucocorticoid assays and the physiological stress response in elk. Wildlife Society Bulletin 29:899-907.
Mitchell, G. J., and S. Smoliak. 1971. Pronghorn antelope range characteristics and food habits in Alberta. Journal of Wildlife Management 35:238-&.
Moen, A. N., S. Whittemore, and B. Buxton. 1982. Effects of disturbance by snowmobiles on heart-rate of captive white-tailed deer. New York Fish and Game Journal 29:176-183.
Morrison, J. R., W. J. Devergie, A. W. Alldredge, A. E. Byrne, and W. W. Andre. 1995. The effects of ski area expansion on elk. Wildlife Society Bulletin 23:481-489.
Mule Deer Working Group. 2003. Mule deer: changing landscapes, changing perspectives. Western Association of Fish and Wildlife Agencies. Creative Resource Strategies. West Linn, OR.
Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.
Nassauer, J. I., J. D. Allan, T. Johengen, S. E. Kosek, and D. Infante. 2004. Exurban residential subdivision development: Effects on water quality and public perception. Urban Ecosystems 7:267-281.
National Atlas of the United States. 2006. Federal Lands of the United States: National Atlas of the United States, Reston, VA.
Naugle, E., editor. 2011. Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA.
Nellemann, C., and R. D. Cameron. 1998. Cumulative impacts of an evolving oil-field complex on the distribution of calving caribou. Canadian Journal of Zoology 76:1425-1430.
Nellemann, C., I. Vistnes, P. Jordhoy, and O. Strand. 2001. Winter distribution of wild reindeer in relation to power lines, roads and resorts. Biological Conservation 101:351-360.
Nellemann, C., I. Vistnes, P. Jordhoy, O. Strand, and A. Newton. 2003. Progressive impact of piecemeal infrastructure development on wild reindeer. Biological Conservation 113:307-317.
Nelson, A. C. 1992. Characterizing exurbia. Journal of Planning Literature 6:350-368.
Nelson, M. E. 1998. Development of migratory behavior in northern white-tailed deer. Canadian Journal of Zoology 76:426-432.
Nelson, P. B. 2003. Geographic perspective on amenity migration across the USA: National- regional- and local-scale analysis. *in* L. A. G. Moss, editor. The amenity migrants: seeking and sustaining mountains and their cultures. CABI Publishing, Cambridge, MA.
Newman, J. M. 2009. Rural subdivision planning in Missoula County, Montana: a planner's perspective. Professional Paper. University of Montana, Missoula, MT. 56 pp.
Nicholson, M. C., R. T. Bowyer, and J. G. Kie. 1997. Habitat selection and survival of mule deer: Tradeoffs associated with migration. Journal of Mammalogy 78:483-504.
Nielsen, S. E., G. B. Stenhouse, and M. S. Boyce. 2006. A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation 130:217-229.
Nielsen, S. E., G. B. Stenhouse, H. L. Beyer, F. Huettmann, and M. S. Boyce. 2008. Can natural disturbance-based forestry rescue a declining population of grizzly bears? Biological Conservation 141:2193-2207.

O'Gara, B. W. 2004a. Disease and parasites. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.
O'Gara, B. W. 2004b. Mortality factors. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.
O'Gara, B. W. 2004c. Behavior. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.
Odell, E. A., and R. L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.
Oehler, M. W., V. C. Bleich, R. T. Bowyer, and M. C. Nicholson. 2005. Mountain sheep and mining: Implications for conservation and management. California Fish and Game 91:149-178.
Olliff, T., K. Legg, and B. Kaeding, editors. 1999. Effects of winter recreation on wildlife of the Greater Yellowstone Area: a literature review and assessment. Yellowstone National Park, Wyoming.
Olsen, S. C. 2010. Brucellosis in the United States: Role and significance of wildlife reservoirs. Vaccine 28:F73-F76.
Pac, D. F., R. J. Mackie, and H. E. Jorgensen. 1991. Mule deer population organization, behavior and dynamics in a northern Rocky Mountain environment. Montana Fish, Wildlife and Parks. Helena, MT.
Paige, C. 2008. A landowner's guide to wildlife friendly fences. Landowner/Wildlife Resource Program, Montana Fish, Wildlife and Parks. Helena, MT. 44 pp.
Papouchis, C. M., F. J. Singer, and W. B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65:573-582.
Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474-488.
Parker, K. L., P. S. Barboza, and T. R. Stephenson. 2005. Protein conservation in female caribou (Rangifer tarandus): Effects of decreasing diet quality during winter. Journal of Mammalogy 86:610-622.
Parker, K. L., P. S. Barboza, and M. P. Gillingham. 2009. Nutrition integrates environmental responses of ungulates. Functional Ecology 23:57-69.
Pauley, G. R., J. M. Peek, and P. Zager. 1993. Predicting white-tailed deer habitat use in northern Idaho. Journal of Wildlife Management 57:904-913.
Pedevillano, C., and R. G. Wright. 1987. The influence of visitors on mountain goat activities in Glacier National Park, Montana. Biological Conservation 39:1-11.
Pekins, P. J., K. S. Smith, and W. W. Mautz. 1998. The energy cost of gestation in white-tailed deer. Canadian Journal of Zoology 76:1091-1097.
Peterson, M. N., X. D. Chen, and J. G. Liu. 2008. Household location choices: Implications for biodiversity conservation. Conservation Biology 22:912-921.
Phillips, G. E., and A. W. Alldredge. 2000. Reproductive success of elk following disturbance by humans during calving season. Journal of Wildlife Management 64:521-530.
Piccolo, B. P., K. M. Hollis, R. E. Warner, T. R. Van Deelen, D. R. Etter, and C. Anchor. 2000. Variation of white-tailed deer home ranges in fragmented urban habitats around Chicago, Illinois. M. C. Brittingham, J. Kays, andR. McPeake, editors. *in* Proceedings of the Ninth Wildlife Damage Management Conference. State College, Pennsylvania, USA.
Picton, H. D. 1980. Land-use impacts on elk in the Gallatin Valley. Journal of Soil and Water Conservation 35:93-95.
Pimm, S. L., and P. Raven. 2000. Biodiversity - Extinction by numbers. Nature 403:843-845.
Plaven, G. 2010. Truck kills 8 bighorn sheep. Billings Gazette. Billings, MT. January 11, 2010. http://billingsgazette.com/news/state-and-regional/montana/article_90a686aa-ff44-11de-99a3-001cc4c03286.html. [Accessed on 23 March 2011].
Polfus, J. L. 2010. Assessing cumulative human impacts on northern woodland caribou with traditional ecological kuowledge and resource selection functions. Thesis, University of Montana, Missoula, USA.

Polfus, J. L., and M. Hebblewhite. 2010. Boreal woodland caribou national resource selection function modeling in support of critical habitat identification. Report for the scientific review for the identification of critical habitat for woodland caribou (Rangifer tarandus caribou), boreal population, in Canada. Environment Canada.

Polfus, J. L., M. Hebblewhite, and K. Heinemeyer. *in review*. Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. Biological Conservation.

Polis, G. A., and D. R. Strong. 1996. Food web complexity and community dynamics. American Naturalist 147:813-846.

Polis, G. A., W. B. Anderson, and R. D. Holt. 1997. Toward an integration of landscape and food web ecology: The dynamics of spatially subsidized food webs. Annual Review of Ecology and Systematics 28:289-316.

Poole, K. G., and G. Mowat. 2005. Winter habitat relationships of deer and elk in the temperate interior mountains of British Columbia. Wildlife Society Bulletin 33:1288-1302.

Poole, K. G., R. Serrouya, and K. Stuart-Smith. 2007. Moose calving strategies in interior montane ecosystems. Journal of Mammalogy 88:139–150.

Porter, W. F., H. B. Underwood, and J. L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment. Journal of Wildlife Management 68:247-256.

Post, E., and D. R. Klein. 1999. Caribou calf production and seasonal range quality during a population decline. Journal of Wildlife Management 63:335-345.

Potvin, F., J. Huot, and F. Duchesneau. 1981. Deer mortality in the Pohénégamook wintering area, Québec. Canadian Field-Naturalist
95:80–84.

Powell, J. 2003. Distribution, habitat use patterns, and elk response to human disturbance in the Jack Morrow Hills, Wyoming. MS Thesis. University of Wyoming, Laramie, WY.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2006. Statistical methods for analysing responses of wildlife to human disturbance. Journal of Applied Ecology 43:164-172.

Proulx, G. 2010. Late-winter habitat use by mule deer, Odocoileus hemionus, in central interior British Columbia. The Canadian Field-Naturalist 122:205-211.

Pruitt, W. O. 1959. Snow as a factor in the winter ecology of the barren ground caribou (Ranifer arcticus). Arctic 12:159-179.

Pulliam, H. R. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Radeloff, V. C., R. B. Hammer, S. I. Stewart, J. S. Fried, S. S. Holcomb, and J. F. McKeefry. 2005. The wildland-urban interface in the United States. Ecological Applications 15:799-805.

Rand, T. A., and S. A. Louda. 2006. Spillover of agriculturally subsidized predators as a potential threat to native insect herbivores in fragmented landscapes. Conservation Biology 20:1720-1729.

Rasker, R., and A. Hansen. 2000. Natural amenities and population growth in the Greater Yellowstone region. Human Ecology Review 7:30-40.

Ray, J. C., K. Redford, R. Steneck, and J. Berger, editors. 2005. Large carnivores and the conservation of biodiversity. Island Press, Washington DC.

Reed, D. F., T. N. Woodard, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management 39:361-367.

Reed, D. F. 1981. Conflicts with civilization. *in* O. C. Wallmo, editor. Mule deer and black-tailed deer of North America. University of Nebraska Press, Lincoln, NE.

Reimers, E., S. Eftestol, and J. E. Colman. 2003. Behavior responses of wild reindeer to direct provocation by a snowmobile or skier. Journal of Wildlife Management 67:747-754.

Reimers, E., F. L. Miller, S. Eftestol, J. E. Colman, and B. Dahle. 2006. Flight by feral reindeer Rangifer tarandus tarandus in response to a directly approaching human on foot or on skis. Wildlife Biology 12:403-413.

Rhoads, C. L., J. L. Bowman, and B. Eyler. 2010. Home range and movement rates of female exurban white-tailed deer. Journal of Wildlife Management 74:987-994.

Riley, S. J., and D. J. Decker. 2000. Wildlife stakeholder acceptance capacity for cougars in Montana. Wildlife Society Bulletin 28:931-939.

Ripple, W. J., E. J. Larsen, R. A. Renkin, and D. W. Smith. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation 102:227-234.

Robinson, L., J. P. Newell, and J. A. Marzluff. 2005. Twenty-five years of sprawl in the Seattle region: growth management responses and implications for conservation. Landscape and Urban Planning 71:51-72.

Rominger, E. M., H. A. Whitlaw, D. L. Weybright, W. C. Dunn, and W. B. Ballard. 2004. The influence of mountain lion predation on bighorn sheep translocations. Journal of Wildlife Management 68:993-999.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634-641.

Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modeling in relation to roads. Journal of Wildlife Management 64:672-684.

Rozell, N. 1999. Moose and the Big City. *in* Alaska Science Forum.

Rudzitis, G. 1999. Amenities increasingly draw people to the rural West. Rural Development Perspectives 14:9-13.

Rumble, M. A., L. Benkobi, and R. S. Gamo. 2005. Elk responses to humans in a densely roaded area. Intermountain Journal of Sciences 11:10-24.

Sabine, D. L., S. F. Morrison, H. A. Whitlaw, W. B. Ballard, G. J. Forbes, and J. Bowman. 2002. Migration behavior of white-tailed deer under varying winter climate regimes in New Brunswick. Journal of Wildlife Management 66:718-728.

Safford, R. K. 2003. Modelling critical winter habitat of four ungulate species in the Robson Valley, British Columbia. British Columbia Journal of Ecosystems and Management 4:1-13.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5:18-32.

Sawyer, H., and F. Lindzey. 2000. Jackson Hole pronghorn study. Wyoming Cooperative Fish & Wildlife Research Unit. Laramie, WY.

Sawyer, H., F. Lindzey, and D. McWhirter. 2005. Mule deer and pronghorn migration in western Wyoming. Wildlife Society Bulletin 33:1266-1273.

Sawyer, H., and B. Rudd. 2005. Pronghorn roadway crossings: a review of available information and potential options. Federal Highway Administration, Wyoming Department of Transportation, Wyoming Game and Fish Department. Cheyenne, WY.

Sawyer, H., R. M. Nielson, F. Lindzey, and L. L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. Journal of Wildlife Management 70:396-403.

Sawyer, H., R. M. Nielson, F. G. Lindzey, L. Keith, J. H. Powell, and A. A. Abraham. 2007. Habitat selection of Rocky Mountain elk in a nonforested environment. Journal of Wildlife Management 71:868-874.

Sawyer, H., M. J. Kauffman, and R. M. Nielson. 2009a. Influence of well pad activity on winter habitat selection patterns of mule deer. Journal of Wildlife Management 73:1052-1061.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009b. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016-2025.

Sawyer, H., R. Neilson, and D. Strickland. 2009c. Sublette mule deer study (phase II): final report 2007 - long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline project area. Western Ecosystems Technology, Inc. Cheyenne, Wyoming, USA.

Sawyer, H., and R. Neilson. 2010. Mule deer monitoring in the Pinedale Anticline project area: 2010 annual report. Western Ecosystems Technology, Inc. Cheyenne, Wyoming, USA.

Sawyer, H., and M. J. Kauffman. 2011. Stopover ecology of a migratory ungulate. Journal of Animal Ecology. Online Version.

Schaefer, J. A., and S. P. Mahoney. 2007. Effects of progressive clearcut logging on Newfoundland Caribou. Journal of Wildlife Management 71:1753-1757.

Schlaepfer, M. A., M. C. Runge, and P. W. Sherman. 2002. Ecological and evolutionary traps. Trends in Ecology & Evolution 17:474-480.

Schneider, R. R., and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. Journal of Wildlife Management 64:513-520.

Schultz, R. D., and J. A. Bailey. 1978. Responses of National Park elk to human activity. Journal of Wildlife Management 42:91-100.

Scott, J. M., F. W. Davis, R. G. McGhie, R. G. Wright, C. Groves, and J. Estes. 2001. Nature reserves: Do they capture the full range of America's biological diversity? Ecological Applications 11:999-1007.

Scott, K. 2007. Emerging trends in cumulative effects assessment in Northern Canada. MS Thesis. University of Toronto, Toronto, ON. 79 pp.

Seagel, T. 2007. Modeling pronghorn responses to landscape variables on CFB Suffield. MS Thesis. University of Calgary, Calgary, AB. 104 pp.

Seip, D. R., C. J. Johnson, and G. S. Watts. 2007. Displacement of mountain caribou from winter habitat by snowmobiles. Journal of Wildlife Management 71:1539-1544.

Serrouya, R., and R. G. D'Eon. 2008. The influence of forest cover on mule deer habitat selection, diet, and nutrition during winter in a deep-snow ecosystem. Forest Ecology and Management 256:452-461.

Shackleton, D. M., C. C. Shank, and B. M. Wikeem. 1999. Natural history of Rocky Mountain and California bighorn sheep. *in* R. Valdez, andP. R. Krausman, editors. Mountain Sheep of North America. University of Arizona Press, Tucson, AZ.

Shapira, I., H. Sultan, and U. Shanas. 2008. Agricultural farming alters predator-prey interactions in nearby natural habitats. Animal Conservation 11:1-8.

Sheldon, D. P. 2005. Pronghorn movement and distribution patterns in relation to roads and fences in southwestern Wyoming. MS Thesis. University of Wyoming, Laramie, WY. 126 pp.

Sheriff, K. A. 2006. Modeling temporal and spatial variation in pronghorn antelope population dynamics in southern Alberta in relation to environmental gradients. MS Thesis. University of Calgary, Calgary, AB. 210 pp.

Shively, K. J., A. W. Alldredge, and G. E. Phillips. 2005. Elk reproductive response to removal of calving season disturbance by humans. Journal of Wildlife Management 69:1073-1080.

Shochat, E., W. L. Stefanov, M. E. A. Whitehouse, and S. H. Faeth. 2004. Urbanization and spider diversity: Influences of human modification of habitat structure and productivity. Ecological Applications 14:268-280.

Shumway, J. M., and S. M. Otterstrom. 2001. Spatial patterns of migration and income change in the mountain West: The dominance of service-based, amenity-rich counties. Professional Geographer 53:492-502.

Siemer, W. F., K. M. Leong, D. J. Decker, and K. K. Smith. 2007. Deer, people, and parks: perspectives of residents in communities near Fire Island National Seashore. Human Dimensions Research Unit, Cornell University. HDRU Series Publication 07-8. Ithaca, NY. 82 pp.

Sime, C. A., and E. Schmidt. 1999. Off-site impacts of rural subdivision on wintering white-tailed deer in Northwest Montana: could man's best friend be wildlife's worst enemy? *in* Proceedings of A Space for Wildlife Odyssey: A symposium on living in the western landscape. Bozeman, Montana.

Sinclair, A. R. E., R. P. Pech, C. R. Dickman, D. Hik, P. Mahon, and A. E. Newsome. 1998. Predicting effects of predation on conservation of endangered prey. Conservation Biology 12:564-575.

Sinclair, A. R. E., and A. E. Byrom. 2006. Understanding ecosystem dynamics for conservation of biota. Journal of Animal Ecology 75:64-79.

Sinclair, A. R. E., J. M. Fryxell, and G. Caughley. 2006. Wildlife ecology, conservation and management. Second edition. Blackwell Publishing Ltd., Malden, MA.
Singer, F. J. 1978. Behavior of mountain goats in rlation to United States Highway 2, Glacier National Park, Montana. Journal of Wildlife Management 42:591-597.
Smith, C. A. 1977. Habitat use patterns and associated movements of white-tailed deer in south-eastern British Columbia. MS Thesis. University of British Columbia, Vancouver, BC. 148 pp.
Smith, D. O., M. Conner, and E. R. Loft. 1989. The distribution of winter mule deer use around home sites. Transactions of the Western States Section of the Wildlife Society 25:77-80.
Sorensen, T., P. D. McLoughlin, D. Hervieux, E. Dzus, J. Nolan, B. Wynes, and S. Boutin. 2008. Determining sustainable levels of cumulative effects for boreal caribou. Journal of Wildlife Management 72:900-905.
Soulé, M. E. 1991. Conservation tactics for a constant crisis. Science 253:744-750.
Spalding, H. 1994. Cumulative effects assessment: concepts and principles. Impact Assessment 12:231-251.
Sparrowe, R. D., and P. F. Springer. 1970. Seasonal activity patterns of white-tailed deer in eastern South Dakota. Journal of Wildlife Management 34:420-&.
St. Clair, C. C. S., and A. Forrest. 2009. Impacts of vehicle traffic on the distribution and behaviour of rutting elk, Cervus elaphus. Behaviour 146:393-413.
Stankowich, T. 2008. Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation 141:2159-2173.
Stemp, R. 1982. Heart rate responses of bighorn sheep. Pages 314-319 *in* Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council. Fort Collins, CO.
Stewart, K. M., R. T. Bowyer, J. G. Kie, N. J. Cimon, and B. K. Johnson. 2002. Temporospatial distributions of elk, mule deer, and cattle: Resource partitioning and competitive displacement. Journal of Mammalogy 83:229-244.
Stockwell, C. A., G. C. Bateman, and J. Berger. 1991. Conflicts in National Parks: a case-study of helicopters and bighorn sheep time budgets at the Grand Canyon. Biological Conservation 56:317-328.
Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007a. Deer-human conflict and hunter access in an exurban landscape. Human-Wildlife Conflicts 1:53-59.
Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007b. Space use and survival of white-tailed deer in an exurban landscape. Journal of Wildlife Management 71:1170-1176.
Stout, R. J., B. A. Knuth, and P. D. Curtis. 1997. Preferences of suburban landowners for deer management techniques: A step towards better communication. Wildlife Society Bulletin 25:348-359.
Sweeney, J. M., and J. R. Sweeney. 1984. Snow depths influencing winter movements of elk. Journal of Mammalogy 65:524-526.
Swihart, R. K., P. M. Picone, A. J. DeNicola, and L. Cornicelli. 1995. Ecology of urban and suburban white-tailed deer. J. B. McAninch, editor. Pages 35-44 *in* Proceedings of the 1993 Symposium of North Central Section, The Wildlife Society. Urban deer: A manageable resource? St. Louis, Missouri, USA.
Tankersley, N. G. 1984. Mineral lick use by Dall sheep in the Watana Creek Hills, Alaska. *in* Proceedings of Biennial Symposium of Northern Wild Sheep and Goat Council. Whitehorse, Yukon.
Taylor, A. R., and R. L. Knight. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951-963.
Telfer, E. S. 1978. Cervid distribution, browse and snow cover in Alberta. Journal of Wildlife Management 42:352-361.
Theobald, D. M., J. R. Miller, and N. T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39:25-36.

Theobald, D. M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10.

Theobald, D. M., T. Spies, J. Kline, B. Maxwell, N. T. Hobbs, and V. H. Dale. 2005. Ecological support for rural land-use planning. Ecological Applications 15:1906-1914.

Theobald, D. M., and W. H. Romme. 2007. Expansion of the US wildland-urban interface. Landscape and Urban Planning 83:340-354.

Thompson, D., K. Longhsore, and C. Lowrey. 2007. The impact of human disturbance on desert bighorn sheep (Ovis canadensis nelsoni) in the Wonderland of Rocks/Queen Mountain Region of Joshua Tree National Park, California. Final report submitted to Joshua Tree National Park. U.S. Geological Survey. Las Vegas, NV. 43 pp.

Thompson, M. J., and R. E. Henderson. 1998. Elk habituation as a credibility challenge for wildlife professionals. Wildlife Society Bulletin 26:477-483.

Thornton, C., and M. S. Quinn. 2009. Coexisting with cougars: public perceptions, attitudes, and awareness of cougars on the urban-rural fringe of Calgary, Alberta, Canada. Human-Wildlife Conflicts 3:282-295.

Tierson, W. C., G. F. Mattfeld, R. W. Sage, and D. F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760-769.

Torbit, S. C., L. H. Carpenter, D. M. Swift, and A. W. Alldredge. 1985. Differential loss of fat and protein by mule deer during winter. Journal of Wildlife Management 49:80-85.

Toweill, D. E., and J. W. Thomas, editors. 2002. North American Elk: Ecology and Management. Smithsonian Institution Press, Washington and London.

Travis, W. R., D. M. Theobald, G. W. Mixon, and T. W. Dickinson. 2005. Western futures: a look into the patterns of land use and future development in the American West. Center of the American West. University of Colorado. Boulder, CO.

Travis, W. R. 2007. New geographies of the American west: land use and the changing patterns of place. Island Press, Covelo, California, USA.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

UNEP. 2001. GLOBIO - global methodology for mapping human impacts on the biosphere. United Nations Environmental Programme. Nairobi, Kenya.

Ungnlate Winter Range Technical Advisory Team. 2005. Desired conditions for mule deer, elk and moose winter range in the Southern Interior of British Columbia. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch. Victoria BC. Wildlife Bullettin No. B-120. 18 pp.

Valdez, R., and P. R. Krausman, editors. 1999. Mountain Sheep of North America. University of Arizona Press, Tucson, Arizona, USA.

Varley, N. 1998. Winter recreation and human disturbance on mountain goats: a review. *in* Proceedings of Biennial Symposium of the Northern Wild Sheep and Goat Council. Whitefish, Montana.

Vistnes, I., and C. Nellemann. 2001. Avoidance of cabins, roads, and power lines by reindeer during calving. Journal of Wildlife Management 65:915-925.

Vistnes, I., and C. Nellemann. 2008. The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. Polar Biology 31:399-407.

Vogel, W. O. 1989. Response of deer to density and distribution of housing in Montana. Wildlife Society Bulletin 17:406-413.

Vore, J. 2010. Big game winter range standard for subdivision development in Montana: justifications and rationale. Montana Fish, Wildlife and Parks. Kalispell, MT.

Wagner, G. D., and J. M. Peek. 2006. Bighorn sheep diet selection and forage quality in central Idaho. Northwest Science 80:246-258.

Wait, S., and H. McNally. 2004. Selection of habitats by wintering elk in a rapidly subdividing area of La Plata County, Colorado. W. W. Shaw, L. K. Harris, andL. VanDruff, editors. Pages 200-209 *in* Proceedings of the fourth international symposium on urban wildlife conservation, Tucson, Arizona, USA.

Wallmo, O. C. 1981. Mule and black-tailed deer distirbution and habitats. *in* O. C. Wallmo, editor. Mule deer and black-tailed deer of North America. University of Nebraska Press, Lincoln, NE.

Walter, W. D., M. J. Lavelle, J. W. Fischer, T. L. Johnson, S. E. Hygnstrom, and K. C. VerCauteren. 2010. Management of damage by elk (Cervus elaphus) in North America: a review. Wildlife Research 37:630-646.

Washington Department of Fish and Wildlife. 2009. Landscape planning for Washington's wildlife: managing for biodiversity in developing areas. Olympia, WA. 88 pp + app.

Wathern, P., editor. 1990. Environmental impact assessment: theory and practice. Routledge, London.

Watkins, B. E., C. J. Bishop, E. J. Bergman, A. Bronson, B. Hale, B. F. Wakeling, L. H. Carpenter, and D. W. Lutz. 2007. Habitat guidelines for mule deer: Colorado plateau shrubland and forest ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

Wear, D. N., M. G. Turner, and R. J. Naiman. 1998. Land cover along an urban-rural gradient: Implications for water quality. Ecological Applications 8:619-630.

Webster, L. 1997. The effects of human related harassment on caribou (Rangifer tarandus). Ministry of Environment. Williams Lake, BC.

Weclaw, P., and R. J. Hudson. 2004. Simulation of conservation and management of woodland caribou. Ecological Modelling 177:75-94.

Wehausen, J. D., L. L. Hicks, D. P. Gardner, and J. Elder. 1977. Bighorn sheep management in the Sierra Nevada. Pages 30-32 *in* Proceedings of Desert Bighorn Council Transactions 21. Las Cruces, NM.

Weir, J. N., S. P. Mahoney, B. McLaren, and S. H. Ferguson. 2007. Effects of mine development on woodland caribou Rangifer tarandus distribution. Wildlife Biology 13:66-74.

Weisenberger, M. E., P. R. Krausman, M. C. Wallace, D. W. DeYoung, and O. E. Maughan. 1996. Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. Journal of Wildlife Management 60:52-61.

White, P. J., T. L. Davis, K. K. Barnowe-Meyer, R. L. Crabtree, and R. A. Garrott. 2007. Partial migration and philopatry of Yellowstone pronghorn. Biological Conservation 135:502-510.

Whittle, K. 2011. Hundreds of antelope hit by trains on the Montana Hi-Line. New West. March 17, 2011. http://www.newwest.net/topic/article/hundreds_of_antelope_hit_by_trains_on_the_montana_hi_line/C41/L41/ [accessed 29 March 2011].

Wild, M. A., N. T. Hobbs, M. S. Graham, and M. W. Miller. 2011. The role of predation in disease control: a comparison of selective and nonselective removal on prion disease dynamics in deer. Journal of Wildlife Diseases 47:78-93.

Williams, J., B. J., R. Ridgeway, K. Aune, and S. Knapp. *In prep.* The conservation of Montana wildlife migrations.

Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. J. Rahm, editor. Pages 531-550 *in* Proceedings of the 69th North American Wildlife and Natural Resources Conference. Resource Stewardship in the 21st Century: A Voyage of Rediscovery. Spokane, WA.

Witham, J. H., and J. M. Jones. 1992. Biology, ecology, and management of deer in the Chicago metropolitan area. Final report. Federal Aid in Wildlife Restoration, W-87-R. Illinois Department of Conservation. Springfield, Illinois, USA.

Wolch, J. R., K. West, and T. E. Gaines. 1995. Transspecies urban theory. Environment and Planning D-Society & Space 13:735-760.

Wolfe, S. A., B. Griffith, and C. A. G. Wolfe. 2000. Response of reindeer and caribou to human activities. Polar Research 19:63-73.

Wood, A. K. 1989. Comparative distribution and habitat use by antelope and mule deer. Journal of Mammalogy 70:335-340.

Woodroffe, R., S. Thirgood, and A. Rabinowitz, editors. 2005. People and wildlife: conflict or coexistence? Cambridge University Press, Cambridge, UK.

Woodward, J. L. 2000. Localized management of white-tailed deer in a suburban environment. MS Thesis. State University of New York, Syracuse, NY. 103 pp.

Worley, K., C. Strobeck, S. Arthur, J. Carey, H. Schwantje, A. Veitch, and D. W. Coltman. 2004. Population genetic structure of North American thinhorn sheep (Ovis dalli). Molecular Ecology 13:2545-2556.

Yoakum, J. D. 2004a. Distribution and abundance. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.

Yoakum, J. D. 2004b. Habitat conservation. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.

Yoakum, J. D. 2004c. Habitat characteristics and requirements. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.

Yoakum, J. D. 2004d. Foraging ecology, diet studies and nutritional values. *in* B. W. O'Gara, andJ. D. Yoakum, editors. Pronghorn: ecology and management. The University Press of Colorado, Boulder, CO.

Yost, A. C., and R. G. Wright. 2001. Moose, caribou, and grizzly bear distribution in relation to road traffic in Denali National Park, Alaska. Arctic 54:41-48.

ATTACHMENT D

science for a changing world

Monitoring CO_2 Emissions in Tree-Kill Areas near the Resurgent Dome at Long Valley Caldera, California

Scientific Investigation Report 2011-5038

U.S. Department of the Interior
U.S. Geological Survey

COVER

Dead trees and thermal ground at Basalt Canyon, Long Valley Caldera, California. (USGS photograph by Deborah Bergfeld, June 2006.)

Monitoring CO_2 Emissions in Tree-Kill Areas near the Resurgent Dome at Long Valley Caldera, California

By Deborah Bergfeld and William C. Evans

Scientific Investigations Report 2011–5038

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

This report and any updates to it are available online at:
http://pubs.usgs.gov/sir/2011/5038/

For more information on the USGS—the Federal source for science about the Earth,its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1-888-ASK-USGS (1-888-275-8747).

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

Suggested citation:
Bergfeld, Deborah, and Evans, W.C., 2011, Monitoring CO_2 emissions in tree kill areas near the resurgent dome at Long Valley Caldera, California: U.S. Geological Survey Scientific Investigations Report 2011-5038, 22 p.

Contents

Figures

Tables

Monitoring CO_2 Emissions in Tree-Kill Areas near the Resurgent Dome at Long Valley Caldera, California

By Deborah Bergfeld and William C. Evans

Abstract

We report results of yearly measurements of the diffuse CO_2 flux and shallow soil temperatures collected since 2006 across two sets of tree-kill areas at Long Valley Caldera, California. These data provide background information about CO_2 discharge during a period with moderate seismicity, but little to no deformation. The tree kills are located at long-recognized areas of weak thermal fluid upflow, but have expanded in recent years, possibly in response to geothermal fluid production at Casa Diablo. The amount of CO_2 discharged from the older kill area at Basalt Canyon is fairly constant and is around 3–5 tonnes of CO_2 per day from an area of about 15,000 m^2. The presence of isobutane in gas samples from sites in and around Basalt Canyon suggests that geothermal fluid production directly effects fluid upflow in the region close to the power plant. The average fluxes at Shady Rest are lower than average fluxes at Basalt Canyon, but the area affected by fluid upflow is larger. Total CO_2 discharged from the central portion of the kill area at Shady Rest has been variable, ranging from 6 to11 tonnes per day across 61,000 m^2. Gas collected at Shady Rest contains no detectable isobutane to link emissions chemically to geothermal fluid production, but two samples from 2009-10 have detectable H_2S and suggest an increasing geothermal character of emitted gas. The appearance of this gas at the surface may signal increased drawdown of water levels near the geothermal productions wells.

Introduction

Localized areas of elevated CO_2 flux and elevated soil temperatures on or around the resurgent dome at Long Valley Caldera, California, are identified by stressed, dying, and dead vegetation (fig.1). Our early work (Bergfeld and others, 2006) indicated that about 8.7 metric tonnes of CO_2 per day (t/d) were emitted from these kill zones, with the highest discharge occurring in areas within a few km of the Casa Diablo geothermal power plant, and that most of the kill zones developed as a response to changing conditions in the shallow hydrothermal system.

This report presents results from 2006–2010 CO_2-flux surveys of two of the largest tree-kill zones and chemical data on gas collected between 1989 and 2010 in and around several of the tree-kill zones. The flux measurements provide baseline data from a time when seismicity has waned and deformation of the resurgent dome has leveled off (http://volcanoes.usgs.gov/lvo/activity/index.php, last accessed December 15, 2010). Because of this, changes in the size of kill zones, increases in soil temperatures or steam discharge, and changes in CO_2 emissions most likely reflect the response of the shallow hydrothermal system to geothermal fluid production at the Casa Diablo power plant. Results from diffuse CO_2-flux and soil-temperature measurements collected under these conditions allow a better understanding of the shallow system and will improve our ability to detect changes in the fluxes of CO_2 and heat associated with magmatic unrest.

Field Locations

Our field studies since 2006 have focused on two main kill zones, herein referred to as Basalt Canyon and Shady Rest. The grid at Basalt Canyon and at Shady Rest are partly composed of measurement sites from the BC, BCE, and SR grids of Bergfeld and others, 2006. The outline of present-day measurement grids are irregular, and the footprints of the grids have varied with time as we encompassed more areas of thermal fluid upflow, or as new areas of kill developed.

The Basalt Canyon grid is about 1.6 km due west of the Casa Diablo power plant (fig. 1) and is sited along a localized SW-NE trending fault (Bergfeld and others, 2006). The grid consists primarily of tree-kill with a zone of live grass in the northeast section. The volcanic rocks in Basalt Canyon include Quaternary rhyolites and basalts (Bailey, 1989). During June 2010, the measurement grid covered about 23,000 m^2 and had 88 measurement sites (table 1). Gas samples occasionally are collected from thermal and nonthermal sites within the grid and from a nearby gas vent, known as Basalt Fumarole (Sorey and others, 1998), that is ~100 m west of the grid boundary.

The Shady Rest grid is about 3.4 km northwest of the Casa Diablo power plant (fig. 1) and, as of June 2010, had 129 measurement sites and covered about 100,000 m^2 (table 1).

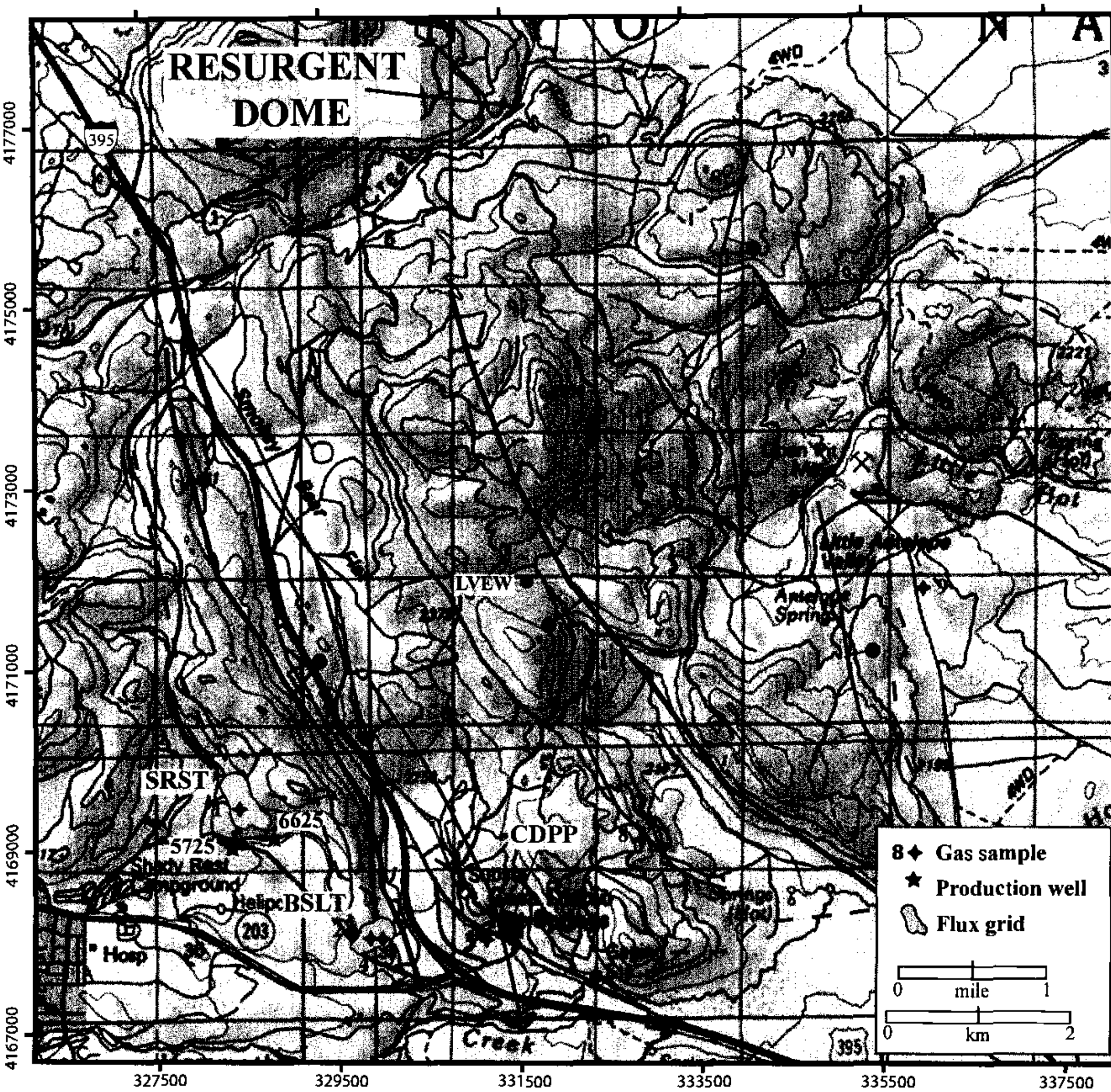


Figure 1. Map showing the resurgent dome, gas sample locations in kill zones, and the 5725 and 6625 production wells. Gray areas labeled BSLT (Basalt Canyon) and SRST (Shady Rest) show the extent of the flux grids. CDPP, Casa Diablo power plant; LVEW, Long Valley Exploration well. Locations where gas samples were collected are identified by a map number that is given in table 2.

Table 1. Summary statistics of flux data collected at Basalt Canyon and Shady Rest from 2006-2010, Long Valley Caldera, California.

[Weighted mean (*W*) and sequential Gaussian simulation (*S*) results given. Values in parentheses indicate the data did not satisfy the lognormal assumption, and are estimates calculated from weighted flux values using the arithmetically-derived mean]

Date	# of sites	Grid area m^2	Maximum flux $gm^{-2}d^{-1}$	Mean flux (*W*) $gm^{-2}d^{-1}$	Discharge (*W*) $t\ d^{-1}$	Range (*W*) $t\ d^{-1}$	Mean flux (*S*) $gm^{-2}d^{-1}$	Discharge (*S*) $t\ d^{-1}$	Range (*S*) $t\ d^{-1}$	Δ means (%)
					ALL BASALT CANYON					
06/2006	64	15.200	2.589	291	4.4	4-6	334	5.1	2-9	14
09/2006	62	15,125	2,602	273	4.1	3-6	330	5.0	2-9	19
06/2007	80	21,825	2.111	162	3.5	3-5	200	4.4	1-8	21
06/2008	83	20,600	3,151	237	4.9	4-7	261	5.4	2-10	10
07/2009	85	26,375	1,693	162	4.3	3-6	243	6.4	2-13	40
06/2010	88	23,125	1,700	162	3.7	3-5	192	4.4	2-10	17
					BASALT CANYON CORE SITES					
06 2006	60	14,800	2,589	283	4.2	3-6	333	4.9	2-8	16
09/2006	59	14,800	2,602	289	4.3	3-7	320	4.7	1-9	10
06/2007	60	14,800	2,111	205	3.0	2-4	255	3.8	<1-8	22
06/2008	60	14,800	3,151	258	3.8	3-6	364	5.4	2-9	34
07/2009	53	14,800	1,581	196	2.9	2-4	247	3.7	1-8	23
06/2010	61	14,800	1,327	182	2.7	2-4	190	2.8	<1-7	4
					ALL SHADY REST					
09/2006	81	61,000	867	121	7.4	6-10	147	9.0	5-12	20
06/2007	90	68,175	1,290	179	12.2	10-16	216	14.7	9-22	19
05/2008	105	77,575	898	93	7.2	6-9	126	9.8	6-13	30
07/2009	106	78,950	1,465	128 (113)	10.1 (8.9)	8-13	146	11.5	8-15	13 (25)
06/2010	129	98,800	1,332	99	9.8	8-12	142	14.0	9-20	36
					SHADY REST CORE SITES					
09/2006	77	61,000	820	112	6.8	5-9	135	8.2	5-12	18
06/2007	77	61,000	1,290	181	11.1	9-14	231	14.1	9-19	24
05/2008	77	61,000	898	102	6.2	5-8	121	7.4	4-11	17
07/2009	77	61,000	1,465	144	8.8	7-11	168	10.2	6-15	15
06/2010	77	61,000	492	111	6.8	5-9	121	7.4	5-10	9

The most recent area of tree kill is focused in the northeast and east portions of the grid. The center of the grid is comprised of mostly bare ground that is surrounded by live vegetation consisting of a mix of grass. brush, and widely spaced pine trees. Volcanic rocks include the same Quaternary-aged rhyolite found at Basalt Canyon (Bailey, 1989). The measurement grid includes a sub-boiling-temperature gas vent, commonly known as the Shady Rest fumarole, that is sampled routinely for gas. Two recently drilled geothermal production wells went online in summer 2006 and are about 0.5 km to the south of the grid (fig. 1).

Methods

Field Methods

The grids were established using pace and compass methods. Physical constraints imposed by dead trees, rock outcrops, steep topography, and roads are such that spacing between measurement sites is irregular. Locations are recorded using a Garmin® GPS, and each site is marked with flagging in an effort to measure the flux at the same spot during subsequent visits. Our goal is to measure flux at each site during each field visit, but sites sometimes are missed, and some sites have been abandoned. It typically requires two days to complete the flux measurements for each grid. In 2006 we made two sets of flux measurements at both grids. In subsequent years we made one set of measurements.

The CO_2-flux measurements were made using a West Systems flux meter, equipped with a LI-COR® 820 infrared CO_2 analyzer and an accumulation chamber. Detailed explanations about measurement techniques and methods for determining flux values are presented in Lewicki and others (2005) and Bergfeld and others (2006). Our protocol includes field calibration of the analyzer using CO_2-free air and a gas standard containing 1,000 ppm CO_2. At Basalt Canyon we use a 6-L accumulation chamber, which provides suffieient volume to compensate for the high fluxes without saturating the capacity of the CO_2 analyzer. At Shady Rest, the flux at most sites can be measured by using a 2.7-L chamber. Our laboratory tests using the large and small chambers show that measured fluxes underestimate the actual flux by about 7 percent and 10 percent, respectively. Soil temperatures are measured adjacent to the accumulation chamber coincident with each flux measurement. The target depth for soil-temperature measurements through 2008 was 10 cm. In 2009–10 soil temperatures were measured at 20 cm.

Gas samples are collected into evacuated glass bottles by inserting a stainless steel tube into the ground at an area of gas discharge. In some cases sample sites consist of a crack in the bedrock, and at other sites the collection tube is driven into the soil. Tygon® tubing is used to connect the stainless steel tube to the sample bottle. The collection apparatus is then purged of air, and the collection bottle is opened until gas stops flowing into the bottle.

Data Reporting

The CO_2 flux is reported as grams of CO_2 per square meter per day ($g/m^2/d$). Total CO_2 discharged from each grid is determined by multiplying the mean flux for all the sites by the grid area. CO_2 discharge is reported in units of metric tonnes of CO_2 emitted per day (t/d). The discharge is not corrected for biogenic CO_2 contributions, nor for the systematic under-estimation of flux revealed in laboratory testing. Many studies of diffuse CO_2 flux in volcanic and geothermal environments have shown that flux data are skewed positively with lognormal distributions (Bergfeld and others, 2001; Chiodini and others, 1998. 2001; Cardellini and others, 2003; Lewicki and others. 2005). Statistical analysis of the flux data from both Basalt Canyon and Shady Rest supports this premise (figs. 2 and 3; note that figs. 2 through 13 are at the back of this report); therefore, calculations of the mean CO_2 flux were determined by using methods that are appropriate for lognormal datasets. For this report we calculated the mean CO_2 flux by using two methods, and the difference in the results is reported as the absolute difference in the mean values divided by the average mean and expressed as a percent (table 1).

The weighted method (*W*) uses minimum variance estimator equations to determine mean flux values. To avoid any bias related to the irregular site spacing, a weighting factor is applied to each measured flux value. Weighting factors are calculated by inputting site location coordinates and measured flux values into the DECLUS module of the GSLIB geostatistical software package (Deutsch and Journel, 1998). Once calculated, the weighted flux data are log-transformed and are tested for a lognormal distribution using D'Agostino's test (Gilbert, 1987), as described in Bergfeld and others (2006). All but one of the weighted datasets satisfies the hypothesis of a lognormal distribution. The log-transformed weighted flux values are used to calculate the mean and 95-percent confidence interval about the mean by using minimum variance estimator equations given in Gilbert (1987) as presented in the appendix of Bergfeld and others (2006). The resulting means, and lower and upper limits from the confidence interval, are back-transformed, and those results are multiplied by the grid area to provide estimates of the total CO_2 discharge for the grid.

The sequential Gaussian simulation method (sGs) for estimating the means for each dataset also uses log-transformed flux values. The method produces multiple equiprobable outcomes of the spatial distribution of the flux over a 5 m^2 grid cell using the sgsim module of the GSLIB program (Deutsch and Journel, 1998), following methods outlined in Cardellini and other (2003) and Lewicki and others (2005). The sGs-technique is superior to using kriging to estimate flux at unsampled locations because it honors the measured flux values (Cardellini and others, 2003). The mean flux is determined from the summation of 1,000 simulations, and results are used to produce contour plots of the flux. Differences in results from the replicate simulations yield a 95-percent upper and lower boundary on the determined discharge and provide a measurement of uncertainty.

The summary statistics for each site visit are given in table 1 and include results for a subset of locations herein defined as "core sites," where measurements have been made on at least 80 percent of the site visits. Because the footprint of the core sites is static, the data are used for temporal comparisons of CO_2 emissions. Basalt Canyon and Shady Rest grids contain 61 and 77 core sites, respectively. At Shady Rest the full contingency of core sites was not established until September 2006. Flux data from the small grid at Shady Rest in June 2006 are not presented.

Results

Basalt Canyon Tree Kills, Soil Temperatures, and CO_2 Emissions

The kill zone at Basalt Canyon is a mixture of old and recent tree kills. The core sites are in the central portion of the grid and are characterized by long-dead, downed and standing trees that are stripped of their bark and are breaking apart. Many of these kills occurred during the mid-1990s and were associated with early power-plant operations at Casa Diablo (Bergfeld and others, 2006). New tree kills include large, mature pines and are found mostly in the northeast part of the grid. These new tree kills are recent enough that the bark is intact and brown needles and pine cones often are attached. The new kills are adjacent to what appears to be healthy forest. Shallow soil temperatures in this part of the grid are up to 50°C (fig. 4). Changes in soil temperature effect different tree species in varying ways (Pregitzer and others, 2000) and may induce stress that would contribute to increased mortality rates; however, at the time of this writing, the exact cause of tree death is not known.

Sites with the highest soil temperatures are clustered in the central section of the Basalt Canyon grid (fig. 4), and are located both along the bottom of the canyon, as well as along the western slope. The highest soil temperature measured at 10 cm was 92.9°C during the July 2007 site visit. Soil at steaming ground sites has low permeability, has been altered to clay, and commonly is encrusted with sulfur-bearing minerals. Steam tends to discharge at discrete points, such as the surface exposures of tree-root tunnels.

Plots of soil temperature versus CO_2 flux at Basalt Canyon show considerable scatter (fig. 5), and correlation coefficients (R) from linear regression of the data are ≤0.4 for all years. The low R-values reflect both the presence of high-temperature sites with moderate flux and sites with normal soil temperatures that have high CO_2 fluxes. There appears to be no difference in correlations between flux and temperatures whether the temperatures are measured at 10 cm or 20 cm.

During this investigation the maximum flux for each set of measurements at Basalt Canyon was between about 1,700 to 3,100 g/m²/d (table 1). Comparison of contour plots of the diffuse CO_2 flux from different years shows that although the intensity of the flux at an individual site may change from year to year, the general pattern across the grid is fairly static (fig. 6). The areas around the two gas-sampling sites often have the largest CO_2 fluxes and are separated from each other by a zone of lower flux sites. The CO_2 fluxes at the non-core sites in the east were lower than the CO_2 fluxes from core sites in the center of the grid (fig. 7).

The raw and weighted flux data for all years for the core sites and the full grid at Basalt Canyon pass D'Agostino's test as having a lognormal distribution. For most years the two methods of estimating the mean flux agree within 25 percent, with slightly higher means and larger confidence intervals estimated using the sGs method (table 1). Summary statistics for the flux data from core sites show that mean fluxes were between about 200–300 g/m²/d. The upper and lower bounds on discharge estimates for all years overlap (fig. 8), and comparison of the flux maps from core sites suggests that emissions were fairly constant during the course of this investigation (fig. 6). Total CO_2 discharge from Basalt Canyon core sites is about 3–5 t/d.

Shady Rest Tree Kills, Soil Temperatures, and CO_2 Emissions

The core sites at Shady Rest are centered on an area of mostly bare ground with some scattered grass, brush, and individual trees. The full grid includes more forested areas along the boundary. Most observed kills are of recent age and are clustered in two groups on the east side of the grid (fig. 9). As compared with Basalt Canyon, the Shady Rest kill areas have fewer old decayed trees, although this may be a function of easy access and firewood scavenging.

Soil-temperature measurements at 10 cm show that, in general, Shady Rest sites are cooler than sites at Basalt Canyon (figs. 4 and 9). In winter, snow will accumulate later and melt sooner from sites around the Shady Rest fumarole, but unlike Basalt Canyon, there are no large patches of steaming ground. We have observed steam issuing only from a few point-source locations at Shady Rest. The highest soil temperature at a grid site was 75.0°C. Plots of soil temperature and CO_2 flux show the data are positively correlated with correlation coefficients around 0.7 for most years (fig. 10).

In general, Shady Rest sites with the highest fluxes are oriented along a north-south trend that incorporates the location of the Shady Rest fumarole (figs. 11 and 12). The maximum flux from each set of measurements was between about 850 and 1,500 g/m²/d (table 1) and was obtained at one of two sites in the north near one of the areas of recent tree kills. In 2009 we discovered a discrete patch of slightly thermal ground with some recent tree kills ~200 m southeast of the main grid boundary. In 2010 the area was incorporated into the Shady Rest grid. The new sites have moderately high fluxes, up to ~300 g/m²/d, and are aligned along a southeast trend in line with the 6625 geothermal production well (fig. 12*E*).

Table 2. Sample locations, gas chemistry in volume percent and permil (‰) carbon isotope values of samples collected on or around the resurgent dome, Long Valley Caldera, California.

[Sites are characterized as discrete gas vents (V), steaming ground (SG), and nonthermal (NT). n-C_4H_{10} and i-C_4H_{10} are normal- and iso-butane. Basalt Canyon Extended grid site 24 (BCE 24), Basalt fumarole (BF), Casa Diablo fumarole (CDF), Casa Diablo north (CDN), Chris' hot spot (CHS), Fumarole Valley (FV); Isha fumarole (ISHA), Shady Rest fumarole (SRF), Teapot (TPT), not analyzed (na), not recorded (nr). Datum for the UTM coordinates is referenced to WGS84 zone 1]

Location	Date	Temp. (C)	Map #	Type	Easting (m)	Northing (m)	CO_2	He	H_2	Ar
							-----------volume percent-----------			
				Basalt Canyon Area						
CHS	12/06/95	91.0	3	SG	329974	4168152	98.6	0.001	0.024	0.020
CHS	09/29/99	nr	3	SG	329974	4168152	98.1	0.001	0.039	0.023
Near CHS	06/08/10	91.5	3 *	SG	329977	4168147	98.8	0.002	0.022	0.012
BCE 24	07/26/04	32.5	4	NT	329872	4168129	84.2	0.001	0.001	0.143
BF	07/31/90	nr	2	V	329698	4168166	96.8	0.006	0.003	0.039
BF	11/01/95	92	2	V	329698	4168166	97.4	0.005	0.021	0.032
BF	08/03/96	nr	2	V	329698	4168166	97.4	0.004	0.010	0.031
BF	06/16/97	nr	2	V	329698	4168166	97.5	0.003	0.013	0.035
BF	01/01/98	nr	2	V	329698	4168166	96.9	0.003	0.009	0.032
BF	07/26/04	91.0	2	V	329698	4168166	97.4	0.004	0.026	0.029
BF	07/14/06	92.0	2	V	329698	4168166	97.6	0.005	0.006	0.027
				Shady Rest						
SRF	09/25/96	90	1	V	328427	4169615	81.4	0.004	0.029	0.159
SRF	06/19/97	nr	1	V	328427	4169615	69.1	0.003	0.011	0.276
SRF	06/06/02	89.6	1	V	328427	4169615	85.1	0.004	0.009	0.130
SRF	07/14/06	91.0	1	V	328427	4169615	85.9	0.005	0.002	0.132
SRF	06/22/09	79.2	1	V	328427	4169615	70.9	0.004	0.035	0.271
SRF	09/08/10	87.9	1	V	328427	4169615	63.5	0.002	0.037	0.343
				Other Kill Areas						
CDN	02/12/03	92.7	5	SG	331005	4167986	92.9	0.001	0.055	0.069
CDF	09/18/02	nr	6	V	331758	4168378	96.7	0.002	0.245	0.050
CDF	07/14/06	94.1	6	V	331758	4168378	97.6	0.001	0.065	0.031
TPT	03/25/04	86.0	7	SG	329860	4169286	73.5	0.004	0.057	0.239
FV	06/09/99	nr	8	V	332894	4169428	69.3	0.001	0.027	0.306
FV	Sept. 1999	nr	8	V	332894	4169428	98.4	0.002	0.014	0.018
FV	10/13/06	nr	8	V	332894	4169428	98.1	0.003	0.021	0.025
ISHA	10/24/89	nr	9	SG	336024	4171860	53.6	0.003	0.008	0.489
ISHA	11/13/03	32.8	9	SG	336024	4171860	36.4	0.004	0.001	0.612

*Near site 3 on figure 1.

O_2	N_2	CH_4	C_2H_6	H_2S	C_3H_8	n-C_4H_{10}	i-C_4H_{10}	$\delta^{13}C$-CO_2 (‰)	N_2/Ar	N_2/O_2
volume percent										
Basalt Canyon Area										
0.05	1.0	0.060	0.001	0.193	<0.0005	<0.0005	0.003	na	52	19
0.10	1.5	0.056	<0.0002	0.204	<0.0005	0.003	0.003	−4.0	65	15
0.03	0.8	0.037	<0.0002	0.364	<0.0005	<0.0005	na	−4.1	65	28
2.7	13.0	0.001	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	−3.4	91	5
0.04	2.9	0.124	<0.0002	0.090	na	na	na	−3.8	76	78
0.06	2.1	0.116	0.001	0.169	<0.0005	<0.0005	0.006	−4.0	67	34
0.11	2.2	0.112	0.001	0.203	<0.0005	<0.0005	0.007	−3.9	69	20
0.02	2.1	0.108	0.001	0.207	<0.0005	<0.0005	0.008	na	60	127
0.15	2.6	0.106	0.000	0.204	<0.0005	<0.0005	0.008	na	80	17
0.06	2.1	0.102	0.000	0.227	<0.0005	<0.0005	0.015	−4.1	75	37
0.02	2.0	0.101	0.001	0.226	<0.0005	<0.0005	0.015	−3.9	74	81
Shady Rest										
3.0	15.0	0.027	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	−3.9	97	5
5.7	25.0	0.023	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	na	90	4
2.7	12.0	0.059	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	−3.7	92	4
2.4	12.0	0.062	0.000	<0.0005	<0.0005	<0.0005	<0.0005	−4.4	87	5
5.7	23.0	0.049	0.002	0.019	<0.0005	<0.0005	<0.0005	na	85	4
7.2	29.0	0.044	<0.0002	0.030	<0.0005	<0.0005	<0.0005	−3.7	84	4
Other Kill Areas										
1.3	5.6	0.031	0.001	0.083	<0.0005	<0.0005	0.009	−4.6	80	4
0.07	2.5	0.041	<0.0002	0.332	0.001	0.001	0.058	−6.9	51	37
0.04	1.7	0.026	<0.0002	0.427	<0.0005	<0.0005	0.035	−5.7	56	45
5.1	21.0	0.046	<0.0002	<0.0005	<0.0005	<0.0005	0.007	−4.4	88	4
5.6	25.0	0.048	0.000	<0.0005	<0.0005	<0.0005	0.020	na	81	4
0.05	1.4	0.063	0.001	0.050	<0.0005	0.001	0.030	−5.4	79	31
0.07	1.5	0.062	<0.0002	0.231	0.001	0.001	0.079	na	58	20
8.5	37.0	0.030	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	na	77	4
12.0	51.0	0.037	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	−5.1	83	4

All but one of the flux datasets from Shady Rest pass D'Agostino's test as having a lognormal distribution. The test was negative for the full grid from 2009, and we calculated the simple arithmetic mean of the weighted flux values (shown in the parentheses in table 1), as well as the mean, by using the minimum variance estimator. For all datasets the mean flux determinations from the sGs method are higher, and the confidence intervals are larger, than those derived from the weighted-flux values (table 1). Differences in the means derived from the two methods are ≤36 percent and generally are better than 25 percent.

Estimates of the total CO_2 emissions from Shady Rest core sites in 2006, 2008, 2009, and 2010 are similar, and the ranges in the discharge estimates for these 4 sets of measurements overlap (fig. 13). The results indicate about 6–9 tonnes of a CO_2 per day (7–10 from sGs) discharged from the central portion of the grid (table 1). The discharge estimate (11–14 t/d) and the contour plot from the 2007 measurements stand out as having higher emissions than in other years (figs. 11 and 13).

Gas Chemistry from Sites on or Around the Resurgent Dome

Table 2 gives analyses of gas samples collected from discrete gas vents (V), steaming ground (SG) sites, and a nonthermal (NT) high flux (500–900 g/m^2/d) site in the Basalt Canyon grid. The gas compositions are dominated by CO_2, but gas from many sites contains significant amounts of atmospheric components (Ar, N_2 and O_2). H_2S is a component in the gas from thermal sites around Basalt Canyon, as well as other sites near the Casa Diablo power plant, but until recently was not detected at the Shady Rest fumarole. CH_4 is detectable in all gas samples, irrespective of location. The carbon isotope composition of CO_2 collected at nine locations is between –6.9 and –3.4 permil. The $\delta^{13}C$ values of CO_2 from sites around Basalt Canyon and Shady Rest are indistinguishable and range from –4.4 to –3.4 permil. These values are similar, but slightly higher than the $\delta^{13}C$ composition of CO_2 from Mammoth Mountain fumarole (–5.5 to –4.5 permil, Sorey and others, 1998). Isobutane (i-C_4H_{10}), the working fluid used at the Casa Diablo power plant, is detected at numerous thermal sites, but has not been found in gas from the Shady Rest fumarole.

Summary

Comparison of the Two Areas

In a visual sense, the kill areas at Basalt Canyon and Shady Rest are distinct. The prominent tree and brush kills in the center of Basalt Canyon have been the focus points for steam and gas upflow for decades, and many of the old logs and stumps are coated with a layer of sulfur. The kill area at Shady Rest contains more subtle features and stands out from its surroundings as unusual in that there is a large area of mostly bare ground. Both Basalt Canyon and Shady Rest are, however, similar in that development of new areas of tree kill is an ongoing phenomena.

The Basalt Canyon and Shady Rest study areas are located over thermal fluid upflow zones. Overall, the CO_2 fluxes are higher at Basalt Canyon than at Shady Rest, but the extent of discharge zone at Basalt Canyon is confined to a smaller area. At Shady Rest the CO_2 flux and soil temperatures are moderately-to-well correlated, indicating that CO_2 and steam are transported together. The correlation between flux and soil temperature at Basalt Canyon is poor. Sites with a low flux and high soil temperatures occur in areas of strong fluid upflow where alteration products, such as clays and mineral sublimates, occlude void spaces, decreasing permeability. The presence of low-temperature, high-flux sites at Basalt Canyon may reflect steam condensation in the subsurface.

During the course of this investigation, total CO_2 emissions from the Basalt Canyon core sites were constant. We estimate that about 3–5 tonnes of CO_2 per day discharge from the central core part of the grid. CO_2 emissions from the Shady Rest core sites were more variable and ranged from 6 to 14 t/d. The variability could be related to changes in the shallow hydrothermal system resulting from geothermal fluid production at the new wells. At present, we do not have the temporal data needed to fully assess this hypothesis, but the alignment of high CO_2 flux sites in the direction of the 6625 well (fig. 12) lends support to this idea.

The composition of gases collected from sites at Shady Rest and Basalt Canyon distinguishes gas across the two areas. While the carbon isotope composition of CO_2 indicates a common source of CO_2, other components, such as isobutane, and until recently H_2S, are distinct to thermal features around Basalt Canyon. All samples collected from the Shady Rest fumarole have entrained air, which tends to oxidize H_2S and may be part of the reason that it rarely is detected. The presence of H_2S in 2009-10 samples could, however, indicate a change in fluid chemistry related to production from the new wells. Isobutane, which is unaffected by the presence of air, has never been detected at Shady Rest.

Isobutane enters the thermal aquifer at Long Valley when occasional leaks in heat exchangers at the Casa Diablo power plant cause it to be injected along with spent geothermal fluids into deep parts of the geothermal reservoir (Evans and others, 2004). It has been detected in gas samples collected at Basalt Canyon since 1995 (table 2) and may have reached the area before that time. The purpose of injection is to provide pressure support in the geothermal reservoir and the presence of isobutane in gas samples at Basalt Canyon shows that volatiles from the injectate have reached the underlying area. The pressure support provided by the injectate would stabilize the depth of boiling in the reservoir and, consequently, would control the upflow of steam and CO_2, producing more constant CO_2 emissions.

The absence of isobutane at Shady Rest may be a function of distance from the injection wells and may indicate the shallow reservoir in the area lacks pressure support.

Without sufficient pressure support, the shallow hydrothermal system would respond to the 2006 onset of fluid production at the 5725 and 6625 wells. Variations in CO_2 emissions since that time may reflect adjustments in the shallow reservoir to the fluid production.

Further Work

Results of CO_2 flux mapping since 2006 provide a well-constrained estimate of diffuse CO_2 emissions at Basalt Canyon. As a tool for volcano monitoring, the baseline information needed is now available for comparison if, in the future, seismicity or deformation rates change. Barring such changes, continued study of CO_2 flux at Basalt Canyon provides only information on geothermal fluid upflow. Our understanding of baseline CO_2 emissions at Shady Rest also is well constrained, but drilling of a new production well west of Shady Rest commenced in late 2010. Additional study of the CO_2 fluxes, and a more in-depth study of soil temperatures, is warranted as the new well goes into production. Collection of gas samples at both sites should continue as part of future monitoring efforts at both sites.

References Cited

Bailey, R.A., 1989, Geologic map of Long Valley Caldera, Mono-Inyo Craters volcanic chain, and vicinity, Mono County, California: U.S. Geological Survey Miscellaneous Investigations Map I-1933, scale 1:62,500.

Bergfeld, D., Evans, W.C., Howle, J.F., Farrar C.D., 2006, Carbon dioxide emissions from vegetation-kill zones around the resurgent dome of Long Valley Caldera, eastern California, USA: Journal of Volcanology and Geothermal Research, v. 152, no. 1-2, p. 140–156.

Bergfeld, D., Goff, F., and Janik, C.J., 2001, Elevated carbon dioxide flux at the Dixie Valley geothermal field, Nevada; relations between surface phenomena and the geothermal reservoir: Chemical Geology, v. 177, no. 1-2, p. 43–66.

Cardellini, C., Chiodini, G., Frondini, F., 2003, Application of stochastic simulation to CO_2 flux from soil, mapping and quantification of gas release: Journal of Geophysical Research, v. 108, no. B9, 2425, doi:10.1029/2002JB002165.

Chiodini, G., Cioni, R., Guidi, M., Raco, B. and Marini, L., 1998, Soil CO_2 flux measurements in volcanic and geothermal areas: Applied Geochemistry, v. 13, no. 5, p. 543–552.

Chiodini, G., Frondini, F., Cardellini, C., Granieri, D., Marini, L., and Ventura, G., 2001, CO_2 degassing and energy release at Solfatara volcano, Campi Flegrei, Italy: Journal of Geophysical Research, v. 106, no. B8, p. 16213–16221.

Deutsch, C.V., Journel, A.G., 1998, GSLIB, geostatistical software library and user's guide (Applied Geostatistics Series), 2nd ed., Oxford University Press, 369 p.

Evans, W.C., Lorenson, T.D., Sorey, M.L., and Bergfeld, D., 2004, Transport of injected isobutane by thermal groundwater in Long Valley Caldera, California, USA, in Wanty, R.B. and Seal II, R.R. eds., Water-Rock Interaction-11, Saratoga Springs, Balkema, p. 125–129.

Gilbert, R.O., 1987, Statistical methods for environmental pollution monitoring: New York, Van Nostrand Reinhold, 320 p.

Lewicki, J.L., Bergfeld, D., Cardellini, C., Chiodini, G., Granieri, D., Varley, N., Werner C., 2005, Comparative soil CO_2 flux measurements and geostatistical estimation methods on Masaya volcano, Nicaragua: Bulletin of Volcanology, v. 68, no. 1, p. 76–90.

Pregitzer, K.S., King, J.S., Burton, A.J., Brown, S.E., 2000, Responses of tree fine roots to temperature: New Phytologist, v. 147, p. 105–115.

Sorey, M.L., Evans, W.C., Kennedy, B.M., Farrar, C.D., Hainsworth, L.J., Hausback, B., 1998, Carbon dioxide and helium emissions from a reservoir of magmatic gas beneath Mammoth Mountain, California: Journal of Geophysical Research, v. 103, no. B7, p. 15303–15323.

Figures 2–13

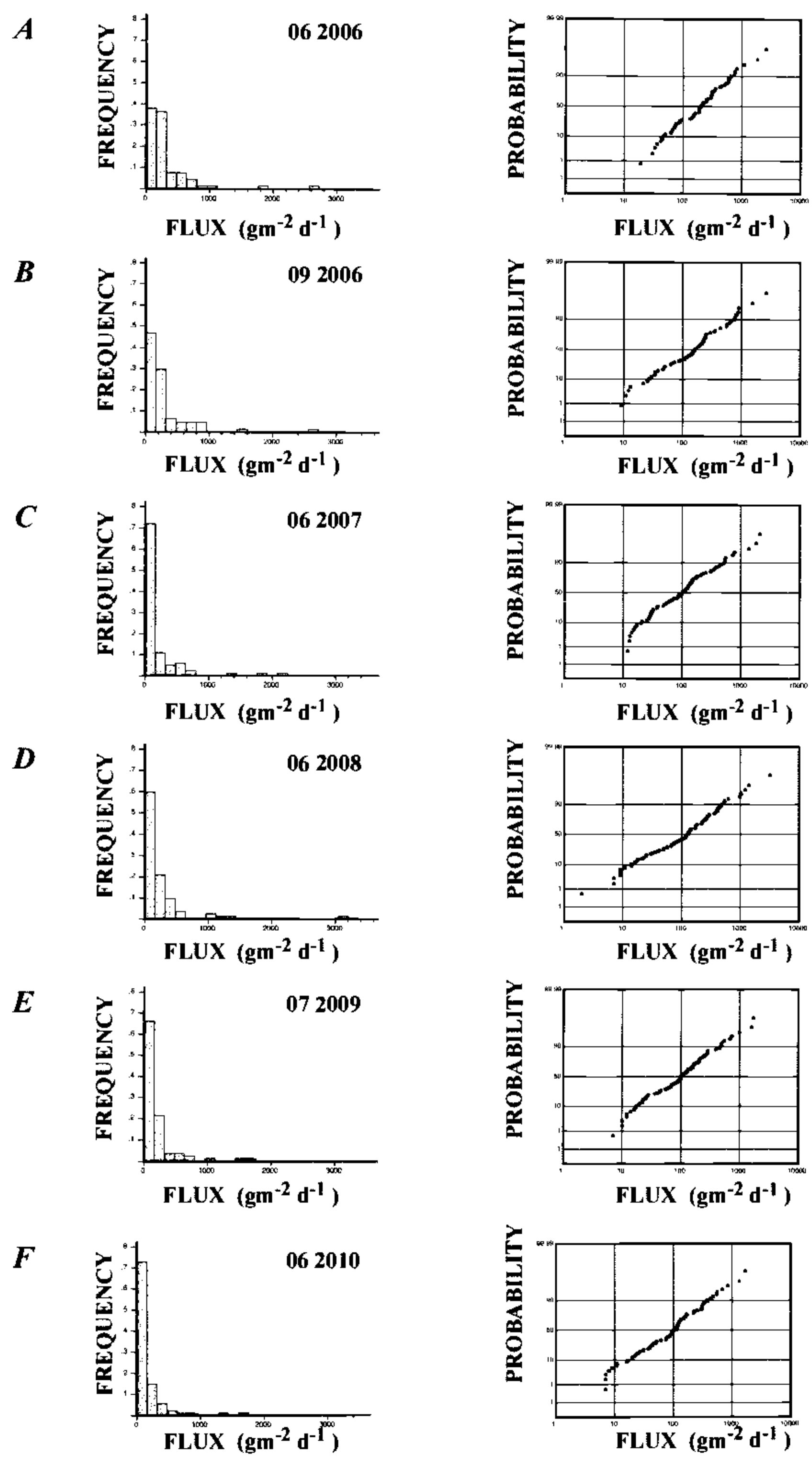


Figure 2. Histograms and cumulative probability plots showing flux values from the Basalt Canyon grid from the June 2006–June 2010 site visits. Flux data are positively skewed. Kinks in the probability plots indicate multiple populations of data, and linear trends within a population suggest a lognormal distribution.

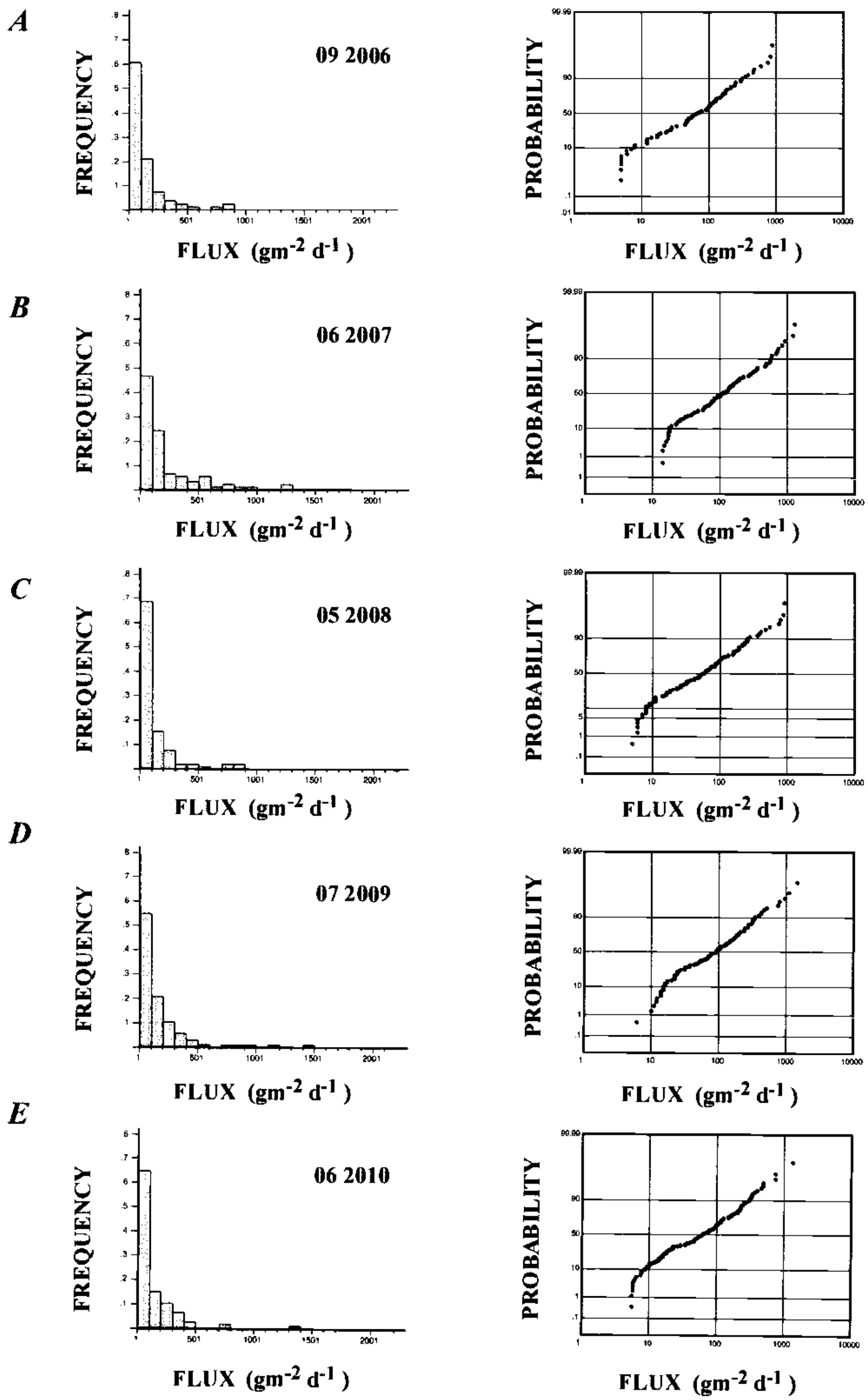


Figure 3. Histograms and cumulative probability plots showing flux values from the Shady Rest grid from the September 2006–June 2010 site visits. Flux data are positively skewed. Kinks in the probability plots indicate multiple populations of data, and linear trends within a population suggest a lognormal distribution.

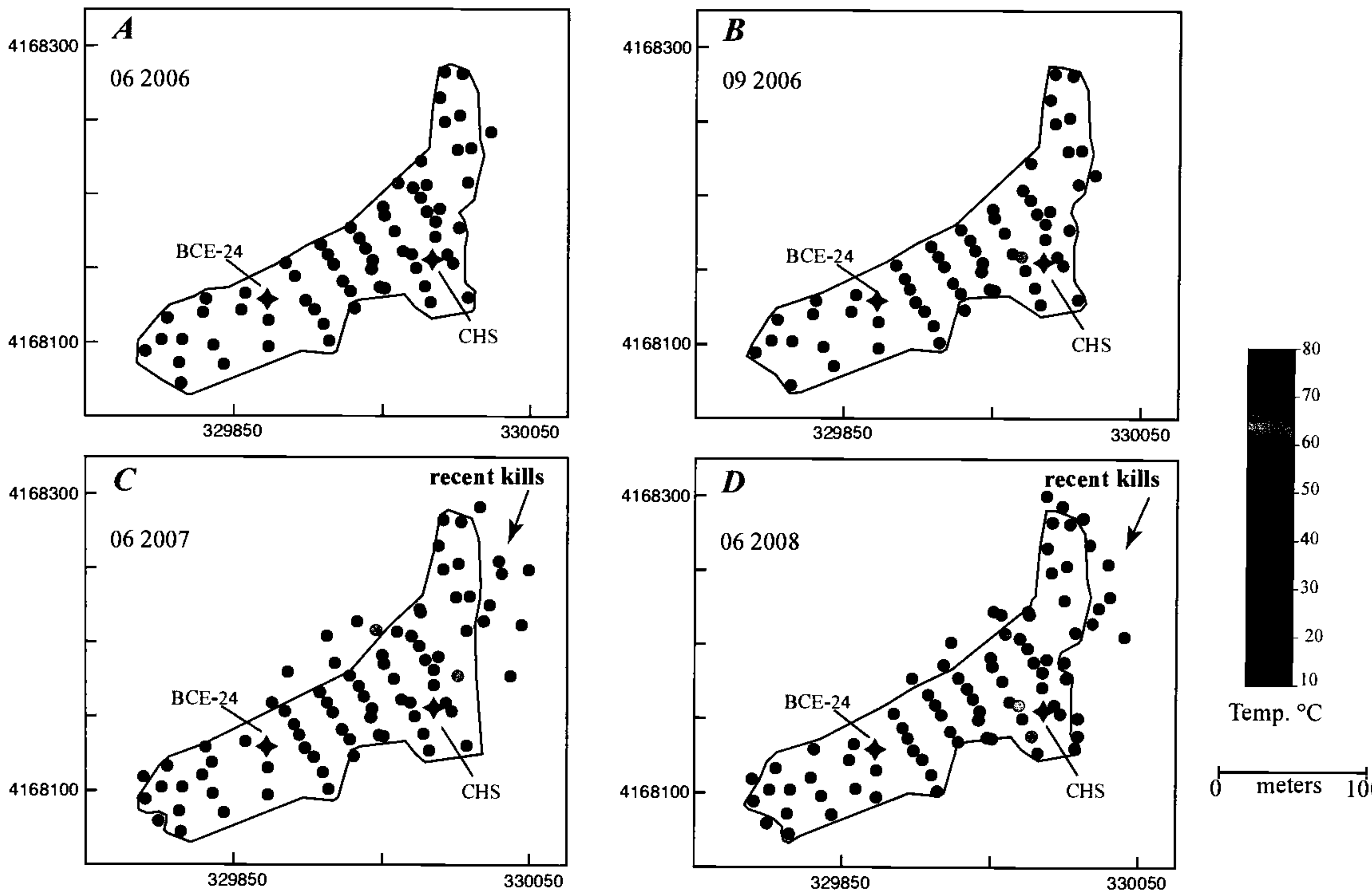


Figure 4. Map showing color-coded soil temperatures at 10 cm for the Basalt Canyon grid from the June 2006–June 2008 site visits. Star symbols are color-coded according to soil temperature and show the CHS and BCE-24 gas-sample locations. The heavy black line delineates the extent of the core sites. Circles marked with an "x" indicate that the location is not a designated core site. The black arrow in *C* and *D* shows the general location of the most recent tree kills.

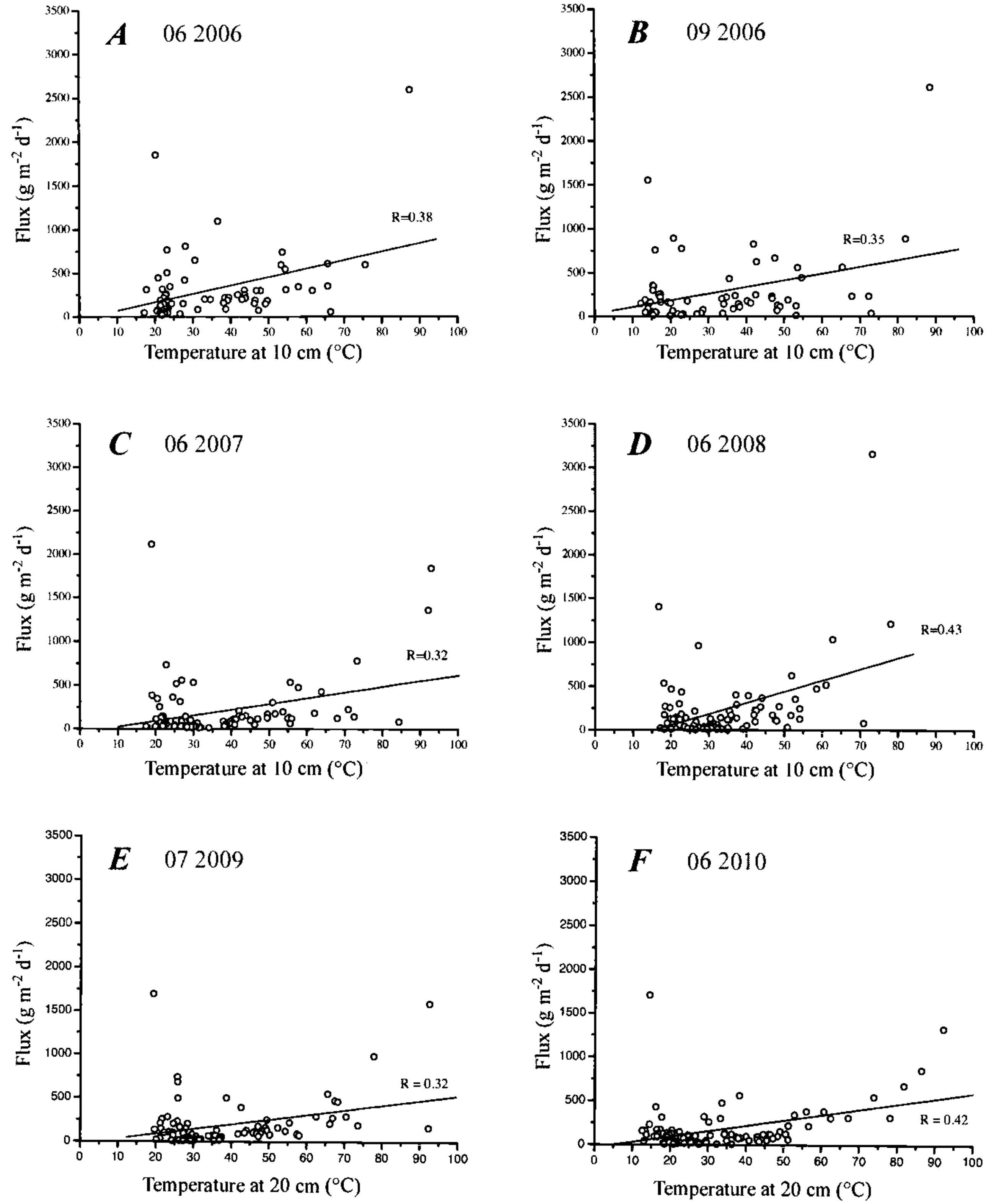


Figure 5. Scatter plots showing CO_2 flux versus soil temperature for the Basalt Canyon grid from June 2006–June 2008 at 10 cm and for July 2009–June 2010 at 20 cm. The R-values are the correlation coefficients calculated for linear regressions of the datasets.

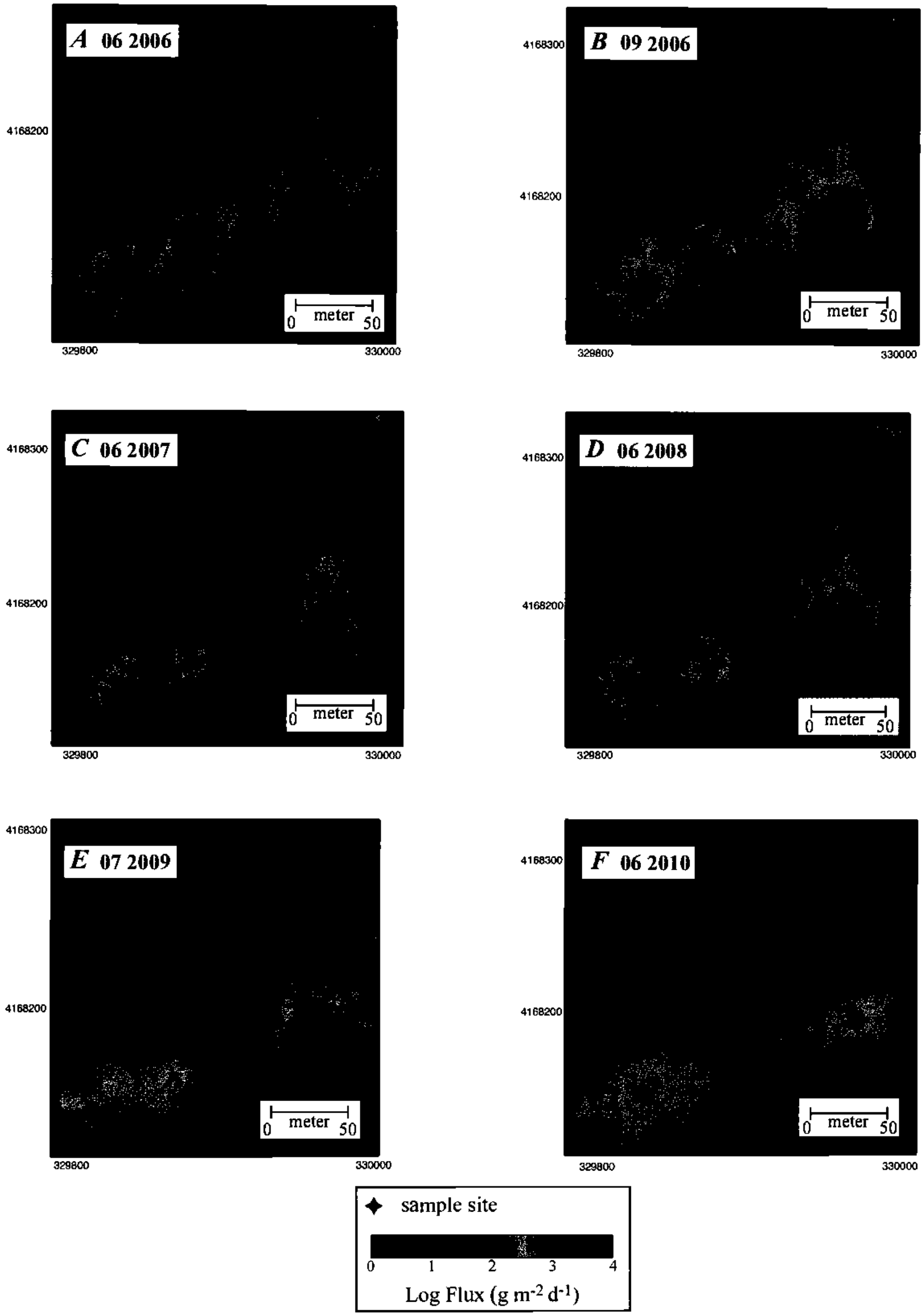


Figure 6. Contour plots from sGs calculations showing the diffuse CO_2 flux at core sites in the Basalt Canyon grid from the June 2006–June 2010 site visits. The black stars show the CHS (east) and BCE-24 (west) gas-sample locations.

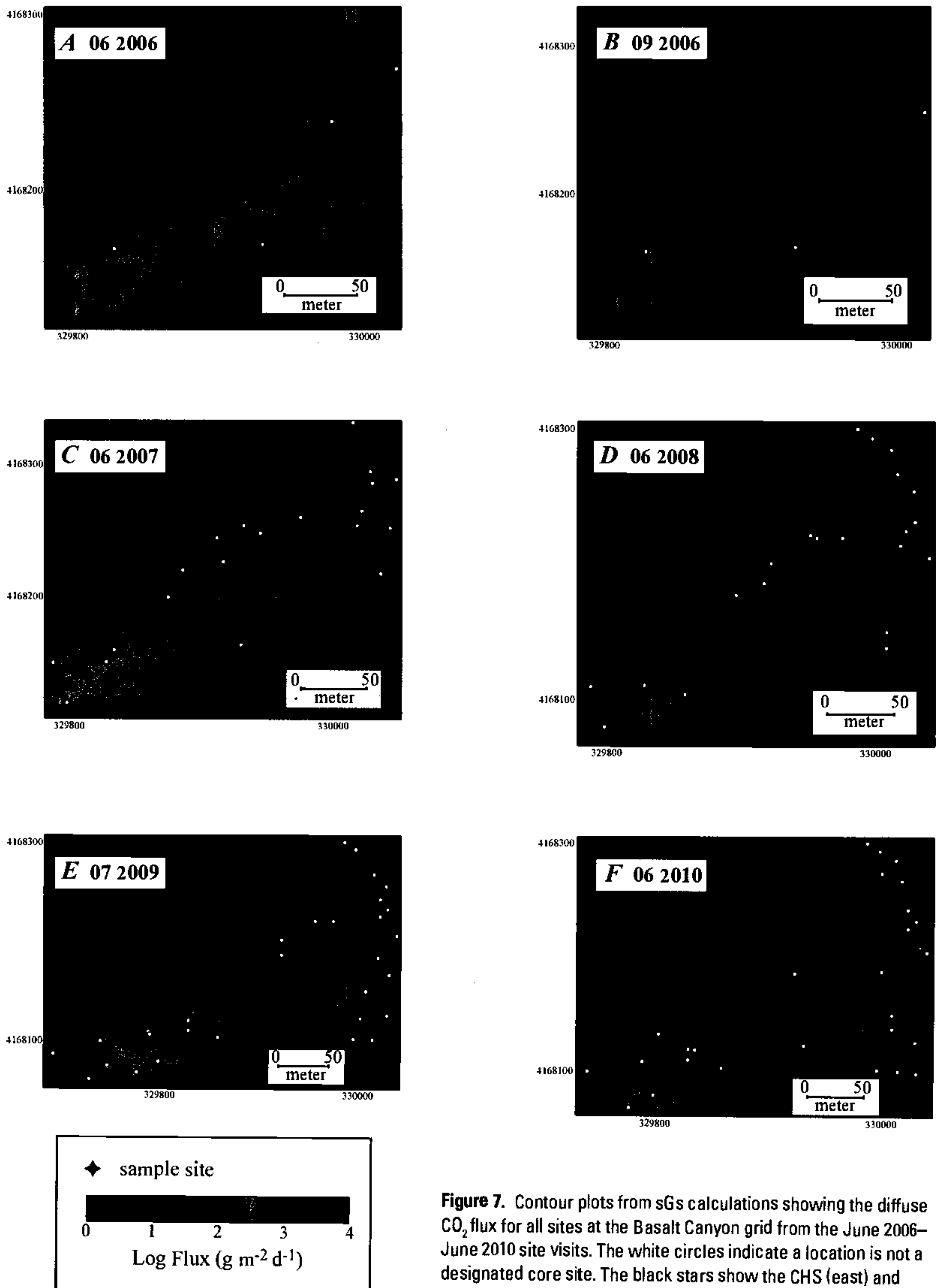


Figure 7. Contour plots from sGs calculations showing the diffuse CO_2 flux for all sites at the Basalt Canyon grid from the June 2006–June 2010 site visits. The white circles indicate a location is not a designated core site. The black stars show the CHS (east) and BCE-24 (west) gas-sample locations.

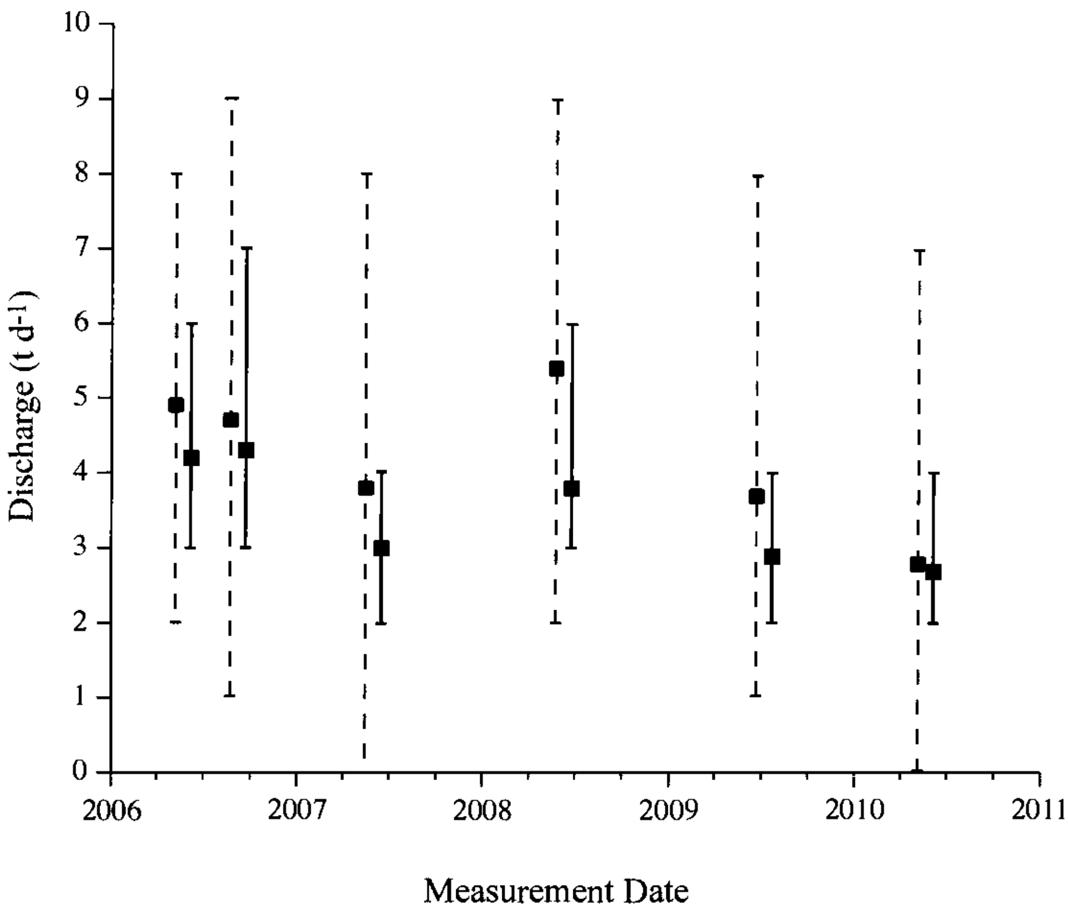
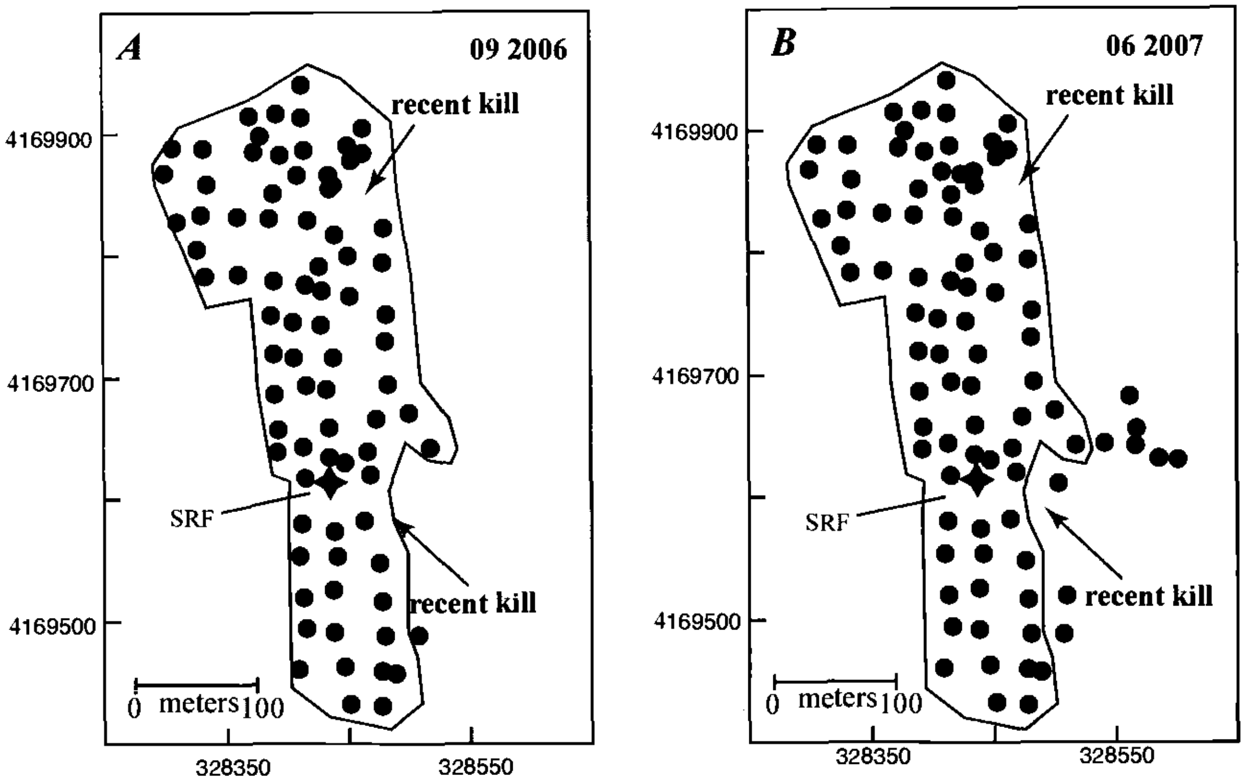
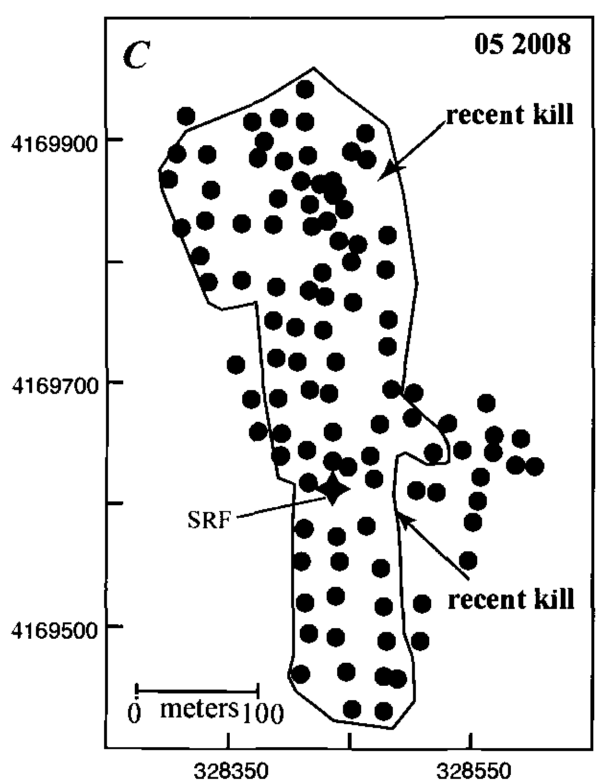


Figure 8. Plot showing the average CO_2 discharge from core sites at Basalt Canyon for 6 sets of measurements between June 2006 and June 2010. Error bars represent the range in emissions estimated for a 95-percent confidence interval. Black squares show average emissions calculated from minimum variance estimator equations. Red squares show average emissions based on sGs determinations and are offset slightly for clarity.





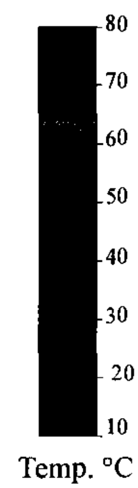


Figure 9. Map showing color-coded soil temperatures at 10 cm at the Shady Rest grid from the September 2006–May 2008 site visits. The star symbol is color-coded according to soil temperature and shows the location of the Shady Rest fumarole. The heavy black line delineates the extent of the core sites. Circles marked with an "x" indicate that the location is not a designated core site. The arrows show general locations of recent tree kills.

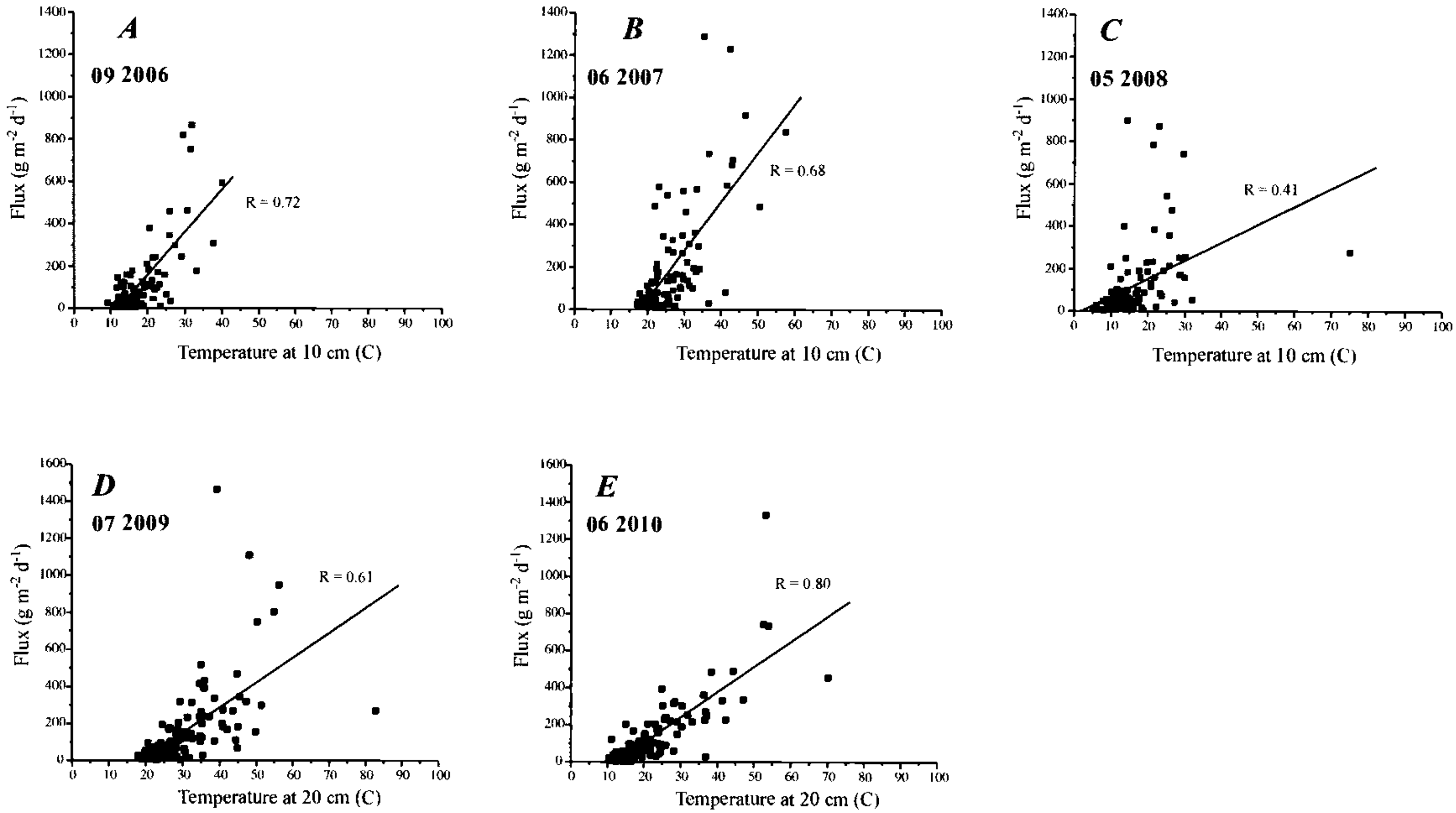


Figure 10. Scatter plots showing CO_2 flux versus soil temperature for the Shady Rest grid from September 2006–May 2008 at 10 cm and for July 2009–June 2010 at 20 cm. Note the larger scale for flux values (y-axis) from the 2009–10 data. The R-values are the correlation coefficients calculated for linear regressions of the datasets.

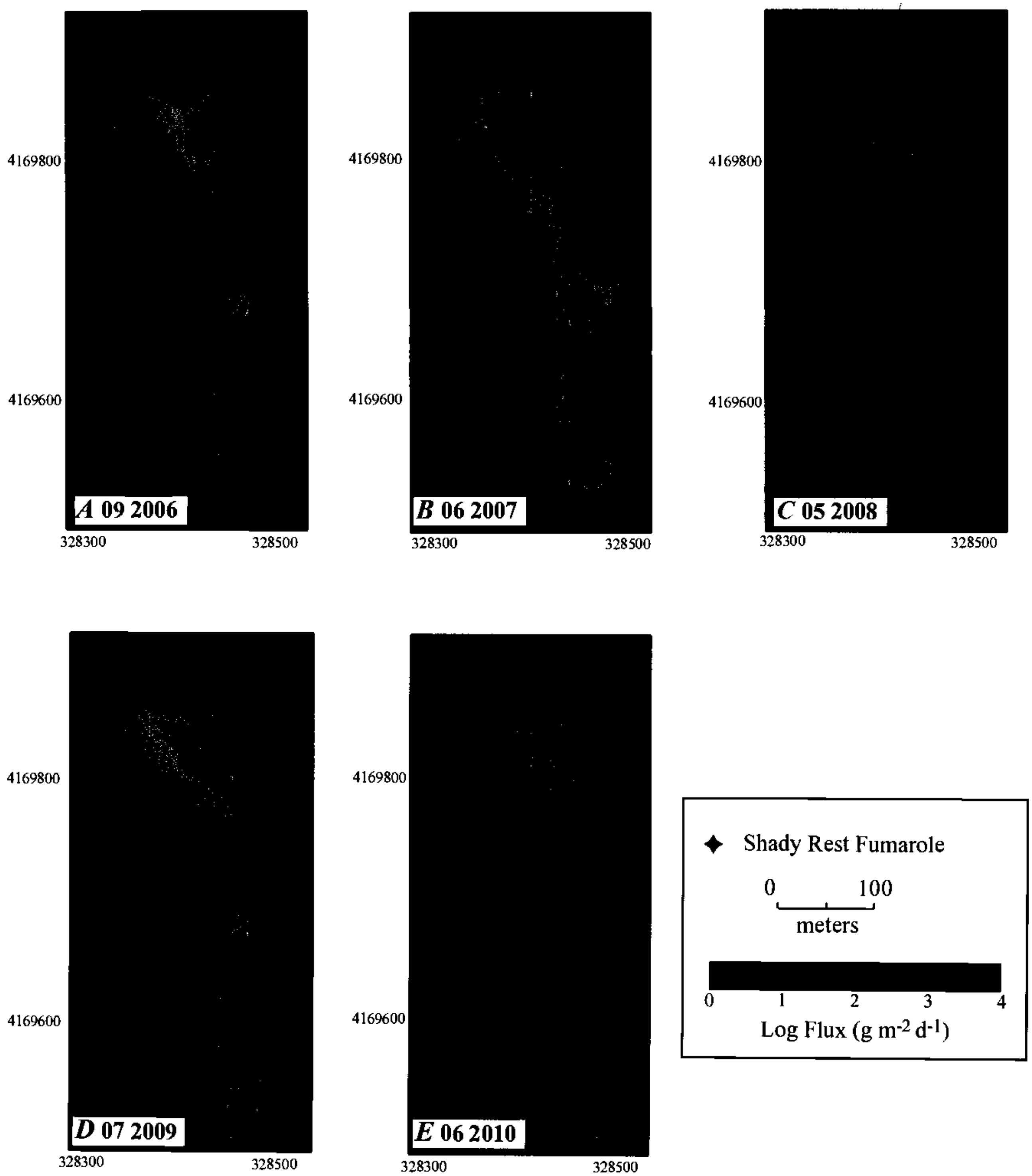
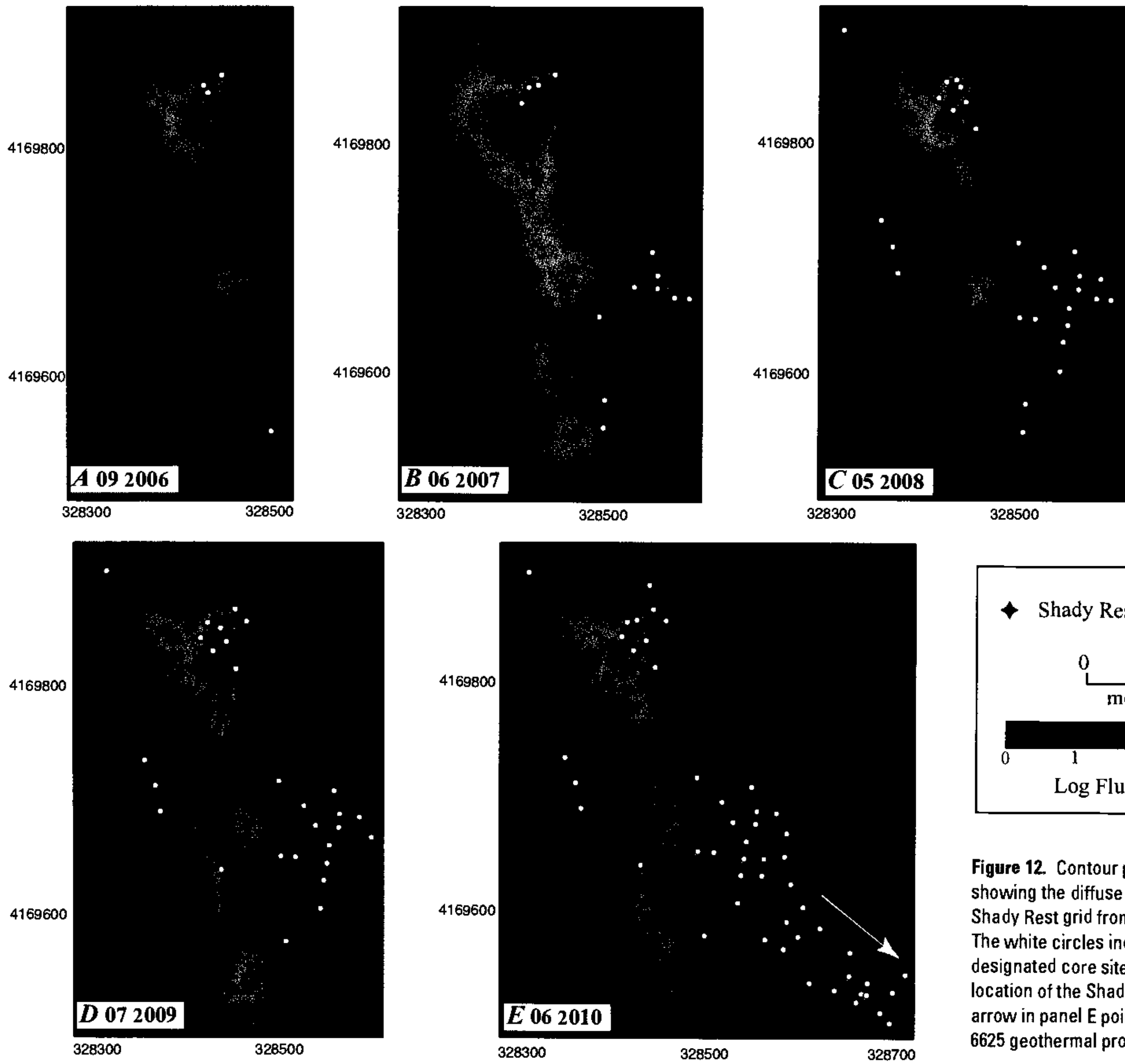


Figure 11. Contour plots from sGs calculations showing the diffuse CO_2 flux at core sites in the Shady Rest grid from the September 2006–June 2010. The black star shows the location for Shady Rest fumarole.



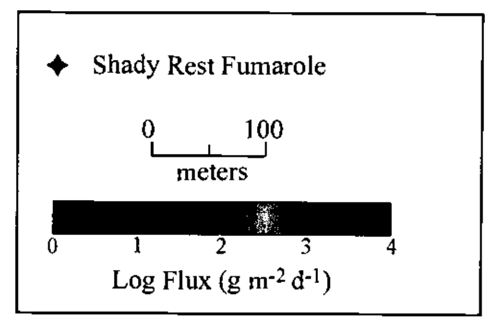


Figure 12. Contour plots from sGs calculations showing the diffuse CO_2 flux for all sites at the Shady Rest grid from September 2006–June 2010. The white circles indicate a location is not a designated core site. The black star shows the location of the Shady Rest fumarole. The white arrow in panel E points toward the location of the 6625 geothermal production well.

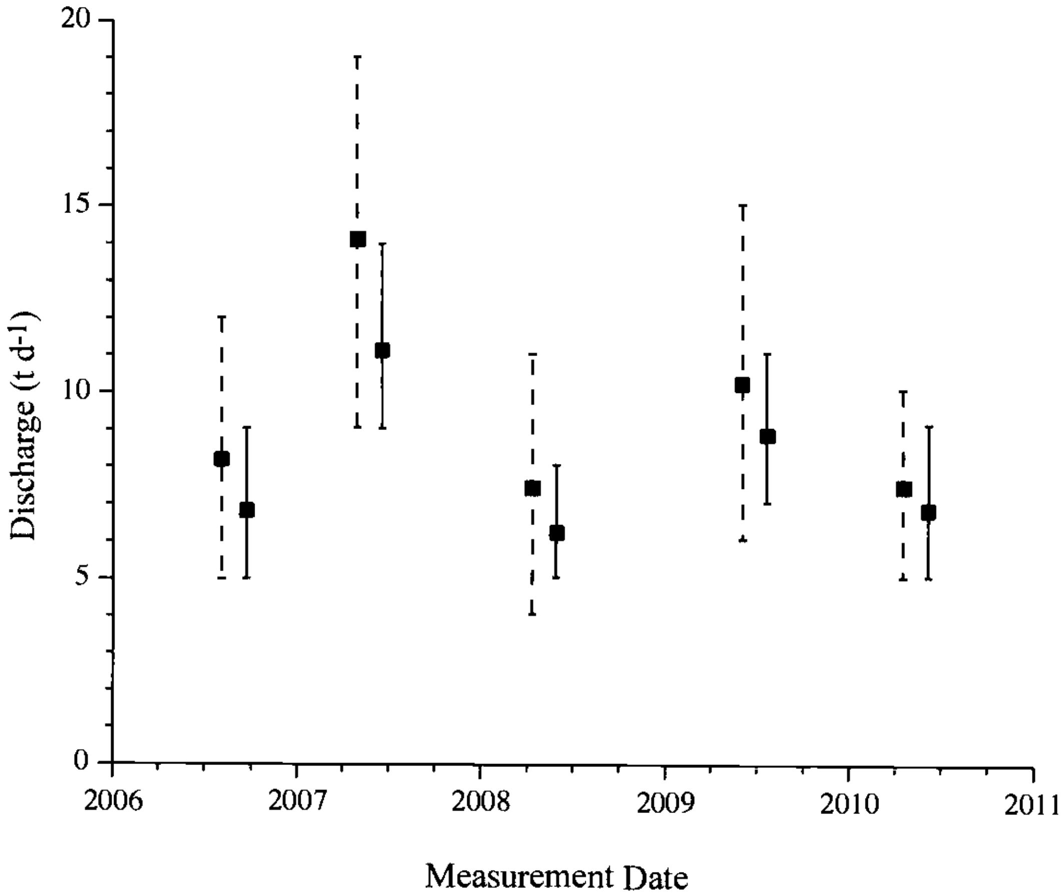


Figure 13. Plot showing the average CO_2 discharge from core sites at Shady Rest for five sets of measurements made between September 2006 and June 2010. Error bars represent the range in emissions estimated for a 95-percent confidence interval. Black squares show average emissions calculated from minimum variance estimator equations. Red squares show average emissions based on sGs determinations and are offset slightly for clarity.

Produced in the Western Region, Menlo Park, California
Manuscript approved for publication March 8, 2011
Text edited by Tracey Suzuki
Layout and design by Judy Weathers

EXHIBIT E

10-K 1 d261816d10k.htm FORM 10-K

Table of Contents

UNITED STATES SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549

Form 10-K

☑ **ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934**

For the fiscal year ended December 31, 2011

or

☐ **TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934**

Commission file number: 001-32347

ORMAT TECHNOLOGIES, INC.

(Exact name of registrant as specified in its charter)

DELAWARE	**88-0326081**
(State or other jurisdiction of incorporation or organization)	*(I.R.S. Employer Identification Number)*

6225 Neil Road, Reno, Nevada 89511-1136
(Address of principal executive offices)

Registrant's telephone number, including area code:
(775) 356-9029

Securities Registered Pursuant to Section 12(b) of the Act:

Title of Each Class	Name of Each Exchange on Which Registered
Ormat Technologies, Inc. Common Stock $0.001 Par Value	New York Stock Exchange

Securities Registered Pursuant to Section 12(g) of the Act:
None

Indicate by check mark if the registrant is a well-known seasoned issuer, as defined in Rule 405 of the Securities Act. Yes ☐ No ☑

Indicate by check mark if the registrant is not required to file reports pursuant to Section 13 or Section 15(d) of the Exchange Act. Yes ☐ No ☑

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days. Yes ☑ No ☐

Indicate by check mark whether the registrant has submitted electronically and posted on its corporate Web site, if any, every Interactive Data File required to be submitted and posted pursuant to Rule 405 of Regulation S-T (§ 232.405 of this chapter) during the preceding 12 months (or for such shorter period that the registrant was required to submit and post such files). Yes ☑ No ☐

Indicate by check mark if disclosure of delinquent filers pursuant to Item 405 of Regulation S-K is not contained herein, and will not be contained, to the best of registrant's knowledge, in definitive proxy or information statements incorporated by reference in Part III of this Form 10-K or any amendment to this Form 10-K. ☐

Indicate by check mark whether the registrant is a large accelerated filer, an accelerated filer, a non-accelerated filer, or a smaller reporting company. See the definitions of "large accelerated filer," "accelerated filer" and "smaller reporting company" in Rule 12b-2 of the Exchange Act. (Check one):

Large accelerated filer	Accelerated filer	Non-accelerated filer	Smaller reporting company
☐	☑	☐ (Do not check if a smaller reporting company)	☐

Indicate by check mark whether the registrant is a shell company (as defined in Rule 12b-2 of the Exchange Act). Yes ☐ No ☑

As of June 30, 2011, the last business day of the registrant's most recently completed second fiscal quarter, the aggregate market value of the registrant's common stock held by non-affiliates of the registrant was $401,116,975 based on the closing price as reported on the New York Stock Exchange.

The number of outstanding shares of common stock of the registrant, as of February 24, 2012, was 45,430,886.

Documents Incorporated by Reference: Part III (Items 10, 11, 12, 13 and 14) incorporates by reference portions of the Registrant's Proxy Statement for its Annual Meeting of Stockholders, which will be filed not later than 120 days after December 31, 2011.

Table of Contents

ORMAT TECHNOLOGIES, INC.
FORM 10-K FOR THE YEAR ENDED DECEMBER 31, 2011
TABLE OF CONTENTS

Glossary of Terms

When the following terms and abbreviations appear in the text of this report, they have the meanings indicated below:

Term	Definition
Amatitlan Loan	Initial $42,000,000 in aggregate principal amount borrowed by our subsidiary Ortitlan from TCW Global Project Fund II, Ltd.
AMM	Administrador del Mercado Mayorista (administrator of the wholesale market — Guatemala)
ARRA	American Recovery and Reinvestment Act of 2009
Auxiliary Power	The power needed to operate a geothermal power plant's auxiliary equipment such as pumps and cooling towers
Availability	The ratio of the time a power plant is ready to be in service, or is in service, to the total time interval under consideration, expressed as a percentage, independent of fuel supply (heat or geothermal) or transmission accessibility
Balance of Plant equipment	Power plant equipment other than the generating units including items such as transformers, valves, interconnection equipment, cooling towers for water cooled power plants, etc.
BLM	Bureau of Land Management of the U.S. Department of the Interior
BOT	Build, operate and transfer
Capacity	The maximum load that a power plant can carry under existing conditions, less auxiliary power
Capacity Factor	The ratio of the average load on a generating resource to its generating capacity during a specified period of time, expressed as a percentage
CARB	California Air Resources Board
CDC	Commonwealth Development Corporation
CGC	Crump Geothermal Company LLC
CNE	National Energy Commission of Nicaragua
CNEE	National Electric Energy Commission of Guatemala
COD	Commercial Operation Date
Company	Ormat Technologies, Inc., a Delaware corporation, and its consolidated subsidiaries
COSO	Committee of Sponsoring Organizations of the Treadway Commission
CPI	Consumer Price Index

CPUC	California Public Utilities Commission
DEG	Deutsche Investitions-und Entwicklungsgesellschaft mbH
DFIs	Development Finance Institutions
DISNORTE	Empresa Distribudora de Electricidad del Norte (a Nicaragua distribution company)

Term	Definition
DISSUR	Empresa Distribudora de Electricidad del Sur (a Nicaragua distribution company)
DOE	U.S. Department of Energy
DOGGR	California Division of Oil, Gas, and Geothermal Resources
DSCR	Debt Service Coverage Ratio
EBITDA	Earnings before interest, taxes, depreciation and amortization
EGS	Enhanced Geothermal Systems
EIS	Environmental Impact Statement
ENATREL	Empresa Nicaraguense de Transmision
ENEL	Empresa Nicaraguense de Electricitdad
Enthalpy	The total energy control of a fluid; the heat plus the mechanical energy content of a fluid (such as a geothermal brine), which, for example, can be partially converted to mechanical energy in an Organic Rankine Cycle.
EPA	U.S. Environmental Protection Agency
EPC	Engineering, procurement and construction
EPS	Earnings per share
ERC	Kenyan Energy Regulatory Commission
ESC	Energy Sales Contract
Exchange Act	U.S. Securities Exchange Act of 1934, as amended
FASB	Financial Accounting Standards Board
FERC	U.S. Federal Energy Regulatory Commission
Flip Date	Date on which the holders of Class B membership units in OPC achieve a target after-tax yield on their investment in OPC.
FPA	U.S. Federal Power Act, as amended
GAAP	Generally accepted accounting principles
GDC	Geothermal Development Company
GDL	Geothermal Development Limited
Geothermal Power Plant	The power generation facility and the geothermal field
Geothermal Steam Act	U.S. Geothermal Steam Act of 1970, as amended
GHG	Greenhouse gas
GNP	Gross National Product

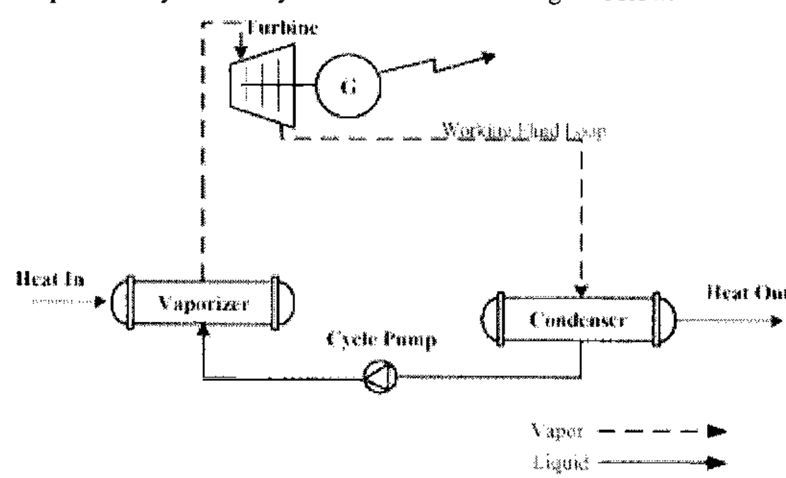
HELCO	Hawaii Electric Light Company
IFC	International Finance Corporation
IID	Imperial Irrigation District
ILA	Israel Land Administration

Term	Definition
INDE	Instituto Nacional de Electrification
INE	Nicaragua Institute of Energy
IPPs	Independent Power Producers
ISO	International Organization for Standardization
ITC	Investment tax credit
ITC Cash Grant	Payment for Specified Renewable Energy property in lieu of Tax Credits under Section 1603 of the ARRA
John Hancock	John Hancock Life Insurance Company (U.S.A.)
KenGen	Kenya Electricity Generating Company Ltd.
Kenyan Energy Act	Kenyan Energy Act, 2006
KETRACO	Kenya Electricity Transmission Company Limited
KLP	Kapoho Land Partnership
kVa	Kilovolt-ampere
KPLC	Kenya Power and Lighting Co. Ltd.
kW	Kilowatt — A unit of electrical power that is equal to 1,000 watts
kWh	Kilowatt hour(s), a measure of power produced
LNG	Liquefied natural gas
Mammoth Pacific	Mammoth-Pacific, L.P.
MACRS	Modified Accelerated Cost Recovery System
MW	Megawatt — One MW is equal to 1,000 kW or one million watts
MWh	Megawatt hour(s), a measure of power produced
NBPL	Northern Border Pipe Line Company
NIS	New Israeli Shekel
NGP	Nevada Geothermal Power Inc.
NV Energy	NV Energy, Inc.
NYSE	New York Stock Exchange
OEC	Ormat Energy Converter
OFC	Ormat Funding Corp., a wholly owned subsidiary of the Company
OFC Senior Secured Notes	8.25% Senior Secured Notes Due 2020 issued by OFC
OFC 2	OFC 2 LLC, a wholly owned subsidiary of the Company
OFC 2 Senior Secured Notes	Senior Secured Notes Due 2034 issued by OFC 2

Olkaria Loan	Initial $105,000,000 in aggregate principal amount borrowed by OrPower 4 from a group of European DFIs
OMPC	Ormat Momotombo Power Company, a wholly owned subsidiary of the Company
OPIC	Overseas Private Investment Corporation

Table of Contents

Term	Definition
OPC	OPC LLC, a consolidated subsidiary of the Company
OPC Transaction	Financing transaction involving four of our Nevada power plants in which institutional equity investors purchased an interest in our special purpose subsidiary that owns such plants.
OrCal	OrCal Geothermal Inc., a wholly owned subsidiary of the Company
OrCal Senior Secured Notes	6.21% Senior Secured Notes Due 2020 issued by OrCal
Organic Rankine Cycle	A process in which an organic fluid such as a hydrocarbon or fluorocarbon (but not water) is boiled in an evaporator to generate high pressure vapor. The vapor powers a turbine to generate mechanical power. After the expansion in the turbine, the low pressure vapor is cooled and condensed back to liquid in a condenser. A cycle pump is then used to pump the liquid back to the vaporizer to complete the cycle. The cycle is illustrated in the figure below:



Ormat International	Ormat International Inc., a wholly owned subsidiary of the Company
Ormat Nevada	Ormat Nevada Inc., a wholly owned subsidiary of the Company
Ormat Systems	Ormat Systems Ltd., a wholly owned subsidiary of the Company
OrPower 4	OrPower 4 Inc., a wholly owned subsidiary of the Company
Ortitlan	Ortitlan Limitada, a wholly owned subsidiary of the Company
Orzunil	Orzunil I de Electricidad, Limitada, a wholly owned subsidiary of the Company
Parent	Ormat Industries Ltd.
PGV	Puna Geothermal Venture, a wholly owned subsidiary of the Company

PLN	PT Perusahaan Listrik Negara
Power plant equipment	Interconnection equipment, cooling towers for water cooled power plant, etc.
PPA	Power purchase agreement
ppm	Part per million

Term	Definition
PTC	Production tax credit
PUA	Israeli Public Utility Authority
PUCH	Public Utilities Commission of Hawaii
PUCN	Public Utilities Commission of Nevada
PUHCA	U.S. Public Utility Holding Company Act of 1935
PUHCA 2005	U.S. Public Utility Holding Company Act of 2005
PURPA	U.S. Public Utility Regulatory Policies Act of 1978
Qualifying Facility(ies)	Certain small power production facilities are eligible to be "Qualifying Facilities" under PURPA, provided that they meet certain power and thermal energy production requirements and efficiency standards. Qualifying Facility status provides an exemption from PUHCA 2005 and grants certain other benefits to the Qualifying Facility.
REC	Renewable Energy Credit
REG	Recovered Energy Generation
RGGI	Regional Greenhouse Gas Initiative
RPM	Revolutions Per Minute
RPS	Renewable Portfolio Standards
SCPPA	Southern California Public Power Authority
SEC	U.S. Securities and Exchange Commission
Senior Unsecured Bonds	7% Senior Unsecured Bonds Due 2017 issued by the Company
Securities Act	U.S. Securities Act of 1933, as amended
SOX Act	Sarbanes-Oxley Act of 2002
Solar PV	Solar photovoltaic
Southern California Edison	Southern California Edison Company
SPE(s)	Special purpose entity(ies)
SRAC	Short Run Avoided Costs
Sunday Energy	Sunday Energy Ltd.
TGL	Tikitere Geothermal Power Limited
Union Bank	Union Bank, N.A.
U.S.	United States of America
U.S. Treasury	U.S. Department of the Treasury
W&M	Watts & More Ltd.

Table of Contents

Cautionary Note Regarding Forward-Looking Statements

This annual report includes "forward-looking statements" within the meaning of the Private Securities Litigation Reform Act of 1995. All statements, other than statements of historical facts, included in this report that address activities, events or developments that we expect or anticipate will or may occur in the future, including such matters as our projections of annual revenues, expenses and debt service coverage with respect to our debt securities, future capital expenditures, business strategy, competitive strengths, goals, development or operation of generation assets, market and industry developments and the growth of our business and operations, are forward-looking statements. When used in this annual report, the words "may", "will", "could", "should", "expects", "plans", "anticipates", "believes", "estimates", "predicts", "projects", "potential", or "contemplate" or the negative of these terms or other comparable terminology are intended to identify forward-looking statements, although not all forward-looking statements contain such words or expressions. The forward-looking statements in this report are primarily located in the material set forth under the headings Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" contained in Part II, Item 1A — "Risk Factors" contained in Part I, and "Notes to Financial Statements" contained in Part II, Item 8 — "Financial Statements and Supplementary Data" contained in Part II of this annual report, but are found in other locations as well. These forward-looking statements generally relate to our plans, objectives and expectations for future operations and are based upon management's current estimates and projections of future results or trends. Although we believe that our plans and objectives reflected in or suggested by these forward-looking statements are reasonable, we may not achieve these plans or objectives. You should read this annual report completely and with the understanding that actual future results and developments may be materially different from what we expect due to a number of risks and uncertainties, many of which are beyond our control. We will not update forward-looking statements even though our situation may change in the future.

Specific factors that might cause actual results to differ from our expectations include, but are not limited to:

- significant considerations, risks and uncertainties discussed in this annual report;
- operating risks, including equipment failures and the amounts and timing of revenues and expenses;
- geothermal resource risk (such as the heat content of the reservoir, useful life and geological formation);
- financial market conditions and the results of financing efforts;
- the impact of fluctuations in natural gas prices on the energy price component under certain of our PPAs;
- environmental constraints on operations and environmental liabilities arising out of past or present operations, including the risk that we may not have, and in the future may be unable to procure, any necessary permits or other environmental authorizations;
- construction or other project delays or cancellations;
- political, legal, regulatory, governmental, administrative and economic conditions and developments in the United States and other countries in which we operate;
- the enforceability of the long-term PPAs for our power plants;
- contract counterparty risk;
- weather and other natural phenomena;
- the impact of recent and future federal, state and local regulatory proceedings and changes, including legislative and regulatory initiatives regarding deregulation and restructuring of the electric utility industry incentives for the production of renewable energy at the federal and state level in the United States and elsewhere, and carbon-related legislation;
- changes in environmental and other laws and regulations to which our company is subject, as well as changes in the application of existing laws and regulations;

- current and future litigation;

- our ability to successfully identify, integrate and complete acquisitions;
- competition from other similar geothermal energy projects, including any such new geothermal energy projects developed in the future, and from alternative electricity producing technologies;
- the effect of and changes in economic conditions in the areas in which we operate;
- market or business conditions and fluctuations in demand for energy or capacity in the markets in which we operate;
- the direct or indirect impact on our company's business resulting from the threat or occurrence of terrorist incidents or cyber-attacks or responses to such threatened or actual incidents or attacks, including the effect on the availability of and premiums on insurance;
- the effect of and changes in current and future land use and zoning regulations, residential, commercial and industrial development and urbanization in the areas in which we operate;
- other uncertainties which are difficult to predict or beyond our control and the risk that we may incorrectly analyze these risks and forces or that the strategies we develop to address them may be unsuccessful; and
- development and construction of the Solar PV projects may not materialize as planned.

PART I

ITEM 1. *BUSINESS*

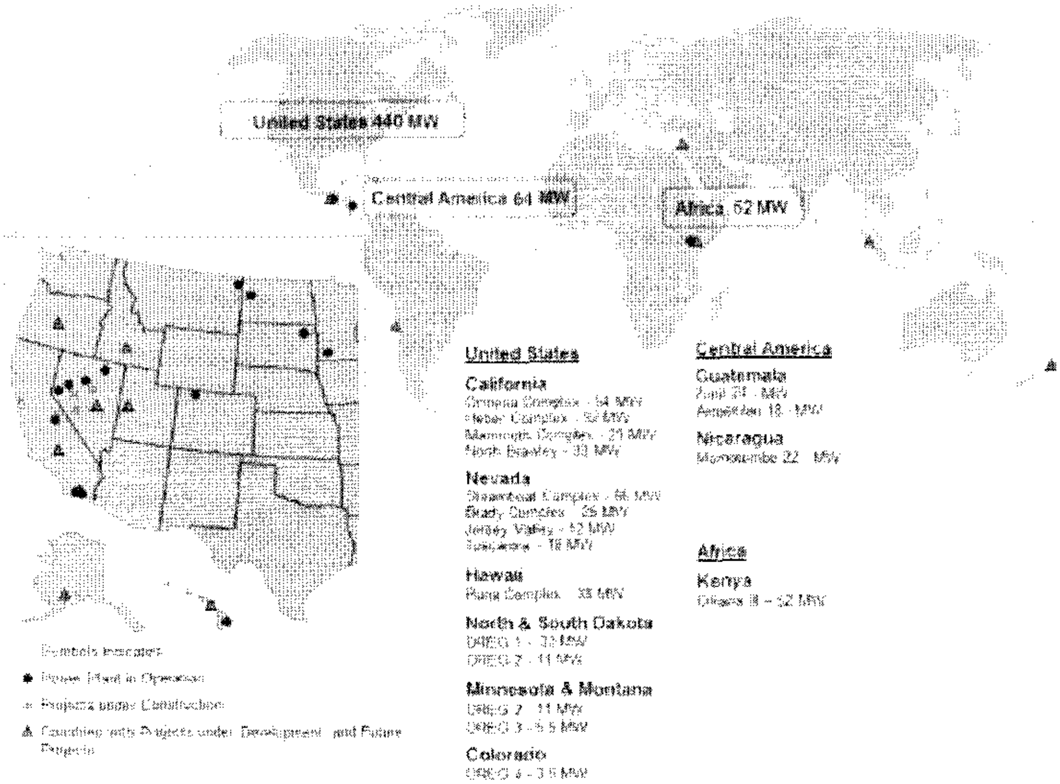
Certain Definitions

Unless the context otherwise requires, all references in this annual report to "Ormat", "the Company", "we", "us", "our company", "Ormat Technologies", or "our" refer to Ormat Technologies, Inc. and its consolidated subsidiaries. A glossary of certain terms and abbreviations used in this annual report appears at the beginning of this report.

Overview

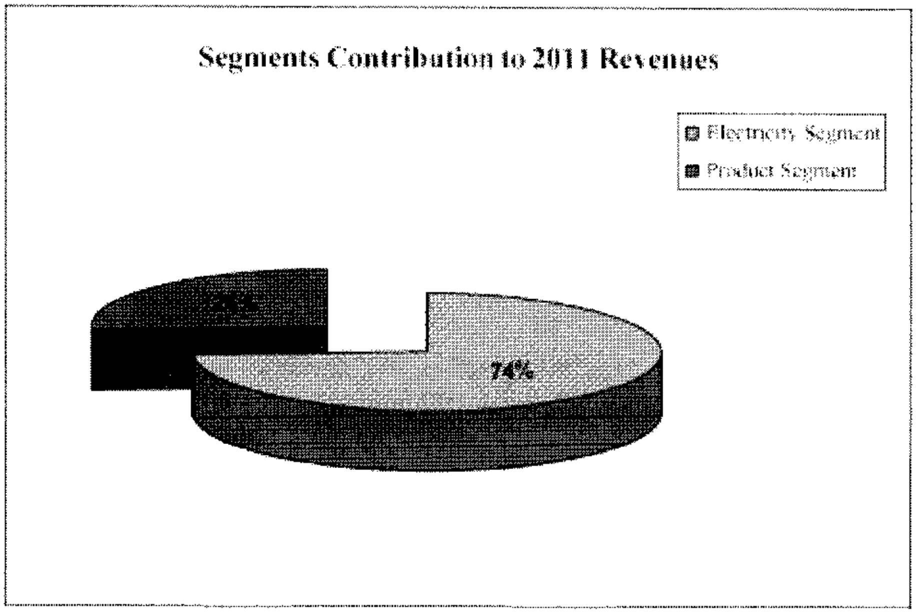
We are a leading vertically integrated company primarily engaged in the geothermal and recovered energy power business. We design, develop, build, own, and operate clean, environmentally friendly geothermal and recovered energy-based power plants, usually using equipment that we design and manufacture. Our geothermal power plants include both power plants that we have built and power plants that we have acquired, while all of our recovered energy-based plants have been constructed by us. We conduct our business activities in two business segments, which we refer to as our Electricity Segment and Product Segment. In our Electricity Segment, we develop, build, own and operate geothermal and recovered energy-based power plants in the United States and geothermal power plants in other countries around the world and sell the electricity they generate. We have expanded our activities in the Electricity Segment to include the ownership and operation of power plants that produce electricity generated by Solar PV systems that we do not manufacture. In our Product Segment, we design, manufacture and sell equipment for geothermal and recovered energy-based electricity generation, remote power units and other power generating units and provide services relating to the engineering, procurement, construction, operation and maintenance of geothermal and recovered energy-based power plants.

The map below shows our current worldwide portfolio of operating geothermal power plants and recovered energy plants, as well as the geothermal and recovered energy-based power plants and a Solar PV power plant that are under construction, and countries with projects under development and exploration.

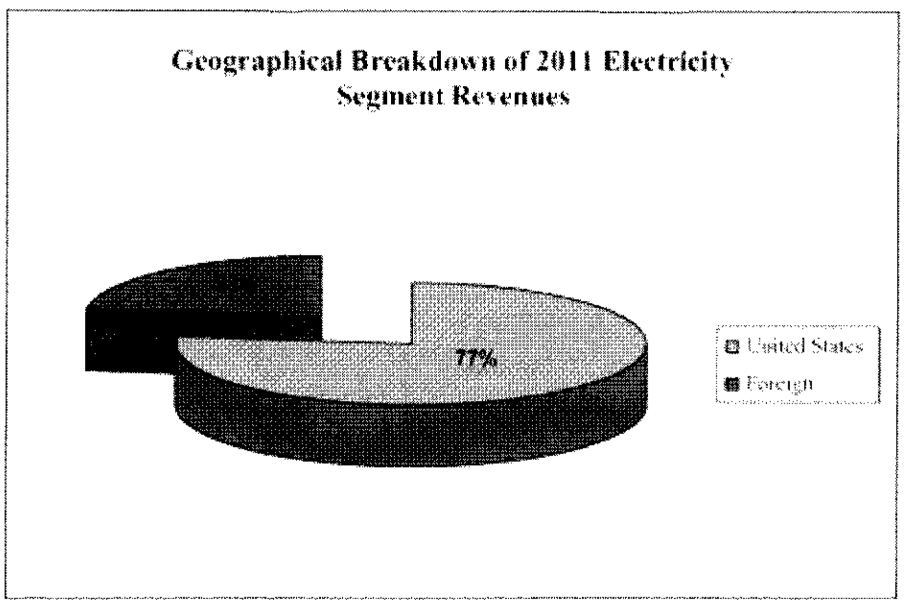


The charts below show the relative contributions of the Electricity Segment and the Product Segment to our consolidated revenues and the geographical breakdown of our segment revenues for our fiscal year ended December 31, 2011. Additional information concerning our segment operations, including year-to-year comparisons of revenues, the geographical breakdown of revenues, cost of revenues, results of operations, and trends and uncertainties is provided below in Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" and Item 8 — "Financial Statements and Supplementary Data".

The following chart sets forth a breakdown of revenues for the year ended December 31, 2011:



The following chart sets forth the geographical breakdown of the revenues attributable to our Electricity Segment for the year ended December 31, 2011:



All of our revenues attributable to our Product Segment for the year ended December 31, 2011 were from foreign operations.

Most of the power plants that we currently own or operate produce electricity from geothermal energy sources. Geothermal energy is a clean, renewable and generally sustainable form of energy derived from the natural heat of the earth. Unlike electricity produced by burning fossil fuels, electricity produced from geothermal energy sources is produced without emissions of certain pollutants such as nitrogen oxide, and with far lower emissions of other pollutants such as carbon dioxide. Therefore, electricity produced from geothermal energy sources contributes significantly less to local and regional incidences of acid rain and global warming than energy produced by burning fossil fuels. Geothermal energy is also an attractive alternative to other sources of energy as part of a national diversification strategy to avoid dependence on any one energy source or politically sensitive supply sources.

In addition to our geothermal energy business, we manufacture products that produce electricity from recovered energy or so-called "waste heat". We also construct, own, and operate recovered energy-based power plants. Recovered energy represents residual heat that is generated as a by-product of gas turbine-driven compressor stations, solar thermal units and a variety of industrial processes, such as cement manufacturing. Such residual heat, which would otherwise be wasted, may be captured in the recovery process and used by recovered energy power plants to generate electricity without burning additional fuel and without additional emissions.

We have expanded our activity to the Solar PV industry. We are constructing a new utility-scale Solar PV project near our Heber complex in California and we are developing other Solar PV projects in Israel.

Company Contact and Sources of Information

We file annual, quarterly and periodic reports, proxy statements and other information with the SEC. You may obtain and copy any document we file with the SEC at the SEC's Public Reference Room at 100 F Street, N.E., Room 1580, Washington D.C. 20549. You may obtain information on the operation of the SEC's Public Reference Room by calling the SEC at 1-800-SEC-0330. The SEC maintains an internet website at http://www.sec.gov that contains reports, proxy and other information statements, and other information regarding issuers that file electronically with the SEC. Our SEC filings are accessible via the internet at that website.

Our reports on Form 10-K, 10-Q and 8-K, and amendments to those reports filed or furnished pursuant to Section 13(a) or 15(d) of the Exchange Act are available through our website at www.ormat.com for downloading, free of charge, as soon as reasonably practicable after these reports are filed with the SEC. Our Code of Business Conduct and Ethics, Code of Ethics Applicable to Senior Executives, Audit Committee Charter, Corporate Governance Guidelines, Nominating and Corporate Governance Committee Charter, Compensation Committee Charter, and Insider Trading Policy, as amended, are also available at our website address mentioned above. If we make any amendments to our Code of Business Conduct and Ethics or Code of Ethics Applicable to Senior Executives or grant any waiver, including any implicit waiver, from a provision of either code applicable to our Chief Executive Officer, Chief Financial Officer or principal accounting officer requiring disclosure under applicable SEC rules, we intend to disclose the nature of such amendment or waiver on our website. The content of our website, however, is not part of this annual report.

You may request a copy of our SEC filings, as well as the foregoing corporate documents, at no cost to you, by writing to the Company address appearing in this annual report or by calling us at (775) 356-9029.

Our Power Generation Business (Electricity Segment)

Power Plants in Operation

The table below summarizes certain key non-financial information relating to our power plants as of February 24, 2012. The generating capacity of certain of our power plants listed below has been updated to reflect changes in the resource temperature and other factors that impact resource capabilities:

Power Plant	Location	Ownership(1)	Generating Capacity in MW(2)
Domestic Geothermal			
Brady Complex	Nevada	100%	25.0
Heber Complex	California	100%	92.0
Jersey Valley(3)	Nevada	100%	12.0

Mammoth Complex	California	100%	29.0
North Brawley[4]	California	100%	33.0
Ormesa Complex	California	100%	54.0
Puna Complex	Hawaii	100%	38.0
Steamboat Complex	Nevada	100%	86.0
Tuscarora[5]	Nevada	100%	18.0
REG			
OREG 1	North and South Dakota	100%	22.0
OREG 2	Montana, North Dakota and Minnesota	100%	22.0
OREG 3	Minnesota	100%	5.5
OREG 4	Colorado	100%	3.5
Total for domestic power plants			**440.0**
Foreign			
Geothermal			
Amatitlan	Guatemala	100%	18.0
Momotombo	Nicaragua	100%	22.0
Olkaria III Complex	Kenya	100%	52.0
Zunil	Guatemala	100%	24.0
Total for foreign power plants			**116.0**
Total for all power plants			**556.0**

(1) We own and operate all of our power plants other than the Momotombo power plant in Nicaragua, which we do not own but which we control and operate through a concession arrangement with the Nicaraguan government. Two financial institutions hold equity interests in one of our consolidated subsidiaries (OPC) that owns the Desert Peak 2 power plant in our Brady complex and the Steamboat Hills, Galena 2 and Galena 3 power plants in our Steamboat complex. In the above table, we show these power plants as being 100% owned because all of the generating capacity is owned by OPC and we control the operation of the power plants. The nature of the equity interests held by the financial institution is described in Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations under the heading "OPC Transaction".

(2) References to generating capacity generally refer to the gross capacity less auxiliary power, in the case of all of our existing domestic and foreign power plants, except for the Zunil power plant. We determine the generating capacity figures in these power plants by taking into account resource capabilities. In the case of

the Zunil power plant, the energy output of the power plant was sold, until September 2011, under a "take or pay" arrangement, under which the revenues are calculated based on 24 MW capacity unrelated to the actual performance of the reservoir. This column represents our net ownership in such generating capacity.

In any given year, the actual power generation of a particular power plant may differ from that power plant's generating capacity due to variations in ambient temperature, the availability of the resource, and operational issues affecting performance during that year. The Capacity Factor of the geothermal power plants in commercial operation in 2011, excluding the North Brawley power plant, which operates at partial load, was approximately 88%. The Capacity Factor of the REG power plants in 2011 was approximately 85%.

(3) The Jersey Valley power plant is not operating at full capacity. Detailed information on the Jersey Valley power plant is provided under "Description of our Power Plants" below.

(4) The North Brawley power plant is not operating at full capacity. Detailed information on the North Brawley power plant is provided under "Description of our Power Plants" below.

(5) The Tuscarora power plant commenced commercial operation on January 11, 2012.

Substantially all of the revenues that we currently derive from the sale of electricity are pursuant to long-term PPAs. Approximately 53.2% of our total revenues in the year ended December 31, 2011 from the sale of electricity by our domestic power plants were derived from power purchasers that currently have investment grade credit ratings. The purchasers of electricity from our foreign power plants are either state-owned or private entities.

New Power Plants

We are currently in various stages of development of new power plants, construction of new power plants and expansion of existing power plants. Our growth plan includes our share of approximately 175 MW in generating capacity from geothermal power plants in the United States and Kenya that are expected to come on-line in the next two years. In addition, we expect to add, in three phases, a total of approximately 42 MW, which is our share in the Sarulla project in Indonesia.

In addition, we are constructing a 10 MW Solar PV project in the U.S. and are developing approximately 18 ground-mounted and roof-top Solar PV projects in Israel. Our share of the expected generation capacity of these projects is 130 MW. However, due to the competition in the Solar PV market in Israel, combined with a relatively low cap on the feed-in-tariff, we expect that only a portion of the Solar PV projects in our Israeli development pipeline will be ultimately constructed.

We have a substantial land position that is expected to support future geothermal development on, which we have started or plan to start exploration activity. This land position is approximately 675,000 acres in 42 sites. This is comprised of various leases and concessions, exploration concessions for geothermal resources and an option to enter into geothermal leases. We have started or plan to start exploration activity at a number of these sites.

Our Product Business (Product Segment)

We design, manufacture and sell products for electricity generation and provide the related services described below. Generally, we manufacture products only against customer orders and do not manufacture products for our own inventory.

Power Units for Geothermal Power Plants. We design, manufacture and sell power units for geothermal electricity generation, which we refer to as OECs. Our customers include contractors and geothermal power plant owners and operators.

Power Units for Recovered Energy-Based Power Generation. We design, manufacture and sell power units used to generate electricity from recovered energy, or so-called "waste heat." This heat is generated as a residual by-product of gas turbine-driven compressor stations, solar thermal units and a variety of industrial processes, such as cement manufacturing, and is not otherwise used for any purpose. Our existing and target customers include interstate natural gas pipeline owners and operators, gas processing plant owners and operators, cement plant owners and operators, and other companies engaged in other energy-intensive industrial processes.

EPC of Power Plants. We engineer, procure, and construct, as an EPC contractor, geothermal and recovered energy power plants on a turnkey basis, using power units we design and manufacture. Our customers are geothermal power plant owners as well as the same customers described above that we target for the sale of our power units for recovered energy-based power generation. Unlike many other companies that provide EPC services, we have an advantage in that we are using our own manufactured equipment and thus have better control over the timing and delivery of required equipment and its related costs.

Remote Power Units and Other Generators. We design, manufacture and sell fossil fuel powered turbo-generators with a capacity ranging between 200 watts and 5,000 watts, which operate unattended in extreme climate conditions, whether hot or cold. Our customers include contractors installing gas pipelines in remote areas. In addition, we design, manufacture, and sell generators for various other uses, including heavy duty direct-current generators.

History

We were formed as a Delaware corporation in 1994 by Ormat Industries Ltd. (also referred to in this annual report as the "Parent", "Ormat Industries", "the parent company", or "our parent"). Ormat Industries was one of the first companies to focus on the development of equipment for the production of clean, renewable and generally sustainable forms of energy. Ormat Industries owns approximately 60% of our outstanding common stock.

Industry Background

Geothermal Energy

Most of our power plants in operation produce electricity from geothermal energy. There are several different sources or methods to obtain geothermal energy, which are described below.

Hydrothermal geothermal-electricity generation — Hydrothermal geothermal energy is derived from naturally occurring hydrothermal reservoirs that are formed when water comes sufficiently close to hot rock to heat the water to temperatures of 300 degrees Fahrenheit or more. The heated water then ascends toward the surface of the earth where, if geological conditions are suitable for its commercial extraction, it can be extracted by drilling geothermal wells. The energy necessary to operate a geothermal power plant is typically obtained from several such wells which are drilled using established technology that is in some respects similar to that employed in the oil and gas industry. Geothermal production wells are normally located within approximately one to two miles of the power plant as geothermal fluids cannot be transported economically over longer distances due to heat and pressure loss. The geothermal reservoir is a renewable source of energy if natural ground water sources and reinjection of extracted geothermal fluids are adequate over the long-term to replenish the geothermal reservoir following the withdrawal of geothermal fluids and if the well field is properly operated. Geothermal energy power plants typically have higher capital costs (primarily as a result of the costs attributable to well field development) but tend to have significantly lower variable operating costs (principally consisting of maintenance expenditures) than fossil fuel-fired power plants that require ongoing fuel expenses. In addition, because geothermal energy power plants produce 24hr/day weather independent power, the variable operating costs are lower.

EGS — An EGS has been broadly defined as a subsurface system that may be artificially created to extract heat from hot rock where the characteristics required for a hydrothermal system, i.e., permeability and aquifers, are non-existent. A geothermal power plant that uses EGS techniques recovers the thermal energy from the subsurface rocks by creating or accessing a system of open fractures in the rock through which water can be injected, heated through contact with the hot rock, returned to the surface in production wells and transferred to a power unit.

Table of Contents

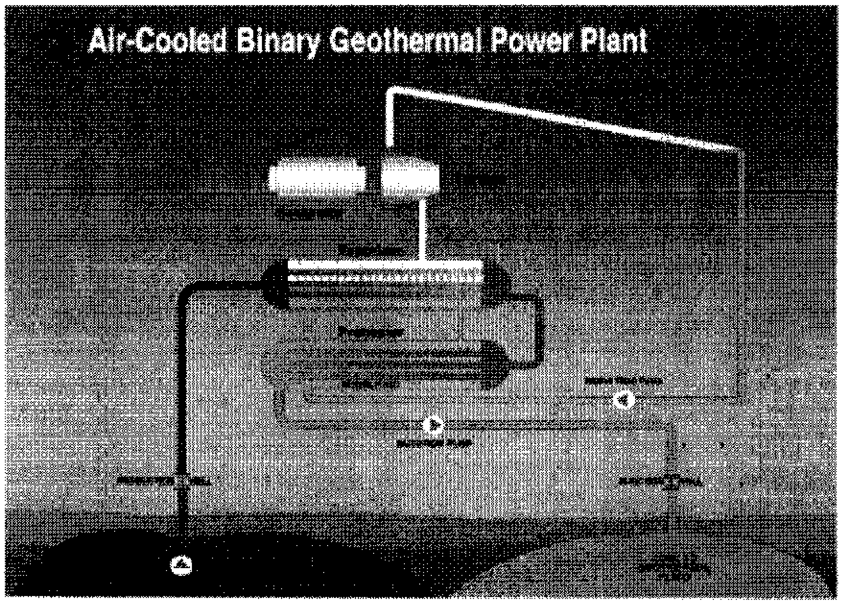
Co-produced Geothermal from Oil and Gas fields, geo-pressurized resources — Another source of geothermal energy is hot water produced from oil and gas production. This application is referred to as "Co-produced Fluids". In some oil and gas fields, water is produced as a by-product of the oil and gas extraction. When the wells are deep the fluids are often at high temperatures and if the water volume is significant, the hot water can be used for power generation in equipment similar to a geothermal power plant.

Geothermal Power Plant Technologies

Geothermal power plants generally employ either binary systems or conventional flash design systems, as described below. In our geothermal power plants, we also employ our proprietary technology of combined geothermal cycle systems.

Binary System

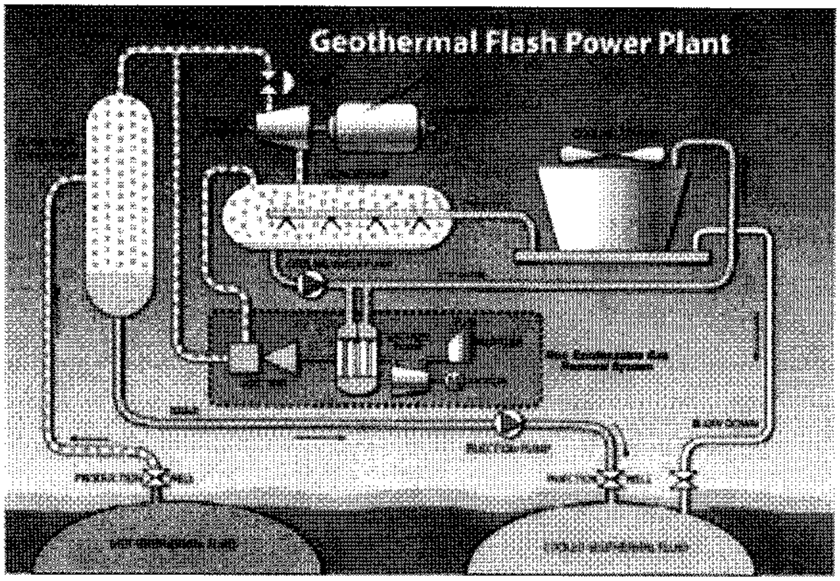
In a geothermal power plant using a binary system, geothermal fluid, either hot water (also called brine) or steam or both, is extracted from the underground reservoir and flows from the wellhead through a gathering system of insulated steel pipelines to a heat exchanger, which heats a secondary working fluid which has a low boiling point. This is typically an organic fluid, such as isopentane or isobutene, which is vaporized and is used to drive the turbine. The organic fluid is then condensed in a condenser which may be cooled by air or by water from a cooling tower. The condensed fluid is then recycled back to the heat exchanger, closing the cycle within the sealed system. The cooled geothermal fluid is then reinjected back into the reservoir. The binary technology is depicted in the graphic below.



Flash Design System

In a geothermal power plant using flash design, geothermal fluid is extracted from the underground reservoir and flows from the wellhead through a gathering system of insulated steel pipelines to flash tanks and/or separators. There, the steam is separated from the brine and is sent to a demister in the plant, where any

remaining water droplets are removed. This produces a stream of dry saturated steam, which drives a turbine generator to produce electricity. In some cases, the brine at the outlet of the separator is flashed a second time (dual flash), providing additional steam at lower pressure used in the low pressure section of the steam turbine to produce additional electricity. Steam exhausted from the steam turbine is condensed in a surface or direct contact condenser cooled by cold water from a cooling tower. The non-condensable gases (such as carbon dioxide) are removed through the removal system in order to optimize the performance of the steam turbines. The condensate is used to provide make-up water for the cooling tower. The hot brine remaining after separation of steam is injected back into the geothermal resource through a series of injection wells. The flash technology is depicted in the graphic below.

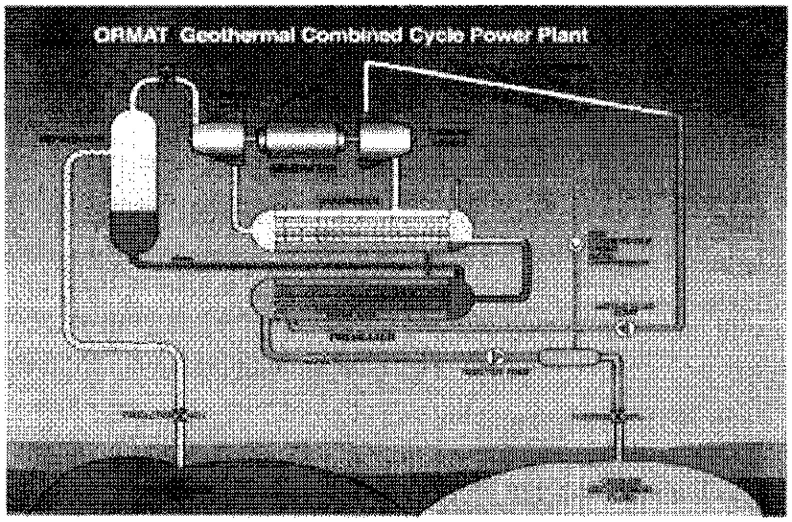


In some instances, the wells directly produce dry steam (the flashing occurring underground). In such cases, the steam is fed directly to the steam turbine and the rest of the system is similar to the flash power plant described above.

Ormat's Proprietary Technology

Our proprietary technology may be used in power plants operating according to the Organic Rankine Cycle, only or in combination with, various other commonly used thermodynamic technologies that convert heat to mechanical power. It can be used with a variety of thermal energy sources, such as geothermal, recovered energy, biomass, solar energy and fossil fuels. Specifically, our technology involves original designs of turbines, pumps, and heat exchangers, as well as formulation of organic motive fluids. All of our motive fluids are non-ozone-depleting substances. Using advanced computerized fluid dynamics and other computer aided design software as well as our test facilities, we continuously seek to improve power plant components, reduce operations and maintenance costs, and increase the range of our equipment and applications. In particular, we are examining ways to increase the output of our plants by utilizing evaporative cooling, cold reinjection, performance simulation programs, and topping turbines. In the geothermal as well as the recovered energy (waste heat) areas, we are examining two-level recovered energy systems and new motive fluids.

We also construct combined cycle geothermal power plants in which the steam first produces power in a backpressure steam turbine and is subsequently condensed in a vaporizer of a binary plant, which produces additional power. Our combined cycle technology is depicted in the graphic below.



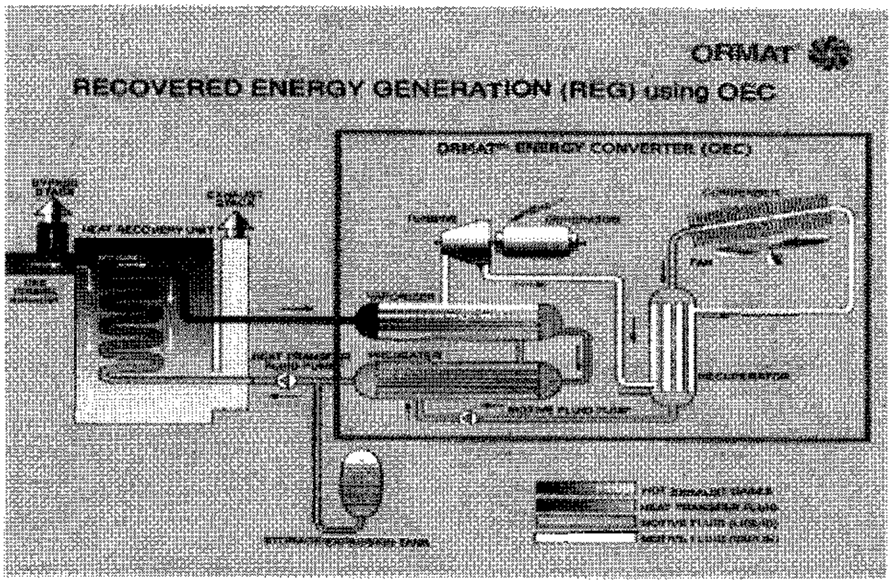
In the conversion of geothermal energy into electricity, our technology has a number of advantages compared with conventional geothermal steam turbine plants. A conventional geothermal steam turbine plant consumes significant quantities of water, causing depletion of the aquifer, and also requires cooling water treatment with chemicals and thus a need for the disposal of such chemicals. A conventional geothermal steam turbine plant also creates a significant visual impact in the form of an emitted plume from the cooling tower during cold weather. By contrast, our binary and combined cycle geothermal power plants have a low profile with minimum visual impact and do not emit a plume when they use air cooled condensers. Our binary and combined cycle geothermal power plants reinject all of the geothermal fluids utilized in the respective processes into the geothermal reservoir. Consequently, such processes generally have no emissions.

Other advantages of our technology include simplicity of operation and easy maintenance, low RPM, temperature and pressure in the OEC, a high efficiency turbine, and the fact that there is no contact between the turbine itself and often corrosive geothermal fluids.

We use the same elements of our technology in our recovered energy products. The heat source may be exhaust gases from a simple cycle gas turbine, low pressure steam, or medium temperature liquid found in the process industry. In most cases, we attach an additional heat exchanger in which we circulate thermal oil to transfer the heat into the OEC's own vaporizer in order to provide greater operational flexibility and control. Once this stage of each recovery is completed, the rest of the operation is identical to the OEC used in our geothermal power plants. The same advantages of using the Organic Rankine Cycle apply here as well. In addition, our technology allows for better load following than conventional steam turbines exhibit, requires no water treatment as it is air cooled, and does not require the continuous presence of a steam licensed operator on site.

Table of Contents

Our REG technology is depicted in the graphic below.



Patents

We have been granted 82 U.S. patents (and about 20 pending patents) that cover our products (mainly power units based on the Organic Rankine Cycle) and systems (mainly geothermal power plants and industrial waste heat recovery plants for electricity production). The system-related patents cover not only a particular component but also the overall effectiveness of the plant's systems from the "fuel" (e.g., geothermal fluid, waste heat, biomass or solar) to generated electricity. The duration of such patents ranges from one year to seventeen years. No single patent on its own is material to our business.

The products-related patents cover components which include turbines, heat exchangers, seals and controls. The system patents cover subjects such as waste heat recovery related to gas pipelines compressors, disposal of non-condensable gases present in geothermal fluids, power plants for very high pressure geothermal resources, and use of two-phase fluids as well as processes related to EGS. A number of patents cover the combined cycle geothermal power plants, in which the steam first produces power in a backpressure steam turbine and is subsequently condensed in a vaporizer of a binary plant, which produces additional power.

Research and Development

We are conducting research and development of new EGS technologies and their application to enhance our power plants without using any additional fluid supply. We are undertaking this development effort at our Desert Peak 2 and Brady power plants in Nevada in cooperation with GeothermEx Inc., and a number of universities and national laboratories, with funding support from the DOE.

We are also continuing with our research and development activities intended to improve plant performance, reduce costs, and increase the breadth of product offerings. The primary focus of our research and development efforts includes continued improvements to our evaporative cooling system, condensing equipment with improved performance and lower land usage, developing new turbine products, and specialized power units designed to reduce fuel consumption and associated costs during a project's development phase.

Additionally, we are continuing to evaluate investment opportunities in new companies with product offerings for renewable energy markets, such as our investment in W&M, a company with whom we are engaged for the development of energy harvesting and system balancing solutions for electrical sources and, in particular, Solar PV.

Market Opportunity

Interest in geothermal energy in the United States remains strong as a result of legislative and regulatory support for renewable energy, and the baseload nature of geothermal energy generation.

Although electricity generation from geothermal resources is currently concentrated mainly in California, Nevada, Hawaii, Idaho and Utah, there are opportunities for development in other states such as Alaska, Arizona, New Mexico, Washington and Oregon due to the availability of geothermal resources and, in some cases, a favorable regulatory environment in such states.

The Western Governors Association estimates that 13,000 MW of identified geothermal resources will be developed by 2025. In a report issued in April 2010 for the World Geothermal Congress, Ruggero Bertani of Enel Green Power forecasted that by 2015 the worldwide installed capacity will increase by approximately 73% from 10,715 MW in 2010 to 18,500 MW in 2015. The report identifies the U.S., Indonesia, the Philippines, New Zealand and Mexico as the main contributors to the forecasted growth.

In a report issued in April 2011, the Geothermal Energy Association identified a total of 146 confirmed and unconfirmed geothermal projects under various phases of consideration or development in 15 U.S. states that have between 4,448 MW and 5,040 MW potential capacity.

The assessments conducted by the Western Governors Association and the Geothermal Energy Association are estimates only. We refer to them only as two possible reference points, but we do not necessarily concur with those estimates.

An additional factor fueling recent growth in the renewable energy industry is global concern about the environment. Power plants that use fossil fuels generate higher levels of air pollution and their emissions have been linked to acid rain and global warming. In response to an increasing demand for "green" energy, many countries have adopted legislation requiring, and providing incentives for, electric utilities to sell electricity generated from renewable energy sources. In the United States, Arizona, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Dakota, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin and the District of Colombia have all adopted RPS, renewable portfolio goals, or similar laws requiring or encouraging electric utilities in such states to generate or buy a certain percentage of their electricity from renewable energy sources or recovered heat sources.

According to the Database of State Incentives for Renewables and Efficiency (DSIRE), twenty nine states (including California, Nevada, and Hawaii, where we have been the most active in our geothermal energy development and in which all of our U.S. geothermal power plants in operation are located) and the District of Columbia define geothermal resources as "renewable."

According to DSIRE, seventeen states have enacted RPS and Alternative Portfolio Standards that include some form of combined heat and power and/or waste heat recovery. The seventeen states are: Arizona, Colorado, Connecticut, Hawaii, Indiana, Maine, Michigan, Nevada, New York, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, and West Virginia.

We believe that these legislative measures and initiatives present a significant market opportunity for us. In California, on April 12, 2011, Governor Jerry Brown signed Senate Bill X1-2 (SBX1-2) to increase California's RPS to 33% by December 31, 2020, among the most aggressive renewable energy goals in the United States. We expect that the additional demand for renewable energy from utilities in states with RPS will outpace a possible reduction in general demand for energy (if any) due to the effect of general economic conditions. We see this increased demand and, in particular, the impact of the increase in California's RPS, as one of the most significant opportunities for us to expand existing projects and build new power plants. In 2010, California's RPS target was to supply at least 20% of the total retail electricity sales from eligible renewable energy resources; California's three large investor-owned utilities collectively served 17% of their 2010 retail electricity sales with renewable power. Due to flexible compliance, California utilities must average 20% through years 2011-2013. The investor-owned utilities have interim targets each year, with a requirement of 25% by 2016. Due to the new 33% target, publicly-owned utilities in California must also procure 33% of retail electricity sales from eligible renewable energy resources by 2020, opening up a significant new market of potential off-takers in years ahead. These utilities do not have interim targets. Nevada's RPS requires NV Energy to supply at least 15% of the total electricity it sells from eligible renewable energy resources by 2013, which will increase to 25% by 2025. In 2010, 14.8% of the electricity retail sales in Nevada were from renewable energy sources. Hawaii's RPS requires each Hawaiian electric utility that sells electricity for consumption in Hawaii to obtain 15% of its net electricity sales from renewable energy sources by December 31, 2015, 20% by December 31, 2020, and 40% by 2030. In 2010, Hawaiian Electric Company and its subsidiaries achieved a consolidated RPS of 20.7%.

In 2006, California passed a state climate change law, AB 32. The goal of AB 32 is to reduce GHG emissions to 1990 levels by the end of 2020. In 2008, CARB approved a Scoping Plan to carry out regulations implementing AB 32. In December 2010, CARB approved cap-and-trade regulations to reduce California's GHG emissions under AB 32. The cap-and-trade regulation, the first phase of which was initiated in January 2012 with compliance obligations commencing in January 2013, will set a statewide limit on emissions from sources responsible for emitting 80% of California's GHGs and, according to CARB, will help establish a price signal needed to drive long-term investment in cleaner fuels and more efficient use of energy. However, implementation of this cap-and-trade program under AB 32 has been the subject of legal challenges that may hinder and/or ultimately thwart its implementation. At the federal level as of 2011, the EPA's Tailoring Rule sets thresholds for when permitting requirements under the Clean Air Act's Prevention of Significant Deterioration and Title V programs apply to certain major sources of GHG emissions. Regional initiatives are also being developed to reduce GHG emissions and to develop trading systems for renewable energy credits. For example, nine Northeast and Mid-Atlantic States are part of the RGGI, a regional cap-and-trade system to limit carbon dioxide. The RGGI is the first mandatory, market-based carbon dioxide emissions reduction program in the United States. The first-in-the-nation auction of carbon dioxide allowances was held in September 2008. Under RGGI, the participating states plan to reduce carbon emissions from power plants by 10%, at a rate of 2.5% per year between 2015 and 2018.

In addition to RGGI, other states have also established the Midwestern Regional Greenhouse Gas Reduction Accord and the Western Climate Initiative. Although individual and regional programs will take some time to develop, their requirements, particularly the creation of any market-based trading mechanism to achieve compliance with emissions caps, should be advantageous to in-state and in-region (and, in some cases, such as RGGI and the State of California, inter-regional) energy generating sources that have low carbon emissions such as geothermal energy. Although it is currently difficult to quantify the direct economic benefit of these efforts to reduce GHG emissions, we believe they will prove advantageous to us.

The federal government also encourages production of electricity from geothermal resources through certain tax subsidies. We are permitted to claim 30% of certain eligible costs of a new geothermal power plant put into service prior to December 31, 2013 in the United States as a one-time credit against our federal income taxes. Projects put into service after that date continue to qualify, but the credit is reduced to 10% (certain tax benefits are impacted by these tax credits as described in the section below). Alternatively, we are permitted to claim a tax credit based on the power produced from a geothermal power plant. These production-based credits, which in 2011 were 2.2 cents per kWh, are adjusted annually for inflation and may be claimed for ten years on the electricity produced by a new geothermal power plant put into service prior to December 31, 2013. The production-based credits are allowed only to the extent the power is sold to a third party. The owner of the power plant must choose between these two types of tax credits described above. In either case, under current tax rules, any unused tax credit has a one-year carry back and a twenty-year carry forward. Another alternative available is a cash grant for Specified Energy Projects in Lieu of Tax Credits from the U.S. Treasury. It is available for certain power plants placed in service by the end of 2011, or on which construction began in 2009, 2010 or 2011 and that are completed by the end of 2013. Please refer to Item 7 — "Management's Discussion and Analysis of Financial Condition and Result of Operations" regarding the valuation allowance we recorded in the year ended December 31, 2011 against deferred tax assets related to the abovementioned tax credits.

Whether we claim tax credits or a cash grant, we are also permitted to depreciate, or write off, most of the cost of the plant. If we claim the one-time 30% (or 10%) tax credit or receive the ITC cash grant, our tax basis in the plant that we can recover through depreciation must be reduced by one-half of the tax credit or cash grant; if we claim other tax credits, there is no reduction in the tax basis for depreciation. For projects that we placed into service after September 8, 2010 and before January 1, 2012, a depreciation "bonus" will permit us to write off 100% of the cost of certain equipment that is part of the geothermal power plant in the year the plant is placed into service, if certain requirements are met. For projects that are placed into service after December 31, 2011 and before January 1, 2013, a similar "bonus" will permit us to write off 50% of the cost of that equipment in the year the power plant is placed into service. After applying any depreciation bonus that is available, we can write off the remainder of our tax basis in the plant, if any, over five years on an accelerated basis, meaning that more of the cost may be deducted in the first few years than during the remainder of the depreciation period.

Collectively, these benefits (to the extent fully utilized) have a present value equivalent to approximately 30% to 40% of the capital cost of a new power plant.

Production of electricity from geothermal resources may also be supported under the "Temporary Program For Rapid Deployment of Renewable Energy and Electric Power Transmission Projects" established with the DOE as part of the DOE's existing Innovative Technology Loan Guarantee Program. The Temporary Program (i) extends the scope of the existing federal loan guarantee program to cover renewable energy projects, renewable energy component manufacturing facilities and electricity transmission projects that embody established commercial, as well as innovative, technologies; and (ii) provides an appropriation to cover the "credit subsidy cost" of such projects (meaning estimated average costs to the federal government from issuing the loan guarantee, equivalent to a lending bank's loan loss reserve). Although the Temporary Program was subject to a September 30, 2011 sunset, Congress has enacted further authorizations and appropriations to provide for a limited amount of subsidized support beyond that date for projects that would have qualified for the Temporary Program. A project supported by the federal guarantee under the new program must pay prevailing federal wages.

Operations outside of the United States may be subject to and/or benefit from requirements under the Kyoto Protocol. In December 2011, the United Nations Climate Change Conference was held in Durban, South Africa. The conference encompassed the 17th Conference of the Parties to the United Nations Framework Convention on Climate Change and the seventh meeting of the Parties to the Kyoto Protocol. Negotiators agreed to start work on a new climate deal that would have legal force and, crucially, require both developed and developing countries to cut their carbon emissions. The terms now need to be agreed by 2015 and will come into effect from 2020. The next Conference of the Parties is scheduled to take place in Qatar in November 2012. Before the Qatar conference in November 2012, the Rio +20 United Nations Conference will take place in Rio de Janeiro in June 2012. The first Rio summit 20 years ago is seen as one of the most ambitious gatherings in the history of the United Nations. More than 100 heads of state signed up to a raft of actions, including efforts to halt the deterioration of the ozone layer, tackle climate change and reduce the loss of biodiversity. These issues have taken center stage in international negotiations over the past two decades.

Outside of the United States, the majority of power generating capacity has historically been owned and controlled by governments. Since the early 1990s, however, many foreign governments have privatized their power generation industries through sales to third parties and have encouraged new capacity development and/or refurbishment of existing assets by independent power developers. These foreign governments have taken a variety of approaches to encourage the development of competitive power markets, including awarding long-term contracts for energy and capacity to independent power generators and creating competitive wholesale markets for selling and trading energy, capacity, and related products. Some countries have also adopted active governmental programs designed to encourage clean renewable energy power generation. Several Latin American countries have rural electrification programs and renewable energy programs. For example, Guatemala, where our Zunil and Amatitlan power plants are located, approved in November 2003 a law which created incentives for power generation from renewable energy sources by, among other things, providing economic and fiscal incentives such as exemptions from taxes on the importation of relevant equipment and various tax exemptions for companies implementing renewable energy projects. Another example is New Zealand, where we (and our Parent before us) have been actively designing and supplying geothermal power solutions since 1986. The New Zealand government's policies to fight climate change include a target for GHG emissions reductions of between 10% and 20% below 1990 levels by 2020 and the target of increasing renewable electricity generation to 90% of New Zealand's total electricity generation by 2025. In Indonesia, the government has implemented policies and regulations intended to accelerate the development of renewable energy and geothermal projects in particular. These include designating approximately 4,000 MW of geothermal projects in its second phase of power acceleration projects to be implemented by 2014, of which the majority is IPP projects and the remaining state utility PLN projects. For the IPP sector, certain regulations for geothermal projects have been implemented providing for incentives such as investment tax credits and accelerated depreciation, and pricing guidelines intended to allow preferential power prices for generators; other regulation are being discussed. In addition, there is a regulation providing feed-in tariffs for small scale renewable energy projects up to 10 MW. On a macro level, the Government of Indonesia committed at the United Nations Climate Change Conference 2009 in Copenhagen to reduce its CO_2 emissions by 20% by 2020, which is intended to be achieved mainly through prevention of deforestation and accelerated renewable energy development. Another example is Chile, where we were recently awarded six exploration concessions. The Chilean Renewable Energy Act of 2008 requires that 5% of electricity sold come from renewable sources beginning in 2010, increasing gradually to 10% by 2024.

We believe that these developments and governmental plans will create opportunities for us to acquire and develop geothermal power generation facilities internationally, as well as create additional opportunities for our Product Segment.

In addition to our geothermal power generation activities, we are pursuing recovered energy-based power generation opportunities in North America and the rest of the world. We believe recovered energy-based power generation may benefit from the increased attention to energy efficiency. For example, in the United States, the FERC has expressed its position that one of the goals of new natural gas pipeline design should be to facilitate the efficient, low-cost transportation of fuel through the use of waste heat (recovered energy) from combustion turbines or reciprocating engines that drive station compressors to generate electricity for use at compressor stations or for commercial sale. FERC has, as a matter of policy, requested natural gas pipeline operators filing for a certificate of approval for new pipeline construction or expansion projects to examine "opportunities to enhance efficiencies for any energy consumption processes in the development and operation" of the new pipeline. We have initially targeted the North American market, where we have built over 20 power plants which generate electricity from "waste heat" from gas turbine-driven compressor stations along interstate natural gas pipelines, from midstream gas processing facilities, and from processing industries in general.

Several states, and to a certain extent, the federal government, have recognized the environmental benefits of recovered energy-based power generation. For example, Colorado, Connecticut, Indiana, Louisiana, Michigan, Nevada, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Utah, and West Virginia allow electric utilities to include recovered energy-based power generation in calculating their compliance with their mandatory or voluntary RPS. In addition, California recently modified the Self Generation Incentive Program (SGIP) which allows recovered energy-based generation to qualify for a per watt incentive. North Dakota, South Dakota, and the U.S. Department of Agriculture (through the Rural Utilities Service) have approved recovered energy-based power generation units as renewable energy resources, which qualifies recovered energy-based power generators (whether in those two states or elsewhere in the United States) for federally funded, low interest loans, but currently do not qualify for an ITC, PTC, or ITC cash grant. Recovery of waste heat is also considered "environmentally friendly" in the western Canadian provinces. We believe that Europe and other markets worldwide may offer similar opportunities in recovered energy-based power generation.

The market for solar power grew significantly in recent years, driven by a combination of favorable government policies and a decline in equipment prices. We are monitoring market drivers in various regions with a view to developing Solar PV power plants in those locations where we can offer competitively priced power generation, particularly where we can develop a Solar PV plant next to one of our existing power plants, and thereby leverage existing infrastructure and otherwise take advantage of operating efficiencies.

Competitive Strengths

Competitive Assets. Our assets are competitive for the following reasons:

- *Contracted Generation.* All of the electricity generated by our geothermal power plants is currently sold pursuant to long-term PPAs.
- *Baseload Generation.* All of our geothermal power plants supply all or a part of the baseload capacity of the electric system in their respective markets. This means they supply electric power on an around-the-clock basis. We have a competitive advantage over other renewable energy sources, such as wind power, solar power or hydro-electric power (to the extent dependent on precipitation), which compete with us to meet electric utilities' renewable portfolio requirements but which cannot serve baseload capacity because of their weather dependence and thus intermittent nature of these other renewable energy sources.
- *Competitive Pricing.* Geothermal power plants, while site specific, are economically feasible to develop, construct, own, and operate in many locations, and the electricity they generate is generally price competitive compared to electricity generated from fossil fuels or other renewable sources under existing economic conditions and existing tax and regulatory regimes.
- *Ability to Finance Our Activities from Internally Generated Cash Flow.* The cash flow generated by our portfolio of operating geothermal and REG power plants provides us with a robust and predictable base for our exploration, development, and construction activities, to a certain level. We believe that this gives us a competitive advantage over certain competitors whose activities are more dependent on external credit and financing sources that may be subject to availability constraints depending on prevailing global credit and market conditions.

Growing Legislative Demand for Environmentally-Friendly Renewable Resource Assets. Most of our currently operating power plants produce electricity from geothermal energy sources. The clean and sustainable characteristics of geothermal energy give us a competitive advantage over fossil fuel-based electricity generation as countries increasingly seek to balance environmental concerns with demands for reliable sources of electricity.

High Efficiency from Vertical Integration.

- Unlike our competitors in the geothermal industry, we are a fully-integrated geothermal equipment, services, and power provider. We design, develop, and manufacture equipment that we use in our geothermal and REG power plants. Our intimate knowledge of the equipment that we use in our operations allows us to operate and maintain our power plants efficiently and to respond to operational issues in a timely and cost-efficient manner. Moreover, given the efficient communications among our subsidiary that designs and manufactures the products we use in our operations and our subsidiaries that own and operate our power plants, we are able to quickly and cost effectively identify and repair mechanical issues and to have technical assistance and replacement parts available to us as and when needed.
- We design, manufacture, and sell to third parties power units and other power generating equipment for geothermal and recovered energy-based electricity generation. Our extensive experience in the development of state-of-the-art, environmentally sound power solutions enables our customers to relatively easily finance their power plants.

Exploration and Drilling Capabilities. We have in-house capabilities to explore and develop geothermal resources. We have established a drilling subsidiary that currently owns nine drilling rigs. We employ an experienced resource group that includes engineers, geologists, and drillers. This resource group executes our exploration and drilling plans for projects that we develop.

Highly Experienced Management Team. We have a highly qualified senior management team with extensive experience in the geothermal power sector. Key members of our senior management team have worked in the power industry for most of their careers and average over 25 years of industry experience.

Technological Innovation. We have been granted 82 U.S. patents (additionally approximately 20 patents are pending) relating to various processes and renewable resource technologies. All of our patents are internally developed. Our ability to draw upon internal resources from various disciplines related to the geothermal power sector, such as geological expertise relating to reservoir management, and equipment engineering relating to power units, allows us to be innovative in creating new technologies and technological solutions.

Limited Exposure to Fuel Price Risk. A geothermal power plant does not need to purchase fuel (such as coal, natural gas, or fuel oil) in order to generate electricity. Thus, once the geothermal reservoir has been identified and estimated to be sufficient for use in a geothermal power plant and the drilling of wells is complete, the plant is not exposed to fuel price or fuel delivery risk apart from the impact fuel prices may have on the price at which we sell power under PPAs that are based on the relevant power purchaser's avoided costs.

Although we are confident in our competitive position in light of the strengths described above, we face various challenges in the course of our business operations, including as a result of the risks described in Item 1A — "Risk Factors" below, the trends and uncertainties discussed under Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" below, and the competition we face in our different business segments described under "Competition" below.

Business Strategy

Our strategy is to continue building a geographically balanced portfolio of geothermal and recovered energy assets, and to continue to be a leading manufacturer and provider of products and services related to renewable energy. We intend to implement this strategy through:

- *Development and Construction of New Geothermal Power Plants* — continuously seeking out commercially exploitable geothermal resources, developing and constructing new geothermal power plants and entering into long-term PPAs providing stable cash flows in jurisdictions where the regulatory, tax and business environments encourage or provide incentives for such development and which meet our investment criteria;
- *Development and Construction of Recovered Energy Power Plants* — establishing a first-to-market leadership position in recovered energy power plants in North America and building on that experience to expand into other markets worldwide;
- *Acquisition of New Assets* — acquiring from third parties additional geothermal and other renewable assets that meet our investment criteria;
- *Manufacturing and Providing Products and Service Related to Renewable Energy* — designing, manufacturing and contracting power plants for our own use and selling to third parties power units and other generation equipment for geothermal and recovered energy-based electricity generation;
- *Increasing Output from Our Existing Power Plants* — increasing output from our existing geothermal power plants by adding additional generating capacity, upgrading plant technology, and improving geothermal reservoir operations, including improving methods of heat source supply and delivery; and
- *Technological Expertise* — investing in research and development of renewable energy technologies and leveraging our technological expertise to continuously improve power plant components, reduce operations and maintenance costs, develop competitive and environmentally friendly products for electricity generation and target new service opportunities.
- In addition, we are considering various opportunities in the solar energy market and recently commenced construction of the Heber Solar project in Imperial Valley, California. There are several reasons for entering the solar energy market including:
  - the recent decline in the cost of Solar PV technologies;
  - the attractive electricity prices that may be achieved in certain regions;

- our ability to leverage EPC and development expertise in geothermal and recovered energy power generation facilities; and
- cost efficiencies we can derive from sharing infrastructure and related facilities, as well as operations and maintenance, with our existing power plants.

- Among other things, we have considered, and expect to continue to consider, a number of different opportunities including:
  - acquisitions and joint ventures;
  - expanding our internal research and development activity, or acquiring other companies engaged in solar research and development activities; and
  - constructing and operating solar electric power generation facilities.

Recent Developments

- On February 16, 2012, Geothermal Development Company (GDC) that is owned by the Government of Kenya, has awarded our subsidiary the first well head power plant project in the Menengai geothermal field in Kenya on a Build-Own-Transfer basis. The award is the result of an international tender for the design, manufacturing, procurement, construction and commissioning of the 6 MW geothermal well head power plant. GDC will supply the steam for conversion to electricity by Ormat's power plant. The Menengai geothermal field is located on the outskirts of the town of Nakuru, about 180 kilometers west of Nairobi.
- On January 30, 2012, the PUCN approved the 20-year PPA that we signed in February 2011 with NV Energy to sell 30 MW from the Dixie Meadows geothermal project that we are developing in Churchill County, Nevada.
- In December 2011, the PUCH approved the 20-year PPA we signed in February 2011 with HELCO to sell to the Hawaii Island grid an additional 8 MW of dispatchable geothermal power. The power is generated from the Puna complex and is sold at a fixed price (subject to escalation) independent of oil prices. Further information on the terms of the PPA is described in "Operation of our Electricity Segment" under "Puna Complex".
- In December 2011, we signed a termination agreement with respect to the PPA and joint operating agreement with NV Energy for the Carson Lake geothermal project in Churchill County, Nevada. Further information is provided under Operation of our Electricity Segment under "Carson Lake Project".
- In December 2011, we signed a 20-year PPA with IID for 10 MW of Solar PV energy from a project located near the Heber geothermal complex in Imperial Valley, California. This will be our first utility- scale Solar PV project. Construction started in 2011 and commercial operation is expected within 18 months, subject to timely completion of the interconnection, for which IID is responsible.
- On December 20, 2011, our subsidiary, Ormat Nevada signed a $21.4 million EPC contract and a credit agreement with Thermo No. 1 BE-01, LLC (Thermo 1), a subsidiary of Cyrq Energy, Inc. (Cyrq), in connection with the construction of an OEC at Thermo 1's existing geothermal power plant in Utah to increase the plant's output and reduce operating costs. Under the credit agreement, we will provide financing in an aggregate principal amount not to exceed $22.7 million that will be used to finance the project construction costs under the EPC contract with Thermo 1. The project is expected to have a relatively short completion schedule and could come online by the middle of 2013.
- On November 22, 2011, our subsidiary, Ormat Nevada, signed a $65.0 million EPC contract and a credit agreement with Lightning Dock Geothermal HI-01, LLC (LDG), a subsidiary of Cyrq, in connection with the construction of LDG's geothermal project in New Mexico. The EPC contract work is scheduled to be released in stages based on LDG's progress in the well field drilling and development necessary to support the project. Early engineering will be released as soon as the basic well field characteristics are

confirmed in order to maintain the project schedule. Further work will be released based on the progress of the well field development. Under the credit agreement we will provide financing in an aggregate principal amount not to exceed $66.0 million that will be used to finance the project construction costs under the EPC contract with LDG. The project is expected to come online by the end of 2013.

- In October 2011, the Chilean Committee on Geothermal Energy Analysis recommended that the Chilean Ministry of Energy award us five exploration concessions in Chile. Under the applicable regulatory framework governing the concessions, in order to maintain the development rights granted under these concessions, we will need to make certain investments in an exploration program over the next two years. Following compliance with these exploration commitments, we may receive an exploitation license, which is the first step toward power plant construction.
- In September 2011, our wholly owned indirect subsidiary, OFC 2, and its project subsidiaries (the Issuers), finalized and signed loan documentation for a 20-year loan for up to $350.0 million aggregate principal amount of OFC 2 Senior Secured Notes due December 31, 2034 under a financing agreement with John Hancock. The transaction will be guaranteed by the DOE's Loan Programs Office in accordance with and subject to the DOE's Loan Guarantee Program under Section 1705 of Title XVII of the Energy Policy Act of 2005. The financing will support power generation from three Nevada-based facilities built in two phases that are expected to generate up to 113 MW of power. The three facilities, Jersey Valley, McGinness Hills, and Tuscarora, will provide baseload power through 20-year PPAs with Nevada Power Company, a subsidiary of NV Energy. The capacity of the first phase is expected to be up to approximately 60 MW. The second phase of development is subject to a feasibility assessment of the geothermal resource, which will be performed following completion of the first phase of each facility and fulfillment of other conditions in the loan documents. On October 31, 2011, OFC 2 and the Issuers completed the sale of $151.7 million aggregate principal amount of Series A of OFC 2 Senior Secured Notes due 2032. The net proceeds from the sale of the Series A of OFC 2 Senior Secured Notes, after deducting transaction fees and expenses, were approximately $141.1 million, and will be used to finance a portion of the construction costs of Phase I of the McGinness Hills and Tuscarora facilities.
- In September 2011, our wholly owned subsidiary, Ormat International, signed a commitment letter with OPIC to provide project financing of up to $310.0 million to refinance and expand our 48 MW Olkaria III geothermal complex located in Naivasha, Kenya. Under the agreed term sheet attached to the commitment letter, the loan will be comprised of a refinancing tranche of up to $85.0 million to prepay the existing loan and fund transaction costs, a construction loan tranche of up to $165.0 million to finance the construction of an additional 36 MW expansion currently underway, and a $60.0 million stand-by facility to finance an additional optional 16 MW capacity expansion, that, if exercised by us, could bring the total capacity of the complex to approximately 100 MW. The maturity dates of the construction tranche and the refinancing tranche are expected to be June 2030 and December 2030, respectively. The maturity date and certain other terms of the stand-by facility will be finalized following our decision, if any, to exercise the option to construct the additional 16 MW expansion.
- We have completed the modification of the 20 MW Burdette (Galena 1) power plant into an evaporative cooling configuration. Evaporative cooling provides increased power generation from air-cooled facilities, compared to regular air-cooled facilities by as much as 30% during the peak heat hours of the day. The implementation of this system in moderate to dry climates, especially in the high desert, generates more energy per year than water-cooled systems, and with a fraction of the water and chemical consumption of traditional water-cooled systems.
- In June 2011, we signed a lease agreement for approximately 300 acres with Kibbutz Revivim in Israel. We plan to use the land to build a Solar PV power plant.
- In June 2011, we entered into a BOT agreement with TGL to explore, develop, supply, construct, own and operate a geothermal power plant in the Tikitere geothermal area near Rotorua, New Zealand. Under the BOT agreement, the parties will jointly develop a geothermal power plant with an estimated capacity of approximately 45 MW. We will own and operate the project for an initial period of 14 years following

commercial operation and then the ownership interests in the project will be transferred to TGL. The project will utilize Ormat's generating units. The BOT agreement is conditional upon receiving regulatory approval and resolution of internal arrangements, such as royalties, between the trusts owning the land. Construction of the power plant will commence following the obtaining of local permits, as well as satisfactory feasibility results following exploration and development activities to be carried out by us.

- In June 2011, two of our subsidiaries signed a supply contract and an EPC contract with Mighty River Power Limited of New Zealand, for the first stage of the Ngatamariki geothermal project valued at a total of approximately $130.0 million. The new power plant is to be constructed on the Ngatamariki Geothermal Field in New Zealand. Construction of the power plant is expected to be completed within 24 months from the contract date. Mighty River Power Limited, a state-owned enterprise, is a New Zealand electricity generation and electricity retailing company.
- In May 2011, we entered into a supply contract with Norske Skog Tasman Limited of New Zealand to supply a new geothermal power plant that is to be constructed in the Kawerau Geothermal Field in New Zealand. The contract is valued at a total of approximately $20.0 million and delivery of the power plant is expected to be completed within 13 months from the contract date.
- In April 2011, we amended and restated the PPA with KPLC, the off-taker of the Olkaria III complex located in Naivasha, Kenya. The amended and restated PPA governs our construction of, and KPLC's purchase of electricity from, a new 36 MW power plant at the Olkaria III complex. The new power plant is scheduled to come online in 2013. The PPA amendment includes an option to increase the combined 84 MW capacity from the new and existing plants to a maximum of 100 MW, subject to monitoring and assessment of the geothermal reservoir capacity.
- In March 2011, we entered into an agreement with the Weyerhaeuser Company granting us an option to enter into geothermal leases covering approximately 264,000 acres of land in Oregon and Washington. Under this agreement we have the exclusive right to explore the land for geothermal resources and may enter into one or more geothermal leases within the optioned land.
- On March 31, 2011, Southern California Edison Company (Southern California Edison) set the demonstrated capacity of the North Brawley power plant at 33 MW. Southern California Edison also agreed to modify the North Brawley PPA to allow us the option of performing an additional capacity demonstration within one year from the first capacity demonstration on March 31, 2011, which may enable us to increase the demonstrated capacity of the plant.

Operations of our Electricity Segment

How We Own Our Power Plants. We customarily establish a separate subsidiary to own interests in each power plant. Our purpose in establishing a separate subsidiary for each plant is to ensure that the plant, and the revenues generated by it, will be the only source for repaying indebtedness, if any, incurred to finance the construction or the acquisition (or to refinance the acquisition) of the relevant plant. If we do not own all of the interest in a power plant, we enter into a shareholders agreement or a partnership agreement that governs the management of the specific subsidiary and our relationship with our partner in connection with the specific power plant. Our ability to transfer or sell our interest in certain power plants may be restricted by certain purchase options or rights of first refusal in favor of our power plant partners or the power plant's power purchasers and/or certain change of control and assignment restrictions in the underlying power plant and financing documents. All of our domestic geothermal and REG power plants, with the exception of the Puna complex, which is an Exempt Wholesale Generator, are Qualifying Facilities under the PURPA, and are eligible for regulatory exemptions from most provisions of the FPA and certain state laws and regulations.

How We Explore and Evaluate Geothermal Resources. Since 2006, we have expanded our exploration activities, particularly in Nevada. These activities generally involve:

- Identifying and evaluating potential geothermal resources using information available to us from public and private resources as described under "Initial Evaluation" below.

- Acquisition of land rights to any geothermal resources our initial evaluation indicates could potentially support a commercially viable power plant, taking into account various factors described under "Land Acquisition" below.
- Conducting geophysical and geochemical surveys on some or all of the sites acquired, as described under "Surveys" below.
- Obtaining permits to conduct exploratory drilling, as described under "Environmental Permits" below.
- Drilling one or more exploratory wells on some or all of the sites to confirm and/or define the geothermal resource where indicated by our surveys, creating access roads to drilling locations and related activities, as described under "Exploratory Drilling" below.
- Drilling a full-size well (as described below) if our exploratory drilling indicates the geothermal resource can support a commercially viable power plant taking into account various factors described under "Exploratory Drilling" below. Drilling a full-size well is the point at which we usually consider a site moves from exploration to construction.

It normally takes us one to two years from the time we start active exploration of a particular geothermal resource to the time we have an operating production well, assuming we conclude the resource is commercially viable.

Initial Evaluation. As part of our initial evaluation, we generally follow the following process, although our process can vary from site to site depending on the particular circumstances involved:

- We evaluate historic, geologic and geothermal information available from public and private databases.
- For some sites, we may obtain and evaluate additional information from other industry participants, such as where oil or gas wells may have been drilled on or near a site.
- We generally create a digital, spatial geographic information systems database containing all pertinent information, including thermal water temperature gradients derived from historic drilling, geologic mapping information (e.g., formations, structure and topography), and any available archival information about the geophysical properties of the potential resource.
- We assess other relevant information, such as infrastructure (e.g., roads and electric transmission lines), natural features (e.g., springs and lakes), and man-made features (e.g., old mines and wells).

Our initial evaluation is usually conducted by our own staff, although we might engage outside service providers for some tasks from time to time. The costs associated with an initial evaluation vary from site to site, based on various factors, including the acreage involved and the costs, if any, of obtaining information from private databases or other sources. On average, our expenses for an initial evaluation of a site range from approximately $20,000 to $100,000.

If we conclude, based on the information considered in the initial evaluation, that the geothermal resource can support a commercially viable power plant, taking into account various factors described below, we proceed to land rights acquisition.

Land Acquisition. For domestic power plants, we either lease or own the sites on which our power plants are located. In our foreign power plants, our lease rights for the plant site are generally contained in the terms of a concession agreement or other contract with the host government or an agency thereof. In certain cases, we also enter into one or more geothermal resource leases (or subleases) or a concession or other agreement granting us the exclusive right to extract geothermal resources from specified areas of land, with the owners (or sublessors) of such land. This documentation will usually give us the right to explore, develop, operate, and maintain the geothermal field, including, among other things, the right to drill wells (and if there are existing wells in the area, to alter them) and build pipelines for transmitting geothermal fluid. In certain cases, the holder of rights in the geothermal resource is a governmental entity and in other cases a private entity. Usually the duration of the lease (or sublease) and concession agreement corresponds to the duration of the relevant PPA, if any. In certain other cases, we own the land where the geothermal resource is located, in which case there are no restrictions on its utilization. Leasehold interests in federal land in the United States are regulated by the BLM and the Minerals Management Service. These agencies have rules governing the geothermal leasing process as discussed under the heading "Description of Our Leases and Lands."

For most of our current exploration sites in Nevada, we acquire rights to use geothermal resource through land leases with the BLM, with various states, or through private leases. Under these leases, we typically pay an up-front non-refundable bonus payment, which is a component of the competitive lease process. In addition, we undertake to pay nominal, fixed annual rent payments for the period from the commencement of the lease through the completion of construction. Upon the commencement of power generation, we begin to pay to the lessors long-term royalty payments based on the use of the geothermal resources as defined in the respective agreements. These payments are contingent on the power plant's revenues. There is a summary of our typical lease terms under the heading "Description of our Leases and Lands."

The up-front bonus and royalty payments vary from site to site and are based, among other things, on current market conditions.

Surveys. Following the acquisition of land rights for a potential geothermal resource, we conduct surface water analyses and soil surveys to determine proximity to possible heat flow anomalies and up-flow/permeable zones and augment our digital database with the results of those analyses. We then initiate a suite of geophysical surveys (e.g., gravity, magnetics, resistivity, magnetotellurics, and spectral surveys) to assess surface and sub-surface structure (e.g., faults and fractures) and develop a roadmap of fluid-flow conduits and overall permeability. All pertinent geophysical data are then used to create three-dimensional geothermal reservoir models that are used to identify drill locations.

We make a further determination of the commercial viability of the geothermal resource based on the results of this process, particularly the results of the geochemical and geophysical surveys. If the results from the geochemical and geophysical surveys are poor (i.e., low derived resource temperatures or poor permeability), we will re-evaluate the commercial viability of the geothermal resource and may not proceed to exploratory drilling.

Exploratory Drilling. If we proceed to exploratory drilling, we generally will use outside contractors to create access roads to drilling sites. After obtaining drilling permits, we generally drill temperature gradient holes and/or slim holes using either our own drilling equipment or outside contractors. However, exploration of some geothermal resources can require drilling a full-size well, particularly where the resource is deep underground. If the slim hole is "dry", it may be capped and the area reclaimed if we conclude that the geothermal resource will not support a commercially viable power project. If the slim hole supports a conclusion that the geothermal resource will support a commercially viable power plant, it may either be:

- Converted to a full-size commercial well, used either for extraction or reinjection of geothermal fluids (Production Well).
- Used as an observation well to monitor and define the geothermal resource.

The costs we incur for exploratory drilling vary from site to site based on various factors, including market demand for drilling contractors and equipment (which may be affected by on-shore oil and gas exploration activities, etc.), the accessibility of the drill site, the geology of the site, and the depth of the resource, among other things. However, on average, exploration drilling costs are approximately $5 million for each site.

At various points during our exploration activities, we re-assess whether the geothermal resource involved will support a commercially viable power plant. In each case, this re-assessment is based on information available at that time. Among other things, we consider the following factors:

- New information obtained concerning the geothermal resource as our exploration activities proceed, and particularly the expected MW capacity power plant the resource can be expected to support.

- Current and expected market conditions and rates for contracted and merchant electric power in the market(s) to be serviced.
- Anticipated costs associated with further exploration activities.
- Anticipated costs for design and construction of a power plant at the site.
- Anticipated costs for operation of a power plant at the site, particularly taking into account the ability to share certain types of costs (such as control rooms) with one or more other power plants that are, or are expected to be, operating near the site.

If we conclude that the geothermal resource involved will support a commercially viable power plant, we proceed to constructing a power plant at the site.

How We Construct Our Power Plants. The principal phases involved in constructing one of our geothermal power plants are as follows:

- Drilling Production Wells.
- Designing the well field, power plant, equipment, controls, and transmission facilities.
- Obtaining any required permits.
- Manufacturing (or in the case of equipment we do not manufacture ourselves, purchasing) the equipment required for the power plant.
- Assembling and constructing the well field, power plant, transmission facilities, and related facilities.

It generally takes approximately two years from the time we drill a Production Well, until the power plant becomes operational.

Drilling Production Wells. As noted above, we consider drilling the first Production Well as the beginning of our construction phase for a power plant. The number of Production Wells varies from plant to plant depending, among other things, on the geothermal resource, the projected capacity of the power plant, the power generation equipment to be used and the way geothermal fluids will be re-injected to maintain the geothermal resource and surface conditions. The Production Wells are normally drilled by our own drilling equipment. In some cases we use outside contractors, generally firms that service the on-shore oil and gas industry.

The cost for each Production Well varies depending, among other things, on the depth and size of the well and market conditions affecting the supply and demand for drilling equipment, labor and operators. On average, however, our costs for each Production Well range from $3 million to $5 million.

Design. We use our own employees to design the well field and the power plant, including equipment that we manufacture. The designs vary based on various factors, including local laws, required permits, the geothermal resource, the expected capacity of the power plant and the way geothermal fluids will be re-injected to maintain the geothermal resource and surface conditions.

Permits. We use our own employees and outside consultants to obtain any required permits and licenses for our power plants that are not already covered by the terms of our site leases. The permits and licenses required vary from site to site, and are described below under the heading "Environmental Permits."

Manufacturing. Generally, we manufacture most of the power generating unit equipment we use at our power plants. Multiple sources of supply are available for all other equipment we do not manufacture.

Construction. We use our own employees to manage the construction work. For site grading, civil, mechanical, and electrical work we use subcontractors.

During the year ended December 31, 2011, one site (Olkaria III Phase III) moved to construction, and during each of the years ended December 31, 2010 and 2009, two sites moved to construction. In 2010 the sites were CD4 at the Mammoth complex and Wild Rose (formerly DH Wells), and in 2009, the sites were Carson Lake and McGinness Hills. During the years ended December 31, 2010 and 2009, we discontinued exploration activities at one site each year. Those sites were Gabbs Valley and Rock Hills, in Nevada. After conducting exploratory drilling in those sites, we concluded that the geothermal resource at those sites would not support commercially viable power plants at this time. The costs associated with exploration activities at those sites were expensed during the years ended December 31, 2010 and 2009, respectively, (see "Write-off of Unsuccessful Exploration Activities" under Item 7 — "Management Discussion and Analysis of Financial Condition and Results of Operations"). Thirteen new sites were added to our exploration and development activities in the year ended December 31, 2011, compared with seven sites in the year ended December 31, 2010 and with six sites in the year ended December 31, 2009.

How We Operate and Maintain Our Power Plants. In the U.S. we usually employ our subsidiary, Ormat Nevada, to act as operator of our power plants pursuant to the terms of an operation and maintenance agreement. Operation and maintenance of our foreign projects are generally provided by our subsidiary that owns the relevant project. Our operations and maintenance practices are designed to minimize operating costs without compromising safety or environmental standards while maximizing plant flexibility and maintaining high reliability. Our operations and maintenance practices for geothermal power plants seek to preserve the sustainable characteristics of the geothermal resources we use to produce electricity and maintain steady-state operations within the constraints of those resources reflected in our relevant geologic and hydrologic studies. Our approach to plant management emphasizes the operational autonomy of our individual plant or complex managers and staff to identify and resolve operations and maintenance issues at their respective power plants; however, each power plant or complex draws upon our available collective resources and experience, and that of our subsidiaries. We have organized our operations such that inventories, maintenance, backup, and other operational functions are pooled within each power plant complex and provided by one operation and maintenance provider. This approach enables us to realize cost savings and enhances our ability to meet our power plant availability goals.

Safety is a key area of concern to us. We believe that the most efficient and profitable performance of our power plants can only be accomplished within a safe working environment for our employees. Our compensation and incentive program includes safety as a factor in evaluating our employees, and we have a well-developed reporting system to track safety and environmental incidents, if any, at our power plants.

How We Sell Electricity. In the United States, the purchasers of power from our power plants are typically investor-owned electric utility companies. Outside of the United States, the purchaser is either a state-owned utility or a privately-owned entity and we typically operate our facilities pursuant to rights granted to us by a governmental agency pursuant to a concession agreement. In each case, we enter into long-term contracts (typically called PPAs) for the sale of electricity or the conversion of geothermal resources into electricity. A power plant's revenues under a PPA used to consist of two payments — energy payments and capacity payments; however our recent PPAs provide for energy payments only. Energy payments are normally based on a power plant's electrical output actually delivered to the purchaser measured in kilowatt hours, with payment rates either fixed or indexed to the power purchaser's "avoided" power costs (i.e., the costs the power purchaser would have incurred itself had it produced the power it is purchasing from third parties, such as us) or rates that escalate at a predetermined percentage each year. Capacity payments are normally calculated based on the generating capacity or the declared capacity of a power plant available for delivery to the purchaser, regardless of the amount of electrical output actually produced or delivered. In addition, most of our domestic power plants located in California are eligible for capacity bonus payments under the respective PPAs upon reaching certain levels of generation.

How We Finance Our Power Plants. Historically we have funded our power plants with a combination of non-recourse or limited recourse debt, lease financing, parent company loans, and internally generated cash, which includes funds from operation, as well as proceeds from loans under corporate credit facilities, sale of securities, and other sources of liquidity. Such leveraged financing permits the development of power plants with a limited amount of equity contributions, but also increases the risk that a reduction in revenues could adversely affect a particular power plant's ability to meet its debt obligations. Leveraged financing also means that distributions of dividends or other distributions by plant subsidiaries to us are contingent on compliance with financial and other covenants contained in the financing documents.

Non-recourse debt or lease financing refers to debt or lease arrangements involving debt repayments or lease payments that are made solely from the power plant's revenues (rather than our revenues or revenues of any other power plant) and generally are secured by the power plant's physical assets, major contracts and agreements, cash accounts and, in many cases, our ownership interest in our affiliate that owns that power plant. These forms of financing are referred to as "project financing." Project financing transactions generally are structured so that all revenues of a power plant are deposited directly with a bank or other financial institution acting as escrow or security deposit agent. These funds are then payable in a specified order of priority set forth in the financing documents to ensure that, to the extent available, they are used to first pay operating expenses, senior debt service (including lease payments) and taxes, and to fund reserve accounts. Thereafter, subject to satisfying debt service coverage ratios and certain other conditions, available funds may be disbursed for management fees or dividends or, where there are subordinated lenders, to the payment of subordinated debt service.

In the event of a foreclosure after a default, our affiliate that owns the power plant would only retain an interest in the assets, if any, remaining after all debts and obligations have been paid in full. In addition, incurrence of debt by a power plant may reduce the liquidity of our equity interest in that power plant because the interest is typically subject both to a pledge in favor of the power plant's lenders securing the power plant's debt and to transfer and change of control restrictions set forth in the relevant financing agreements.

Limited recourse debt refers to project financing as described above with the addition of our agreement to undertake limited financial support for our affiliate that owns the power plant in the form of certain limited obligations and contingent liabilities. These obligations and contingent liabilities may take the form of guarantees of certain specified obligations, indemnities, capital infusions and agreements to pay certain debt service deficiencies. To the extent we become liable under such guarantees and other agreements in respect of a particular power plant, distributions received by us from other power plants and other sources of cash available to us may be required to be used to satisfy these obligations. To the extent of these limited recourse obligations, creditors of a project financing of a particular power plant may have direct recourse to us.

We have also used a financing structure to monetize PTCs and other favorable tax benefits derived from the financed power plants and an operating lease arrangement for one of our power plants.

How We Mitigate International Political Risk. We generally purchase insurance policies to cover our exposure to certain political risks involved in operating in developing countries, as described below under the heading "Insurance". To date, our political risk insurance contracts are with the Multilateral Investment Guaranty Agency (MIGA), a member of the World Bank Group, and Zurich Re, a private insurance and re-insurance company. Such insurance policies generally cover, subject to the limitations and restrictions contained therein, 80% to 90% of our revenue loss derived from a specified governmental act such as confiscation, expropriation, riots, the inability to convert local currency into hard currency, and, in certain cases, the breach of agreements. We have obtained such insurance for all of our foreign power plants in operation.

Description of Our Leases and Lands

We have domestic leases on approximately 481,000 acres of federal, state, and private land in California, Nevada, Utah, Alaska, Hawaii, Oregon, and Idaho. The approximate breakdown between federal, state, and private leases is as follows:

- 72% are leases with the U.S. government, acting through the BLM;

Table of Contents

- 15% are leases with various states, none of which is currently material; and
- 13% are leases with private landowners and/or leaseholders.

Each of the leases within each of the categories has standard terms and requirements, as summarized below. We own approximately 6,700 acres of land in Nevada and California. Internationally, our land position includes approximately 365,000 acres, most of which are geothermal exploration licenses in six prospects in Chile. In addition, we own land, a portion of which is used for our Heber Solar PV project.

Bureau of Land Management Geothermal Leases

Certain of our domestic project subsidiaries have entered into geothermal resources leases with the U.S. government, pursuant to which they have obtained the right to conduct their geothermal development and operations on federally-owned land. These leases are made pursuant to the Geothermal Steam Act and the lessor under such leases is the U.S. government, acting through the BLM.

BLM geothermal leases grant the geothermal lessee the right and privilege to drill for, extract, produce, remove, utilize, sell, and dispose of geothermal resources on certain lands, together with the right to build and maintain necessary improvements thereon. The actual ownership of the geothermal resources and other minerals beneath the land is retained in the federal mineral estate. The geothermal lease does not grant to the geothermal lessee the exclusive right to develop the lands, although the geothermal lessee does hold the exclusive right to develop geothermal resources within the lands. The geothermal lessee does not have the right to develop minerals unassociated with geothermal production and cannot prohibit others from developing the minerals present in the lands. The BLM may grant multiple leases for the same lands and, when this occurs, each lessee is under a duty to not unreasonably interfere with the development rights of the other. Because BLM leases do not grant to the geothermal lessee the exclusive right to use the surface of the land, BLM may grant rights to others for activities that do not unreasonably interfere with the geothermal lessee's uses of the same land; such other activities may include recreational use, off-road vehicles, and/or wind or solar energy developments.

Certain BLM leases issued before August 8, 2005 include covenants that require the projects to conduct their operations under the lease in a workmanlike manner and in accordance with all applicable laws and BLM directives and to take all mitigating actions required by the BLM to protect the surface of and the environment surrounding the land. Additionally, certain leases contain additional requirements, some of which concern the mitigation or avoidance of disturbance of any antiquities, cultural values or threatened or endangered plants or animals, the payment of royalties for timber, and the imposition of certain restrictions on residential development on the leased land.

BLM leases entered into after August 8, 2005 require the geothermal lessee to conduct operations in a manner that minimizes impacts to the land, air, water, to cultural, biological, visual, and other resources, and to other land uses or users. The BLM may require the geothermal lessee to perform special studies or inventories under guidelines prepared by the BLM. The BLM reserves the right to continue existing leases and to authorize future uses upon or in the leased lands, including the approval of easements or rights-of-way. Prior to disturbing the surface of the leased lands, the geothermal lessee must contact the BLM to be apprised of procedures to be followed and modifications or reclamation measures that may be necessary. Subject to BLM approval, geothermal lessees may enter into unit agreements to cooperatively develop a geothermal resource. The BLM reserves the right to specify rates of development and to require the geothermal lessee to commit to a communalization or unitization agreement if a common geothermal resource is at risk of being overdeveloped.

Typical BLM leases issued to geothermal lessees before August 8, 2005 have a primary term of ten years and will renew so long as geothermal resources are being produced or utilized in commercial quantities, but cannot exceed a period of forty years after the end of the primary term. If at the end of the forty-year period geothermal steam is still being produced or utilized in commercial quantities and the lands are not needed for other purposes, the geothermal lessee will have a preferential right to renew the lease for a second forty-year term, under terms and conditions as the BLM deems appropriate.

Table of Contents

BLM leases issued after August 8, 2005 have a primary term of ten years. If the geothermal lessee does not reach commercial production within the primary term the BLM may grant two five-year extensions if the geothermal lessee: (i) satisfies certain minimum annual work requirements prescribed by the BLM for that lease, or (ii) makes minimum annual payments. Additionally, if the geothermal lessee is drilling a well for the purposes of commercial production, the primary term (as it may have been extended) may be extended for five years and as long thereafter as steam is being produced and used in commercial quantities (meaning the geothermal lessee either begins producing geothermal resources in commercial quantities or has a well capable of producing geothermal resources in commercial quantities and is making diligent efforts to utilize the resource) for thirty-five years. If, at the end of the extended thirty-five year term, geothermal steam is still being produced or utilized in commercial quantities and the lands are not needed for other purposes, the geothermal lessee will have a preferential right to renew the lease for fifty-five years, under terms and conditions as the BLM deems appropriate.

For BLM leases issued before August 8, 2005, the geothermal lessee is required to pay an annual rental fee (on a per acre basis), which escalates according to a schedule described therein, until production of geothermal steam in commercial quantities has commenced. After such production has commenced, the geothermal lessee is required to pay royalties (on a monthly basis) on the amount or value of (i) steam, (ii) by-products derived from production, and (iii) commercially de-mineralized water sold or utilized by the project (or reasonably susceptible to such sale or use).

For BLM leases issued after August 8, 2005, (i) a geothermal lessee who has obtained a lease through a non-competitive bidding process will pay an annual rental fee equal to $1.00 per acre for the first ten years and $5.00 per acre each year thereafter; and (ii) a geothermal lessee who has obtained a lease through a competitive process will pay a rental equal to $2.00 per acre for the first year, $3.00 per acre for the second through tenth year and $5.00 per acre each year thereafter. Rental fees paid before the first day of the year for which the rental is owed will be credited towards royalty payments for that year. For BLM leases issued, effective, or pending on August 5, 2005 or thereafter, royalty rates are fixed between 1-2.5% of the gross proceeds from the sale of electricity during the first ten years of production under the lease. The royalty rate set by the BLM for geothermal resources produced for the commercial generation of electricity but not sold in an arm's length transaction is 1.75% for the first ten years of production and 3.5% thereafter. The royalty rate for geothermal resources sold by the geothermal lessee or an affiliate in an arm's length transaction is 10% of the gross proceeds from the arm's length sale. The BLM may readjust the rental or royalty rates at not less than twenty year intervals beginning thirty-five years after the date geothermal steam is produced.

In the event of a default under any BLM lease, or the failure to comply with any of the provisions of the Geothermal Steam Act or regulations issued under the Geothermal Steam Act or the terms or stipulations of the lease, the BLM may, 30 days after notice of default is provided to the relevant project, (i) suspend operations until the requested action is taken, or (ii) cancel the lease.

Private Geothermal Leases

Certain of our domestic project subsidiaries have entered into geothermal resources leases with private parties, pursuant to which they have obtained the right to conduct their geothermal development and operations on privately owned land. In many cases, the lessor under these private geothermal leases owns only the geothermal resource and not the surface of the land.

Typically, the leases grant our project subsidiaries the exclusive right and privilege to drill for, produce, extract, take and remove from the leased land water, brine, steam, steam power, minerals (other than oil), salts, chemicals, gases (other than gases associated with oil), and other products produced or extracted by such project subsidiary. The project subsidiaries are also granted certain non-exclusive rights pertaining to the construction and operation of plants, structures, and facilities on the leased land. Additionally, the project subsidiaries are granted the right to dispose of waste brine and other waste products as well as the right to reinject into the leased

Table of Contents

land water, brine, steam, and gases in a well or wells for the purpose of maintaining or restoring pressure in the productive zones beneath the leased land or other land in the vicinity. Because the private geothermal leases do not grant to the lessee the exclusive right to use the surface of the land, the lessor reserves the right to conduct other activities on the leased land in a manner that does not unreasonably interfere with the geothermal lessee's uses of the same land, which other activities may include agricultural use (farming or grazing), recreational use and hunting, and/or wind or solar energy developments.

The leases provide for a term consisting of a primary term in the range of five to 30 years, depending on the lease, and so long thereafter as lease products are being produced or the project subsidiary is engaged in drilling, extraction, processing, or reworking operations on the leased land.

As consideration under most of our project subsidiaries' private leases, the project subsidiary must pay to the lessor a certain specified percentage of the value "at the well" (which is not attributable to the enhanced value of electricity generation), gross proceeds, or gross revenues of all lease products produced, saved, and sold on a monthly basis. In certain of our project subsidiaries' private leases, royalties payable to the lessor by the project subsidiary are based on the gross revenues received by the lessee from the sale or use of the geothermal substances, either from electricity production or the value of the geothermal resource "at the well".

In addition, pursuant to the leases, the project subsidiary typically agrees to commence drilling, extraction or processing operations on the leased land within the primary term, and to conduct such operations with reasonable diligence until lease products have been found, extracted and processed in quantities deemed "paying quantities" by the project subsidiary, or until further operations would, in such project subsidiary's judgment, be unprofitable or impracticable. The project subsidiary has the right at any time within the primary term to terminate the lease and surrender the relevant land. If the project subsidiary has not commenced any such operations on said land (or on the unit area, if the lease has been unitized), or terminated the lease within the primary term, the project subsidiary must pay to the lessor, in order to maintain its lease position, annually in advance, a rental fee until operations are commenced on the leased land.

If the project subsidiary fails to pay any installment of royalty or rental when due and if such default continues for a period of fifteen days specified in the lease, for example, after its receipt of written notice thereof from the lessor, then at the option of the lessor, the lease will terminate as to the portion or portions thereof as to which the project subsidiary is in default. If the project subsidiary defaults in the performance of any obligations under the lease, other than a payment default, and if, for a period of 90 days after written notice is given to it by the lessor of such default, the project subsidiary fails to commence and thereafter diligently and in good faith take remedial measures to remedy such default, the lessor may terminate the lease.

We do not regard any property that we lease as material unless and until we begin construction of a power plant on the property, that is, until we drill a production well on the property.

Exploration Concessions in Chile

We have been awarded six exploration concessions in Chile, under which we have the rights to start exploration work with an original term of two years. Prior to the last six months of the original term of each exploration concession, we can request its extension for an additional period of two years. According to applicable regulations, the extension of the exploration concession is subject to the receipt by the Ministry of Energy of evidence that at least 25% of the planned investments for the execution of the project, as reflected in the relevant proposal submitted during the tender process, has been invested. Following submission of the request, the Ministry of Energy has three months in which it may grant or deny the extension.

Description of Our Power Plants

Domestic Power Plants

The following descriptions summarize certain industry metrics for our domestic power plants:

Brady Complex

Location	Churchill County, Nevada
Generating Capacity	25 MW
Number of Power Plants	2 (Brady and Desert Peak 2 power plants).
Technology	The Brady complex utilizes binary and flash systems. The complex uses air and water cooled systems.
Subsurface Improvements	12 production wells and 6 injection wells are connected to the plants through a gathering system.
Major Equipment	Three OEC units and three steam turbines along with Balance of Plant equipment.
Age	The Brady power plant commenced commercial operations in 1992 and a new OEC unit was added in 2004. The Desert Peak 2 power plant commenced commercial operation in 2007.
Land and Mineral Rights	The Brady complex area is comprised of mainly BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases, and the Brady power plant holds right of ways from the BLM and from the private owner that allows access to and from the plant.
Resource Information	The resource temperature at Brady is 278 degrees Fahrenheit and at Desert Peak 2 is 370 degrees Fahrenheit. The Brady and Desert Peak geothermal systems are located within the Hot Springs Mountains, approximately 60 miles northeast of Reno, Nevada, in northwestern Churchill County. The dominant geological feature of the Brady area is a linear NNE-trending band of hot ground that extends for a distance of two miles. The Desert Peak geothermal field is located within the Hot Springs Mountains, which form part of the western boundary of the Carson Sink. The structure is characterized by east-titled fault blocks and NNE-trending folds. Geologic structure in the area is dominated by high-angle normal faults of varying displacement.

Resource Cooling	Approximately 4 degrees Fahrenheit per year was observed at Brady during the past 15 years of production. The temperature decline at Desert Peak is less than 1 degree Fahrenheit per year.
Sources of Makeup Water	Condensed steam is used for makeup water.

Power Purchaser	Brady power plant — Sierra Pacific Power Company. Desert Peak 2 power plant — Nevada Power Company.
PPA Expiration Date	Brady power plant — 2022. Desert Peak 2 power plant — 2027.
Financing	OFC Senior Secured Notes (Brady) and OPC Transaction (Desert Peak 2).

Heber Complex

Location	Heber, Imperial County, California
Generating Capacity	92 MW
Number of Power Plants	5 (Heber 1, Heber 2, Heber South, G-1 and G-2).
Technology	The Heber 1 plant utilizes dual flash and the Heber 2, Heber South, G-1 and G-2 plants utilize binary systems. The complex uses a water cooled system.
Subsurface Improvements	31 production wells and 34 injection wells connected to the plants through a gathering system.
Major Equipment	17 OEC units and 1 steam turbine with the Balance of Plant equipment.
Age	The Heber 1 plant commenced commercial operations in 1985 and the Heber 2 plant in 1993. The G-1 plant commenced commercial operation in 2006 and the G-2 plant in 2005. The Heber South plant commenced commercial operation in 2008.
Land and Mineral Rights	The total Heber area is comprised of mainly private leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The resource supplying the flash flowing Heber 1 wells averages 350 degrees Fahrenheit. The resource supplying the pumped Heber 2 wells averages 318 degrees Fahrenheit.

Heber production is from deltaic sedimentary sandstones deposited in the subsiding Salton Trough of California's Imperial Valley. Produced fluids rise from near the magmatic heated basement rocks (18,000 feet) via fault/fracture zones to the near surface. Heber 1 wells produce directly from deep (4,000 to 8,000 feet) fracture zones. Heber 2 wells

	produce from the nearer surface (2,000 to 4,000 feet) matrix permeability sandstones in the horizontal outflow plume fed by the fractures from below and the surrounding ground waters. Scale deposition in the flashing Heber 1 producers is controlled by down hole chemical inhibition supplemented with occasional mechanical cleanouts and acid treatments. There is no scale deposition in the Heber 2 production wells.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Sources of Makeup Water	Water is provided by condensate and by the IID.
Power Purchaser	2 PPAs with Southern California Edison and 1 PPA with SCPPA.
PPA Expiration Date	Heber 1 — 2015, Heber 2 — 2023, and Heber South — 2031. The output from the G-1 and G-2 power plants is sold under the PPAs of Southern California Edison and SCPPA.
Financing	OrCal Senior Secured Notes.
Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues. We plan to enhance the complex and add 6 MW, if negotiation on new PPA will succeed.

Jersey Valley Power Plant

Location	Pershing County, Nevada
Generating Capacity	12 MW (See supplemental information below)
Number of Power Plants	1
Technology	The Jersey Valley power plant utilizes an air cooled binary system.
Subsurface Improvements	2 production wells and 4 injection wells are connected to the plant through a gathering system. The drilling of the third production well was completed and will be used in the future as required. Drilling of additional injection wells is currently under development.
Major Equipment	2 OEC units together with the Balance of Plant equipment.

Table of Contents

Age	Construction of the power plant was completed at the end of 2010 and the off-taker approved commercial operation status under the PPA effective on August 30, 2011.
Land and Mineral Rights	The Jersey Valley area is comprised of BLM leases. The leases are held

	by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants.
	The power plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from leased property and access across leased property under surface rights granted in leases from BLM.
Resource Information	The Jersey Valley geothermal reservoir consists of a small high-permeability area surrounded by a large low-permeability area. The high-permeability area has been defined by wells drilled along an interpreted fault trending west-northwest. Static water levels are artesian; two of the wells along the permeable zone have very high productivities, as indicated by Permeability Index (PI) values exceeding 20 gpm/psi.

The average temperature of the resource is 330 degrees Fahrenheit.

Power Purchaser	Nevada Power Company.
PPA Expiration Date	January 1, 2032
Financing	Corporate funds.
	Once the Jersey Valley power plant reaches certain operational targets and meets other conditions precedent we have the ability to borrow additional funds under the OFC 2 Senior Secured Notes.
	We have submitted an application for the ITC cash grant for the power plant.
Supplemental Information	The Jersey Valley power plant is currently operating below its designed capacity. This is primarily due to the need to shut down one of the injection wells that was rendered unusable by old mining wells that we believe were not adequately plugged when abandoned by the mining operator that previously operated on the land.
	We have drilled an additional injection well, which is being connected to the plant.
	We have identified targets for additional wells and will continue to drill to improve injection capacity.

Mammoth Complex

Location	Mammoth Lakes, California

Table of Contents

Generating Capacity	29 MW
Number of Power Plants	3 (G-1, G-2, and G-3).
Technology	The Mammoth complex utilizes air cooled binary systems.

Subsurface Improvements	11 production wells and 5 injection wells connected to the plants through a gathering system.
Major Equipment	8 Rotoflow expanders together with the Balance of Plant equipment.
Age	The G-1 plant commenced commercial operations in 1984 and G-2 and G-3 commenced commercial operation in 1990.
Land and Mineral Rights	The total Mammoth area is comprised mainly of BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands." We recently purchased land at Mammoth that was owned by a third party. This purchase will reduce royalty expenses for the Mammoth complex.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The average resource temperature is 339 degrees Fahrenheit. The Casa Diablo/Basalt Canyon geothermal field at Mammoth lies on the southwest edge of the resurgent dome within the Long Valley Caldera. It is believed that the present heat source for the geothermal system is an active magma body underlying the Mammoth Mountain to the northwest of the field. Geothermal waters heated by the magma flow from a deep source (> 3,500 feet) along faults and fracture zones from northwest to southeast east into the field area. The produced fluid has no scaling potential.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Power Purchaser	Southern California Edison.
PPA Expiration Date	G-1 — 2014, G2 and G-3 — 2020.
Financing	50% — OFC Senior Secured Notes and 50% — corporate funds.

Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues.

We are in the process of repowering the Mammoth complex by replacing part of the old units with new Ormat-manufactured equipment. The replacement of the equipment will optimize generation and add approximately 3 MW of generating capacity to the complex..

North Brawley Power Plant

Location	Imperial County, California
Generating Capacity	33 MW (See supplemental information below)
Number of Power Plants	1
Technology	The North Brawley power plant utilizes a water-cooled binary system.
Subsurface Improvements	16 production wells and 21 injection wells are currently connected to the plant through a gathering system. An additional production well is currently being completed.
Major Equipment	5 OEC units together with the Balance of Plant equipment.
Age	The power plant was placed in service on January 15, 2010 with commercial operation having commenced on March 31, 2011.
Land and Mineral Rights	The total North Brawley area is comprised of private leases. The leases are held by production. The scheduled expiration date for all of these leases is after the end of the expected useful life of the power plant. The plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	North Brawley production is from deltaic and marine sedimentary sands and sandstones deposited in the subsiding Salton Trough of the Imperial Valley. Based on seismic refraction surveys the total thickness of these sediments in the Brawley area is over 15,000 feet. The shallow production reservoir (1,500 – 4,500 feet) that was developed is fed by fractures and matrix permeability and is

Table of Contents

conductively heated from the underlying fractured reservoir which convectively circulates magmatically heated fluid. Produced fluid salinity ranges from 20,000 to 50,000 ppm, and the moderate scaling and corrosion potential is chemically inhibited. The temperature of the deeper fractured reservoir fluids exceed 525 degrees Fahrenheit, but the fluid is not yet developed because of severe scaling and corrosion potential. The deep reservoir is not dedicated to the North Brawley power plant.

The average produced fluid resource temperature is 335 degrees Fahrenheit.

Sources of Makeup Water	Water is provided by IID.
Power Purchaser	Southern California Edison
PPA Expiration Date	2031
Financing	Corporate funds and ITC cash grant from the U.S. Treasury.
Supplemental Information	The ramp up of the field has been slow and expensive. While we believe that the reservoir is large enough to support the originally designed generation capacity of 50 MW, the operation of the production wells, injection wells and the handling of the geothermal fluid has been a challenge. On March 31, 2011, Southern California Edison set the demonstrated capacity of the power plant at 33MW. Southern California Edison also agreed to modify the PPA to allow us the option of performing an additional capacity demonstration until March 31, 2012. There is ongoing work to increase the generation of the power plant. We have set new targets for production wells and identified improvements that we can make to the injection wells, all in parallel with our effort to reduce the operating expenses, mostly through modifications that would extend the service time of the production pumps. The power plant currently has an interim transmission agreement with IID. A transmission study that is in progress will allow IID to enter into a permanent transmission agreement. To date the study has been delayed due to extensive analysis by the utility and maintenance activity on the transmission corridor.

OREG 1 Power Plant

Location	Four gas compressor stations along the Northern Border natural gas pipeline in North and South Dakota
Generating Capacity	22 MW
Number of Units	4

Table of Contents

Technology	The OREG 1 power plant utilizes our air cooled OEC units.
Major Equipment	4 WHOH and 4 OEC units together with the Balance of Plant equipment.
Age	The OREG 1 power plant commenced commercial operations in 2006.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Basin Electric Power Cooperative.

PPA Expiration Date	2031
Financing	Corporate funds.

OREG 2 Power Plant

Location	Four gas compressor stations along the Northern Border natural gas pipeline; one in Montana, two in North Dakota, and one in Minnesota
Generating Capacity	22 MW
Number of Units	4
Technology	The OREG 2 power plant utilizes our air cooled OEC units.
Major Equipment	4 WHOH and 4 OEC units together with the Balance of Plant equipment.
Age	The OREG 2 power plant commenced commercial operations during 2009.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Basin Electric Power Cooperative.
PPA Expiration Date	2034
Financing	Corporate funds.

OREG 3 Power Plant

Location	A gas compressor station along Northern Border natural gas pipeline in Martin County, Minnesota
Generating Capacity	5.5 MW
Number of Units	1

Technology	The OREG 3 power plant utilizes our air cooled OEC units.
Major Equipment	One WHOH and one OEC unit along with the Balance of Plant equipment.
Age	The OREG 3 power plant commenced commercial operations during 2010.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Great River Energy
PPA Expiration Date	2029
Financing	Corporate funds.

OREG 4 Power Plant

Location	A gas compressor station along natural gas pipeline in Denver, Colorado
Generating Capacity	3.5 MW
Number of Units	1
Technology	The OREG 4 power plant utilizes our air cooled OEC units.
Major Equipment	2 WHOH and 1 OEC unit together with the Balance of Plant equipment.
Age	The OREG 4 power plant commenced commercial operations during 2009.
Land	Easement from Trailblazer Pipeline Company.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Highline Electric Association
PPA Expiration Date	2029
Financing	Corporate funds.

Ormesa Complex

Location	East Mesa, Imperial County, California
Generating Capacity	54 MW
Number of Power Plants	4 (OG I, OG II, GEM 2 and GEM 3).
Technology	The OG plants utilize a binary system and the GEM plants utilize a flash system. The complex uses a water cooling system.

Table of Contents

Subsurface Improvements	32 production wells and 52 injection wells connected to the plants through a gathering system.
Material Major Equipment	32 OEC units and 2 steam turbines with the Balance of Plant equipment.
Age	The various OG I units commenced commercial operations between 1987 and 1989, and the OG II plant commenced commercial operation in 1988. Between 2005 and 2007 a significant portion of the old equipment in the OG plants was replaced (including turbines through repowering). The GEM plants commenced commercial operation in 1989, and a new bottoming unit was added in 2007.
Land and Mineral Rights	The total Ormesa area is comprised of BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The resource temperature is an average of 307 degrees Fahrenheit. Production is from sandstones. Productive sandstones are between 1,800 and 6,000 feet, and have only matrix permeability. The currently developed thermal anomaly was created in geologic time by conductive heating and direct outflow from an underlying convective fracture system. Produced fluid salinity ranges from 2,000 ppm to 13,000 ppm, and minor scaling and corrosion potential is chemically inhibited.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Sources of Makeup Water	Water is provided by the IID.
Power Purchaser	Southern California Edison under a single PPA.
PPA Expiration Date	2018
Financing	OFC Senior Secured Notes.
Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues.

Puna Complex

Location	Puna district, Big Island, Hawaii
Generating Capacity	38 MW
Number of Power Plants	2
Technology	The Puna plants utilize our geothermal combined cycle and binary systems. The plants use an air cooled system.
Subsurface Improvements	5 production wells and 4 injection wells connected to the plants through a gathering system. We are preparing to drill a sixth production well.
Major Equipment	One plant consists of 10 OEC units consisting of 10 binary turbines, 10 steam turbines and two bottoming units along with the Balance of Plant equipment. The second plant consists of 2 OEC units along with Balance of Plant equipment.
Age	The first plant commenced commercial operation in 1993. The second plant was placed in service in 2011, but has not yet reached commercial operation.

Land and Mineral Rights	The Puna area is comprised of a private lease. The private lease is between PGV and KLP and it expires in 2046. PGV pays annual rental payment to KLP, which is adjusted every 5 years based on the CPI. The state of Hawaii owns all mineral rights (including geothermal resources) in the state. The state has issued a Geothermal Resources Mining Lease to KLP, and KLP in turn has entered into a sublease agreement with PGV, with the state's consent. Under this arrangement, the state receives royalties of approximately 3% of the gross revenues.
Access to Property	Direct access to the leased property is readily available via county public roads located adjacent to the leased property. The public roads are at the north and south boundaries of the leased property.
Resource Information	The geothermal reservoir at Puna is located in volcanic rock along the axis of the Kilauea Lower East Rift Zone. Permeability and productivity are controlled by rift-parallel subsurface fissures created by volcanic activity. They may also be influenced by lens-shaped bodies of pillow basalt which have been postulated to exist along the axis of the rift at depths below 7,000 feet. The distribution of reservoir temperatures is strongly influenced by the configuration of subsurface fissures and temperatures are among the hottest of any geothermal field in the world, with maximum measured temperatures consistently above 650 degrees Fahrenheit.
Resource Cooling	The resource temperature is stable.
Power Purchaser	3 PPAs with HELCO (see "Supplemental Information" below).

Table of Contents

PPA Expiration Date	December 31, 2027.
Financing	Operating Lease. We have submitted an application for an ITC cash grant for the new 8 MW power plant.
Supplemental Information	The construction of the new 8 MW power plant has been completed and it was placed in service. We signed a new PPA with HELCO that was recently approved by the PUCH, under which the Puna power plant will deliver to the HELCO grid an additional dispatchable 8 MW and will revise the pricing for the energy that is sold from the Puna complex as follows: For the first on-peak 25 MW, the energy price has not changed from HELCO avoided cost. For the next on-peak 5 MW, the price has changed from a diesel-based price to a flat rate of 11.8 cents per kWh escalated by 1.5% per year. For the new on-peak 8 MW, the price is 9 cents per kWh for up to 30,000 MWh/year and 6 cents per kWh above 30,000 MWh/year, escalated by 1.5% per year. • For the first off-peak 22 MW the energy price has not changed from avoided cost.

The off-peak energy above 22 MW is dispatchable:

- For the first off-peak 5 MW, the price has changed from diesel-based price to a flat rate of 11.8 cents per kWh escalated by 1.5% per year.
- For the energy above 27 MW (up to 38 MW) the price is 6 cents per kWh, escalated by 1.5% per year.

The capacity payment for the first 30 MW remains the same ($160 kW/year for the first 25 MW and $100.95 kW/year for the additional 5 MW). For the new 8MW power plant the annual capacity payment is $2 million.

Steamboat Complex

Location

Steamboat, Washoe County, Nevada

Generating Capacity

86 MW

Number of Power Plants

7 (Steamboat 1A, Steamboat 2 and 3, Burdette (Galena 1), Steamboat Hills, Galena 2 and Galena 3).

Technology

The Steamboat complex utilizes a binary system (except for Steamboat Hills, which utilizes a single flash system). The complex uses air and water cooling systems.

Subsurface Improvements

23 production wells and 8 injection wells connected to the plants through a gathering system.

Major Equipment

12 individual air cooled OEC units and one steam turbine together with the Balance of Plant equipment.

Age

The Steamboat 1A plant commenced commercial operation in 1988 and the other plants commenced commercial operation in 1992, 2005, 2007 and 2008. During 2008, the Rotoflow expanders at Steamboat 2 and 3 were replaced with four turbines manufactured by us and we repowered Steamboat 1A.

Land and Mineral Rights

The total Steamboat area is comprised of 41% private leases, 41% BLM leases and 18% private land owned by us. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants.

The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

We have easements for the transmission lines we use to deliver power to our power purchasers.

Resource Information

The resource temperature is an average of 292 degrees Fahrenheit.

The Steamboat geothermal field is a typical basin and range geothermal reservoir. Large and deep faults that occur in the rocks allow circulation of ground water to depths exceeding 10,000 feet below the surface. Horizontal zones of permeability permit the hot water to flow eastward

	in an out-flow plume.
	Steamboat Hills and Galena 2 power plants produce hot water from fractures associated with normal faults. The rest of the power plants acquire their geothermal water from the horizontal out-flow plume.
	The water in the Steamboat reservoir has a low total solids concentration. Scaling potential is very low unless the fluid is allowed to flash which will result in calcium carbonate scale. Injection of cooled water for reservoir pressure maintenance prevents flashing.
Resource Cooling	2 degrees Fahrenheit per year was observed during the past 20 years of production.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Sources of Makeup Water	Water is provided by condensate and the local utility.
Power Purchaser	Sierra Pacific Power Company (for Steamboat 1A, Steamboat 2 and 3, Burdette, Steamboat Hills, and Galena 3) and Nevada Power Company (for Galena 2).
PPA Expiration Date	Steamboat 1A — 2018, Steamboat 2 and 3 — 2022, Burdette — 2026, Steamboat Hills — 2018, Galena 3 — 2028, and Galena 2 — 2027.

Financing	OFC Senior Secured Notes (Steamboat 1A, Steamboat 2 and 3, and Burdette) and OPC Transaction (Steamboat Hills, Galena 2, and Galena 3).

Tuscarora Power Plant

Location	Elko County, Nevada
Projected Generating Capacity	18 MW
Number of Power Plants	1
Technology	The Tuscarora power plant utilizes a water cooled binary system.
Subsurface Improvements	3 production and 5 injection wells are connected to the power plant. A fourth production well is under development.
Major Equipment	2 water cooled OEC units with the Balance of Plant equipment.
Age	The power plant commenced commercial operation on January 11, 2012.
Land and Mineral Rights	The Tuscarora area is comprised of private and BLM leases.
	The leases are currently held by payment of annual rental payments, as described in "Description of Our Leases and Lands."
	The plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Resource Information	The Tuscarora geothermal reservoir consists of an area of approximately 2.5 square miles. The reservoir is contained in both Tertiary and Paleozoic (basement) rocks. The Paleozoic section consists primarily of sedimentary rocks, overlain by Tertiary volcanic rocks. Thermal fluid in the native state of the reservoir flows upward and to the north through apparently southward-dipping, basement formations. At an elevation of roughly 2,500 feet with respect to mean sea level, the upwelling thermal fluid enters the Tertiary volcanic rocks and flows directly upward, exiting to the surface at Hot Sulphur Springs. The resource temperature averages 346 degrees Fahrenheit.
Resource Cooling	Will be established in the future.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Sources of Makeup Water	Water is provided from two water makeup wells. A third makeup well will be added.
Power Purchaser	Nevada Power Company

Table of Contents

PPA Expiration Date	2032
Financing	OFC 2 Senior Secured Notes. We plan to file an application for an ITC cash grant for the power plant.

Foreign Power Plants

The following descriptions summarize certain industry metrics for our foreign power plants:

Amatitlan Power Plant (Guatemala)

Location	Amatitlan, Guatemala
Generating Capacity	18 MW
Number of Power Plants	1
Technology	The Amatitlan power plant utilizes an air cooled binary system and a small back pressure steam turbine (1MW).
Subsurface Improvements	5 production wells and 2 injection wells connected to the plants through a gathering system.
Major Equipment	1 steam turbine and 2 OEC units together with the Balance of Plant equipment.
Age	The plant commenced commercial operation in 2007.
Land and Mineral Rights	Total resource concession area (under usufruct agreement with INDE) is for a term of 25 years from April 2003. Leased and company owned property is approximately 3% the of concession area. Under the

	agreement with INDE, the power plant company pays royalties of 3.5% of revenues up to 20.5 MW and 2% of revenues exceeding 20.5 MW.
	The generated electricity is sold at the plant fence. The transmission line is owned by INDE.
Resource Information	The resource temperature is an average of 530 degrees Fahrenheit.
	The Amatitlan geothermal area is located on the north side of the Pacaya Volcano at approximately 5,900 feet above sea level.
	Hot fluid circulates up from a heat source beneath the volcano, through deep faults to shallower depths, and then cools as it flows horizontally to the north and northwest to hot springs on the southern shore of Lake Amatitlan and the Michatoya River Valley.
Resource Cooling	Approximately 2 degrees Fahrenheit per year.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.

Power Purchasers	INDE and another local purchaser.
PPA Expiration Date	Contract with INDE expires in 2028.
Financing	Senior secured project loan from TCW Global Project Fund II, Ltd.
Supplemental Information	The power plant was registered by the United Nations Framework Convention on Climate Change as a Clean Development Mechanism. It is expected to offset emissions of approximately 83,000 tons of CO_2 per year.
	The power plant has a long-term contract to sell all of its emission reduction credits to a European buyer.

Momotombo Power Plant (Nicaragua)

Location	Momotombo, Nicaragua
Generating Capacity	22 MW
Number of Power Plants	1
Technology	The Momotombo power plant utilizes single flash and binary systems. The plant uses air and water cooled systems.
Subsurface Improvements	10 production wells and 7 injection wells connected to the plants through a gathering system.
Major Equipment	1 steam turbine and 1 OEC unit together with the Balance of Plant equipment.
Age	The plant commenced commercial operation in 1983 and was already in existence when we signed the concession agreement in 1999.
Land and Mineral Rights	The total Momotombo area is under a concession agreement which

	expires in 2014.
	We sell the generated electricity at the boundary of the plant. The transmission line is owned by the utility.
Resource Information	The resource temperature is an average of 466.5 degrees Fahrenheit.
	The Momotombo geothermal reservoir is located within sedimentary and andesitic volcanic formations that relate to the Momotombo volcano.
	Main flow paths in the geothermal system are a hot reservoir layer. The shallow layer conducted deep fluids that eventually will be discharged at surface at the eastern edge of the geothermal system at the shore of the Lake Managua.
Resource Cooling	Approximately 3.5 degrees Fahrenheit per year was observed during the past 10 years of production.

Access to Property	Direct access to public roads and access across the property are provided under surface rights granted pursuant to the concession assignment agreement.
Sources of Makeup Water	Condensed steam is used for makeup water.
Power Purchaser	DISNORTE and DISSUR
PPA Expiration Date	2014
Financing	A loan from Bank Hapoalim B.M, which was repaid in full in 2010.

Olkaria III Complex (Kenya)

Location	Naivasha, Kenya
Generating Capacity	52 MW
Number of Power Plants	2 (Olkaria III Phase 1 and Olkaria III Phase 2).
Technology	The Olkaria III complex utilizes an air cooled binary system.
Subsurface Improvements	10 production wells and 3 injection wells connected to the plants through a gathering system.
Major Equipment	6 OEC units together with the Balance of Plant equipment.
Age	Phase I plant commenced commercial operation in 2000 and was incorporated into the phase II plant in January 2009.
Land and Mineral Rights	The total Olkaria III area is comprised of government leases. A license granted by the Kenyan government provides exclusive rights of use and possession of the relevant geothermal resources for an initial period of 30 years, expiring in 2029, which initial period may be extended for two additional five-year terms. The Kenyan Minister of Energy has the right to terminate or revoke the license in the event work in or under the license area stops during a period of six months, or there is a failure to

comply with the terms of the license or the provisions of the law relating to geothermal resources. Royalties are paid to the Kenyan government monthly based on the amount of power supplied to the power purchaser and an annual rent.

The power generated is purchased at the metering point located immediately after the power transformers in the 220 kV sub-station within the power plant, before the transmission lines which belong to the utility.

Resource Information	The resource temperature is an average of 570 degrees Fahrenheit. The Olkaria III geothermal field is on the west side of the greater Olkaria geothermal area located at approximately 6,890 feet above sea level within the Rift Valley.

Table of Contents

	Hot geothermal fluids rise up from deep in the northeastern portion of the concession area, penetrating a low permeability zone below 3280 feet ASL to a high productivity, two-phase zone identified between 3,280 and 4,270 feet ASL.
Resource Cooling	The resource temperature is stable.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.
Power Purchaser	KPLC
PPA Expiration Date	2029
Financing	Senior secured project finance loan from a group of European DFIs.
Supplemental Information	See "Projects under Construction — Olkaria III Phase III (Kenya)." We have signed a commitment letter issued by OPIC to provide up to \$310 million to refinance and expand the Olkaria III complex. See "New Financing of our Project" in Item 7. If the Phase III of Olkaria III is completed by November 2015, the expiration date of the PPA will be extended until 2033.

Zunil Power Plant (Guatemala)

Location	Zunil, Guatemala
Generating Capacity	24 MW
Number of Power Plants	1
Technology	The Zunil power plant utilizes an air cooled binary system.
Major Equipment	7 OEC units together with the Balance of Plant equipment.

Age	The plant commenced commercial operation in 1999.
Land and Mineral Rights	The land owned by the plant includes the power plant, workshop and open yards for equipment and pipes storage. Pipelines for the gathering system transit through a local agricultural area's right of way acquired by us. The geothermal wells and resource are owned by INDE. Our produced power is sold at our property line; power transmission lines are owned and operated by INDE.
Access to Property	Direct access to public roads.
Power Purchaser	INDE

PPA Expiration Date	2019
Financing	Senior Secured project loan from IFC and CDC that was repaid in full in November 2011.
Supplemental Information	Through August 2011, the energy output of the power plant was sold under a "take or pay" arrangement, under which the revenues were calculated based on 24 MW capacity regardless of the actual performance of the power plant. From September 2011, the energy portion of revenues is paid based on the actual generation of the power plant, while the capacity portion remains the same. The actual generation of the power plant is based on a capacity of approximately 13 MW. In 2011, the energy revenues were approximately 21% of the total revenues of the power plant.

Projects under Construction

We are in varying stages of construction or enhancement of domestic and foreign projects. Based on our current construction schedule, we have new generating capacity of approximately 145 MW under construction in California, Nevada, and Hawaii (including Mammoth expansion described above).

The following is a description of the projects currently undergoing construction:

Carson Lake Project (U.S.)

Location	Churchill County, Nevada
Projected Generating Capacity	20 MW
Projected Technology	The Carson Lake power plant will utilize a binary system.
Condition	Received the approval of the BLM for the required EIS and for the permitting required to start the drilling of additional wells.
Subsurface Improvements	Awaiting drilling permits.
Land and Mineral Rights	The Carson Lake area is comprised of BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands."

	Unless steam is produced in commercial quantities, the primary term for these leases will expire commencing August 31, 2016.
	The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.

Table of Contents

Financing	Corporate funds.
Projected Operation	To be determined.
Supplemental Information	Permitting delays have prevented substantial progress on the project site and on transmission until late last year and have had a significant impact on the development plan and the economics of the project. As a result, in December 2011, we terminated the project's PPA and joint operating agreement with NV Energy. We are continuing to work on the project.

CD4 Project (Mammoth Complex) (U.S.)

Location	Mammoth Lakes, California
Projected Generating Capacity	30 MW
Projected Technology	The CD4 power plant will utilize an air cooled binary system.
Condition	Drilling activity.
Subsurface Improvements	We have completed 1 production well and 1 injection well. Continued drilling is subject to receipt of additional permits.
Land and Mineral Rights	The total Mammoth area is comprised mainly of BLM leases, several of which are held by production and the remainder of which are the subject of a unitization agreement that is pending BLM approval. The expiration date of the leases (assuming approval of the unitization agreement) is after the end of the expected useful life of the power plant.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Power Purchaser	We have not executed a PPA.
Financing	Corporate funds.

Projected Operation	To be determined.
Supplemental Information	As part of the process to secure a transmission line, we are participating in the Southern California Edison Wholesale Distribution Access Tariff Transition Cluster Generator Interconnection Process to deliver energy into the Southern California Edison system at the Casa Diablo Substation.

Heber Solar PV Project (U.S.)

Location	Imperial County, California
Projected Generating Capacity	10 MW (24,500 MWh per year)
Projected Technology	Solar PV.
Condition	Procurement.
Land	The Heber Solar area is comprised of land that we own.
Access to Property	Direct access to public roads from the leased property and access across the leased property.
Power Purchaser	IID
PPA Expiration Date	20 years after date of COD.
Financing	Corporate funds.
Projected Operation	2013
Supplemental Information	Commercial operation is expected within 18 months from the signing of the PPA, subject to timely completion of the interconnection that is to be provided by IID.

McGinness Hills Project (U.S.)

Location	Lander County, Nevada
Projected Generating Capacity	30 MW
Projected Technology	The McGinness Hills power plant will utilize an air cooled binary system.
Subsurface Improvements	5 production wells and 3 injection wells have been drilled.
Material Equipment	Power plant equipment on site.
Condition	Field development is still in process and construction is in an advanced stage.
Land and Mineral Rights	The McGinness Hills area is comprised of private and BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands." Unless steam is produced in commercial quantities, the primary term for

these leases will expire commencing September 30, 2017.

The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Power Purchaser	Nevada Power Company
PPA Expiration Date	20 years after date of COD.
Financing	OFC 2 Senior Secured Notes. We plan to file an application for an ITC cash grant for the project.
Projected Operation	Third quarter of 2012.
Supplemental Information	Commercial operation of the power plant is expected in the second half of 2012.

Olkaria III – Phase III (Kenya)

Location	Naivasha, Kenya
Projected Generating Capacity	36 MW
Technology	The phase III of the Olkaria III complex will utilize an air cooled binary system.
Condition	Field development and manufacturing of the power plant is in progress.
Subsurface Improvement	Two production wells have been drilled.
Land and Mineral Rights	The total Olkaria III area is comprised of government leases. See description above under "Olkaria III complex."
Resource Information	The Olkaria III geothermal field is on the west side of the greater Olkaria geothermal area located within the Rift Valley at approximately 6,890 feet above sea level. Hot geothermal fluids rise up from deep in the northeastern portion of the concession area through low permeability at a shallow depth to a high productivity two-phase region from 3,280 to 4,270 feet above sea level. The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.

Table of Contents

Power Purchaser	KPLC
PPA Expiration Date	20 years from COD.
Financing	Corporate funds.
Projected Operation	2013
Supplemental Information	We amended and restated the existing PPA with KPLC. The amended and restated PPA provides for the construction of a new 36 MW power plant at the Olkaria III complex. The PPA amendment includes an option for additional capacity up to 100 MW. We have signed a commitment letter with OPIC to provide up to $310 million to refinance and expand the Olkaria III complex. See description in Item 7 under "New Financing of our Projects."

Wild Rose (formerly DH Wells) Project (U.S.)

Location	Mineral County, Nevada
Projected Generating Capacity	15-20 MW
Projected Technology	The Wild Rose power plant will utilize a binary system.
Material Equipment	Drilling equipment for wells.
Condition	Field development is in progress.
Subsurface Improvement	3 wells have been drilled. We are continuing with the drilling activity.
Land and Mineral Rights	The Wild Rose area is comprised of BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands." Unless steam is produced in commercial quantities, the primary term for these leases will expire commencing September 30, 2017. The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Power Purchaser	We have not executed a PPA yet for this power plant.
Financing	Corporate funds.
Projected Operation	2013

Attachment F

From: William C Evans <wcevans@usgs.gov>
Date: March 20, 2012 11:02:33 AM PDT
To: Scott Cashen <scottcashen@gmail.com>
Cc: dbergfel@usgs.gov
Subject: Re: Tree-kills at Long Valley

Hi Scott, Happy to answer as best we can. We're also comfortable with your attributing these (and previous) comments to us:

1) We cannot envision any new effects on the tree kills solely due to a change to pentane. Ideally the working fluid loop (containing the pentane) is only in thermal contact with the water loop, and its internal pressure should have no impact the water that gets injected into the ground. If a leak occurs in the heat exchanger, pentane could be injected along with the water, analogous to previous injections of isobutane[1]. In the new powerplant, the lower pressure in the working fluid loop might result in less leakage. Neither pentane nor isobutane are listed as toxic gases, and when leaked through the heat exchanger, these gases would be diluted to low concentrations in the environment. Although we are not botanists, it seems unlikely that either of these gases would be directly responsible for the tree mortality.

2) Small temperature changes in the injected water are not likely to have significant hydrologic effects. The balance of pressure between production and injection zones is the main factor preserving the stability of a geothermal system. If the pressure in the hot production aquifer is not completely supported by injected water, water table drop can allow steam and gas to reach the surface. Complete support is usually impossible to achieve, and this is the most likely reason that surface heating (and e.g., tree kill) develops near geothermal power plants. We cannot offer any expertise on impacts to fish.

3) Indeed, CO_2 at high concentrations is toxic to animal life. We have not observed any dead animals in the thermal tree-kill areas nor are we aware of any reports of such. We have noticed that certain species of grass

appear to thrive in association with these areas, but we lack the expertise to comment on whether animals are attracted to these sites.

[1]Evans, W. C., Lorenson, T. D., Sorey, M. L., and Bergfeld, D., 2004a, Transport of injected isobutane by thermal groundwater in Long Valley caldera, California, USA, *in* Wanty, R. B. and Seal II, R. R. eds: *Water-Rock Interaction-11*, Saratoga Springs, 2004, p. 125-129.

William C. Evans
U.S. Geological Survey
345 Middlefield Rd. M/S 434
Menlo Park, CA 94025
(650) 329-4514; fax (650) 329-4463
wcevans@usgs.gov

From:	Scott Cashen <scottcashen@gmail.com>
To:	William C Evans <wcevans@usgs.gov>
Cc:	dbergfel@usgs.gov
Date:	03/19/2012 07:17 PM
Subject:	Re: Tree-kills at Long Valley

Thanks Bill and Deb, I appreciate the response. I have a couple follow-up questions related to item #3. The new power plant will use pentane instead of isobutane. The pentane will be pressurized to 212 PSIG (versus 500 PSIG for the isobutane). Does the change to pentane have any potential to affect the tree-kills?

In addition, according to the DEIR, the new facility will involve the "return of slightly warmer (3-4 F) rather than cooler geothermal fluid injection temperatures. The return of slightly warmer injection fluid would diminish whatever adverse effect on the injection reservoir that may be occurring from the existing return of slightly cooler injection fluid to the injection reservoir. As such, there would be no new potential for adverse impact on the Hot Creek headsprings habitat of the Owens tui chub as a result of the Project." Are there any implications of slightly warmer injection temperatures?

I've read about the hazards of elevated CO_2 levels to humans, especially near the ground surface or when the gas becomes trapped in a structure (e.g., snow cave). Did you observe (or hear any anecdotal accounts of) any dead wildlife at your study sites? I would think small mammals, especially those that use burrows, would be susceptible to heightened mortality. Additionally, I question whether some species might be attracted to sites that have elevated soil temperatures. Just curious if you had any observations related to wildlife because I believe it poses several interesting scientific questions.

Finally, do you mind if I attach your email to my comments, or otherwise cite personal communication? I certainly understand if you prefer not to be cited in that manner.

Thanks again for all your help,

Scott Cashen, M.S.
Wildlife and Forest Ecology Consultant
3264 Hudson Ave.
Walnut Creek, CA 94597

Office: (925) 256-9185
Cell: (510) 517-0100
scottcashen@gmail.com

On Mar 19, 2012, at 4:58 PM, William C Evans wrote:

Hi Scott, Thanks for your note. Deb and I are pleased to see your honest efforts on this important review. We've discussed your three points and pretty much agree with you on the first two. Here is our feedback:

1. We stand behind the wording in our published reports, including[1]: "The high concentration of thermal and diffuse CO_2 degassing areas around the power plant leaves little doubt that some areas owe their existence to the geothermal operations." This is more inference than speculation.
2. We have not pinpointed the exact cause of tree death, nor do we attribute every dead tree to geothermal operations, but the relation between the overall timing and pattern of vegetation kill and changes in geothermal operations is clear. We stand behind[2]: "...changes in the size of kill zones, increases in soil temperatures or steam discharge, and changes in CO_2 emissions most likely reflect the response of the shallow hydrothermal system to geothermal fluid production at the Casa Diablo power plant." The formation of steaming ground is a well-known impact of development at geothermal sites world-wide. The cause and effect relation is largely established even if the precise mechanism by which the trees die is not established.
3. The size of the kill areas is expanding under the current production regime. However, a relocation of the power plant that does not involve changes to the fluid production/injection scheme would not be expected to speed up or otherwise alter this process.

1Bergfeld, D., Evans W.C., Howle, J.F., and Farrar, C.D., 2006, Carbon dioxide emissions from vegetation-kill zones around the resurgent dome of Long Valley caldera, eastern California, USA: Journal of Volcanology and Geothermal Research v. 152, p. 140-156.
2Bergfeld, D. and Evans, W.C., 2011, Monitoring CO_2 emissions in tree kill areas near the resurgent dome at Long Valley Caldera, California: U.S. Geological Survey Scientific Investigations Report 2011-5038, 22 p.

Please let us know if you have any more questions or need any more information.

Sincerely, Bill Evans and Deb Bergfeld

William C. Evans
U.S. Geological Survey
345 Middlefield Rd. M/S 434
Menlo Park, CA 94025
(650) 329-4514; fax (650) 329-4463
wcevans@usgs.gov

From:	Scott Cashen <scottcashen@gmail.com>
To:	wcevans@usgs.gov, dbergfel@usgs.gov
Date:	03/18/2012 10:51 PM
Subject:	Tree-kills at Long Valley

Hi Bill and Deb:

Bill, I spoke with you last year about the work you and Deb have been doing to examine the tree-kills at Basalt Canyon and Shady Rest. Mammoth Pacific has proposed a new power plant to replace the existing MP-1 power plant at Casa Diablo. The original Draft Environmental Impact Report (DEIR) provided no discussion of the tree-kill issue. The DEIR was subsequently revised and it is now open for comments. The Revised DEIR states the following with respect to the tree-kill issue:

""there has been speculation that use of the geothermal resource in the Casa Diablo area may affect vegetation (Bergfeld and Evans 2011). A cause and effect relationship has not been established, but the issue should be studied with respect to future projects that would increase utilization of the resource or expand wellfield development. However, the proposed MP-I Replacement Project would not change the utilization of the existing geothermal wellfield or expand wellfield development. Therefore, the Project would have no adverse incremental cumulative impacts on the geothermal resource and would not add to the impacts of geothermal operations on vegetation, if any are established."

I have the following questions and comments pertaining to these statements:

1) I would not characterize the statements made in your 2011 paper as "speculation," but as inferences. In fact, Bill I seem to recall you telling me that the tree-kills were undoubtedly a result of geothermal energy production at Casa Diablo. Please correct me if I am wrong in this regard.

2) In my opinion, the DEIR's statement that a cause and effect relationship has not been established is misleading. We know that elevated CO_2 and soil temperature levels can directly or indirectly (i.e., through stress) kill trees. That said, perhaps it is impossible to prove whether the elevated CO_2 and soil temperature levels are due to energy production (although there appears to be strong correlation).

3) I disagree with the rationale used for the conclusion that the Project "would not add to the impacts of geothermal operations on vegetation." Doesn't your data suggest the tree-kill areas are expanding, and thus, that ongoing geothermal development (at present levels) may contribute to further expansions over time?

Thank you for any input you have. I understand this is a complex issue, and I want my comments on the DEIR to be accurate and fair.

Scott Cashen, M.S.
Wildlife and Forest Ecology Consultant
3264 Hudson Ave.
Walnut Creek, CA 94597
Office: (925) 256-9185
Cell: (510) 517-0100
scottcashen@gmail.com

Attachment G

PNW
Pacific Northwest Research Station

Science FINDINGS

INSIDE

Issue one hundred forty / march 2012

"*Science affects the way we think together.*"
Lewis Thomas

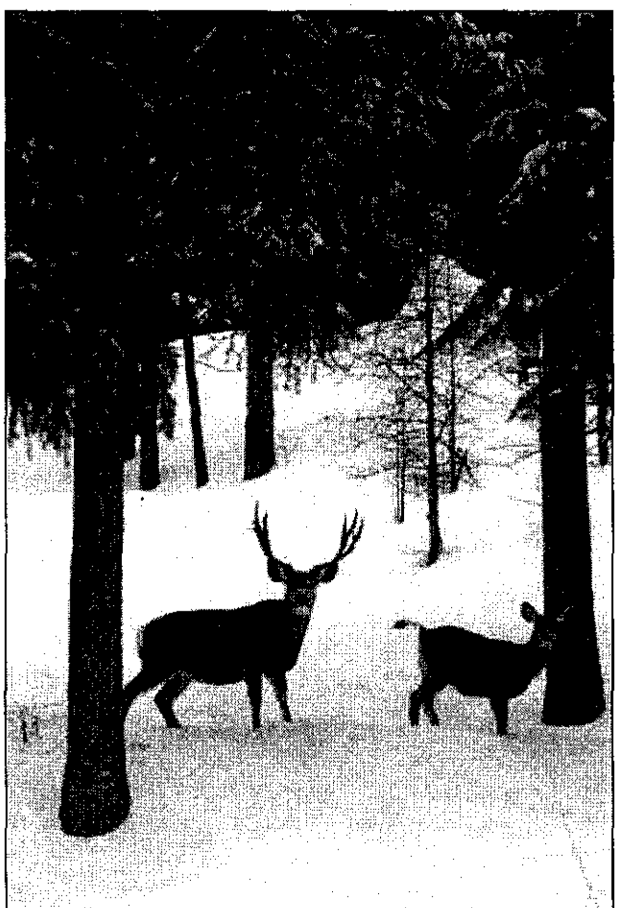
Seasonal Neighbors: Residential Development Encroaches on Mule Deer Winter Range in Central Oregon

"*The question is not whether your part of the world is going to change. The question is how.*"
—Edward T. McMahon

Situated in the high desert east of the Cascade Range, Deschutes County in central Oregon boasts a pleasant climate and a unique combination of geological features, making it a mecca for year-round outdoor recreationists. Hunters, fishermen, campers, hikers, mountain bikers, rock climbers, water sport enthusiasts, off-road vehicle riders, skiers, golfers, and wildlife viewers have helped make it the fastest growing county in Oregon.

A booming outdoor recreation industry, coupled with traditional activities related to timber sales, ranching and agriculture, have boosted Deschutes County's population nearly sevenfold since 1960. Most of that growth occurred in the past 20 years—the population almost doubled between 1990 and 2010, concentrated around the county seat of Bend and four major destination resorts. A report released by the county in 2004 anticipates about 70 percent more population by 2025.

The area's civic leaders, land use planners, and public land managers are charged with a delicate balancing act: fostering a vibrant economy while working to ensure that the area's attractions remain healthy and sustainable for future generations. So when two large areas of private forest in central Oregon were being considered for high-density housing and



Nick Myatt/ODFW

In the winter, mule deer migrate to lower elevations in central Oregon. Roads and residential development are disrupting this migration.

IN SUMMARY

Mule deer populations in central Oregon are in decline, largely because of habitat loss. Several factors are likely contributors. Encroaching juniper and invasive cheatgrass are replacing deer forage with high nutritional value, such as bitterbrush and sagebrush. Fire suppression and reduced timber harvests mean fewer acres of early successional forest, which also offer forage opportunities. Human development, including homes and roads, is another factor. It is this one that scientists with the Pacific Northwest Research Station and their collaborators investigated in a recent study.

As part of an interagency assessment of the ecological effects of resort development near Bend, Oregon, researchers examined recent and potential development rates and patterns and evaluated their impact on mule deer winter range.

They found that residential development in central Oregon is upsetting traditional migratory patterns, reducing available habitat, and possibly increasing stress for mule deer. Many herds of mule deer spend the summer in the Cascade Range and move to lower elevations during the winter. An increasing number of buildings, vehicle traffic, fencing, and other obstacles that accompany human land use are making it difficult for mule deer to access and use their winter habitat. The study provides valuable information for civic leaders, land use planners, and land managers to use in weighing the ecological impact of various land use decisions in central Oregon.

recreation, the Pacific Northwest Research Station was asked to evaluate the potential ecological impacts.

Jeff Kline, a research forester and economist with the station, created a set of fine-scale land use projections to support the resulting interagency assessment of the possible ecological effects of the proposed resort on a parcel known as Skyline Forest. Because a primary interest was the impact on mule deer winter range, Kline also used his land use projections to separately evaluate where future development is likely to affect the deer's traditional migratory patterns in the greater Bend area.

KEY FINDINGS

- In the central Oregon study area, mule deer that summer in the mountains migrate to lower elevations for wintering. Increasing residential development in their traditional winter range is causing direct and indirect habitat loss that could contribute to a decline in mule deer population.
- By 2000, development in traditional mule deer crossing areas was sufficient to disrupt migratory patterns.
- Projections suggest greater development in the future, especially in key wintering areas and along migration corridors.
- Even at low building densities, development could adversely affect mule deer migration and winter use through fencing, collisions with motor vehicles, and human activities on private and public property.

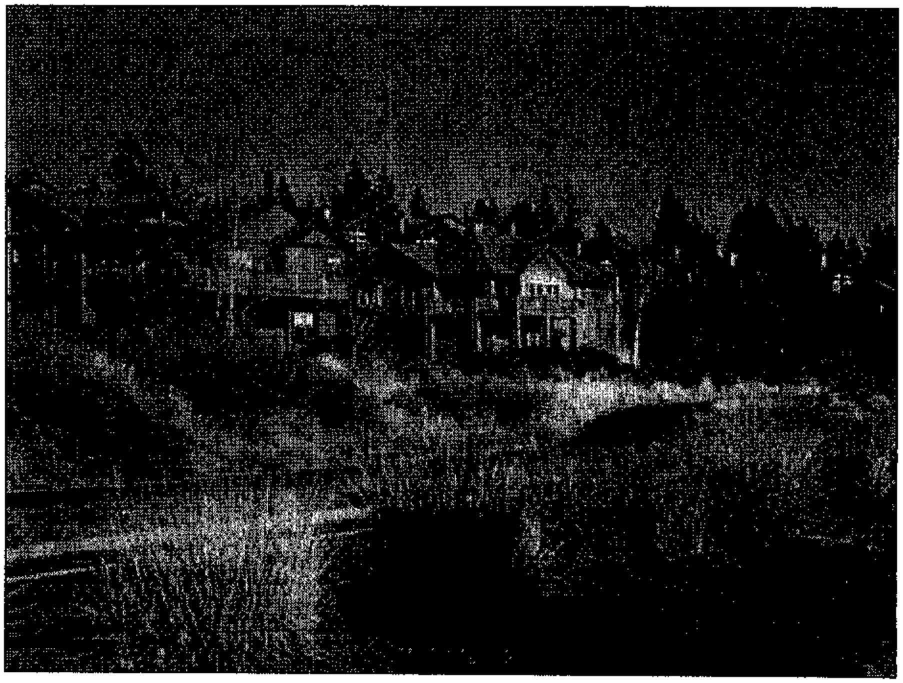
LAND USE PROJECTIONS IN CENTRAL OREGON

As a foundation for his land use projections, Kline used historical data that was originally created by counting buildings in aerial photos taken during the 1970s, '80s, '90s, and 2000s. The data are used to construct a statistical model that correlates new buildings with population trends and certain socioeconomic variables, such as the buildings' location relative to cities and transportation corridors. The model forecasts where buildings will be built in the future if trends follow the rates and patterns of the past.

"My projections are what you might call 'naïve projections,'" says Kline. "They just say 'here's what happened in the past, and if we follow the same pattern and the same correlation in the future, this is what would happen.'"

When Kline overlaid maps of mule deer habitat with maps showing his land use projections, a major problem was revealed: land development is increasingly infringing on mule deer habitat and blocking passage between the deer's summer and winter ranges. By 2000, development was already present in many locations within mule deer winter range, "some of it at sufficiently high densities to influence winter use and migratory patterns," says Kline.

The problem is not so much that development is spreading out across the wide area of the deer's winter range, he notes, but that it tends to locate in "key choke points." It affects the deer's ability to move freely among the lower elevation areas where they are accustomed to wintering. "In some locations, development coincides with narrow sections of winter range with the potential to disrupt movement of individuals throughout the range," says Kline.



Jeff Kline

The population of Deschutes County, Oregon, nearly doubled between 1990 and 2010, with most of the growth concentrated around the city of Bend.

In addition, as residential development increases, land managers with responsibility for protecting adjacent public lands are removing brush and trees within defined limits to protect property against fire. These preventive measures reduce forage and cover needed by wintering mule deer. "Residential developments have a footprint that extends way beyond the development," says Glen Ardt, a wildlife habitat biologist with the Oregon Department of Fish and Wildlife (ODFW) who collaborated with Kline on the study. "There is also indirect loss of habitat due to disturbance from the people and pets that radiates out from these residences."

STRESSED OUT IN CENTRAL OREGON

Along with Rocky Mountain elk and bald eagles, mule deer are often used as iconic representations of the Old West. They provided essential life support for Native Americans and early pioneers, and they continue to be a valuable economic, aesthetic, and ecological resource for central Oregon. In fact, deer hunting and wildlife viewing are major sources of revenue for the state. According to ODFW, residents and nonresidents spent $517.9 million on activities related to hunting and $1.02 billion on activities related to wildlife viewing in 2008.

Despite long-term management by ODFW, average spring mule deer population in the Upper Deschutes management area has shrunk by nearly 55 percent since 1960. Several factors are likely at play, including fewer quality foraging opportunities brought about by various changes on the landscape. Invasive cheatgrass and encroaching juniper are crowding out more nutritious plants such as bitterbrush and sagebrush. Wildfire suppression and less timber harvesting has led to fewer acres of early successional forest, which provide foraging opportunities for the deer. Human development in the deer's traditional winter habitat is another factor.

Laurie Houston

Recreational opportunities in Deschutes County have attracted visitors and new residents but may negatively affect the deer's browsing habits.

Like many Oregonians and visitors from around the world, mule deer enjoy spending time in the high Cascades in the summer. They browse on the forest undergrowth and accumulate fat reserves for the coming winter. However, as forest composition in the mountains has changed in recent decades due to fire suppression, it is becoming harder for mule deer to find nutrient-dense forage, says Ardt.

"A lot of white fir has come in underneath the ponderosa pine and has reduced the amount of forage that's out there. Forage for deer, like bitterbrush and buckbrush, gets shaded out when the forest canopy overtops it and it doesn't get the sunlight it needs to live," he says. In addition, more traffic on forest roads and an intensification of recreational activities—off-road vehicle use and mountain biking in particular—disturbs wildlife and affects browsing habits. Consequently, many deer enter the cold season without a sufficient layer of fat to sustain them through the winter.

Deer are not equipped to handle deep snow, so by the time a foot or so has accumulated in the higher elevations, they migrate down the mountain, attempting to spread out on the desert west and east of Bend. Dodging motor vehicles and finding quality forage in the flatlands are only two of the challenges they face as winter approaches. With each passing season, they encounter more and more obstacles along the paths they have traditionally used to access their winter range.

"Not only do you have loss of habitat (owing to development and recreation), but you have development breaking up the habitat and inhibiting movement," says Kline. "In the mountainous West, the most likely place people are going to develop is the lower elevation flats, so you have development locating right where the grazing animals want to congregate in the wintertime."

Ardt believes that a main contributor to the decrease in the mule deer population in central Oregon is stress. Insecurity in their environment causes deer to react much as humans do when faced with the unexpected. "When disturbance occurs, wildlife either freeze, flee, or fight. And just because they don't flee, it doesn't mean they aren't being disturbed," he says. "Studies have shown that when an animal is disturbed, its cortisol level goes up—that's a stress hormone."

Even if forage is available, the deer may not browse if they are disturbed, and undernourished or stressed-out deer can die prematurely. Stress also can cause a doe in poor condition to abort or reabsorb a fetus, says Ardt, which further reduces the herd. "If they are disturbed, they are using energy they wouldn't otherwise, which can be critical in mid to late winter when their body condition is at its poorest or during the post-fawning and rearing periods when energy demands are higher," he says.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscriptions and change of address information to:

pnw_pnwpubs@fs.fed.us

Rhonda Mazza, editor; rmazza@fs.fed.us

C. Hugh Luce, layout; chluce@fs.fed.us

Science Findings is online at: http://www.fs.fed.us/pnw/publications/scifi.shtml

To receive this publication electronically, change your delivery preference here:

http://www.fs.fed.us/pnw/publications/subscription.shtml

USDA United States Department of Agriculture

Forest Service

TRACKING MIGRATORY PATTERNS

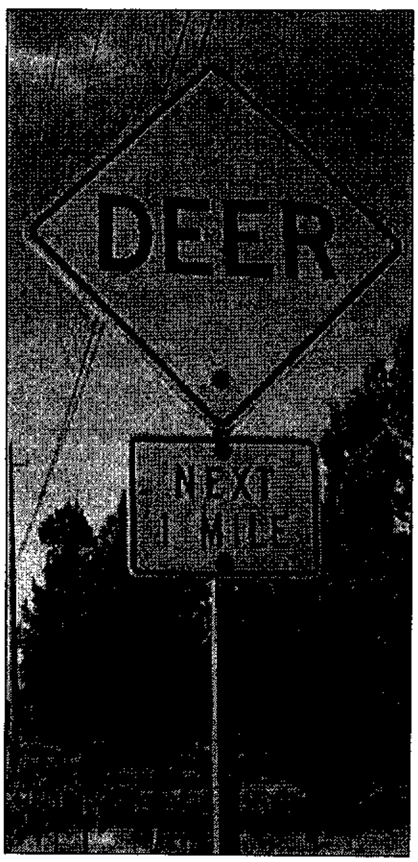
In the 1960s, the ODFW conducted its first study to try to determine exactly how mule deer move from their winter range to their summer range in central Oregon. At that time, deer were trapped, tagged, and collared, which provided a way for biologists, foresters, loggers, hunters, and others to observe deer movements and report sightings to the ODFW. "These methods allowed us to better identify summer and winter ranges, project movement between the two, and determine animal distribution between wildlife management units," says Ardt.

In 2005, the agency embarked on a new study to update and refine its understanding of deer behavior and movement. The Oregon Department of Transportation (ODOT) provided funding to the ODFW to purchase global positioning system (GPS) collars that are helping to determine mule deer crossing behavior on Highway 97, the main highway that runs north and south through the Bend metropolitan area and separates the deer's summer and winter ranges.

A total of 457 mule deer in central and south-central Oregon have been fitted with GPS collars and 250 of these collars have been recovered. The remaining collars are expected to be recovered within the next year. Although observations from the 1960s revealed that deer were moving across Highway 97 to the flatlands east of Bend to winter, data collected from the GPS collars indicate that deer are choosing to go north instead of east. "A lot of that is probably due to the amount of traffic that's on Highway 97 now between Bend and Sunriver [a popular resort]," says Ardt. As it turns out, more deer are killed on secondary and residential access roads than on the main highway.

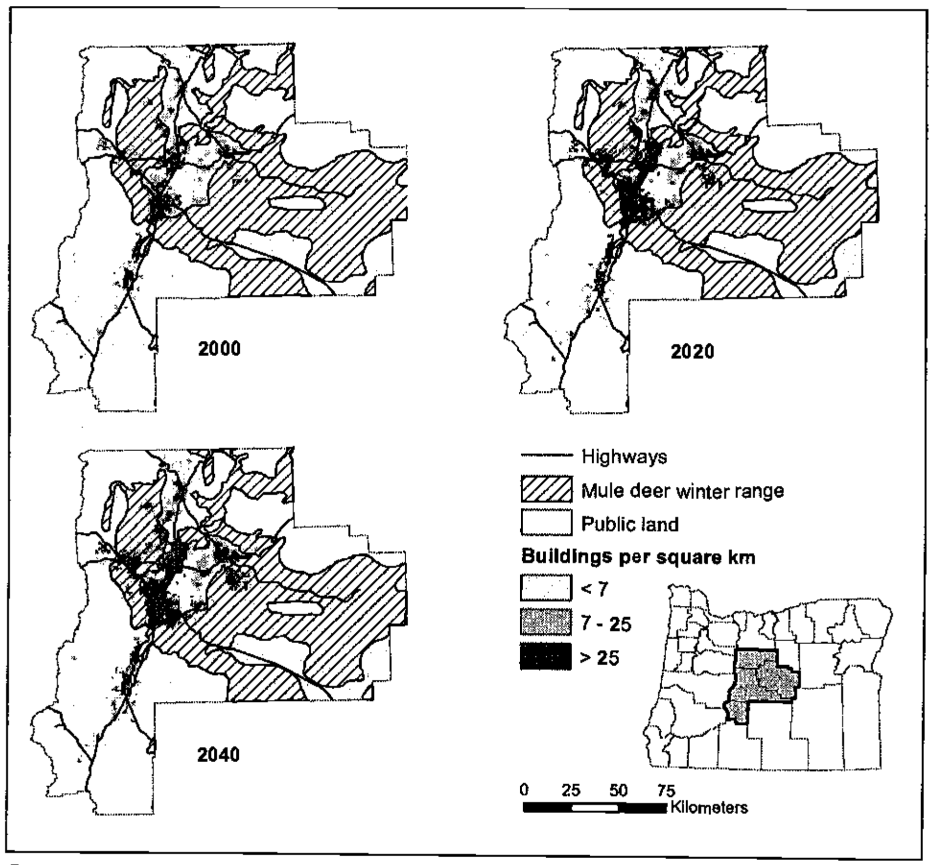
One might wonder why, if people and cars stress them so much, deer can be found munching on the landscaping in people's backyards in the winter. Ardt speculates that it's because it is where they have always wintered, and data from GPS tracking supports that theory. "Telemetry data show deer moving through another deer's summer or winter area to get to their own, thereby showing their strong fidelity for a particular area," he says. It's the homing instinct in action.

Jeff Kline



Jeff Kline

Mule deer outfitted with GPS collars revealed strong fidelity to a particular area, even if it meant crossing major roads to get there.



By 2040, development in and around Bend, Oregon, is projected to further constrain mule deer access to winter habitat.

WANTING OUR DEER AND DEVELOPMENT, TOO

Kline's projections indicated that the Skyline Forest property could be developed as early as 2020. He says this finding originally was met with some skepticism because the property is currently zoned as forest land, but he points out that zoning laws can change and land developers can work around existing codes.

"Just because land is zoned the way it is doesn't mean that things won't happen—things do happen—people get exceptions," he says. "And the history in our land use data suggests that it is so—we can see development in areas that were previously forest and farmland. The land use planning system gives some level of protection, but it's not infallible. Some people tend to think of it as a permanent protection, but it really isn't."

It would seem that Skyline Forest is an example of how things can change. The property's owner wanted to build a resort, but the Deschutes Land Trust has been working to conserve as much of the land as possible. In June 2009, the Oregon legislature passed a bill that permitted the property's current owner to develop a small portion of the land if they sell the remainder to the trust for preservation. The owner was given a five-year time limit on the deal, but the downturn in the housing market has stalled the plans, so the future of Skyline Forest is still unknown.

Kline says his projections give landscape planners and managers data to inform their decisionmaking about what conservation measures may be necessary for certain plots of land, given population trends and past development patterns. "They could use information like this to figure out where development is likely to be," he says. "We're not trying to make any judgments about whether development is good or bad. We're just saying, 'here's how buildings are growing on this landscape.'"

Jeff Kline

Conservation easements and land use zoning are tools that could be used to maintain existing mule deer migration corridors.

Several options are available that could meet a variety of land use goals in the area, says Kline. "Land use planning might do the job, but there might be other things to consider that would augment planning," he says, such as establishing conservation easements or an outright purchase of land that is set aside for habitat conservation. He also suggests that policymakers might consider providing consistent or increased funding to existing state programs that protect and enhance critical winter habitat.

"The fate of animals is...indissolubly connected with the fate of men."
—Émile Zola

LAND MANAGEMENT IMPLICATIONS

- Resource managers may want to initiate or expand efforts to work with landowners, local land use planning officials, and nonprofit conservation organizations to consider how to address anticipated development within mule deer winter range.
- Modified land use zoning, conservation easements, and land purchases might be considered to help maintain existing migration corridors and minimize disturbances associated with new development.
- Policymakers might consider providing more consistent or increased funding to existing state programs that protect and enhance habitat.

FOR FURTHER READING

Kline, J.D.; Moses, A.; Burcsu, T. 2010. Anticipating forest and range land development in central Oregon for landscape analysis, with an example application involving mule deer. Environmental Management. 45(5): 974–984.

Kline, J.D.; Moses, A.; Lettman, G.; Azuma, D.L. 2007. Modeling forest and rangeland development in rural locations, with examples from eastern Oregon. Landscape and Urban Planning. 83(3): 320–332.

Oregon Department of Fish and Wildlife. 2009. Oregon Mule Deer Initiative. Oregon Department of Fish and Wildlife, Salem, OR. http://www.dfw.state.or.us/wildlife/hot_topics/mule_deer_initiative.asp.

Theobald, D.M.; Miller, J.R.; Hobbs, N.T. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning. 39: 25–36.

Vogel, W.O. 1989. Response of deer to density and distribution of housing in Montana. Wildlife Society Bulletin. 17: 406–413.

WRITER'S PROFILE

Marie Oliver is a science writer based in Philomath, Oregon.

Science
FINDINGS

U.S. Department of Agriculture
Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, $300

PRSRT STD
US POSTAGE
PAID
PORTLAND OR
PERMIT N0 G-40

SCIENTIST PROFILE

JEFF KLINE is a research forester and economist with the PNW Research Station at the Corvallis Forestry Sciences Laboratory. He has a Ph.D. in environmental and natural resource economics from the University of Rhode Island. His current research examines the effects of population growth and land use change on forests and their management, as well as related changes in how the public uses and values forests.

Kline can be reached at:
Pacific Northwest Research Station
USDA Forest Service
Forestry Sciences Laboratory
3200 SW Jefferson Way
Corvallis, OR 97331

Phone: (541) 758-7776
E-mail: jkline@fs.fed.us

COLLABORATORS

Glen Ardt, Oregon Department of Fish and Wildlife

Theresa Burcsu, Oregon State University, Institute for Natural Resources

Gary Lettman, Oregon Department of Forestry

Scott Cashen, M.S.
Senior Biologist / Forest Ecologist
3264 Hudson Avenue, Walnut Creek, CA 94597. (925) 256-9185. scottcashen@gmail.com

Scott Cashen has 20 years of professional experience in natural resources management. During that time he has worked as a field biologist, forester, environmental consultant, and instructor of Wildlife Management. Mr. Cashen currently operates an independent consulting business that focuses on CEQA/NEPA compliance issues, endangered species, scientific field studies, and other topics that require a high level of scientific expertise.

Mr. Cashen has knowledge and experience with many taxa, biological resource issues, and environmental regulations. This knowledge and experience has made him a highly sought after biological resources expert. To date, he has been retained as a biological resources expert for over 40 projects. Mr. Cashen's role in this capacity has encompassed all stages of the environmental review process, from initial document review through litigation support and expert witness testimony.

Mr. Cashen is a recognized expert on the environmental impacts of renewable energy development. He has been involved in the environmental review process for 28 renewable energy projects, and he has been a biological resources expert for more of California's solar energy projects than any other private consultant. In 2010, Mr. Cashen testified on 5 of the Department of the Interior's "Top 6 Fast-tracked Solar Projects" and his testimony influenced the outcome of each of these projects.

Mr. Cashen is a versatile scientist capable of addressing numerous aspects of natural resource management simultaneously. Because of Mr. Cashen's expertise in both forestry and biology, Calfire had him prepare the biological resource assessments for all of its fuels treatment projects in Riverside and San Diego Counties following the 2003 Cedar Fire. Mr. Cashen has led field studies on several special-status species, including plants, fish, reptiles, amphibians, birds, and mammals. Mr. Cashen has been the technical editor of several resource management documents, and his strong scientific writing skills have enabled him to secure grant funding for several clients.

AREAS OF EXPERTISE

- CEQA, NEPA, and Endangered Species Act compliance issues
- Comprehensive biological resource assessments
- Endangered species management
- Renewable energy
- Forest fuels reduction and timber harvesting
- Scientific field studies, grant writing and technical editing

EDUCATION

M.S. Wildlife and Fisheries Science - The Pennsylvania State University (1998)
B.S. Resource Management - The University of California, Berkeley (1992)

PROFESSIONAL EXPERIENCE

Litigation Support / Expert Witness

As a biological resources expert, Mr. Cashen reviews CEQA/NEPA documents and provides his client(s) with an assessment of biological resource issues. He then prepares written comments on the scientific and legal adequacy of the project's environmental documents (e.g., EIR). For projects requiring California Energy Commission (CEC) approval, Mr. Cashen has submitted written testimony (opening and rebuttal) in conjunction with oral testimony before the CEC.

Mr. Cashen can lead field studies to generate evidence for legal testimony, and he can incorporate testimony from his deep network of species-specific experts. Mr. Cashen's clients have included law firms, non-profit organizations, and citizen groups.

REPRESENTATIVE EXPERIENCE

Solar Energy Facilities

- Abengoa Mojave Solar Project
- Avenal Energy Power Plant
- Beacon Solar Energy Project
- Blythe Solar Power Project
- Calico Solar Project
- Calipatria Solar Farm II
- Carrizo Energy Solar Farm
- Catalina Renewable Energy Project
- Fink Road Solar Farm
- Genesis Solar Energy Project
- Heber Solar Energy Facility
- Imperial Valley Solar Project
- Ivanpah Solar Electric Generating
- Maricopa Sun Solar Complex
- Mt. Signal and Calexico Solar
- San Joaquin Solar I & II
- Solar Gen II Projects
- SR Solis Oro Loma
- Vestal Solar Facilities
- Victorville 2 Power Project

Geothermal Energy Facilities

- East Brawley Geothermal
- Mammoth Pacific 1 Replacement
- Western GeoPower Plant and

Wind Energy Facilities

- Catalina Renewable Energy Project
- Ocotillo Express Wind Energy
- San Diego County Wind Ordinance
- Tres Vaqueros Repowering Project
- Vasco Winds Relicensing Project

Biomass Facilities

- Tracy Green Energy Project

Development Projects

- Alves Ranch
- Aviano
- Chula Vista Bayfront Master Plan
- Columbus Salame
- Concord Naval Weapons Station
- Faria Annexation
- Live Oak Master Plan
- Napa Pipe
- Roddy Ranch
- Rollingwood
- Sprint-Nextel Tower

Project Management

Mr. Cashen has managed several large-scale wildlife, forestry, and natural resource management projects. Many of these projects have required hiring and training field crews, coordinating with other professionals, and communicating with project stakeholders. Mr. Cashen's experience in study design, data collection, and scientific writing make him an effective project manager, and his background in several different natural resource disciplines enable him to address the many facets of contemporary land management in a cost-effective manner.

REPRESENTATIVE EXPERIENCE

Wildlife Studies

- Peninsular Bighorn Sheep Resource Use and Behavior Study: (*CA State Parks*)
- "KV" Spotted Owl and Northern Goshawk Inventory: (*USFS, Plumas NF*)
- Amphibian Inventory Project: (*USFS, Plumas NF*)
- San Mateo Creek Steelhead Restoration Project: (*Trout Unlimited and CA Coastal Conservancy, Orange County*)
- Delta Meadows State Park Special-status Species Inventory: (*CA State Parks, Locke*)

Natural Resources Management

- Mather Lake Resource Management Study and Plan – (*Sacramento County*)
- Placer County Vernal Pool Study – (*Placer County*)
- Weidemann Ranch Mitigation Project – (*Toll Brothers, Inc., San Ramon*)
- Ion Communities Biological Resource Assessments – (*Ion Communities, Riverside and San Bernardino Counties*)
- Del Rio Hills Biological Resource Assessment – (*The Wyro Company, Rio Vista*)

Forestry

- Forest Health Improvement Projects – (*CalFire, SD and Riverside Counties*)
- San Diego Bark Beetle Tree Removal Project – (*SDG&E, San Diego Co.*)
- San Diego Bark Beetle Tree Removal Project – (*San Diego County/NRCS*)
- Hillslope Monitoring Project – (*CalFire, throughout California*)

Biological Resources

Mr. Cashen has a diverse background with biological resources. He has conducted comprehensive biological resource assessments, habitat evaluations, species inventories, and scientific peer review. Mr. Cashen has led investigations on several special-status species, including ones focusing on the foothill yellow-legged frog, mountain yellow-legged frog, desert tortoise, steelhead, burrowing owl, California spotted owl, northern goshawk, willow flycatcher, Peninsular bighorn sheep, red panda, and forest carnivores.

REPRESENTATIVE EXPERIENCE

Avian

- Study design and Lead Investigator - Delta Meadows State Park Special-Status Species Inventory *(CA State Parks: Locke)*
- Study design and lead bird surveyor - Placer County Vernal Pool Study *(Placer County: throughout Placer County)*
- Surveyor - Willow flycatcher habitat mapping *(USFS: Plumas NF)*
- Independent surveyor - Tolay Creek, Cullinan Ranch, and Guadacanal Village restoration projects *(Ducks Unlimited/USGS: San Pablo Bay)*
- Study design and Lead Investigator - Bird use of restored wetlands research *(Pennsylvania Game Commission: throughout Pennsylvania)*
- Study design and surveyor - Baseline inventory of bird species at a 400-acre site in Napa County *(HCV Associates: Napa)*
- Surveyor - Baseline inventory of bird abundance following diesel spill *(LFR Levine-Fricke: Suisun Bay)*
- Study design and lead bird surveyor - Green Valley Creek Riparian Restoration Site *(City of Fairfield: Fairfield, CA)*
- Surveyor - Burrowing owl relocation and monitoring *(US Navy: Dixon, CA)*
- Surveyor - Pre-construction raptor and burrowing owl surveys *(various clients and locations)*
- Surveyor - Backcountry bird inventory *(National Park Service: Eagle, Alaska)*
- Lead surveyor - Tidal salt marsh bird surveys (*Point Reyes Bird Observatory: throughout Bay Area*)
- Surveyor – Pre-construction surveys for nesting birds (*various clients and locations)*

Amphibian

- Crew Leader - Red-legged frog, foothill yellow-legged frog, and mountain yellow-legged frog surveys *(USFS: Plumas NF)*

- Surveyor - Foothill yellow-legged frog surveys *(PG&E: North Fork Feather River)*
- Surveyor - Mountain yellow-legged frog surveys *(El Dorado Irrigation District: Desolation Wilderness)*
- Crew Leader - Bullfrog eradication *(Trout Unlimited: Cleveland NF)*

Fish and Aquatic Resources

- Surveyor - Hardhead minnow and other fish surveys *(USFS: Plumas NF)*
- Surveyor - Weber Creek aquatic habitat mapping (*El Dorado Irrigation District: Placerville, CA*)
- Surveyor - Green Valley Creek aquatic habitat mapping *(City of Fairfield: Fairfield, CA)*
- GPS Specialist - Salmonid spawning habitat mapping *(CDFG: Sacramento River)*
- Surveyor - Fish composition and abundance study (*PG&E: Upper North Fork Feather River and Lake Almanor*)
- Crew Leader - Surveys of steelhead abundance and habitat use *(CA Coastal Conservancy: Gualala River estuary)*
- Crew Leader - Exotic species identification and eradication *(Trout Unlimited: Cleveland NF)*

Mammals

- Principal Investigator – Peninsular bighorn sheep resource use and behavior study (*California State Parks: Freeman Properties*)
- Scientific Advisor –Study on red panda occupancy and abundance in eastern Nepal *(The Red Panda Network: CA and Nepal)*
- Surveyor - Forest carnivore surveys *(University of CA: Tahoe NF)*
- Surveyor - Relocation and monitoring of salt marsh harvest mice and other small mammals *(US Navy: Skagg's Island, CA)*
- Surveyor – Surveys for Monterey dusky-footed woodrat. Relocation of woodrat houses (*Touré Associates: Prunedale*)

Natural Resource Investigations / Multiple Species Studies

- Scientific Review Team Member – Member of the science review team assessing the effectiveness of the US Forest Service's implementation of the Herger-Feinstein Quincy Library Group Act.
- Lead Consultant - Baseline biological resource assessments and habitat mapping for CDF management units *(CDF: San Diego, San Bernardino, and Riverside Counties)*

- Biological Resources Expert – Peer review of CEQA/NEPA documents (*Adams Broadwell Joseph & Cardoza: California)*
- Lead Consultant - Pre- and post-harvest biological resource assessments of tree removal sites *(SDG&E: San Diego County)*
- Crew Leader - T&E species habitat evaluations for Biological Assessment in support of a steelhead restoration plan *(Trout Unlimited: Cleveland NF)*
- Lead Investigator - Resource Management Study and Plan for Mather Lake Regional Park *(County of Sacramento: Sacramento, CA)*
- Lead Investigator - Biological Resources Assessment for 1,070-acre Alfaro Ranch property *(Yuba County, CA)*
- Lead Investigator - Wildlife Strike Hazard Management Plan *(HCV Associates: Napa)*
- Lead Investigator - Del Rio Hills Biological Resource Assessment *(The Wyro Company: Rio Vista, CA)*
- Lead Investigator – Ion Communities project sites (*Ion Communities: Riverside and San Bernardino Counties*)
- Surveyor – Tahoe Pilot Project: Validation of California's Wildlife Habitat Relationships (CWHR) Model *(University of California: Tahoe NF)*

Forestry

Mr. Cashen has five years of experience working as a consulting forester on projects throughout California. Mr. Cashen has consulted with landowners and timber operators on forest management practices; and he has worked on a variety of forestry tasks including selective tree marking, forest inventory, harvest layout, erosion control, and supervision of logging operations. Mr. Cashen's experience with many different natural resources enable him to provide a holistic approach to forest management, rather than just management of timber resources.

REPRESENTATIVE EXPERIENCE

- Lead Consultant - CalFire fuels treatment projects *(SD and Riverside Counties)*
- Lead Consultant and supervisor of harvest activities – San Diego Gas and Electric Bark Beetle Tree Removal Project *(San Diego)*
- Crew Leader - Hillslope Monitoring Program *(CalFire: throughout California)*
- Consulting Forester – Forest inventories and timber harvest projects *(various clients throughout California)*

Grant Writing and Technical Editing

Mr. Cashen has prepared and submitted over 50 proposals and grant applications. Many of the projects listed herein were acquired through proposals he wrote. Mr. Cashen's clients and colleagues have recognized his strong scientific writing skills and ability to generate technically superior proposal packages. Consequently, he routinely prepares funding applications and conducts technical editing for various clients.

PERMITS

U.S. Fish and Wildlife Service Section 10(a)(1)(A) Recovery Permit for the Peninsular bighorn sheep

CA Department of Fish and Game Scientific Collecting Permit

PROFESSIONAL ORGANIZATIONS / ASSOCIATIONS

The Wildlife Society (Conservation Affairs Committee member)

Cal Alumni Foresters

Mt. Diablo Audubon Society

OTHER AFFILIATIONS

Scientific Advisor and Grant Writer – *The Red Panda Network*

Scientific Advisor – *Mt. Diablo Audubon Society*

Grant Writer – *American Conservation Experience*

Scientific Advisor and Land Committee Member – *Save Mt. Diablo*

TEACHING EXPERIENCE

Instructor: Wildlife Management - The Pennsylvania State University, 1998

Teaching Assistant: Ornithology - The Pennsylvania State University, 1996-1997

Curriculum Vitae

VERNON C. BLEICH

Eastern Sierra Center for Applied
Population Ecology (ESCAPE)

11537 36X St. SW
Dickinson, ND 58601
760/937-5020
701/225-7834
vbleich@ndsupernet.com

Personal Interests:

Hockey (I am a former goaltender), family life, banjo, gardening, hunting, and fishing.

Professional Goals:

To help ensure the persistence of populations of large mammals and their habitats through the study of their ecology and behavior, to apply that knowledge in meaningful conservation efforts, and to impart that knowledge through professional activities including publications, teaching, and other public contacts.

Education:

Ph.D. University of Alaska Fairbanks (Wildlife Biology, 1993). Thesis: "Sexual Segregation in Desert-Dwelling Mountain Sheep."

M.A. California State University, Long Beach (Biology, 1973). Thesis: "Ecology of Rodents at the Seal Beach Naval Weapons Station, Fallbrook Annex, San Diego County, California."

B.S. California State University, Long Beach (Zoology, 1970).

Professional Background:

Senior Conservation Scientist, Eastern Sierra Center for Applied Population Ecology (2007 - present). I provide expertise on natural resource conservation issues, particularly as they relate to large mammals in desert, mountain, and plains environments.

Senior Environmental Scientist, California Department of Fish and Game (2001 – 2008; now retired). I served as the project leader for the Sierra Nevada Bighorn Sheep Recovery Program, a project to conserve mountain sheep in that range and restore them to formerly occupied habitats; I continued to function as the Regional Large Mammal and Desert specialist, with an emphasis on mountain sheep and mule deer in southeastern California.

I served as chair of the Sierra Nevada Bighorn Sheep Recovery Team (also referred to as the Sierra Nevada Bighorn Sheep Science Advisory Group), and continued to serve as a member of the Peninsular Bighorn Sheep Recovery Team.

Senior Wildlife Biologist, California Department of Fish and Game (1999 - 2001). I served as the Regional Large Mammal and Desert Specialist, with an emphasis on mountain sheep and mule deer in southeastern California. At the request of the US Fish and wildlife Service I was appointed by the Department of Fish and Game to serve on the Peninsular Bighorn Sheep Recovery Team.

Senior Wildlife Biologist, California Department of Fish and Game (1993 - 1999). I served as the Regional Large Mammal Specialist and supervised the activities of 5 journeyman wildlife biologists in eastern California. Emphasis species included mountain sheep, mule deer, pronghorn, tule elk, and sage grouse in eastern California.

Associate Wildlife Biologist, California Department of Fish and Game (1986 - 1993). I served as the Regional mountain sheep specialist, and supervised the activities of 5 journeyman wildlife biologists in eastern California. Emphasis species included mountain sheep, mule deer, pronghorn, tule elk, and sage grouse in eastern California.

Project Leader, California Department of Fish and Game, Federal Aid in Wildlife Restoration Project W-26-D (1978 - 1986). I supervised 2 technicians, and planned and implemented habitat management projects designed to benefit waterfowl, sage grouse, mule deer, and mountain sheep in eastern California.

Assistant Wildlife Biologist, California Department of Fish and Game (1975 - 1978). I was an Area Biologist responsible for management of mule deer, mountain sheep, and the Endangered Stephens' kangaroo rat, as well as for environmental review activities in Riverside and San Bernardino counties, California.

Junior Aquatic Biologist, California Department of Fish and Game (1974 - 1975). I was responsible for fisheries management activities, with an emphasis on wild trout and the Endangered unarmored three-spined stickleback in Los Angeles and San Bernardino counties, California.

Park Ranger, Department of Recreation, City of Long Beach, California (1970 - 1973). I was responsible for public education activities, routine patrol, and coordination with other law enforcement agencies in El Dorado Regional Park, Long Beach, California.

Academic Appointments:

Research Professor, Department of Natural Resources and Environmental Science, University of Nevada, Reno (2007 - Present).

Affiliate Faculty, Department of Biological Sciences, Idaho State University, Pocatello, Idaho (2005 - Present).

Senior Research Associate, Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska (1998 - Present).

Affiliate Assistant Professor of Wildlife Ecology, Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, Alaska (1993 - 1998).

Research Associate, Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska (1993 - present).

Adjunct Assistant Professor of Natural Resource Science, Department of Natural Resource Science, University of Rhode Island, Kingston (1992 - 1994).

Instructor, Mt. San Jacinto College, San Jacinto, California. I instructed an introductory course entitled, "Wildlife Management" (1976 - 1986).

Assistant Professor, Department of Biology, Rio Hondo College, Whittier, California. I instructed lecture and laboratory sections of General Zoology (biology major emphasis), General Biology (general education emphasis), and Marine Biology (1973 - 1974).

Teaching Assistant, California State University, Long Beach. I instructed laboratory sections of General Biology (for non-majors) and General Zoology (for majors) (1972 - 1973).

Graduate Research Assistant, California State University, Long Beach. I prepared specimens and curated the collection of mammals (> 10,000 specimens) in the Bird and Mammal Museum, and instructed laboratory sections of General Ecology (for majors), General Mammalogy (for majors), and Advanced Mammalogy (1970-1972).

Graduate Student Supervision:

Chair of Graduate Committee:

Kevin L. Monteith (Ph.D.), Reproductive ecology of migratory and resident mule deer in the eastern Sierra Nevada, California. Idaho State University, Pocatello. Graduation expected December, 2010. Co-chair with Dr. R. T. Bowyer.

Michael W. Oehler (M.S.), Ecology of mountain sheep: effects of mining and precipitation. University of Alaska Fairbanks. *Graduated December 1999.* Current position: Wildlife Biologist, National Park Service, Theodore Roosevelt National Park, Medora, North Dakota. Co-chair with Dr. R. T. Bowyer.

Becky M. Pierce (Ph.D.), Predator-prey dynamics between mountain lions and mule deer: effects on distribution, population regulation, habitat selection and prey selection. University of Alaska Fairbanks. *Graduated May 1999.* Current position: Associate Wildlife Biologist, California Department of Fish and Game. Co-chair with Dr. R. T. Bowyer.

Graduate Committee Membership:

Cody J. McKee (M.S.), Ecology of mule deer in the eastern Mojave Desert, California. University of Nevada, Reno (Graduation expected June 2011).

Jeffrey T. Villepique (Ph.D.), Interactions between mountain lions and mountain sheep: an assessment of forage benefits and predation risk. Idaho State University, Pocatello (Graduation expected December 2010).

Sabrina Morano (Ph.D.), Reproductive biology of mule deer in the White Mountains, Inyo and Mono counties, California. University of Nevada, Reno (Graduation expected June 2011).

Jericho C. Whiting (Ph.D.), Behavior and ecology of reintroduced Rocky Mountain bighorn sheep. Idaho State University, Pocatello. *Graduated December 2008.* Current position: Wildlife Biologist, Idaho National Laboratory, Twin Falls.

Cody A. Schroeder (M.S.), Habitat selection by mountain sheep: forage benefits or risk of predation? Idaho State University, Pocatello. *Graduated September 2007.* Current position: Doctoral Student, University of Nevada, Reno.

Jason P. Marshal (Ph.D.), Foraging ecology and water relationships of mule deer in a Sonoran Desert environment. University of Arizona, Tucson. *Graduated May 2005.* Current position: Lecturer, University of the Witwatersrand, South Africa.

Heather E. Johnson (M.S.), Antler breakage in tule elk in Owens Valley, California: nutritional causes and behavioral consequences. University of Arizona, Tucson. *Graduated January 2004.* Current position: Doctoral Student and Research Associate, University of Montana, Missoula.

Jennifer L. Rechel (Ph.D. [Geography]), Influence of neighborhood effects and friction surfaces on the spatial distribution and movement strategies of desert-dwelling mountain sheep (*Ovis canadensis*). University of California, Riverside. *Graduated August 2003.* Current position: Wildlife Biologist, U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Riverside, California.

Holly B. Ernest (Ph.D.), Ecological genetics of mountain lions (*Puma concolor*) in California. University of California, Davis. *Graduated December 2001.* Current position: Research Geneticist, School of Veterinary Medicine, University of California, Davis.

Esther S. Rubin (Ph.D.), The ecology of bighorn sheep (*Ovis canadensis*) in the peninsular ranges of California. University of California, Davis. *Graduated December 2000.* Current position: Conservation Biologist, The Conservation Biology Institute, Borrego Springs, California.

Nancy G. Andrew (M.S.), Demography and habitat use of desert-dwelling mountain sheep in the East Chocolate Mountains, Imperial County, California. University of Rhode Island, Kingston. *Graduated May 1994.* Current position: Staff Environmental Scientist, California Department of Fish and Game.

Awards and Honors:

Honorary Lifetime Membership, 2010 (in recognition to long and continuing service to the Society for the Conservation of Bighorn Sheep)

Wild Sheep Biologist Wall of Fame Award, 2009 (in recognition of significant contributions to the conservation of wild sheep in North America) (Wild Sheep Foundation)

Lifetime Achievement Award, 2008 (In recognition of contributions toward the conservation of mountain sheep in California) (California Chapter of the Foundation for North American Wild Sheep)

Honor Plaque 2007 (Group Award, in recognition of outstanding contributions toward the recovery of mountain sheep in the Sierra Nevada) (Desert Bighorn Council)

State Statesman Award, 2006 (In recognition of outstanding contributions to the wild sheep of California) (Foundation for North American Wild Sheep)

Trail Blazer Award, 2004 (In recognition of efforts on behalf of mountain sheep conservation in California) (California Chapter of the Foundation for North American Wild Sheep)

Director's Achievement Award, 2004 (In recognition of editorial services for California Fish and Game (California Department of Fish and Game)

Annual Achievement Award, 2004 (In recognition of conservation of mule deer and their habitats) (Southern California Chapter, California Deer Association)

Alumni Achievement Award for Professional Excellence, 2002 (University of Alaska Alumni Association)

Outstanding Alumnus Award, 2002 (College of Science, Engineering, and Mathematics, University of Alaska Fairbanks)

Sustained Superior Accomplishment Award, 2002 (California Department of Fish and Game)

The Desert Ram Award, 2001 (Desert Bighorn Council)

Outstanding Publication Award for a Monograph, 1998 (The Wildlife Society)

Award of Appreciation, 1998 (San Fernando Valley Chapter of Safari Club International, CA)

Professional Membership, Boone and Crockett Club, 1998 (Boone and Crockett Club)

Certificate of Appreciation, 1997 (Society for the Conservation of Bighorn Sheep)

"Ol' Irongut" Award, 1996 (California Department of Fish and Game, Division of Air Services)

Resources Agency/University of California Fellowship, 1996 (Sponsored jointly by the California Resources Agency and the University of California, Davis)

Director's Achievement Award, 1992 (California Department of Fish and Game)

Outstanding Biology Department Alumnus, 1988 (California State University, Long Beach)

Professional of the Year, 1985 (Western Section of The Wildlife Society)

California Wildlife Officer of the Year, 1984 (Shikar-Safari Foundation)

Award of Honor, 1984 (Society for the Conservation of Bighorn Sheep)

Honorary Lifetime Member, 1984 (Banning [California] Sportsman's Club)

Professional and Fraternal Memberships:

American Society of Mammalogists (Life Member)
The Boone and Crockett Club (Professional Member)
The Wildlife Society
Society for Conservation Biology
Southwestern Association of Naturalists
Wild Sheep Foundation
National Rifle Association
California Chapter, Foundation for North American Wild Sheep
Society for the Conservation of Bighorn Sheep
Minnesota-Wisconsin Chapter, Foundation for North American Wild Sheep

Licenses and Certifications:

California Community College Credential (#45476, Lifetime)
State of California Certified Blaster's License (#2087)
Certified Wildlife Biologist (1981 - The Wildlife Society)
California Hunter Safety Instructor (#1984)

Other Professional Activities:

Editorial Activities:

Editor-in-Chief, *California Fish and Game* (2009 - present)

Associate Editor, *California Fish and Game* (1995 - 2009).

Editor, *Transactions of the Western Section of The Wildlife Society* (1988).

Associate Editor, *Transactions of the Western Section of The Wildlife Society* (1986-87).

Reviewer for Journals:

Conservation Biology, Journal of Wildlife Management, Wildlife Society Bulletin, Journal of Mammalogy, The Condor, California Fish and Game, Transactions of the Western Section of the Wildlife Society, Western North American Naturalist, Desert Bighorn Council Transactions, Southwestern Naturalist, Proceedings of the Northern Wild Sheep and Goat Council, Journal of Wildlife Diseases, Great Basin Naturalist, Bulletin of the Southern California Academy of Sciences, Journal of Zoology (London), Vida Silvestre Neotropical, Wildlife Biology, Wildlife Monographs, European Journal of Wildlife Research, Biological Conservation, Journal of Arid Environments (An average of about 12 reviews per year).

Other Activities:

2008 – Present: Member, Big Game Records Committee, Boone and Crockett Club

2007 – Present: Advisory Board Member, Texas Bighorn Society

2007 – Present: Science Advisor, Society for the Conservation of Bighorn Sheep

2006 - Present: Member, Ad Hoc Committee on Professional Membership, Boone and Crockett Club.

1998 - 2002: Coach and member of Board of Trustees, Sierra Roller Hockey League.

1995-96: Vice Chairman, The Desert Bighorn Council.

1994-98: Member, Board of Directors, The Wildlife Forensic DNA Foundation.

1993 - Present: Member, Wildlife Management Professional Advisory Committee, Foundation for North American Wild Sheep.

1991: Member, Committee on Support of Symposia and Conferences, The Wildlife Society.

1989-1993: Member, Board of Trustees, Friends of the Eastern California Museum; Vice-chairman, 1991-1992; Chairman, 1993.

1987-1988: Chairman, The Desert Bighorn Council.

1988: Co-chairman, Wildlife Water Development Symposium, Western Section of The Wildlife Society.

Refereed Publications:

Bleich, V. C. *In review*. Perceived threats to mountain sheep: levels of concordance among western states, provinces, and territories. Desert Bighorn Council Transactions.

Marshal, J. P., and **V. C. Bleich**. *In review*. Geographic variation in relationships between El Nino Southern Oscillation and mule deer harvest in California, USA. Southwestern Naturalist.

Jaeger, J. R., J. D. Wehausen, and **V. C. Bleich**. *In review*. Incentives for migration by female mountain sheep: water requirements, nutritional gains, or decreased predation risk? Journal of Mammalogy.

Holl, S. A., and **V. C. Bleich**. *In review*. Responses of large mammals to fire and rain in the San Gabriel Mountains, California. Southwestern Naturalist.

Marshal, J. P., **V. C. Bleich**, P. R. Krausman, A. Neibergs, M. L. Reed, and N. G. Andrew. *In review*. Habitat use and diets of mule deer and feral ass in the Sonoran Desert. Journal of Arid Environments.

Whiting, J. C., R. T. Bowyer, J. T. Flinders, **V. C. Bleich**, and J. G. Kie. *In press*. Sexual segregation and use of water by bighorn sheep: implications for conservation. Animal Conservation.

Villepique, J. T., B. M. Pierce, **V. C. Bleich**, and R. T. Bowyer. *In press*. Diets of mountain lions following a decline in mule deer numbers. Southwestern Naturalist.

Bleich, V. C. *In press*. Considerations for reprovisioning wildlife water developments: mountain sheep in desert ecosystems. California Fish and Game.

Gibson, R. M., **V. C. Bleich**, C. W. McCarthy, and T. L. Russi. *In press*. Recreational hunting can lower population size in Greater Sage-grouse. Studies in Avian Biology.

Schroeder, C. A., R. T. Bowyer, **V. C. Bleich**, and T. R. Stephenson. *In press*. Ramifications of sexual segregation for an endangered alpine ungulate: Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*. Arctic, Antarctic, and Alpine Research.

Bleich, V. C., J. P. Marshal, and N. G. Andrew. 2010. Habitat use by a desert ungulate: predicting effects of water availability on mountain sheep. Journal of Arid Environments

74:638-645.

Krausman, P. R., D. E. Naugle, M. R. Frisina, R. Northrup, **V. C. Bleich**, W. M. Block, M. C. Wallace, and J. D. Wright. 2009. Livestock grazing, wildlife habitat, and rangeland values. Rangelands 31(5):15-19.

Holl, S. A., and **V. C. Bleich**. 2009. Reconstructing the San Gabriel Mountains bighorn sheep population. California Fish and Game 95:77-87.

Clifford, D. L., B. A. Schumaker, T. R. Stephenson, **V. C. Bleich**, M. Leonard-Cahn, B. J. Gonzales, W. M. Boyce, and J. A. K. Mazet. 2009. Assessing disease risk at the wildlife-livestock interface: a study of Sierra Nevada bighorn sheep. Biological Conservation 142:2559-2568.

Bleich, V. C., J. H. Davis, J. P. Marshal, S. G. Torres, and B. J. Gonzales. 2009. Mining activity and habitat use by mountain sheep. European Journal of Wildlife Research 55:183-191.

Pease, K. M., A. H. Freedman, J. P. Pollinger, J. E. McCormack, W. Buermann, J. Rodzen, J. Banks, E. Meredith, **V. C. Bleich**, R. J. Schaefer, K. Jones, and R. K. Wayne. 2009. Landscape genetics of California mule deer (*Odocoileus hemionus*): the roles of ecological and historical factors in generating differentiation. Molecular Ecology 18:1848-1862.

Duffy, L. K., M. W. Oehler, R. T. Bowyer, and **V. C. Bleich**. 2009. Mountain sheep: an environmental epidemiological survey of variation in metal exposure and physiological biomarkers following mine development. American Journal of Environmental Sciences 5:296-303.

Marshal, J. P., J. W. Cain III, **V. C. Bleich**, and S. S. Rosenstock. 2009. Intrinsic and extrinsic sources of variation in the population dynamics of an arid-environment large herbivore. Canadian Journal of Zoology 87:103-111.

Villepique, J. T., **V. C. Bleich**, R. A. Botta, B. M. Pierce, T. R. Stephenson, and R. T. Bowyer. 2008. Evaluating GPS collar error: a critical evaluation of Televilt POSREC-Science™ Collars and a method for screening location data. California Fish and Game 94:155-168.

Bleich, V. C., H. E. Johnson, S. A. Holl, L. Konde, S. G. Torres, and P. R. Krausman. 2008. Fire history in a chaparral ecosystem: implications for conservation of a native ungulate. Rangeland Ecology and Management 61:571-579.

Marshal, J. P., P. R. Krausman, and **V. C. Bleich**. 2008. Body condition of desert mule deer is related to rainfall. Southwestern Naturalist 53:311-318.

Marshal, J. P., **V. C. Bleich**, and N. G. Andrew. 2008. Evidence for interspecific competition between feral ass and mountain sheep in a desert environment. Wildlife Biology 14:228-236.

Bleich, V. C., and R. A. Weaver. 2007. Status of mountain sheep in California: comparisons between 1957 and 2007. Desert Bighorn Council Transactions 49:55-67.

Wehausen, J. D., and **V. C. Bleich**. 2007. Influence of aerial search time on survey results. Desert Bighorn Council Transactions 49:23-29.

Bowyer, R. T., **V. C. Bleich**, X. Manteca, J. C. Whiting, and K. M. Stewart. 2007. Sociality, mate choice, and timing of mating in American bison (*Bison bison*): effects of large males. Ethology 113:1048-1060.

Epps, C. W., J. D. Wehausen, **V. C. Bleich**, S. G. Torres, and J. S. Brashares. 2007. Optimizing dispersal and corridor models using landscape genetics. Journal of Applied Ecology 44:714-724.

Bleich, V. C., T. R. Stephenson, B. M. Pierce, and M. J. Warner. 2007. Body condition of mule deer while injured and following recovery. Southwestern Naturalist 52:164-167.

Johnson, H. E., **V. C. Bleich**, and P. R. Krausman. 2007. Mineral deficiencies in tule elk, Owens Valley, California. Journal of Wildlife Diseases 43:61-74.

Johnson, H. E., **V. C. Bleich**, P. R. Krausman, and J. L. Koprowski. 2007. Effects of antler breakage on mating behavior in male tule elk (*Cervus elaphus nannodes*). European Journal of Wildlife Research 53:9-15.

Bleich, V. C. 2006. Mountain sheep in California: perspectives on the past, and prospects for the future. Biennial Symposium of the Northern Wild Sheep and Goat Council 15:1-13.

Marshal, J. P., **V. C. Bleich**, P. R. Krausman, M. L. Reed, and N. G. Andrew. 2006. [Invited paper] Factors affecting habitat use and distribution of mule deer in an arid environment. Wildlife Society Bulletin 34:609-619.

Bleich, V. C., N. G. Andrew, M. J. Martin, G. P. Mulcahy, A. M. Pauli, and S. S. Rosenstock. 2006. [Invited paper] Quality of water available to wildlife: comparisons among artificial and natural sources. Wildlife Society Bulletin 34:627-632.

Bleich, V. C., S. Nelson, P. J. Wood, H. R. Wood, and R. A. Noles. 2006. [Invited paper] Retrofitting gallinaceous guzzlers: enhancing water availability and safety for wildlife. Wildlife Society Bulletin 34:633-636.

Marshal, J. P., P. R. Krausman, **V. C. Bleich**, S. S. Rosenstock, and W. B. Ballard. 2006. [Invited paper] Gradients of forage biomass and ungulate use near wildlife water developments. Wildlife Society Bulletin 34:620-626.

Rominger, E. M., **V. C. Bleich**, and E. J. Goldstein. 2006. [Letter] Bighorn sheep, mountain lions, and the ethics of conservation. Conservation Biology 20:1041.

Marshal, J. P., L. M. Lesicka, **V. C. Bleich**, P. R. Krausman, G. P. Mulcahy, and N. G. Andrew. 2006. Demography of desert mule deer in southeastern California. California Fish and Game 92:55-66.

Bleich, V. C., B. M. Pierce, J. Jones, and R. T. Bowyer. 2006. Variance in survival rates among young mule deer in the Sierra Nevada, California. California Fish and Game 92:24-38.

Johnson, H. E., **V. C. Bleich**, and P. R. Krausman. 2005. Antler breakage in tule elk, Owens Valley, California. Journal of Wildlife Management 69:1747-1752.

Rosenstock, S. S., **V. C. Bleich**, M. J. Rabe, and C. Reggiardo. 2005. Water quality at wildlife water sources in the Sonoran Desert, United States. Rangeland Ecology and Management 58:623-627.

Marshal, J. P., P. R. Krausman, and **V. C. Bleich**. 2005. Rainfall, temperature, and forage dynamics affect nutritional quality of desert mule deer forage. Rangeland Ecology and Management 58:360-365.

Bleich, V. C., J. T. Villepique, T. R. Stephenson, B. M. Pierce, and G. M. Kutliyev. 2005. Efficacy of aerial telemetry as an aid to capture specific individuals: a comparison of two techniques. Wildlife Society Bulletin 33:332-336.

Bleich, V. C. 2005. [Invited paper] In my opinion: politics, promises, and illogical legislation confound wildlife conservation. Wildlife Society Bulletin 33:66-73.

Wehausen, J. D., **V. C. Bleich**, and R. R. Ramey II. 2005. Correct nomenclature for Sierra Nevada bighorn sheep. California Fish and Game 91:216-218.

Oehler, M. W., **V. C. Bleich**, R. T. Bowyer, and M. C. Nicholson. 2005. Mountain sheep and mining: implications for conservation and management. California Fish and Game 91:149-178.

Marshal, J. P., P. R. Krausman, and **V. C. Bleich**. 2005. Dynamics of mule deer forage in the Sonoran Desert. Journal of Arid Environments 60:593-609.

Bleich, V. C., and S. G. Torres. 2004. [Guest Editorial] International involvement in wildlife conservation. Wildlife Society Bulletin 32:1013-1014.

Krausman, P. R., **V. C. Bleich**, J. W. Cain III, T. R. Stephenson, D. W. DeYoung, P. W. McGrath, P. K. Swift, B. M. Pierce, and B. D. Jansen. 2004. Neck lesions in ungulates from collars incorporating satellite technology. Wildlife Society Bulletin 32:987-991.

Marshal, J. P., **V. C. Bleich**, N. G. Andrew, and P. R. Krausman. 2004. Seasonal forage use by desert mule deer in southeastern California. Southwestern Naturalist 49:501-505.

Holl, S. A., **V. C. Bleich**, and S. G. Torres. 2004. Population dynamics of bighorn sheep in the San Gabriel Mountains, California, 1967-2002. Wildlife Society Bulletin 32:412-426.

Pierce, B. M., R. T. Bowyer, and **V. C. Bleich**. 2004. Habitat selection by mule deer: forage benefits or risk of predation? Journal of Wildlife Management 68:533-541.

Bleich, V. C., E. F. Cassirer, L. E. Oldenburg, V. L. Coggins, and D. L. Hunter. 2004. Predation by a golden eagle, *Aquila chrysaetos*, on a juvenile mountain sheep, *Ovis canadensis*. California Fish and Game 90:91-93.

Epps, C. W., D. R. McCullough, J. D. Wehausen, **V. C. Bleich**, and J. L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18:102-113.

Long, E. S., D. M. Fecske, R. A. Sweitzer, J. A. Jenks, B. M. Pierce, and **V. C. Bleich**. 2003. Efficacy of photographic scent stations to detect mountain lions. Western North American Naturalist 63:529-532.

Bleich, V. C. 2003. The potential for botulism in desert-dwelling mountain sheep. Desert Bighorn Council Transactions 47:2-8.

Epps, C. W., **V. C. Bleich**, J. D. Wehausen, and S. G. Torres. 2003. Status of bighorn sheep in California. Desert Bighorn Council Transactions 47:20-35.

Oehler, M. W., Sr., R. T. Bowyer, and **V. C. Bleich**. 2003. Home ranges of mountain sheep: effects of precipitation in a desert ecosystem. Mammalia 67:385-402.

Weckerly, F. W., **V. C. Bleich**, C.-L. B. Chetkiewicz, and Mark A. Ricca. 2003. Body weight and rumen-reticulum capacity in tule elk and mule deer. Journal of Mammalogy 84:659-664.

Ernest, H. B., W. M. Boyce, **V. C. Bleich**, B. M. May, S. J. Stiver, and S. G. Torres. 2003. Genetic structure of mountain lion (*Puma concolor*) populations in California. Conservation Genetics 4:353-366.

Bleich, V. C., T. R. Stephenson, N. J. Holste, I. C. Snyder, J. P. Marshal, P. W. McGrath, and B. M. Pierce. 2003. Effects of tooth extraction on selected biological parameters of female mule deer. Wildlife Society Bulletin 31:233-236.

Marshal, J., P. R. Krausman, **V. C. Bleich**, W. B. Ballard, and J. S. McKeever. 2002. Rainfall, el Nino, and dynamics of mule deer in the Sonoran Desert, California. Journal of Wildlife Management 66:1283-1289.

Stephenson, T. R., **V. C. Bleich**, B. M. Pierce, and G. P. Mulcahy. 2002. Validation of mule deer body composition using *in vivo* and post-mortem indices of nutritional condition. Wildlife Society Bulletin 30:557-564.

Swift, P. K., **V. C. Bleich**, T. R. Stephenson, A. E. Adams, B. J. Gonzales, B. M. Pierce, and J. P. Marshal. 2002. Tooth extraction from mule deer in the absence of chemical immobilization. Wildlife Society Bulletin 30:253-255.

Bleich, V. C., C. S. Y. Chun, R. W. Anthes, T. E. Evans, and J. K. Fischer. 2001. [Invited Paper] Visibility bias and development of a sightability model for tule elk. Alces 37:315-327.

Drew, M. L., **V. C. Bleich**, S. G. Torres, and R. G. Sasser. 2001. Early pregnancy detection in mountain sheep using a pregnancy-specific protein B assay. Wildlife Society Bulletin 29:1182-1185.

Rosenstock, S. S., J. J. Hervert, **V. C. Bleich**, and P. R. Krausman. 2001. Muddying the water with poor science: a reply to Broyles and Cutler. Wildlife Society Bulletin 29:734-738 [peer edited].

Bleich, V. C. 2001. On wildlife management in national monuments. The Wildlifer 306:59 [letter].

Andrew, N. G., **V. C. Bleich**, A. D. Morrison, L. M. Lesicka, and P. Cooley. 2001. Wildlife mortalities associated with artificial water sources in the Sonoran Desert. Wildlife Society Bulletin 29:275-280.

Thompson, J. R., **V. C. Bleich**, S. G. Torres, and G. P. Mulcahy. 2001. Translocation techniques for mountain sheep: does the method matter? Southwestern Naturalist 46:87-93.

Bleich, V. C., and B. M. Pierce. 2001. Accidental mass mortality of migrating mule deer. Western North American Naturalist 61:124-125.

Chao-chin, C., B. B. Chomel, R. W. Kasten, R. Heller, K. M. Kocan, H. Ueno, K. Yamamoto, **V. C. Bleich**, B. M. Pierce, B. J. Gonzales, P. K. Swift, W. M. Boyce, S. S. Jang, H.-J. Boulouis, and Y. Piemont. 2000. *Bartonella* spp. isolated from domestic and wild ruminants in North America. Emerging Infectious Diseases 6:306-311.

Singer, F. J., **V. C. Bleich**, and M. A. Gudorf. 2000. [Invited Paper] Restoration of bighorn sheep metapopulations in and near western national parks. Restoration Ecology 8(4S):14-24.

Bleich, V. C., and M. W. Oehler. 2000. [Invited paper] Wildlife education in the United States: thoughts from agency biologists. Wildlife Society Bulletin 28:542-545.

Rubin, E. S., W. M. Boyce, and **V. C. Bleich**. 2000. Reproductive strategies of desert bighorn sheep. Journal of Mammalogy 81:769-786.

Schaefer, R. J., S. G. Torres, and **V. C. Bleich**. 2000. Survivorship and cause-specific mortality in sympatric populations of mountain sheep and mule deer. California Fish and Game 86:127-135.

Pierce, B. M., **V. C. Bleich**, and R. T. Bowyer. 2000. Prey selection by mountain lions and coyotes: effects of hunting style, body size, and reproductive status. Journal of Mammalogy 81:462-472.

Swift, P. K., J. D. Wehausen, H. B. Ernest, R. S. Singer, A. M. Pauli, H. Kinde, T. E. Rocke, and **V. C. Bleich**. 2000. Desert bighorn sheep mortality due to presumptive type C botulism in California. Journal of Wildlife Diseases 36:184-189.

Pierce, B. M., **V. C. Bleich**, and R. T. Bowyer. 2000. Social organization of mountain lions: does a land-tenure system regulate population size? Ecology 81:1533-1543.

Bleich, V. C. 1999. Wildlife conservation and wilderness management: uncommon objectives and conflicting philosophies. North American Wild Sheep Conference Proceedings 2:195-205.

Bleich, V. C., and A. M. Pauli. 1999. Distribution and intensity of hunting and trapping activity in the East Mojave National Scenic Area, California. California Fish and Game 85:148-160.

Pierce, B. M., **V. C. Bleich**, J. D. Wehausen, and R. T. Bowyer. 1999. Migratory patterns of mountain lions: implications for social regulation and conservation. Journal of Mammalogy 80:986-992.

Bleich, V. C. 1999. Mountain sheep and coyotes: patterns of predator evasion in a mountain ungulate. Journal of Mammalogy 80:283-289.

Bleich, V. C., and B. M. Pierce. 1999. Expandable and economical radio collars for juvenile mule deer. California Fish and Game 85:56-62.

Hill, S. D., and **V. C. Bleich**. 1999. Monitoring wildlife water sources using low Earth orbiting satellites (LEOS). Wildlife Society Bulletin 27:25-27.

Andrew, N. G., **V. C. Bleich**, and P. V. August. 1999. Habitat selection by mountain sheep in the Sonoran Desert: implications for conservation in the United States and Mexico. California Wildlife Conservation Bulletin 12:1-30.

Grigione, M. M., P. Burman, **V. C. Bleich**, and B. M. Pierce. 1999. Identifying individual mountain lions (*Felis concolor*) by their tracks: refinement of an innovative technique. Biological Conservation 88:25-32.

Bleich, V. C. 1998. Importance of observer experience in determining age and sex of mountain sheep. Wildlife Society Bulletin 26:877-880.

de Ropp, J. S., J. H. Theis, J. I. Mead, and **V. C. Bleich**. 1998. Limitations of nuclear magnetic resonance (NMR) analysis of fecal bile for taxonomic identification of contemporary and extinct mammals. California Fish and Game 84:112-118.

Bleich, V. C., and T. J. Taylor. 1998. Survivorship and cause-specific mortality in five populations of mule deer. Great Basin Naturalist 58:265-272.

Pierce, B. M., **V. C. Bleich**, C. L.-B. Chetkiewicz, and J. D. Wehausen. 1998. Timing of feeding bouts of mountain lions. Journal of Mammalogy 79:222-226.

Bleich, V. C., R. T. Bowyer, and J. D. Wehausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1-50.

Andrew, N. G., **V. C. Bleich**, P. V. August, and S. G. Torres. 1997. Demography of mountain sheep in the East Chocolate Mountains, California. California Fish and Game 83:68-77.

Andrew, N. G., L. M. Lesicka, and **V. C. Bleich**. 1997. An improved fence design to protect water sources for native ungulates. Wildlife Society Bulletin 25:823-825.

Bleich, V. C., S. G. Torres, J. D. Wehausen, and T. A. Swank. 1996. [Invited paper] History of transplanting mountain sheep - California. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 10:164-166.

Torres, S. G., **V. C. Bleich**, and J. D. Wehausen. 1996. Status of bighorn sheep in California, 1995. Desert Bighorn Council Transactions 40:27-34.

Oehler, M. W., **V. C. Bleich**, and R. T. Bowyer. 1996. Error associated with LORAN-C: effects of aircraft altitude and geographic location. Desert Bighorn Council Transactions 40:19-21.

Bleich, V. C. 1996. Interactions between coyotes (*Canis latrans*) and mountain sheep (*Ovis canadensis*). Southwestern Naturalist 41:81-82.

Davis, J. L., C. L.-B. Chetkiewicz, **V. C. Bleich**, G. Raygorodetsky, B. M. Pierce, J. W. Ostergard, and J. D. Wehausen. 1996. A device to safely remove immobilized mountain lions from trees and cliffs. Wildlife Society Bulletin 24:537-539.

Bleich, V. C., B. M. Pierce, J. L. Davis, and V. L. Davis. 1996. Thermal characteristics of mountain lion dens. Great Basin Naturalist 56:276-278.

Main, M. B., F. W. Weckerly, and **V. C. Bleich**. 1996. [Invited Paper] Sexual segregation in ungulates: new directions for research. Journal of Mammalogy 77:449-461.

Cronin, M. A., and **V. C. Bleich**. 1995. Mitochondrial DNA variation among populations and subspecies of mule deer in California. California Fish and Game 81:45-54.

Bleich, V. C., and M. V. Price. 1995. Aggressive behavior of *Dipodomys stephensi*, an endangered species, and *Dipodomys agilis*, a sympatric congener. Journal of Mammalogy 76:646-651.

Torres, S. G., **V. C. Bleich**, and J. D. Wehausen. 1994. Status of bighorn sheep in California,

1993. Desert Bighorn Council Transactions 38:17-28.

Bleich, V. C., and S. G. Torres. 1994. [Invited Paper] California's mountain sheep management program. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 9:186-195.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, M. C. Nicholson, and R. W. Anthes. 1994. [Lead Article] Responses of mountain sheep *Ovis canadensis* to helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 45:1-7.

Jaeger, J. R., J. D. Wehausen, **V. C. Bleich**, and C. L. Douglas. 1993. Limits in the resolution of LORAN-C for aerial telemetry studies. Desert Bighorn Council Transactions 37:20-23.

Torres, S. G., **V. C. Bleich**, and A. M. Pauli. 1993. Status of bighorn sheep in California, 1992. Desert Bighorn Council Transactions 37:47-52.

Torres, S. G., **V. C. Bleich**, and A. M. Pauli. 1993. An analysis of hunter harvest of mountain sheep in California, 1987-1992. Desert Bighorn Council Transactions 37:37-40.

Jessup, D. A., W. L. Goff, D. Stiller, M. N. Oliver, **V. C. Bleich**, and W. M. Boyce. 1993. A retrospective serologic survey for *Anaplasma* spp. infection in three bighorn sheep (*Ovis canadensis*) populations in California. Journal of Wildlife Diseases 29:547-554.

Thompson, J. R., and **V. C. Bleich**. 1993. A comparison of mule deer survey techniques in the Sonoran Desert of California. California Fish and Game 79:70-75.

Bleich, V. C. 1993. Comments on research, publications, and California's longest continuously published journal. California Fish and Game 79:42-43.

Bleich, V. C., M. C. Nicholson, A. T. Lombard, and P. V. August. 1992. Preliminary tests of mountain sheep habitat models using a geographic information system. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 8:256-263.

Bleich, V. C., R. T. Bowyer, D. J. Clark, and T. O. Clark. 1992. Quality of forages eaten by mountain sheep in the eastern Mojave Desert, California. Desert Bighorn Council Transactions 36:41-47.

Bleich, V. C., S. G. Torres, D. A. Jessup, and G. P. Mulcahy. 1992. Status of mountain sheep in California, 1991. Desert Bighorn Council Transactions 36:76-77.

Krausman, P. R., **V. C. Bleich**, J. A. Bailey, D. Armentrout, and R. R. Ramey II. 1992. What is a minimum viable population? Desert Bighorn Council Transactions 36:68-75.

Jaeger, J. R., J. D. Wehausen, and **V. C. Bleich**. 1991. Evaluation of time-lapse photography to estimate population parameters. Desert Bighorn Council Transactions 35:5-8.

Bleich, V. C., and D. A. Jessup. 1991. Status of bighorn sheep in California, 1990. Desert

Bighorn Council Transactions 35:11-12.

Bleich, V. C., and D. Racine. 1991. Mountain beaver (*Aplodontia rufa*) from Inyo County, California. California Fish and Game 77:153-155.

Bleich, V. C., J. G. Stahmann, R. T. Bowyer, and J. E. Blake. 1990. Osteoporosis, osteomalacia, and cranial asymmetry in a mountain sheep (*Ovis canadensis*). Journal of Wildlife Diseases 26:372-376.

Bleich, V. C. 1990. On Calcium deficiency and brittle antlers. Journal of Wildlife Diseases 26:588.

Bleich, V. C., J. D. Wehausen, and S. A. Holl. 1990. Desert-dwelling mountain sheep: conservation implications of a naturally fragmented distribution. Conservation Biology 4:383-390.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, R. L. Vernoy, and R. W. Anthes. 1990. Responses of mountain sheep to aerial sampling using helicopters. California Fish and Game 76:197-204.

Bleich, V. C., J. D. Wehausen, J. A. Keay, J. G. Stahmann, and M. W. Berbach. 1990. Radiotelemetry collars and mountain sheep: a cautionary note. Desert Bighorn Council Transactions 34:6-8.

Bleich, V. C., J. D. Wehausen, K. R. Jones, and R. A. Weaver. 1990. Status of bighorn sheep in California, 1989 and translocations from 1971 through 1989. Desert Bighorn Council Transactions 34:24-26.

Pauli, A. M., and **V. C. Bleich**. 1988. Additional records of the spotted bat (*Euderma maculatum*) from California. Great Basin Naturalist 48:563.

Wehausen, J. D., **V. C. Bleich**, B. Blong, and T. L. Russi. 1987. Recruitment dynamics in a southern California mountain sheep population. Journal of Wildlife Management 51:86-98.

Holl, S. A., and **V. C. Bleich**. 1987. Mineral lick use by mountain sheep in the San Gabriel Mountains, California. Journal of Wildlife Management 51:381-383.

Wehausen, J. D., **V. C. Bleich**, and R. A. Weaver. 1987. Mountain sheep in California: a historical perspective on 108 years of full protection. Western Section of The Wildlife Society Transactions 23:65-74.

Schwartz, O. A., **V. C. Bleich**, and S. A. Holl. 1986. Genetics and the conservation of mountain sheep *Ovis canadensis nelsoni*. Biological Conservation 37:179-190.

Bleich, V. C. 1986. Early breeding in free-ranging mountain sheep. Southwestern Naturalist 31:530-531.

Schwartz, O. A., and **V. C. Bleich**. 1985. Optimal foraging in Barn Owls? Rodent frequencies in diet and fauna. Bulletin of the Southern California Academy of Science 84:41-45.

Bowyer, R. T., and **V. C. Bleich**. 1984. Distribution and taxonomic affinities of mule deer, *Odocoileus hemionus*, from Anza-Borrego Desert State Park, California. California Fish and Game 70:53-57.

Bowyer, R. T., and **V. C. Bleich**. 1984. Effects of cattle grazing on selected habitats of southern mule deer. California Fish and Game 70:240-247.

Bleich, V. C., and R. A. Weaver. 1983. "Improved" sand dams for wildlife habitat management. Journal of Range Management 36:130.

Bleich, V. C. 1983. Comments on helicopter use by wildlife agencies. Wildlife Society Bulletin 11:304-306.

Bleich, V. C. 1982. Additional notes on species richness of mammals at Bodie, California. Southwestern Naturalist 27:121-122.

Bleich, V. C., L. J. Coombes, and J. H Davis. 1982. Horizontal wells as a wildlife habitat improvement technique. Wildlife Society Bulletin 10:324-329.

Bleich, V. C. 1982. An illustrated guide to aging the lambs of mountain sheep. Desert Bighorn Council Transactions 26:59-62.

Bleich, V. C., L. J. Coombes, and G. W. Sudmeier. 1982. Volunteers and wildlife habitat management: twelve years together. CAL-NEVA Wildlife Transactions 1982:64-68.

Bleich, V. C. 1982. Horizontal wells for mountain sheep: desert bighorn "Get the shaft". Desert Bighorn Council Transactions 26:63-64.

Bleich, V. C., L. J. Coombes, and G. W. Sudmeier. 1982. Volunteer participation in California wildlife habitat management projects. Desert Bighorn Council Transactions 26:56-58.

Paysen, T. E., J. A. Derby, H. Black, **V. C. Bleich**, and J. W. Mincks. 1980. A vegetation classification system applied to southern California. USDA Forest Service General Technical Report PSW-45:1-33.

Bleich, V. C. 1979. *Microtus californicus scirpensis* not extinct. Journal of Mammalogy 60:851-852.

Bleich, V. C., and B. Blong. 1978. A magnificent frigatebird in San Bernardino County, California. Western Birds 9:129.

Bleich, V. C. 1978. Breeding bird census: annual grassland. American Birds 32:121.

Bleich, V. C. 1977. Dipodomys stephensi. Mammalian Species 73:1-3.

Schwartz, O. A., and **V. C. Bleich**. 1976. The development of thermoregulation in two species of woodrats, *Neotoma lepida* and *Neotoma albigula.* Comparative Biochemistry and Physiology 54A:211-213.

Bleich, V. C. 1975. Roadrunner predation on ground squirrels in California. Auk 92:147-149.

Bleich, V. C., and O. A. Schwartz. 1975. Water balance and fluid consumption in the southern grasshopper mouse, *Onychomys torridus.* Great Basin Naturalist 35:62-64.

Bleich, V. C., and O. A. Schwartz. 1975. Observations on the home range of the desert woodrat, *Neotoma lepida intermedia.* Journal of Mammalogy 56:518-519.

Bleich, V. C. 1975. Diving times and distances in the Pied-billed Grebe. Wilson Bulletin 87:278-280.

Bleich, V. C., and O. A. Schwartz. 1975. Parturition in the white-throated woodrat. Southwestern Naturalist 20:271-272.

Schwartz, O. A., and **V. C. Bleich**. 1975. Comparative growth in two species of woodrats, *Neotoma lepida intermedia* and *Neotoma albigula venusta.* Journal of Mammalogy 56:653-656.

Bleich, V. C. 1974. Muskrats (*Ondatra zibethicus*) in Amargosa Canyon, Inyo and San Bernardino counties, California. Murrelet 55:7-8.

Bleich, V. C. 1974. Abnormal dentition in a grizzly bear. Murrelet 55:11.

Bleich, V. C., and O. A Schwartz. 1974. Interspecific and intergeneric maternal care in woodrats *(Neotoma)*. Mammalia 38:381-387.

Bleich, V. C., and O. A. Schwartz. 1974. Western range extension of Stephens' Kangaroo rat (*Dipodomys stephensi*), a threatened species. California Fish and Game 60:208-210.

Book Chapters and Proceedings of Symposia:

Bleich, V. C., and B. M. Pierce. 2005. [Invited contribution] Management of mountain lions in California. Pages 63-69 *in* E. L. Buckner and J. Reneau, editors. Records of North American big game. 12th edition. Boone and Crockett Club, Missoula, Montana, USA.

Rubin, E. S., and **V. C. Bleich**. 2005. [Invited contribution] Sexual segregation: a necessary consideration in wildlife conservation. Pages 379-391 *in* K. E. Ruckstuhl and P. Neuhaus, editors. Sexual segregation in vertebrates: ecology of the two sexes. Cambridge University Press, Cambridge, United Kingdom.

Bleich, V. C., J. G. Kie, E. R. Loft, T. R. Stephenson, M. W. Oehler, Sr., and A. L. Medina.

2005. [Invited contribution] Managing rangelands for wildlife. Pages 873-897 *in* C. E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Pierce, B. M., and **V. C. Bleich**. 2003. [Invited Contribution] Mountain lion. Pages 744-757 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild Mammals of North America. Second Edition. The Johns Hopkins University Press, Baltimore, Maryland.

Torres, S. G., and **V. C. Bleich**. 1999. [Invited Contribution] Desert bighorn sheep: California. Pages 170-173 *in* D. E. Toweill and V. Geist, editors. Return of royalty: a celebration of success. Boone and Crockett Club, Missoula, Montana.

Bleich, V. C., and S. G. Torres. 1999. [Invited Contribution] California bighorn sheep: California. Pages 130-133 *in* D. E. Toweill and V. Geist, editors. Return of royalty: a celebration of success. Boone and Crockett Club, Missoula, Montana.

Bleich, V. C. 1998. [Invited Contribution] *Microtus californicus* (Peale 1848). Pages 90-92 *in* D. J. Haffner, E. Yensen, and G. L. Kirkland, Jr., editors. North American rodents: status survey and conservation action plan. International Union for the Conservation of Nature, Gland, Switzerland.

Kie, J. G., **V. C. Bleich**, A. L. Medina, J. D. Yoakum, and J. W. Thomas. 1996. [Invited Contribution] Managing rangelands for wildlife. Pages 663-688 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, Maryland.

Bleich, V. C., J. D. Wehausen, R. R. Ramey II, and J. L. Rechel. 1996. [Invited Contribution] Metapopulation theory and mountain sheep: implications for conservation. Pages 353-373 *in* D. R. McCullough, editor. Metapopulations and wildlife conservation. Island Press, Covelo, California.

Bleich, V. C., J. D. Wehausen, and S. A. Holl. 1995. Desert-dwelling mountain sheep: conservation implications of a naturally fragmented distribution. Pages 102-109 *in* D. Ehrenfeld, editor. Readings from Conservation Biology: wildlife and forests. The Sheridan Press, Hanover, Pennsylvania. [Reprinted from Conservation Biology 4:383-390].

Bleich, V. C., J. D. Wehausen, and S. A. Holl. 1995. Desert-dwelling mountain sheep: conservation implications of a naturally fragmented distribution. Pages 71-78 *in* D. Ehrenfeld, editor. Readings from Conservation Biology: the landscape perspective. The Sheridan Press, Hanover, Pennsylvania. [Reprinted from Conservation Biology 4:383-390].

Bleich, V. C. 1992. History of wildlife water developments, Inyo County, California. Pp. 100-106 *in* C. A. Hall, V. Doyle-Jones, and B. Widawski, editors. The history of water: eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. University of California White Mountain Research Station, Bishop.

Bleich, V. C., and D. B. Koch. 1992. [Abstract] Tule elk on private lands: species preservation, habitat protection, or wildlife commercialization? Page 78 *in* R. D. Brown, editor. The biology of deer. Springer-Verlag, New York, New York.

Bleich, V. C., C. D. Hargis, J. A. Keay, and J. D. Wehausen. 1991. Interagency coordination and the restoration of wildlife populations. Pages 277-284 *in* J. Edelbrock and S. Carpenter, editors. Natural areas and Yosemite: prospects for the future. U.S. National Park Service, Denver Service Center, Denver, Colorado.

Bleich, V. C. 1990. [Invited Paper] Horizontal wells for wildlife water development. Pages 51-58 *in* G. K. Tsukamoto and S. J. Stiver, editors. Wildlife water development. Nevada Department of Wildlife, Reno.

Bleich, V. C., and A. M. Pauli. 1990. Mechanical evaluation of artificial watering devices built for mountain sheep in California. Pages 65-72 *in* G. K. Tsukamoto and S. J. Stiver, editors. Wildlife water development. Nevada Department of Wildlife, Reno.

Bleich, V. C. 1990. Affiliations of volunteers participating in California wildlife water development projects. Pages 187-192 *in* G. K. Tsukamoto and S. J. Stiver, editors. Wildlife water development. Nevada Department of Wildlife, Reno.

Bleich, V. C. 1990. Costs of translocating mountain sheep. Pages 67-75 *in* P. R. Krausman and N. S. Smith, editors. Managing wildlife in the southwest. Arizona Chapter of The Wildlife Society, Phoenix.

Bleich, V. C., and S. A. Holl. 1982. [Invited Paper] Management of chaparral habitat for mule deer and mountain sheep in southern California. Pages 247-254 *in* C. E. Conrad and W. C. Oechel, Technical Coordinators. Proceedings of the symposium on the dynamics and management of Mediterranean-type ecosystems. USDA Forest Service, General Technical Report PSW-58.

Bleich, V. C. 1982. [Invited Paper] Review comments. Pages 567-568 *in* C. E. Conrad and W. C. Oechel, Technical Coordinators. Proceedings of the symposium on the dynamics and management of Mediterranean-type ecosystems. USDA Forest Service, General Technical Report PSW-58.

Bowyer, R. T., and **V. C. Bleich**. 1980. Ecological relationships between southern mule deer and California black oak. Pages 292-296 *in* T. R. Plumb, Technical Coordinator. Proceedings of the Symposium on the ecology, management, and utilization of California oaks. USDA Forest Service, General Technical Report PSW-44.

Agency Reports:

Sierra Nevada Bighorn Sheep Recovery Program [**V. C. Bleich**, H. E. Johnson, B. M. Pierce, C. R. Schroeder, T. R. Stephenson, and J. T. Villepique]. 2006. Sierra Nevada bighorn sheep in 2006. Outdoor California 67(2):10-17.

Bleich, V. C. 2005. Sierra Nevada bighorn sheep. Pages 226-227 *in* California Department of Fish and Game (compiler). The status of rare, threatened, and endangered plants and animals of California 2002-2004. California Department of Fish and Game, Sacramento, California, USA.

Bleich, V. C. 2005. Peninsular bighorn sheep. Pages 228-230 in California Department of Fish and Game (compiler). The status of rare, threatened, and endangered plants and animals of California 2002-2004. California Department of Fish and Game, Sacramento, California, USA.

Sierra Nevada Bighorn Sheep Recovery Program [V. C. **Bleich**, B. M. Pierce, T. R. Stephenson, J. T. Villepique, and J. D. Wehausen]. 2004. Sierra Nevada Bighorn Sheep Progress Report 2003. Outdoor California 65(1):4-17.

U.S. Fish and Wildlife Service [C. Benz, V. **Bleich**, W. Boyce, D. Craig, D. Graber, H. Quigley, P. Stine, S. Torres, and J. Wehausen]. 2003. Draft recovery plan for the Sierra Nevada bighorn sheep. U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Fish and Wildlife Service [D. Armentrout, V. **Bleich**, W. Boyce, T. Davis, J. DeForge, D. Freeman, M. Jorgensen, S. Ostermann, E. Rubin, O. Ryder, P. Sorensen, S. Torres, and J. Wehausen]. 2000. Recovery plan for bighorn sheep in the peninsular ranges, California. U.S. Fish and Wildlife Service, Portland, Oregon.

Singer, F., W. Adrian, F. Allendorf, J. Bailey, J. Berger, V. **Bleich**, M. Bogan, P. Brussard, S. Buskirk, N. T. Hobbs, T. Smith, D. Stevens, C. Van Riper III, E. Vyse, and G. White. 1996. Bighorn sheep in the Rocky Mountain region. National Biological Service, Ft. Collins, Colorado. 55 pp.

Gudorf, M., P. Y. Sweanor, F. J. Singer, A. Blankenship, V. **Bleich**, T. Easterly, J. Emmerich, C. Eustace, L. Irby, D. Jaynes, B. Jellison, R. Kissell, J. Lindsay, J. Parks, T. Peters, K. Reid, S. Stewart, and T. Voss. 1996. Bighorn sheep habitat assessment of the greater Bighorn Canyon National Recreation Area. National Park Service and National Biological Service Cooperative Report, Bighorn Canyon National Recreation Area, Lovell, Wyoming. 43 pp.

Gudorf, M., P. Sweanor, F. Singer, V. **Bleich**, J. Cordova, C. Hake, L. Lee, T. Lytle, P. Perrotti, S. Petersburg, and B. Sloan. 1995. Bighorn sheep habitat assessment of the greater Colorado National Monument area. National Park Service and National Biological Service Cooperative Report, Colorado National Monument, Fruita, Colorado. 52 pp.

Holl, S. A., and V. C. **Bleich**. 1983. San Gabriel mountain sheep: biological and management considerations. USDA Forest Service, San Bernardino National Forest, San Bernardino, California. 136 pp.

Bleich, V. C. 1980. Amargosa vole study. California Department of Fish and Game, Nongame Wildlife Investigations Job Final Report W-54-R-10. 8 pp.

Gould, G. I., Jr., and **V. C. Bleich**. 1977. Amargosa vole study: progress report. Nongame Wildlife Investigations Job Progress Report W-54-R-10 California Department of Fish and Game, Sacramento. 4pp.

Bleich, V. C. 1975. Wildlife section including habitat and vegetation types in the Lake Mathews study area. Pages 84-130 *in* A study of the fish and wildlife resources of the Metropolitan Water District property at Lake Mathews with habitat improvement recommendations. California Department of Fish and Game, Long Beach.

Bleich, V. C. 1972. An annotated checklist of the mammals occurring in the Tecopa-Dumont Sand Dunes Study Area. Pages 75-77, appendix *in* M. A. Romero, editor. Amargosa Canyon-Dumont Dunes Proposed Natural Area. House of Impressions, Sun Valley, California.

Bleich, V. C. 1972. Checklist of the terrestrial vertebrates of the Seal Beach Naval Weapons Station, Fallbrook Annex, San Diego County, California. U.S. Navy, WPNSTAFBAINST 11015.2:7-13.

Book Reviews and Obituaries:

Weaver, R. A., and **V. C. Bleich**. 2009. Bonnar Blong. Desert Bighorn Council Transactions.

Bleich, V. C. 1994. Marvin Wood, 1909-1994. Wild Sheep 17(4):8.

Bleich, V. C. 1992. [Review of] Midnight wilderness: journeys in Alaska's Arctic National Wildlife Refuge, by D. S. Miller. California Fish and Game 78:85-86.

Bleich, V. C. 1992. [Review of] Natural history of the White-Inyo Range, eastern California, edited by C. A. Hall, Jr. California Fish and Game 78:84-85.

Bleich, V. C. 1987. James C. Bicket, 1947-1986. Wildlife Society Bulletin 15:477-478.

Bleich, V. C. 1987. J. D. "Don" Landells, 1926-1986. Western Section of The Wildlife Society Transactions 22:iv.

Bleich, V. C. 1987. James C. Bicket, 1947-1986. Western Section of The Wildlife Society Transactions 22:v.

Bleich, V. C. 1979. [Review of] Wild geese, by M. A. Ogilvie. California Fish and Game 66:282-283.

Bleich, V. C. 1977. [Review of] Mammals of the world, by E. P. Walker. California Fish and Game 63:73.

Bleich, V. C. 1975. [Review of] The carnivores, by R. F. Ewer. California Fish and Game

61:255-256.

Popular Articles:

Bleich, V. C. 2009. A brief history of the CDFG bighorn sheep habitat enhancement program. California Wild Sheep, Winter 2009:8-10.

Bleich, V. C. 2009. Some thoughts on "Water dispensaries keep mountain bighorn sheep alive. California Wild Sheep, Fall 2009:28-30.

Bleich, V. C. 2009. Parting shots [letter]. Bighorn (The Official Magazine of the Texas Bighorn Society), Spring 2009:30.

Bleich, V. C. 2009. Implications of fire history for conserving bighorn sheep. Boone and Crockett Club Trophy Points 3 (July 2009). Available at: http://www.boone-crockett.org/news/featured_story.asp?area=news&ID=52

Darby, N., J. Dungan, K. Stewart, **V. Bleich**, and D. Hughson. 2009. Responses of mule deer to experimental manipulation of water sources: preliminary results from the first year. Mojave National Preserve Science Newsletter 1:1-3.

Bleich, V. C., H. E. Johnson, S. A. Holl, L. Konde, S. G. Torres, and P. R. Krausman. 2009. Implications of fire history for conserving bighorn sheep. California Wild Sheep, Summer 2009:29.

Bleich, V. C. 2009. Some thoughts on water development in wilderness. California Wild Sheep, Spring 2009:8-9.

Bleich, V. C. 2008. Mountain sheep in California: some perspectives on the past, and prospects for the future (Part IV). California Wild Sheep, Fall 2008:14-15.

Bleich, V. C. 2008. Mountain sheep in California: some perspectives on the past, and prospects for the future (Part III). California Wild Sheep, Summer 2008:10-11.

Bleich, V. C. 2008. Mountain sheep in California: some perspectives on the past, and prospects for the future (Part II). California Wild Sheep, Spring 2008:12-13.

Bleich, V. C. 2007. Mountain sheep in California: some perspectives on the past and some prospects for the future (Part I). California Wild Sheep, Winter 2007:12-13.

Bleich, V. C. 2007. The Sierra Nevada bighorn sheep recovery program. Conservation Connection 16:11.

Bleich, V. C. 2007. The Sierra Nevada bighorn sheep recovery program. California Wild Sheep, Fall 2007:16-17.

Bleich, V. C., and B. M. Pierce. 2007. Management of mountain lions in California: history, basic biology, and citizen initiatives [part II]. Conservation Connection 15:12. Reprinted with permission from Records of North American Big Game, 12th Edition)

Monteith, K. L., and **V. C. Bleich**. 2007. Mule deer fawn survival in central Sierra Nevada. Outdoor California 6(3):26-29.

Bleich, V. C., and B. M. Pierce. 2007. Management of mountain lions in California: history, basic biology, and citizen initiatives [part II]. California Wild Sheep, Summer 2007:8-9. Reprinted with permission from Records of North American Big Game, 12th Edition)

Bleich, V. C., and B. M. Pierce. 2007. Management of mountain lions in California: history, basic biology, and citizen initiatives [part I]. Conservation Connection 14:18-19. Reprinted with permission from Records of North American Big Game, 12th Edition)

Bleich, V. C., and B. M. Pierce. 2007. Management of mountain lions in California: history, basic biology, and citizen initiatives [part I]. California Wild Sheep, Spring 2007:18-19. Reprinted with permission from Records of North American Big Game, 12th Edition)

Monteith, K. L., and **V. C. Bleich**. Mule deer fawn survival in the central Sierra Nevada. California Deer, Winter 2007:6-8.

Bleich, V. C. 2006. The potential for death at the waterhole. Conservation Connection 12:13. [Reprinted from California Wild Sheep, Fall 2006:8-9].

Monteith, K. L., and **V. C. Bleich**. 2006. Fawn survival: central Sierra Nevada. Mule Deer Foundation Magazine 9:16-18.

Bleich, V. C., and N. G. Andrew. 2006. Bighorn sheep in California: how many are there, and how are they doing? Foundation for North American Wild Sheep Conservation Connection 11:5-6. [Reprinted from California Wild Sheep, Summer 2006:4-5].

Bleich, V. C. 2006. The potential for death at the waterhole. California Wild Sheep, Fall 2006:8-9.

Bleich, V. C., and N. G. Andrew. 2006. Bighorn sheep in California: how many are there, and how are they doing? California Wild Sheep, Summer 2006:4-5.

Bleich, V. C. 2002. Restoring bighorn sheep to the Sierra Nevada: a project of interest to the Boone and Crockett Club. Fair Chase 17(1):22-26.

Bleich, V. C. 2001. Restoring bighorn sheep to the Sierra Nevada: a new challenge for wildlife biologists. Wild Sheep 24(4):47-50,52.

Bleich, V. C. 2001. Summer ranges, winter ranges, and migratory mule deer: putting the parts of a puzzle in place. Outdoor California 62(4):20-23.

Anderson, L. A., and **V. C. Bleich**. 2000. Desert bighorns in California: a success story for wildlife biologists and sheep hunters. Fair Chase 15(4):13-15.

Bleich, V. C., B. M. Pierce, S. G. Torres, and T. Lupo. 2000. Using space age technology to study mountain lion ecology. Outdoor California 61(3):24-25.

Torres, S. G., and **V. C. Bleich**. 2000. Mountain lions — California's elusive predator. Outdoor California 61(3):4-6.

Bleich, V. C., and N. G. Andrew. 2000. Mountain sheep, mule deer, and burros in the brush: flourishing wild burros impact habitats and native big game. Tracks 17:10-12.

Pauli, A. M., and **V. C. Bleich**. 1999. Gambel's quail hunting opportunities abundant within Mojave National Preserve. Pages 8-9,14 *in* A. J. Kenward, editor. Upland Game California. California Department of Fish and Game, Sacramento.

Bleich, V. C. 1999. Desert deer investigation launched. Outdoor California 60(5):13-15.

Bleich, V. C. 1999. [Letter] America's wilderness. National Geographic Magazine 195(3):xv.

Bleich, V. C. 1997. Securing large carnivores. Wildlife Control Technology 4(2):39.

Bleich, V. C. 1996. Assisting researchers can augment your income. Wildlife Control Technology 3(6):4.

Pierce, B. M., and **V. C. Bleich**. 1996. Round Valley deer study. Mule Deer 2(4):10-13.

Bleich, V. C. 1995. California's newest sheep hunting opportunity: the East Chocolate Mountains. Wild Sheep 18(4):19-22.

Pierce, B. M., and **V. C. Bleich**. 1995. California deer management: the Round Valley investigation. California Hunter Magazine 4(4):32-33.

Bleich, V. C., and S. G. Torres. 1995. The "book" rams are still out there. Tracks 12:9.

Bleich, V. C., and S. G. Torres. 1993. History and current status of mountain sheep in California. Wild Sheep 16(4):15-19.

Bleich, V. C. 1993. Sexual segregation in desert-dwelling mountain sheep. Wild Sheep 16(4):13-14.

Bleich, V. C. 1993. Mountain sheep habitat: using a geographic information system. Boone and Crockett Club News Journal 8(4):39-40.

Bleich, V. C. 1992. Round Valley deer facing long comeback trail. Tracks 9:9,15.

Bleich, V. C. 1990. Status of bighorn sheep in California: a brief synopsis. Wild Sheep

13(2):55.

Bleich, V. C. 1988. Distribution and early history of mountain sheep in California. Pages 1-3 *in* B. W. Wilson, editor. California desert bighorn sheep: a guidebook for the hunter. Society for the Conservation of Bighorn sheep, Los Angeles, California.

Bleich, V. C. 1988. Modern management of mountain sheep in California. Pages 4-6 *in* B. W. Wilson, editor. California desert bighorn sheep: a guidebook for the hunter. Society for the Conservation of Bighorn sheep, Los Angeles, California.

Bleich, V. C. 1983. Big game guzzlers and mountain sheep. Outdoor California 44(6):10.

Davis, J. H., and **V. C. Bleich**. 1980. Time-lapse photography: a new focus on wildlife. Outdoor California 41(4):7-9.

Coombes, L. J., and **V. C. Bleich**. 1979. Horizontal wells: the DFG's new slant on water for wildlife. Outdoor California 40(3):10-12.

Presentations at Professional Meetings

From 1972 to the present, I have been an author or coauthor of more than 100 presentations at professional meetings. I was selected to present the keynote address, "Ecology of mountain sheep: Ramifications for disease transmission and population persistence" at the April 2007 Workshop on Respiratory Disease in Mountain Sheep: Knowledge Gaps and Future Research held at the University of California, Davis. Details pertaining to these presentations are available upon request.

Grants and Fellowships

During 1973 - 2007, I competed successfully for and received project-specific funding in the amount of $1,636,247 from internal and external sources. Details of grants and other funding received are available upon request.

Comment Letter 9B

Elizabeth Klebaner
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080-7037

March 15, 2012

Dear Ms. Klebaner,

You have asked me to provide you with the most recent data available regarding the output of the geothermal plant, known as Mammoth Pacific I, located near Mammoth Lakes, California. The reported capacity and generation for this facility for the four most recent years is available through the California Energy Commission's Quarterly Fuel and Energy Report ("QFER") database for generating unit output.[1] The reported capacity and generation data for this facility are locatable by searching for the facility by name under the "Select by Power Plant Name" option. The database was most recently updated on May 25, 2011, per http://energyalmanac.ca.gov/electricity/web_qfer/, and contains annual data through the year 2010. The reported capacity and generation for the above-referenced facility are as follows:

9B-01 1. "Mammoth Pacific 1 – Mammoth Pacific LP" (name as it appears in the CEC QFER database)

This facility is listed in the CEC QFER database with "Plant ID" T0035, located in Mono County, California. The CEC lists monthly and annual output in megawatt hours (MWh) for each of the facility's two 5 Mw units, for each of the years 2001-2010, inclusive. On an annual basis over the last four years for which data is provided (2007-2010), output for unit 1 has ranged from a minimum of 16,384 MWh in 2007 to a maximum of 24,735 MWh in 2009. The output for unit 2 has ranged from a minimum of 16,090 MWh in 2007 to a maximum of 26,485 in 2010. Expressed in capacity factor terms,[2] the annual capacity factor for unit 1 has ranged from 37% to 56%. The annual capacity factor for unit 2 has ranged from 37% to 60%.

On a monthly basis, the highest generation for unit 1 in the 2007-2010 time period was 3,125 gwh in December 2008. This corresponds to an 84 percent capacity factor for that month, well above the four year average of 46 percent, and shows that the unit's annual and multi-year output was indeed well below what it was physically capable of producing on time scales of a month. Similarly, for unit 2, the highest monthly generation in the 2007-2010 time period was 3,141 gwh in December 2009. This also corresponds to an 84 percent capacity factor for that month, well above the four year average of 48 percent for unit 2, and shows that the unit's annual and multi-year output was indeed well below what it was physically capable of producing on time scales of a month.

---

[1] The Commission's QFER database is available online at http://energyalmanac.ca.gov/electricity/web_qfer/Power_Plant_Statistical_Information.php.

[2] The capacity factor is the ratio of actual output to potential output if operated continuously at 100 percent of rated capacity.

9B-01 Cont.

I have attached to this letter a spreadsheet showing the CEC data on which I have relied, and my calculations of various monthly and annual capacity factors and averages.

Sincerely,

David Marcus

David Marcus

Sumary of CEC data regarding capacity and generation of the Mammoth Pacific Geothermal plants in M

QFER #: T0035

Name: Mammoth Pacific 1
Capacity: 10 Mw

	Mwh	Cap. Fac.
2010	48609.2	55.5%
2009	43981.8	50.2%
2008	40861	46.5%
2007	32474	37.1%
Average	165926	47.3%

Unit level data:

MP1, unit 1

	Mwh	Cap. Fac.
2010	22124	50.51%
2009	24734.8	56.47%
2008	18000	40.98%
2007	16384	37.41%
Average	81242.8	46.3%
Max month	3125	84.01%

MP1, unit 2

	Mwh	Cap. Fac.
2010	26485.2	60.47%
2009	19247	43.94%
2008	22861	52.05%
2007	16090	36.74%
Average	84683.2	48.3%
Max month	3141	84.44%

All data from: http://energyalmanac.ca.gov/electricity/web_qfer/Power_Plant_Statistical_Information.ph

RESUME

DAVID I. MARCUS
P.O. Box 1287
Berkeley, CA 94701-1287

March 2012

Employment

Self-employed, March 1981 - Present

Consultant on energy and electricity issues. Clients have included Imperial Irrigation District, the cities of Albuquerque and Boulder, the Rural Electrification Administration (REA), BPA, EPA, the Attorney Generals of California and New Mexico, alternative energy and cogeneration developers, environmental groups, labor unions, other energy consultants, and the Navajo Nation. Projects have included economic analyses of utility resource options and power contracts, utility restructuring, utility bankruptcy, nuclear power plants, non-utility cogeneration plants, and offshore oil and hydroelectric projects. Experienced user of production cost models to evaluate utility economics. Very familiar with western U.S. grid (WSCC) electric resources and transmission systems and their operation and economics. Have also performed EIR/EIS reviews, need analyses of proposed coal, gas and hydro powerplants, transmission lines, and coal mines. Have presented expert testimony before FERC, the California Energy Commission, the Public Utility Commissions of California, New Mexico, and Colorado, the Interstate Commerce Commission, and the U.S. Congress.

Environmental Defense Fund (EDF), October 1983 - April 1985

Economic analyst, employed half time at EDF's Berkeley, CA office. Analyzed nuclear power plant economics and coal plant sulfur emissions in New York state, using ELFIN model. Wrote critique of Federal coal leasing proposals for New Mexico and analysis of southwest U.S. markets for proposed New Mexico coal-fired power plants.

California Energy Commission (CEC), January 1980 - February 1981

Advisor to Commissioner. Wrote "California Electricity Needs," Chapter 1 of Electricity Tomorrow, part of the CEC's 1980 Biennial Report. Testified before California PUC and coauthored CEC staff brief on alternatives to the proposed 2500 megawatt Allen-Warner Valley coal project.

CEC, October 1977 - December 1979

Worked for CEC's Policy and Program Evaluation Office. Analyzed supply-side alternatives to the proposed Sundesert nuclear power plant and the proposed Point Concepcion LNG terminal. Was the CEC's technical expert in PG&E et. al. vs. CEC lawsuit, in which the U.S. Supreme Court ultimately upheld the CEC's authority to regulate nuclear powerplant siting.

Energy and Resources Group, U.C. Berkeley, Summer 1976

Developed a computer program to estimate the number of fatalities in the first month after a major meltdown accident at a nuclear power plant.

Federal Energy Agency (FEA), April- May 1976

Consultant on <u>North Slope Crude. Where To? How?</u>, a study by FEA's San Francisco office on the disposition of Alaskan oil.

Angeles Chapter, Sierra Club, September 1974 - August 1975

Reviewed EIRs and EISs. Chaired EIR Subcommittee of the Conservation Committee of the Angeles Chapter, January - August 1975.

Bechtel Power Corporation (BPC), June 1973 - April 1974

Planning and Scheduling Engineer at BPC's Norwalk, California office. Worked on construction planning for the Vogtle nuclear power plant (in Georgia).

<u>Education</u>

Energy and Resources Group, U.C. Berkeley, 1975 - 1977

M.A. in Energy and Resources. Two year master's degree program, with course work ranging from economics to engineering, law to public policy. Master's thesis on the causes of the 1972-77 boom in the price of yellowcake (uranium ore). Fully supported by scholarship from National Science Foundation.

University of California, San Diego, 1969 - 1973

B.A. in Mathematics. Graduated with honors. Junior year abroad at Trinity College, Dublin, Ireland.

<u>Professional Publications</u>

"Rate Making for Sales of Power to Public Utilities," with Michael D. Yokell, in <u>Public Utilities Fortnightly</u>, August 2, 1984.

Comment Letter 9C

Technical Consultation, Data Analysis and Litigation Support for the Environment

2S03 Eastbluff Dr., Suite 206
Newport Beach, California 9040S
Fax: (949) 717-0069

Matt Hagemann
Tel: (949) 887-9013
Email: mhagemann@swape.com

March 22, 2012

Elizabeth Klebaner
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080-7037

Subject: **Comments on the Proposed Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report**

Dear Ms. Klebaner:

I have reviewed the February 2012 Revised Draft Environmental Impact Report (RDEIR) for the proposed Mammoth Pacific I Replacement Project (Project) to replace an existing geothermal power plant (MP–I) with a new plant (M–1) in the vicinity of Mammoth Lakes, California. The proposed M–1 plant would be capable of generating approximately 18.8 MW of electricity. Both the new and the existing plants would operate over a two year transition period until the new plant is at full generating capacity. Currently, power is being produced from three plants, MP-I, MP-II, and PLES-1. An additional power generating facility, Casa Diablo IV (CD–4), has been proposed for the area and would produce an additional 33 MW of electricity.

9C-01

My review has focused on cumulative impacts to water resources. I have found that the RDEIR fails to adequately evaluate cumulative impacts that could result from the operation of the plant in conjunction with other future projects. Because cumulative impacts were not properly evaluated, they are unmitigated.

The proposed CD-4 facility includes the drilling of up to 14 new production wells over the life of the plant (RDEIR, p. S-17). The RDEIR includes a map (Fig. 40) that shows a total of three existing production wells. Therefore, addition of CD-4 to the Casa Diablo geothermal complex will increase, by more than four times, the number of production wells in the wellfield. With the addition of the 33 MW CD-4 facility, the expansion of the well field is matched by an equally substantial increase in power generation at the Casa Diablo geothermal complex. Section S, Cumulative Effects, provides no analysis of the combined effects of MP-I, MP-II, and PLES-1 and CD-4 on the geothermal aquifer and the discharge to

9C-01 Cont. Hot Creek Headsprings. No analysis is provided to determine if the operation of the wells for M-1 along with the operation of the 16 proposed CD-4 wells will potentially deplete the thermal qualities of the geothermal aquifer and alter the discharge from the Hot Creek Headsprings.

9C-02 Monitoring is in place for the existing three wells to determine impacts to Hot Creek; however, it is my opinion that the monitoring would be inadequate to mitigate the combined impacts from the MP-I, MP-II, PLES-I, CD-4 facilities and the proposed M-1 facility. Because of the greatly expanded area and volume of geothermal fluid extraction, a new monitoring plan is necessary to mitigate the impact on thermal resources from existing and proposed power production activities at the Casa Diablo geothermal complex.

The RDEIR needs to be revised to include an analysis of the impacts on geothermal resources from the operation of all existing and proposed generating facilities at the Casa Diablo complex and to include any measures necessary to mitigate those impacts.

Sincerely,

Matt Hagemann, P.G., C.Hg.

SWAPE Technical Consultation, Data Analysis and Litigation Support for the Environment

2503 Eastbluff Dr., Suite 206
Newport Beach, California 92660
Tel: (949) 887-9013
Fax: (949) 717-0069
Email: mhagemann@swape.com

Matthew F. Hagemann, P.G., C.Hg., QSD, QSP

Geologic and Hydrogeologic Characterization
Industrial Stormwater Compliance
Investigation and Remediation Strategies
Litigation Support and Testifying Expert
CEQA Review

Education:

M.S. Degree, Geology, California State University Los Angeles, Los Angeles, CA, 1984.
B.A. Degree, Geology, Humboldt State University, Arcata, CA, 1982.

Professional Certification:

California Professional Geologist
California Certified Hydrogeologist
Qualified SSWPP Developer and Practitioner

Professional Experience:

Matt has 25 years of experience in environmental policy, assessment and remediation. He spent nine years with the U.S. EPA in the RCRA and Superfund programs and served as EPA's Senior Science Policy Advisor in the Western Regional Office where he identified emerging threats to groundwater from perchlorate and MTBE. While with EPA, Matt also served as a Senior Hydrogeologist in the oversight of the assessment of seven major military facilities undergoing base closure. He led numerous enforcement actions under provisions of the Resource Conservation and Recovery Act (RCRA) while also working with permit holders to improve hydrogeologic characterization and water quality monitoring.

Matt has worked closely with U.S. EPA legal counsel and the technical staff of several states in the application and enforcement of RCRA, Safe Drinking Water Act and Clean Water Act regulations. Matt has trained the technical staff in the States of California, Hawaii, Nevada, Arizona and the Territory of Guam in the conduct of investigations, groundwater fundamentals, and sampling techniques.

Positions Matt has held include:

- Founding Partner, Soil/Water/Air Protection Enterprise (SWAPE) (2003 – present);
- Geology Instructor, Golden West College, 2010 – present;
- Senior Environmental Analyst, Komex H2O Science, Inc (2000 -- 2003);

- Executive Director, Orange Coast Watch (2001 – 2004);
- Senior Science Policy Advisor and Hydrogeologist, U.S. Environmental Protection Agency (1989– 1998);
- Hydrogeologist, National Park Service, Water Resources Division (1998 – 2000);
- Adjunct Faculty Member, San Francisco State University, Department of Geosciences (1993 – 1998);
- Instructor, College of Marin, Department of Science (1990 – 1995);
- Geologist, U.S. Forest Service (1986 – 1998); and
- Geologist, Dames & Moore (1984 – 1986).

Senior Regulatory and Litigation Support Analyst:

With SWAPE, Matt's responsibilities have included:

- Lead analyst and testifying expert in the review of numerous environmental impact reports under CEQA that identify significant issues with regard to hazardous waste, water resources, water quality, air quality, greenhouse gas emissions and geologic hazards.
- Lead analyst and testifying expert in the review of environmental issues in license applications for large solar power plants before the California Energy Commission.
- Stormwater analysis, sampling and best management practice evaluation at industrial facilities.
- Manager of a project to provide technical assistance to a comunity adjacent to a former Naval shipyard under a grant from the U.S. EPA.
- Technical assistance and litigation support for vapor intrusion concerns.
- Manager of a project to evaluate numerous formerly used military sites in the western U.S.
- Manager of a comprehensive evaluation of potential sources of perchlorate contamination in Southern California drinking water wells.
- Manager and designated expert for litigation support under provisions of Proposition 65 in the review of releases of gasoline to sources drinking water at major refineries and hundreds of gas stations throughout California.
- Expert witness on two cases involving MTBE litigation.
- Expert witness and litigation support on the impact of air toxins and hazards at a school.
- Expert witness in litigation at a former plywood plant.

With Komex H2O Science Inc., Matt's duties included the following:

- Senior author of a report on the extent of perchlorate contamination that was used in testimony by the former U.S. EPA Administrator and General Counsel.
- Senior researcher in the development of a comprehensive, electronically interactive chronology of MTBE use, research, and regulation.
- Senior researcher in the development of a comprehensive, electronically interactive chronology of perchlorate use, research, and regulation.
- Senior researcher in a study that estimates nationwide costs for MTBE remediation and drinking water treatment, results of which were published in newspapers nationwide and in testimony against provisions of an energy bill that would limit liability for oil companies.
- Research to support litigation to restore drinking water supplies that have been contaminated by MTBE in California and New York.
- Expert witness testimony in a case of oil production-related contamination in Mississippi.
- Lead author for a multi-volume remedial investigation report for an operating school in Los Angeles that met strict regulatory requirements and rigorous deadlines.

- Development of strategic approaches for cleanup of contaminated sites in consultation with clients and regulators.

Executive Director:

As Executive Director with Orange Coast Watch, Matt led efforts to restore water quality at Orange County beaches from multiple sources of contamination including urban runoff and the discharge of wastewater. In reporting to a Board of Directors that included representatives from leading Orange County universities and businesses, Matt prepared issue papers in the areas of treatment and disinfection of wastewater and control of the dischrge of grease to sewer systems. Matt actively participated in the development of countywide water quality permits for the control of urban runoff and permits for the discharge of wastewater. Matt worked with other nonprofits to protect and restore water quality, including Surfrider, Natural Resources Defense Council and Orange County CoastKeeper as well as with business institutions including the Orange County Business Council.

Hydrogeology:

As a Senior Hydrogeologist with the U.S. Environmental Protection Agency, Matt led investigations to characterize and cleanup closing military bases, including Mare Island Naval Shipyard, Hunters Point Naval Shipyard, Treasure Island Naval Station, Alameda Naval Station, Moffett Field, Mather Army Airfield, and Sacramento Army Depot. Specific activities were as follows:

- Led efforts to model groundwater flow and contaminant transport, ensured adequacy of monitoring networks, and assessed cleanup alternatives for contaminated sediment, soil, and groundwater.
- Initiated a regional program for evaluation of groundwater sampling practices and laboratory analysis at military bases.
- Identified emerging issues, wrote technical guidance, and assisted in policy and regulation development through work on four national U.S. EPA workgroups, including the Superfund Groundwater Technical Forum and the Federal Facilities Forum.

At the request of the State of Hawaii, Matt developed a methodology to determine the vulnerability of groundwater to contamination on the islands of Maui and Oahu. He used analytical models and a GIS to show zones of vulnerability, and the results were adopted and published by the State of Hawaii and County of Maui.

As a hydrogeologist with the EPA Groundwater Protection Section, Matt worked with provisions of the Safe Drinking Water Act and NEPA to prevent drinking water contamination. Specific activities included the following:

- Received an EPA Bronze Medal for his contribution to the development of national guidance for the protection of drinking water.
- Managed the Sole Source Aquifer Program and protected the drinking water of two communities through designation under the Safe Drinking Water Act. He prepared geologic reports, conducted public hearings, and responded to public comments from residents who were very concerned about the impact of designation.

- Reviewed a number of Environmental Impact Statements for planned major developments, including large hazardous and solid waste disposal facilities, mine reclamation, and water transfer.

Matt served as a hydrogeologist with the RCRA Hazardous Waste program. Duties were as follows:

- Supervised the hydrogeologic investigation of hazardous waste sites to determine compliance with Subtitle C requirements.
- Reviewed and wrote "part B" permits for the disposal of hazardous waste.
- Conducted RCRA Corrective Action investigations of waste sites and led inspections that formed the basis for significant enforcement actions that were developed in close coordination with U.S. EPA legal counsel.
- Wrote contract specifications and supervised contractor's investigations of waste sites.

With the National Park Service, Matt directed service-wide investigations of contaminant sources to prevent degradation of water quality, including the following tasks:

- Applied pertinent laws and regulations including CERCLA, RCRA, NEPA, NRDA, and the Clean Water Act to control military, mining, and landfill contaminants.
- Conducted watershed-scale investigations of contaminants at parks, including Yellowstone and Olympic National Park.
- Identified high-levels of perchlorate in soil adjacent to a national park in New Mexico and advised park superintendent on appropriate response actions under CERCLA.
- Served as a Park Service representative on the Interagency Perchlorate Steering Committee, a national workgroup.
- Developed a program to conduct environmental compliance audits of all National Parks while serving on a national workgroup.
- Co-authored two papers on the potential for water contamination from the operation of personal watercraft and snowmobiles, these papers serving as the basis for the development of nation-wide policy on the use of these vehicles in National Parks.
- Contributed to the Federal Multi-Agency Source Water Agreement under the Clean Water Action Plan.

Policy:

Served senior management as the Senior Science Policy Advisor with the U.S. Environmental Protection Agency, Region 9. Activities included the following:

- Advised the Regional Administrator and senior management on emerging issues such as the potential for the gasoline additive MTBE and ammonium perchlorate to contaminate drinking water supplies.
- Shaped EPA's national response to these threats by serving on workgroups and by contributing to guidance, including the Office of Research and Development publication, Oxygenates in Water: Critical Information and Research Needs.
- Improved the technical training of EPA's scientific and engineering staff.
- Earned an EPA Bronze Medal for representing the region's 300 scientists and engineers in negotiations with the Administrator and senior management to better integrate scientific principles into the policy-making process.
- Established national protocol for the peer review of scientific documents.

Geology:

With the U.S. Forest Service, Matt led investigations to determine hillslope stability of areas proposed for timber harvest in the central Oregon Coast Range. Specific activities were as follows:

- Mapped geology in the field, and used aerial photographic interpretation and mathematical models to determine slope stability.
- Coordinated his research with community members who were concerned with natural resource protection.
- Characterized the geology of an aquifer that serves as the sole source of drinking water for the city of Medford, Oregon.

As a consultant with Dames and Moore, Matt led geologic investigations of two contaminated sites (later listed on the Superfund NPL) in the Portland, Oregon, area and a large hazardous waste site in eastern Oregon. Duties included the following:

- Supervised year-long effort for soil and groundwater sampling.
- Conducted aquifer tests.
- Investigated active faults beneath sites proposed for hazardous waste disposal.

Teaching:

From 1990 to 1998, Matt taught at least one course per semester at the community college and university levels:

- At San Francisco State University, held an adjunct faculty position and taught courses in environmental geology, oceanography (lab and lecture), hydrogeology, and groundwater contamination.
- Served as a committee member for graduate and undergraduate students.
- Taught courses in environmental geology and oceanography at the College of Marin.

Matt currently teaches Physical Geology (lecture and lab) to students at Golden West College in Huntington Beach, California.

Invited Testimony, Reports, Papers and Presentations:

Hagemann, M.F., 2008. Disclosure of Hazardous Waste Issues under CEQA. Presentation to the Public Environmental Law Conference, Eugene, Oregon.

Hagemann, M.F., 2008. Disclosure of Hazardous Waste Issues under CEQA. Invited presentation to U.S. EPA Region 9, San Francisco, California.

Hagemann, M.F., 2005. Use of Electronic Databases in Environmental Regulation, Policy Making and Public Participation. Brownfields 2005, Denver, Coloradao.

Hagemann, M.F., 2004. Perchlorate Contamination of the Colorado River and Impacts to Drinking Water in Nevada and the Southwestern U.S. Presentation to a meeting of the American Groundwater Trust, Las Vegas, NV (served on conference organizing committee).

Hagemann, M.F., 2004. Invited testimony to a California Senate committee hearing on air toxins at schools in Southern California, Los Angeles.

Brown, A., Farrow, J., Gray, A. and **Hagemann, M.**, 2004. An Estimate of Costs to Address MTBE Releases from Underground Storage Tanks and the Resulting Impact to Drinking Water Wells. Presentation to the Ground Water and Environmental Law Conference, National Groundwater Association.

Hagemann, M.F., 2004. Perchlorate Contamination of the Colorado River and Impacts to Drinking Water in Arizona and the Southwestern U.S. Presentation to a meeting of the American Groundwater Trust, Phoenix, AZ (served on conference organizing committee).

Hagemann, M.F., 2003. Perchlorate Contamination of the Colorado River and Impacts to Drinking Water in the Southwestern U.S. Invited presentation to a special committee meeting of the National Academy of Sciences, Irvine, CA.

Hagemann, M.F., 2003. Perchlorate Contamination of the Colorado River. Invited presentation to a tribal EPA meeting, Pechanga, CA.

Hagemann, M.F., 2003. Perchlorate Contamination of the Colorado River. Invited presentation to a meeting of tribal repesentatives, Parker, AZ.

Hagemann, M.F., 2003. Impact of Perchlorate on the Colorado River and Associated Drinking Water Supplies. Invited presentation to the Inter-Tribal Meeting, Torres Martinez Tribe.

Hagemann, M.F., 2003. The Emergence of Perchlorate as a Widespread Drinking Water Contaminant. Invited presentation to the U.S. EPA Region 9.

Hagemann, M.F., 2003. A Deductive Approach to the Assessment of Perchlorate Contamination. Invited presentation to the California Assembly Natural Resources Committee.

Hagemann, M.F., 2003. Perchlorate: A Cold War Legacy in Drinking Water. Presentation to a meeting of the National Groundwater Association.

Hagemann, M.F., 2002. From Tank to Tap: A Chronology of MTBE in Groundwater. Presentation to a meeting of the National Groundwater Association.

Hagemann, M.F., 2002. A Chronology of MTBE in Groundwater and an Estimate of Costs to Address Impacts to Groundwater. Presentation to the annual meeting of the Society of Environmental Journalists.

Hagemann, M.F., 2002. An Estimate of the Cost to Address MTBE Contamination in Groundwater (and Who Will Pay). Presentation to a meeting of the National Groundwater Association.

Hagemann, M.F., 2002. An Estimate of Costs to Address MTBE Releases from Underground Storage Tanks and the Resulting Impact to Drinking Water Wells. Presentation to a meeting of the U.S. EPA and State Underground Storage Tank Program managers.

Hagemann, M.F., 2001. From Tank to Tap: A Chronology of MTBE in Groundwater. Unpublished report.

Hagemann, M.F., 2001. Estimated Cleanup Cost for MTBE in Groundwater Used as Drinking Water. Unpublished report.

Hagemann, M.F., 2001. Estimated Costs to Address MTBE Releases from Leaking Underground Storage Tanks. Unpublished report.

Hagemann, M.F., and VanMouwerik, M., 1999. Potential Water Quality Concerns Related to Snowmobile Usage. Water Resources Division, National Park Service, Technical Report.

VanMouwerik, M. and **Hagemann, M.F.** 1999, Water Quality Concerns Related to Personal Watercraft Usage. Water Resources Division, National Park Service, Technical Report.

Hagemann, M.F., 1999, Is Dilution the Solution to Pollution in National Parks? The George Wright Society Biannual Meeting, Asheville, North Carolina.

Hagemann, M.F., 1997, The Potential for MTBE to Contaminate Groundwater. U.S. EPA Superfund Groundwater Technical Forum Annual Meeting, Las Vegas, Nevada.

Hagemann, M.F., and Gill, M., 1996, Impediments to Intrinsic Remediation, Moffett Field Naval Air Station, Conference on Intrinsic Remediation of Chlorinated Hydrocarbons, Salt Lake City.

Hagemann, M.F., Fukunaga, G.L., 1996, The Vulnerability of Groundwater to Anthropogenic Contaminants on the Island of Maui, Hawaii. Hawaii Water Works Association Annual Meeting, Maui, October 1996.

Hagemann, M. F., Fukanaga, G. L., 1996, Ranking Groundwater Vulnerability in Central Oahu, Hawaii. Proceedings, Geographic Information Systems in Environmental Resources Management, Air and Waste Management Association Publication VIP-61.

Hagemann, M.F., 1994. Groundwater Characterization and Cleanup at Closing Military Bases in California. Proceedings, California Groundwater Resources Association Meeting.

Hagemann, M.F. and Sabol, M.A., 1993. Role of the U.S. EPA in the High Plains States Groundwater Recharge Demonstration Program. Proceedings, Sixth Biennial Symposium on the Artificial Recharge of Groundwater.

Hagemann, M.F., 1993. U.S. EPA Policy on the Technical Impracticability of the Cleanup of DNAPL-contaminated Groundwater. California Groundwater Resources Association Meeting.

Hagemann, M.F., 1992. Dense Nonaqueous Phase Liquid Contamination of Groundwater: An Ounce of Prevention... Proceedings, Association of Engineering Geologists Annual Meeting, v. 35.

Other Experience:

Selected as subject matter expert for the California Professional Geologist licensing examination, 2009-2011.

Comment Letter 9D

Clark & Associates
Environmental Consulting, Inc

OFFICE
12405 Venice Blvd
Suite 331
Los Angeles, CA 90066

PHONE
310-907-6165

FAX
310-398-7626

EMAIL
jclark.assoc@gmail.com

March 22, 2012

Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080-7037

Attn: Ms. Elizabeth Klebaner

Subject: **Comment Letter on Proposed Mammoth Pacific MP-1 Plant Replacement Revised Draft Environmental Impact Report (RDEIR)**

Dear Ms. Klebaner:

At the request of Adams Broadwell Joseph and Cardozo (ABJC), Clark and Associates (Clark) has reviewed materials related to the above referenced project, including the Revised Draft Environmental Impact Report (RDEIR) prepared for Mono County. The proponent, Mammoth Pacific, L.P. (MPLP), is proposing to replace an existing geothermal plant with a new geothermal plant. Clark's review of the materials in no way constitutes a validation of the conclusions or materials contained within the plan. If we do not comment on a specific item, this does not constitute acceptance of the item.

Project Description

MPLP operates an existing geothermal development complex northeast of the junction of US Highway 395 and State Route 203, and located about 2.5 miles east of the Town of Mammoth Lakes in Mono County, California[1]. The Casa Diablo geothermal complex includes

[1] 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February 2012.

multiple generating stations including the 14 megawatt (MW) Mammoth Pacific I unit (MP-1), the 15 MW Mammoth Pacific II unit ("MP-II"), and the 15 MW PLES-I unit ("PLES-I") – totaling 44 MW in net generating capacity at the site. MPLP is proposing to replace the existing Mammoth Pacific I (MP-I) geothermal power plant with new plant designated as "M-1."

The existing MP-I plant and the replacement M-1 plant would each be located on a 90-acre parcel of private land owned by MPLP.[2] The replacement M-1 plant would be built approximately 500 feet northeast of the existing MP-I plant. The new M-1 plant and associated structures and equipment would occupy a little more than 3 acres. The existing entrances to the MPLP geothermal complex would provide access to the new M-1 plant site.

The MP-I plant was the first geothermal power plant to be built at the Casa Diablo geothermal complex, commencing operation in 1984.[3] The MP-I plant uses a binary cycle technology (i.e., the use of a secondary motive fluid to extract heat from geothermal fluid to generate electricity). The design capacity of the existing MP-I plant is 14 "net" megawatts (MW). [4] The MP-I plant itself (without surrounding supporting shops, pumps, wells, etc., none of which would be altered by the proposed project) occupies about 2.5 acres.

The design capacity of the M-1 plant would be approximately 18.8 MW (net).[5] According to the Proponent,[6] no new geothermal wells would

---

[2] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

[3] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

[4] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

[5] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012. Pg 2-2

be constructed for the replacement plant; it would use the same geothermal fluid from the existing geothermal wells that currently supply MP-I. According to the RDEIR, the total brine flow for the MPLP complex would not increase beyond what is currently permitted.

The proposed binary technology uses both high and moderate temperature geothermal resources to extract heat energy from geothermal fluid.[7] With this process geothermal fluids are produced from production wells either by artesian flow or by pumping. Once delivered to the power plant, the heat in the geothermal fluid is transferred to the "motive" fluid in multiple stage non-contact heat exchangers. The motive fluid currently used in MP-I is isobutane. Isobutane or methylpropane is a commonly used refrigerant (also known as R-600a). Isobutane is a colorless gas with gasoline-like odor. Isobutane is flammable and there are reports of

9D-01 explosions with the use of isobutene as a refrigerant.

The geothermal heat vaporizes the motive fluid and turns the binary turbine. The vaporized motive fluid exits the turbine and is condensed in an air-cooled condenser system that uses large fans to pull air over the tubes carrying the motive fluid. The condensed motive fluid is then pumped back to the heat exchangers for re-heating and vaporization, completing the closed cycle. The cooled geothermal fluid from the heat exchangers is pumped under pressure to the geothermal injection wells.

The existing MP-I plant uses isobutane as the binary motive fluid. The new M-1 plant would use n-pentane as the binary motive fluid.

9D-02 Pentane is also a flammable gas. Bulk quantities of n-pentane would be stored in pressure vessels and bulk storage containers on the M-1 power plant site.

---

[6] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012. Pg 2-2

[7] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

According to the proponent, a new 12.47 kV substation/switching station would be constructed adjacent to the M-1 plant and would be connected to an existing transmission line on the site via a new interconnection line. All of the proposed new geothermal facilities would be located on the same private parcel on which the existing MP-I plant is located.

During M-1 plant startup operations, the existing MP-I plant would continue to operate until the new M-1 plant becomes commercial, after which time MPLP would close and dismantle the old MP-I plant. According to the RDEIR, the transition period during which both MP-I and M-1 operations would overlap is two years, or until the M-1 plant is commissioned.[8] Thereafter, the MP-I power plant facilities would be removed from the site; plant foundations and above ground pipeline would be removed; and a retention pond on the MP-I site would be removed. The former MP-I site would then be graded and the pad covered with gravel to provide an all weather surface for continuing MPLP operations on the site.

The M-1 replacement plant would operate 24 hours per day, 7 days per week. Plant and well field operations would be integrated via a computer link to the existing power plant control room. The expected life of the proposed M-1 replacement power plant would be a nominal 30 years. The existing MPLP staff would continue to operate the replacement M-1 plant. No new operational staff would be needed for the M-1 plant.

9D-03

Up to 200 people may be temporarily employed during M-1 plant construction.

[8] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012. Pg 2-2

The County has released a Revised DEIR for the proposed project. According to the RDEIR[9], "supplemental environmental information was compiled and analyzed, including:

1. A revised and supplemented construction air emission analysis (see Appendix G);
2. A supplemented emergency generator air emission analysis (see Appendix H); "

This RDEIR was issued prematurely without considering the serious flaws in the Proponent's analysis of the project, and these flaws are replicated in the RDEIR. The flaws include:

1. a failure to document the operational emissions for the existing and proposed projects;
2. a failure to provide technical specifications for the vapor recovery unit (VRU) which proponents claim will reduce ROG emissions;
3. a failure to estimate the impacts from the co-operation of the new and existing plants during the proposed 2 year period for start up of the new plant; and
4. a failure to determine the cumulative impacts from the existing and future projects on air quality in the basin.

9D-04

I. Failure To Document The Operational Emissions For The Existing And Proposed Projects

According to the RDEIR,[10] "after abatement the annual potential fugitive emissions of n-pentane from the Project would be about 37.4 tons annually, based on the estimated daily losses. According to the RDEIR,

---

[9] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

[10] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

9D-04 Cont.

this would represent about a 60 percent decrease in fugitive reactive organic gases (ROG) emissions from the MP-I Project as the aging MP-I plant has fugitive losses of up to 500 pounds per day (91.3 tons per year) of isobutane. The RDEIR does not provide documentation validating the current emission estimates or the claimed reduction in operational emissions in the RDEIR or the RDEIR appendices. The proponents must provide clear documentation of their claims for operational emissions at the site in a revised RDEIR.

II. Failure To Provide Technical Specifications For The Vapor Recovery Unit (VRU) Which Proponents Claim Will Reduce ROG Emissions

9D-05

According to the RDEIR, "the Proponent has estimated that up to 205 pounds per day of fugitive n-pentane emissions would be released to the atmosphere from very tiny leaks of n-pentane through valves, flanges, seals, and other connections. Air leaked into the n-pentane condensers would be captured in the proposed OEC Unit vapor recovery units (VRU). Some n-pentane vapors would be discharged to the atmosphere from the OEC Unit, VRU and from maintenance VRU during OEC Unit maintenance activities."[11]

The RDEIR does not include a description of the VRU in the RDEIR text, and no manufacturer's guarantee or verifiable emission control efficiency information for the VRU is provided in the Appendices to the RDEIR. The proponent's claims regarding reductions in n-pentane emissions cannot be validated. The proponent must provide VRU technical specifications in order to validate any claims for ROG emission reductions in a revised DEIR.

---

[11] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

III. Failure To Estimate The Impacts From Co-Operation Of The New And Existing Plants During The Proposed 2 Year Period For Start Up Of The New Plant

9D-06

The RDEIR's air quality analysis is deficient and does not include an analysis of the co-operation of the new and existing plants during the 2-year period of start up for the proposed M-1 plant. As noted in the DEIR and RDEIR, "*The transition period during which both MP-I and M-1 operations would overlap may be up to a maximum of two years after the M-1 plant is commissioned*"[12] *(emphasis added).* No air quality analysis is presented wherein both plants are operational (per the DEIR[13] and RDEIR[14]). The RDEIR does not include a condition proponent requiring the proponent to limit operations of the two facilities such that there is no net increase in emissions during the period of co-operation. In addition, the RDEIR does not exclude the proponent from extending the period in which both plants are operating together. Unless the proponent is willing to be held to those conditions, estimates of potential air quality emission reductions are meaningless.

9D-07

9D-08

IV. Failure To Determine The Combined Impacts From The Existing And Future Projects On Air Quality In The Basin

Evaluations of proposed projects under the California Environmental Quality Act (CEQA) must consider the broad impacts on

---

[12] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

[13] County of Mono. 2011. Initial Study Mammoth Pacific-1 (MP-1) Replacement Project. February 2011.

[14] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

9D-08 Cont.

air quality for an air basin. According to the RDEIR[15], "the proposed MP–I Replacement Project would be located among the other existing geothermal projects which comprise the Casa Diablo geothermal complex." The proponent[16] claims that the Casa Diablo geothermal complex is not a single project rather a series of independent geothermal power plant projects with separate power purchase agreements, separate agency approvals, and the capability to operate independently. The proponent then states that the projects share a "common control room and other facilities for economy and operational efficiencies." The proponent's description clearly details a single project with multiple inputs.

9D-09

Based upon the proponent's previous analyses of the Casa Diablo geothermal complex, it is clear that the cumulative ROG emissions from the complex exceed the Imperial County Air Pollution Control District's (ICAPCD's) Daily CEQA Significance Threshold of the 55 lbs per day of ROG. According to the RDEIR, the current ROG emissions from the MP-1 plant are 500 lbs per day (91.3 tons/year). The replacement plant, M-1, is assumed to release 205 lbs per day of ROG (37.4 tons per year). Co-operation of the MP-I and M-I plants at 50% capacity could result in the emission of approximately 350 lbs per day of ROG. The cumulative analysis presented in the RDEIR reflects that emissions from M-1, MP-I (combined emissions 350 lbs/day), MP-II, PLES-I and the proposed CD-4 project will total 1,336 lbs of ROG per day (244 tons per year). The combined emissions from existing projects (MP-I at 50% capacity, MP-II, and PLES-1), reasonably foreseeable future projects (CD-4) and the Project (M-1) are significantly higher than the ICAPCD Daily CEQA

[15] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

[16] CAJA. 2012. Mammoth Pacific I Replacement Project Revised Draft Environmental Impact Report, California Clearinghouse Number 2011022020. February, 2012.

9D-09 Cont. Threshold, amounting to 1686 lbds/day. The Project's contribution to combined emissions is significant, accounting for 350 lbs/day of uncontrolled ROG emissions.

9D-10 Following the decommissioning of MP-I and the commissioning of M-1, the cumulative emissions from the Casa Diablo Geothermal Complex would be more than 1,000 lbs per day, well in excess of the ICAPCD's Daily CEQA Significance Threshold of the 55 lbs per day of ROG. The Project's contribution to combined emissions would be significant, accounting for 205 lbs/day of uncontrolled ROG emissions.

A recirculated RDEIR should include a proper cumulative analysis detailing the impacts of all pollutants on a region that is in non-attainment under an applicable federal or state ambient air quality standard.

Conclusion

A revised DEIR should be prepared that addresses the above analytical deficiencies. This concludes my comments.

Sincerely,

James Clark, Ph.D.

James J. J. Clark, Ph.D.

Principal Toxicologist

Toxicology/Exposure Assessment Modeling

Risk Assessment/Analysis/Dispersion Modeling

Clark & Associates
Environmental Consulting, Inc

OFFICE
12405 Venice Blvd.
Suite 331
Los Angeles, CA 90066

PHONE
310-907-6165

FAX
310-398-7626

EMAIL
jclark.assoc@gmail.com

Education:

Ph.D., Environmental Health Science, University of California, 1995

M.S., Environmental Health Science, University of California, 1993

B.S., Biophysical and Biochemical Sciences, University of Houston, 1987

Professional Experience:

Dr. Clark is a well recognized toxicologist, air modeler, and health scientist. He has 20 years of experience in researching the effects of environmental contaminants on human health including environmental fate and transport modeling (SCREEN3, AEROMOD, ISCST3, Johnson-Ettinger Vapor Intrusion Modeling); exposure assessment modeling (partitioning of contaminants in the environment as well as PBPK modeling); conducting and managing human health risk assessments for regulatory compliance and risk-based clean-up levels; and toxicological and medical literature research.

Significant projects performed by Dr. Clark include the following:

LITIGATION SUPPORT

Case: James Harold Caygle, et al, v. Drummond Company, Inc. Circuit Court for the Tenth Judicial Circuit, Jefferson County, Alabama. Civil Action. CV-2009

Client: Environmental Litgation Group, Birmingham, Alabama

Dr. Clark performed an air quality assessment of emissions from a coke factory located in Tarrant, Alabama. The assessment reviewed include a comprehensive review of air quality standards, measured concentrations of pollutants from factory, an inspection of the facility and detailed assessment of the impacts on the community. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Rose Roper V. Nissan North America, et al. Superior Court of the State Of California for the County Of Los Angeles – Central Civil West. Civil Action. NC041739

Client: Rose, Klein, Marias, LLP, Long Beach, California

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to multiple chemicals, including benzene, who later developed a respiratory distress. A review of the individual's medical and occupational history was performed to prepare an exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to respiratory irritants. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: O'Neil V. Sherwin Williams, et al. United States District Court Central District of California

Client: Rose, Klein, Marias, LLP, Long Beach, California

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to petroleum distillates who later developed a bladder cancer. A review of the individual's medical and occupational history was performed to prepare a quantitative exposure assessment. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Summary judgment for defendants.

Case: Moore V., Shell Oil Company, et al. Superior Court of the State Of California for the County Of Los Angeles

Client: Rose, Klein, Marias, LLP, Long Beach, California

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to chemicals while benzene who later developed a leukogenic disease. A review of the individual's medical and occupational history was performed to prepare a quantitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to refined petroleum hydrocarbons. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Raymond Saltonstall V. Fuller O'Brien, KILZ, and Zinsser, et al. United States District Court Central District of California

Client: Rose, Klein, Marias, LLP, Long Beach, California

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to benzene who later developed a leukogenic disease. A review of the individual's medical and occupational history was performed to prepare a quantitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to refined petroleum hydrocarbons. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Richard Boyer and Elizabeth Boyer, husband and wife, V. DESCO Corporation, et al. Circuit Court of Brooke County, West Virginia. Civil Action Number 04-C-7G.

Client: Frankovitch, Anetakis, Colantonio & Simon, Morgantown, West Virginia.

Dr. Clark performed a toxicological assessment of a family exposed to chlorinated solvents released from the defendant's facility into local drinking water supplies. A review of the individual's medical and occupational history was performed to prepare a qualitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to chlorinated solvents. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: JoAnne R. Cook, V. DESCO Corporation, et al. Circuit Court of Brooke County, West Virginia. Civil Action Number 04-C-9R

Client: Frankovitch, Anetakis, Colantonio & Simon, Morgantown, West Virginia.

Dr. Clark performed a toxicological assessment of an individual exposed to chlorinated solvents released from the defendant's facility into local drinking water supplies. A review of the individual's medical and occupational history was performed to prepare a qualitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to chlorinated solvents. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Patrick Allen And Susan Allen, husband and wife, and Andrew Allen, a minor, V. DESCO Corporation, et al. Circuit Court of Brooke County, West Virginia. Civil Action Number 04-C-W

Client: Frankovitch, Anetakis, Colantonio & Simon, Morgantown, West Virginia.

Dr. Clark performed a toxicological assessment of a family exposed to chlorinated solvents released from the defendant's facility into local drinking water supplies. A review of the individual's medical and occupational history was performed to prepare a qualitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to chlorinated solvents. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Michael Fahey, Susan Fahey V. Atlantic Richfield Company, et al. United States District Court Central District of California Civil Action Number CV-06 7109 JCL.

Client: Rose, Klein, Marias, LLP, Long Beach, California

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to refined petroleum hydrocarbons who later developed a leukogenic disease. A review of the individual's medical and occupational history was performed to prepare a qualitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to refined petroleum hydrocarbons. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Settlement in favor of plaintiff.

Case: Constance Acevedo, et al., V. California Spray-Chemical Company, et al., Superior Court of the State Of California, County Of Santa Cruz. Case No. CV 146344

Dr. Clark performed a comprehensive exposure assessment of community members exposed to toxic metals from a former lead arsenate manufacturing facility. The former manufacturing site had undergone a DTSC mandated removal action/remediation for the presence of the toxic metals at the site. Opinions were presented regarding the elevated levels of arsenic and lead (in attic dust and soils) found throughout the community and the potential for harm to the plaintiffs in question.

Case Result: Settlement in favor of defendant.

Case: Michael Nawrocki V. The Coastal Corporation, Kurk Fuel Company, Pautler Oil Service, State of New York Supreme Court, County of Erie, Index Number I2001-11247

Client: Richard G. Berger Attorney At Law, Buffalo, New York

Dr. Clark performed a toxicological assessment of an individual occupationally exposed to refined petroleum hydrocarbons who later developed a leukogenic disease. A review of the individual's medical and occupational history was performed to prepare a qualitative exposure assessment. The exposure assessment was evaluated against the known outcomes in published literature to exposure to refined petroleum hydrocarbons. The results of the assessment and literature have been provided in a declaration to the court.

Case Result: Judgement in favor of defendant.

SELECTED AIR MODELING RESEARCH/PROJECTS

Client – Confidential

Dr. Clark performed a comprehensive evaluation of criteria pollutants, air toxins, and particulate matter emissions from a carbon black production facility to determine the impacts on the surrounding communities. The results of the dispersion model will be used to estimate acute and chronic exposure concentrations to multiple contaminants and will be incorporated into a comprehensive risk evaluation.

Client – Confidential

Dr. Clark performed a comprehensive evaluation of air toxins and particulate matter emissions from a railroad tie manufacturing facility to determine the impacts on the surrounding communities. The results of the dispersion model have been used to estimate acute and chronic exposure concentrations to multiple contaminants and have been incorporated into a comprehensive risk evaluation.

Client – Los Angeles Alliance for a New Economy (LAANE), Los Angeles, California

Dr. Clark is advising the LAANE on air quality issues related to current flight operations at the Los Angeles International Airport (LAX) operated by the Los Angeles World Airport (LAWA) Authority. He is working with the LAANE and LAX staff to develop a comprehensive strategy for meeting local community concerns over emissions from flight operations and to engage federal agencies on the issue of local impacts of community airports.

Client – City of Santa Monica, Santa Monica, California

Dr. Clark is advising the City of Santa Monica on air quality issues related to current flight operations at the facility. He is working with the City staff to develop a comprehensive strategy for meeting local community concerns over emissions from flight operations and to engage federal agencies on the issue of local impacts of community airports.

Client: Omnitrans, San Bernardino, California

Dr. Clark managed a public health survey of three communities near transit fueling facilities in San Bernardino and Montclair California in compliance with California Senate Bill 1927. The survey included an epidemiological survey of the effected communities, emission surveys of local businesses, dispersion modeling to determine potential emission concentrations within the communities, and a comprehensive risk assessment of each community. The results of the study were presented to the Governor as mandated by Senate Bill 1927.

Client: Confidential, San Francisco, California

Summarized cancer types associated with exposure to metals and smoking. Researched the specific types of cancers associated with exposure to metals and smoking. Provided causation analysis of the association between cancer types and exposure for use by non-public health professionals.

Client: Confidential, Minneapolis, Minnesota

Prepared human health risk assessment of workers exposed to VOCs from neighboring petroleum storage/transport facility. Reviewed the systems in place for distribution of petroleum hydrocarbons to identify chemicals of concern (COCs), prepared comprehensive toxicological summaries of COCs, and quantified potential risks from carcinogens and non-carcinogens to receptors at or adjacent to site. This evaluation was used in the support of litigation.

Client – United Kingdom Environmental Agency

Dr. Clark is part of team that performed comprehensive evaluation of soil vapor intrusion of VOCs from former landfill adjacent residences for the United Kingdom's Environment

Agency. The evaluation included collection of liquid and soil vapor samples at site, modeling of vapor migration using the Johnson Ettinger Vapor Intrusion model, and calculation of site-specific health based vapor thresholds for chlorinated solvents, aromatic hydrocarbons, and semi-volatile organic compounds. The evaluation also included a detailed evaluation of the use, chemical characteristics, fate and transport, and toxicology of chemicals of concern (COC). The results of the evaluation have been used as a briefing tool for public health professionals.

EMERGING/PERSISTENT CONTAMINANT RESEARCH/PROJECTS

Client: Ameren Services, St. Louis, Missouri

Managed the preparation of a comprehensive human health risk assessment of workers and residents at or near an NPL site in Missouri. The former operations at the Property included the servicing and repair of electrical transformers, which resulted in soils and groundwater beneath the Property and adjacent land becoming impacted with PCB and chlorinated solvent compounds. The results were submitted to U.S. EPA for evaluation and will be used in the final ROD.

Client: City of Santa Clarita, Santa Clarita, California

Dr. Clark is managing the oversight of the characterization, remediation and development activities of a former 1,000 acre munitions manufacturing facility for the City of Santa Clarita. The site is impacted with a number of contaminants including perchlorate, unexploded ordinance, and volatile organic compounds (VOCs). The site is currently under a number of regulatory consent orders, including an Immanent and Substantial Endangerment Order. Dr. Clark is assisting the impacted municipality with the development of remediation strategies, interaction with the responsible parties and stakeholders, as well as interfacing with the regulatory agency responsible for oversight of the site cleanup.

Client: Confidential, Los Angeles, California

Prepared comprehensive evaluation of perchlorate in environment. Dr. Clark evaluated the production, use, chemical characteristics, fate and transport, toxicology, and remediation of perchlorate. Perchlorates form the basis of solid rocket fuels and have recently been detected in water supplies in the United States. The results of this research were presented to the USEPA, National GroundWater, and ultimately published in a recent book entitled *Perchlorate in the Environment.*

Client – Confidential, Los Angeles, California

Dr. Clark is performing a comprehensive review of the potential for pharmaceuticals and their by-products to impact groundwater and surface water supplies. This evaluation will include a review if available data on the history of pharmaceutical production in the United States; the chemical characteristics of various pharmaceuticals; environmental fate and transport; uptake by xenobiotics; the potential effects of pharmaceuticals on water treatment systems; and the potential threat to public health. The results of the evaluation may be used as a briefing tool for non-public health professionals.

PUBLIC HEALTH/TOXICOLOGY

Client: Brayton Purcell, Novato, California

Dr. Clark performed a toxicological assessment of residents exposed to methyl-tertiary butyl ether (MTBE) from leaking underground storage tanks (LUSTs) adjacent to the subject property. The symptomology of residents and guests of the subject property were evaluated against the known outcomes in published literature to exposure to MTBE. The study found that residents had been exposed to MTBE in their drinking water; that concentrations of MTBE detected at the site were above regulatory guidelines; and, that the symptoms and outcomes expressed by residents and guests were consistent with symptoms and outcomes documented in published literature.

Client: Confidential, San Francisco, California

Identified and analyzed fifty years of epidemiological literature on workplace exposures to heavy metals. This research resulted in a summary of the types of cancer and non-cancer diseases associated with occupational exposure to chromium as well as the mortality and morbidity rates.

Client: Confidential, San Francisco, California

Summarized major public health research in United States. Identified major public health research efforts within United States over last twenty years. Results were used as a briefing tool for non-public health professionals.

Client: Confidential, San Francisco, California

Quantified the potential multi-pathway dose received by humans from a pesticide applied indoors. Part of team that developed exposure model and evaluated exposure concentrations in a comprehensive report on the plausible range of doses received by a specific person. This evaluation was used in the support of litigation.

Client: Covanta Energy, Westwood, California

Evaluated health risk from metals in biosolids applied as soil amendment on agricultural lands. The biosolids were created at a forest waste cogeneration facility using 96% whole tree wood chips and 4 percent green waste. Mass loading calculations were used to estimate Cr(VI) concentrations in agricultural soils based on a maximum loading rate of 40 tons of biomass per acre of agricultural soil. The results of the study were used by the Regulatory agency to determine that the application of biosolids did not constitute a health risk to workers applying the biosolids or to residences near the agricultural lands.

Client – United Kingdom Environmental Agency

Oversaw a comprehensive toxicological evaluation of methyl-*tertiary* butyl ether (M*t*BE) for the United Kingdom's Environment Agency. The evaluation included available data on the production, use, chemical characteristics, fate and transport, toxicology, and remediation of M*t*BE. The results of the evaluation have been used as a briefing tool for public health professionals.

Client – Confidential, Los Angeles, California

Prepared comprehensive evaluation of *tertiary* butyl alcohol (TBA) in municipal drinking water system. TBA is the primary breakdown product of M*t*BE, and is suspected to be the primary cause of M*t*BE toxicity. This evaluation will include available information on the production, use, chemical characteristics, fate and transport in the environment, absorption, distribution, routes of detoxification, metabolites, carcinogenic potential, and remediation of TBA. The results of the evaluation were used as a briefing tool for non-public health professionals.

Client – Confidential, Los Angeles, California

Prepared comprehensive evaluation of methyl *tertiary* butyl ether (MTBE) in municipal drinking water system. MTBE is a chemical added to gasoline to increase the octane rating and to meet Federally mandated emission criteria. The evaluation included available data on the production, use, chemical characteristics, fate and transport, toxicology, and remediation of MTBE. The results of the evaluation have been were used as a briefing tool for non-public health professionals.

Client – Ministry of Environment, Lands & Parks, British Columbia

Dr. Clark assisted in the development of water quality guidelines for methyl tertiary-butyl ether (MTBE) to protect water uses in British Columbia (BC). The water uses to be considered includes freshwater and marine life, wildlife, industrial, and agricultural (e.g., irrigation and livestock watering) water uses. Guidelines from other jurisdictions for the protection of drinking water, recreation and aesthetics were to be identified.

Client: Confidential, Los Angeles, California

Prepared physiologically based pharmacokinetic (PBPK) assessment of lead risk of receptors at middle school built over former industrial facility. This evaluation is being used to determine cleanup goals and will be basis for regulatory closure of site.

Client: Kaiser Venture Incorporated, Fontana, California

Prepared PBPK assessment of lead risk of receptors at a 1,100-acre former steel mill. This evaluation was used as the basis for granting closure of the site by lead regulatory agency.

RISK ASSESSMENTS/REMEDIAL INVESTIGATIONS

Client: Confidential, Atlanta, Georgia

Researched potential exposure and health risks to community members potentially exposed to creosote, polycyclic aromatic hydrocarbons, pentachlorophenol, and dioxin compounds used at a former wood treatment facility. Prepared a comprehensive toxicological summary of the chemicals of concern, including the chemical characteristics, absorption, distribution, and carcinogenic potential. Prepared risk characterization of the carcinogenic and non-carcinogenic chemicals based on the exposure assessment to quantify the potential risk to members of the surrounding community. This evaluation was used to help settle class-action tort.

Client: Confidential, Escondido, California

Prepared comprehensive Preliminary Endangerment Assessment (PEA) of dense non-aqueous liquid phase hydrocarbon (chlorinated solvents) contamination at a former printed circuit board manufacturing facility. This evaluation was used for litigation support and may be used as the basis for reaching closure of the site with the lead regulatory agency.

Client: Confidential, San Francisco, California

Summarized epidemiological evidence for connective tissue and autoimmune diseases for product liability litigation. Identified epidemiological research efforts on the health effects of medical prostheses. This research was used in a meta-analysis of the health effects and as a briefing tool for non-public health professionals.

Client: Confidential, Bogotá, Columbia

Prepared comprehensive evaluation of the potential health risks associated with the redevelopment of a 13.7 hectares plastic manufacturing facility in Bogotá, Colombia The risk assessment was used as the basis for the remedial goals and closure of the site.

Client: Confidential, Los Angeles, California

Prepared comprehensive human health risk assessment of students, staff, and residents potentially exposed to heavy metals (principally cadmium) and VOCs from soil and soil vapor at 12-acre former crude oilfield and municipal landfill. The site is currently used as a middle school housing approximately 3,000 children. The evaluation determined that the site was safe for the current and future uses and was used as the basis for regulatory closure of site.

Client: Confidential, Los Angeles, California

Managed remedial investigation (RI) of heavy metals and volatile organic chemicals (VOCs) for a 15-acre former manufacturing facility. The RI investigation of the site included over 800 different sampling locations and the collection of soil, soil gas, and groundwater samples. The site is currently used as a year round school housing approximately 3,000 children. The Remedial Investigation was performed in a manner that did not interrupt school activities and met the time restrictions placed on the project by the overseeing regulatory agency. The RI Report identified the off-site source of metals that impacted groundwater beneath the site and the sources of VOCs in soil gas and groundwater. The RI included a numerical model of vapor intrusion into the buildings at the site from the vadose zone to determine exposure concentrations and an air dispersion model of VOCs from the proposed soil vapor treatment system. The Feasibility Study for the Site is currently being drafted and may be used as the basis for granting closure of the site by DTSC.

Client: Confidential, Los Angeles, California

Prepared comprehensive human health risk assessment of students, staff, and residents potentially exposed to heavy metals (principally lead), VOCs, SVOCs, and PCBs from soil, soil vapor, and groundwater at 15-acre former manufacturing facility. The site is currently used as a year round school housing approximately 3,000 children. The evaluation determined that the site was safe for the current and future uses and will be basis for regulatory closure of site.

Client: Confidential, Los Angeles, California

Prepared comprehensive evaluation of VOC vapor intrusion into classrooms of middle school that was former 15-acre industrial facility. Using the Johnson-Ettinger Vapor Intrusion model, the evaluation determined acceptable soil gas concentrations at the site that did not pose health threat to students, staff, and residents. This evaluation is being used to determine cleanup goals and will be basis for regulatory closure of site.

Client –Dominguez Energy, Carson, California

Prepared comprehensive evaluation of the potential health risks associated with the redevelopment of 6-acre portion of a 500-acre oil and natural gas production facility in Carson, California. The risk assessment was used as the basis for closure of the site.

Kaiser Ventures Incorporated, Fontana, California

Prepared health risk assessment of semi-volatile organic chemicals and metals for a fifty-year old wastewater treatment facility used at a 1,100-acre former steel mill. This evaluation was used as the basis for granting closure of the site by lead regulatory agency.

ANR Freight - Los Angeles, California

Prepared a comprehensive Preliminary Endangerment Assessment (PEA) of petroleum hydrocarbon and metal contamination of a former freight depot. This evaluation was as the basis for reaching closure of the site with lead regulatory agency.

Kaiser Ventures Incorporated, Fontana, California

Prepared comprehensive health risk assessment of semi-volatile organic chemicals and metals for 23-acre parcel of a 1,100-acre former steel mill. The health risk assessment was used to determine clean up goals and as the basis for granting closure of the site by lead regulatory agency. Air dispersion modeling using ISCST3 was performed to determine downwind exposure point concentrations at sensitive receptors within a 1 kilometer radius of the site. The results of the health risk assessment were presented at a public meeting sponsored by the Department of Toxic Substances Control (DTSC) in the community potentially affected by the site.

Unocal Corporation - Los Angeles, California

Prepared comprehensive assessment of petroleum hydrocarbons and metals for a former petroleum service station located next to sensitive population center (elementary school). The assessment used a probabilistic approach to estimate risks to the community and was used as the basis for granting closure of the site by lead regulatory agency.

Client: Confidential, Los Angeles, California

Managed oversight of remedial investigation most contaminated heavy metal site in California. Lead concentrations in soil excess of 68,000,000 parts per billion (ppb) have been measured at the site. This State Superfund Site was a former hard chrome plating operation that operated for approximately 40-years.

Client: Confidential, San Francisco, California

Coordinator of regional monitoring program to determine background concentrations of metals in air. Acted as liaison with SCAQMD and CARB to perform co-location sampling and comparison of accepted regulatory method with ASTM methodology.

Client: Confidential, San Francisco, California

Analyzed historical air monitoring data for South Coast Air Basin in Southern California and potential health risks related to ambient concentrations of carcinogenic metals and volatile organic compounds. Identified and reviewed the available literature and calculated risks from toxins in South Coast Air Basin.

IT Corporation, North Carolina

Prepared comprehensive evaluation of potential exposure of workers to air-borne VOCs at hazardous waste storage facility under SUPERFUND cleanup decree. Assessment used in developing health based clean-up levels.

Professional Associations

American Public Health Association (APHA)

Association for Environmental Health and Sciences (AEHS)

American Chemical Society (ACS)

California Redevelopment Association (CRA)

International Society of Environmental Forensics (ISEF)

Society of Environmental Toxicology and Chemistry (SETAC)

Publications and Presentations:

Books and Book Chapters

Sullivan, P., **J.J. J. Clark,** F.J. Agardy, and P.E. Rosenfeld. (2007). *Synthetic Toxins In The Food, Water and Air of American Cities*. Elsevier, Inc. Burlington, MA.

Sullivan, P. and **J.J. J. Clark**. 2006. *Choosing Safer Foods, A Guide To Minimizing Synthetic Chemicals In Your Diet.* Elsevier, Inc. Burlington, MA.

Sullivan, P., Agardy, F.J., and **J.J.J. Clark**. 2005. *The Environmental Science of Drinking Water*. Elsevier, Inc. Burlington, MA.

Sullivan, P.J., Agardy, F.J., **Clark, J.J.J.** 2002. *America's Threatened Drinking Water: Hazards and Solutions*. Trafford Publishing, Victoria B.C.

Clark, J.J.J. 2001. "TBA: Chemical Properties, Production & Use, Fate and Transport, Toxicology, Detection in Groundwater, and Regulatory Standards" in *Oxygenates in the Environment.* Art Diaz, Ed.. Oxford University Press: New York.

Clark, J.J.J. 2000. "Toxicology of Perchlorate" in *Perchlorate in the Environment.* Edward Urbansky, Ed. Kluwer/Plenum: New York.

Clark, J.J.J. 1995. Probabilistic Forecasting of Volatile Organic Compound Concentrations At The Soil Surface From Contaminated Groundwater. UMI.

Baker, J.; **Clark, J.J.**; Stanford, J.T. 1994. Ex Situ Remediation of Diesel Contaminated Railroad Sand by Soil Washing. Principles and Practices for Diesel Contaminated Soils, Volume III. P.T. Kostecki, E.J. Calabrese, and C.P.L. Barkan, eds. Amherst Scientific Publishers, Amherst, MA. pp 89-96.

Journal and Proceeding Articles

Tam L. K.., Wu C. D., Clark J. J. and **Rosenfeld, P.E.** (2008) A Statistical Analysis Of Attic Dust And Blood Lipid Concentrations Of Tetrachloro-p-Dibenzodioxin (TCDD) Toxicity Equialency Quotients (TEQ) In Two Populations Near Wood Treatment Facilities. Organohalogen Compounds, Volume 70 (2008) page 002254.

Tam L. K.., Wu C. D., Clark J. J. and **Rosenfeld, P.E.** (2008) Methods For Collect Samples For Assessing Dioxins And Other Environmental Contaminants In Attic Dust: A Review. Organohalogen Compounds, Volume 70 (2008) page 000527

Hensley A.R., Scott, A., Rosenfeld P.E., **Clark, J.J.J.** (2007). "Attic Dust And Human Blood Samples Collected Near A Former Wood Treatment Facility." *Environmental Research.* 105:194-199.

Rosenfeld, P.E., **Clark, J. J.**, Hensley, A.R., and Suffet, I.H. 2007. "The Use Of An Odor Wheel Classification For The Evaluation of Human Health Risk Criteria For Compost Facilities" Water Science & Technology. 55(5): 345-357.

Hensley A.R., Scott, A., Rosenfeld P.E., **Clark, J.J.J.** 2006. "Dioxin Containing Attic Dust And Human Blood Samples Collected Near A Former Wood Treatment Facility." The 26th International Symposium on Halogenated Persistent Organic Pollutants – DIOXIN2006, August 21 – 25, 2006. Radisson SAS Scandinavia Hotel in Oslo Norway.

Rosenfeld, P.E., **Clark, J. J.** and Suffet, I.H. 2005. "The Value Of An Odor Quality Classification Scheme For Compost Facility Evaluations" The U.S. Composting Council's 13th Annual Conference January 23 - 26, 2005, Crowne Plaza Riverwalk, San Antonio, TX.

Rosenfeld, P.E., **Clark, J. J.** and Suffet, I.H. 2004. "The Value Of An Odor Quality Classification Scheme For Urban Odor" WEFTEC 2004. 77th Annual Technical Exhibition & Conference October 2 - 6, 2004, Ernest N. Morial Convention Center, New Orleans, Louisiana.

Clark, J.J.J. 2003. "Manufacturing, Use, Regulation, and Occurrence of a Known Endocrine Disrupting Chemical (EDC), 2,4-Dichlorophnoxyacetic Acid (2,4-D) in California Drinking Water Supplies." National Groundwater Association Southwest Focus Conference: Water Supply and Emerging Contaminants. Minneapolis, MN. March 20, 2003.

Rosenfeld, P. and **J.J.J. Clark**. 2003. "Understanding Historical Use, Chemical Properties, Toxicity, and Regulatory Guidance" National Groundwater Association Southwest Focus Conference: Water Supply and Emerging Contaminants. Phoenix, AZ. February 21, 2003.

Clark, J.J.J., Brown A. 1999. Perchlorate Contamination: Fate in the Environment and Treatment Options. In Situ and On-Site Bioremediation, Fifth International Symposium. San Diego, CA, April, 1999.

Clark, J.J.J. 1998. Health Effects of Perchlorate and the New Reference Dose (RfD). Proceedings From the Groundwater Resource Association Seventh Annual Meeting, Walnut Creek, CA, October 23, 1998.

Browne, T., **Clark, J.J.J.** 1998. Treatment Options For Perchlorate In Drinking Water. Proceedings From the Groundwater Resource Association Seventh Annual Meeting, Walnut Creek, CA, October 23, 1998.

Clark, J.J.J., Brown, A., Rodriguez, R. 1998. The Public Health Implications of MtBE and Perchlorate in Water: Risk Management Decisions for Water Purveyors. Proceedings of the National Ground Water Association, Anaheim, CA, June 3-4, 1998.

Clark J.J.J., Brown, A., Ulrey, A. 1997. Impacts of Perchlorate On Drinking Water In The Western United States. U.S. EPA Symposium on Biological and Chemical Reduction of Chlorate and Perchlorate, Cincinnati, OH, December 5, 1997.

Clark, J.J.J.; Corbett, G.E.; Kerger, B.D.; Finley, B.L.; Paustenbach, D.J. 1996. Dermal Uptake of Hexavalent Chromium In Human Volunteers: Measures of Systemic Uptake From Immersion in Water At 22 PPM. Toxicologist. 30(1):14.

Dodge, D.G.; **Clark, J.J.J.**; Kerger, B.D.; Richter, R.O.; Finley, B.L.; Paustenbach, D.J. 1996. Assessment of Airborne Hexavalent Chromium In The Home Following Use of Contaminated Tapwater. Toxicologist. 30(1):117-118.

Paulo, M.T.; Gong, H., Jr.; **Clark, J.J.J.** (1992). Effects of Pretreatment with Ipratroprium Bromide in COPD Patients Exposed to Ozone. American Review of Respiratory Disease. 145(4):A96.

Harber, P.H.; Gong, H., Jr.; Lachenbruch, A.; **Clark, J.**; Hsu, P. (1992). Respiratory Pattern Effect of Acute Sulfur Dioxide Exposure in Asthmatics. American Review of Respiratory Disease. 145(4):A88.

McManus, M.S.; Gong, H., Jr.; Clements, P.; **Clark, J.J.J.** (1991). Respiratory Response of Patients With Interstitial Lung Disease To Inhaled Ozone. American Review of Respiratory Disease. 143(4):A91.

Gong, H., Jr.; Simmons, M.S.; McManus, M.S.; Tashkin, D.P.; Clark, V.A.; Detels, R.; **Clark, J.J.** (1990). Relationship Between Responses to Chronic Oxidant and Acute

Ozone Exposures in Residents of Los Angeles County. American Review of Respiratory Disease. 141(4):A70.

Tierney, D.F. and **J.J.J. Clark.** (1990). Lung Polyamine Content Can Be Increased By Spermidine Infusions Into Hyperoxic Rats. American Review of Respiratory Disease. 139(4):A41.

EXHIBIT E

10-K 1 d261816d10k.htm FORM 10-K

Table of Contents

UNITED STATES SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549

Form 10-K

☑ **ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934**

For the fiscal year ended December 31, 2011

or

☐ **TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934**

Commission file number: 001-32347

ORMAT TECHNOLOGIES, INC.

(Exact name of registrant as specified in its charter)

DELAWARE	**88-0326081**
(State or other jurisdiction of incorporation or organization)	*(I.R.S. Employer Identification Number)*

6225 Neil Road, Reno, Nevada 89511-1136
(Address of principal executive offices)

Registrant's telephone number, including area code:
(775) 356-9029

Securities Registered Pursuant to Section 12(b) of the Act:

Title of Each Class	Name of Each Exchange on Which Registered
Ormat Technologies, Inc. Common Stock $0.001 Par Value	New York Stock Exchange

Securities Registered Pursuant to Section 12(g) of the Act:
None

Indicate by check mark if the registrant is a well-known seasoned issuer, as defined in Rule 405 of the Securities Act. Yes ☐ No ☑

Indicate by check mark if the registrant is not required to file reports pursuant to Section 13 or Section 15(d) of the Exchange Act. Yes ☐ No ☑

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days. Yes ☑ No ☐

Indicate by check mark whether the registrant has submitted electronically and posted on its corporate Web site, if any, every Interactive Data File required to be submitted and posted pursuant to Rule 405 of Regulation S-T (§ 232.405 of this chapter) during the preceding 12 months (or for such shorter period that the registrant was required to submit and post such files). Yes ☑ No ☐

Indicate by check mark if disclosure of delinquent filers pursuant to Item 405 of Regulation S-K is not contained herein, and will not be contained, to the best of registrant's knowledge, in definitive proxy or information statements incorporated by reference in Part III of this Form 10-K or any amendment to this Form 10-K. ☐

Indicate by check mark whether the registrant is a large accelerated filer, an accelerated filer, a non-accelerated filer, or a smaller reporting company. See the definitions of "large accelerated filer," "accelerated filer" and "smaller reporting company" in Rule 12b-2 of the Exchange Act. (Check one):

Large accelerated filer	Accelerated filer	Non-accelerated filer	Smaller reporting company
☐	☑	☐ (Do not check if a smaller reporting company)	☐

Indicate by check mark whether the registrant is a shell company (as defined in Rule 12b-2 of the Exchange Act). Yes ☐ No ☑

As of June 30, 2011, the last business day of the registrant's most recently completed second fiscal quarter, the aggregate market value of the registrant's common stock held by non-affiliates of the registrant was $401,116,975 based on the closing price as reported on the New York Stock Exchange.

The number of outstanding shares of common stock of the registrant, as of February 24, 2012, was 45,430,886.

Documents Incorporated by Reference: Part III (Items 10, 11, 12, 13 and 14) incorporates by reference portions of the Registrant's Proxy Statement for its Annual Meeting of Stockholders, which will be filed not later than 120 days after December 31, 2011.

Table of Contents

ORMAT TECHNOLOGIES, INC.

FORM 10-K FOR THE YEAR ENDED DECEMBER 31, 2011

TABLE OF CONTENTS

Table of Contents

Glossary of Terms

When the following terms and abbreviations appear in the text of this report, they have the meanings indicated below:

Term	Definition
Amatitlan Loan	Initial $42,000,000 in aggregate principal amount borrowed by our subsidiary Ortitlan from TCW Global Project Fund II, Ltd.
AMM	Administrador del Mercado Mayorista (administrator of the wholesale market — Guatemala)
ARRA	American Recovery and Reinvestment Act of 2009
Auxiliary Power	The power needed to operate a geothermal power plant's auxiliary equipment such as pumps and cooling towers
Availability	The ratio of the time a power plant is ready to be in service, or is in service, to the total time interval under consideration, expressed as a percentage, independent of fuel supply (heat or geothermal) or transmission accessibility
Balance of Plant equipment	Power plant equipment other than the generating units including items such as transformers, valves, interconnection equipment, cooling towers for water cooled power plants, etc.
BLM	Bureau of Land Management of the U.S. Department of the Interior
BOT	Build, operate and transfer
Capacity	The maximum load that a power plant can carry under existing conditions, less auxiliary power
Capacity Factor	The ratio of the average load on a generating resource to its generating capacity during a specified period of time, expressed as a percentage
CARB	California Air Resources Board
CDC	Commonwealth Development Corporation
CGC	Crump Geothermal Company LLC
CNE	National Energy Commission of Nicaragua
CNEE	National Electric Energy Commission of Guatemala
COD	Commercial Operation Date
Company	Ormat Technologies, Inc., a Delaware corporation, and its consolidated subsidiaries
COSO	Committee of Sponsoring Organizations of the Treadway Commission
CPI	Consumer Price Index

CPUC	California Public Utilities Commission
DEG	Deutsche Investitions-und Entwicklungsgesellschaft mbH
DFIs	Development Finance Institutions
DISNORTE	Empresa Distribudora de Electricidad del Norte (a Nicaragua distribution company)

Table of Contents

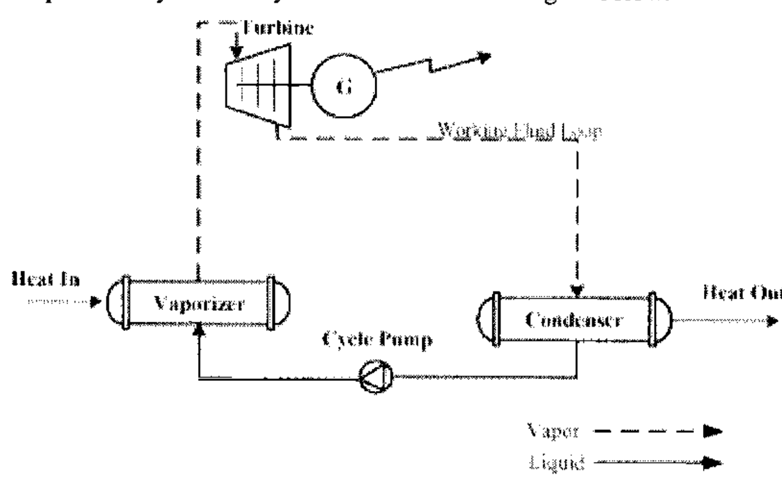
Term	Definition
DISSUR	Empresa Distribudora de Electricidad del Sur (a Nicaragua distribution company)
DOE	U.S. Department of Energy
DOGGR	California Division of Oil, Gas, and Geothermal Resources
DSCR	Debt Service Coverage Ratio
EBITDA	Earnings before interest, taxes, depreciation and amortization
EGS	Enhanced Geothermal Systems
EIS	Environmental Impact Statement
ENATREL	Empresa Nicaraguense de Transmision
ENEL	Empresa Nicaraguense de Electricitdad
Enthalpy	The total energy control of a fluid; the heat plus the mechanical energy content of a fluid (such as a geothermal brine), which, for example, can be partially converted to mechanical energy in an Organic Rankine Cycle.
EPA	U.S. Environmental Protection Agency
EPC	Engineering, procurement and construction
EPS	Earnings per share
ERC	Kenyan Energy Regulatory Commission
ESC	Energy Sales Contract
Exchange Act	U.S. Securities Exchange Act of 1934, as amended
FASB	Financial Accounting Standards Board
FERC	U.S. Federal Energy Regulatory Commission
Flip Date	Date on which the holders of Class B membership units in OPC achieve a target after-tax yield on their investment in OPC.
FPA	U.S. Federal Power Act, as amended
GAAP	Generally accepted accounting principles
GDC	Geothermal Development Company
GDL	Geothermal Development Limited
Geothermal Power Plant	The power generation facility and the geothermal field
Geothermal Steam Act	U.S. Geothermal Steam Act of 1970, as amended
GHG	Greenhouse gas
GNP	Gross National Product

HELCO	Hawaii Electric Light Company
IFC	International Finance Corporation
IID	Imperial Irrigation District
ILA	Israel Land Administration

Term	Definition
INDE	Instituto Nacional de Electrification
INE	Nicaragua Institute of Energy
IPPs	Independent Power Producers
ISO	International Organization for Standardization
ITC	Investment tax credit
ITC Cash Grant	Payment for Specified Renewable Energy property in lieu of Tax Credits under Section 1603 of the ARRA
John Hancock	John Hancock Life Insurance Company (U.S.A.)
KenGen	Kenya Electricity Generating Company Ltd.
Kenyan Energy Act	Kenyan Energy Act, 2006
KETRACO	Kenya Electricity Transmission Company Limited
KLP	Kapoho Land Partnership
kVa	Kilovolt-ampere
KPLC	Kenya Power and Lighting Co. Ltd.
kW	Kilowatt — A unit of electrical power that is equal to 1,000 watts
kWh	Kilowatt hour(s), a measure of power produced
LNG	Liquefied natural gas
Mammoth Pacific	Mammoth-Pacific, L.P.
MACRS	Modified Accelerated Cost Recovery System
MW	Megawatt — One MW is equal to 1,000 kW or one million watts
MWh	Megawatt hour(s), a measure of power produced
NBPL	Northern Border Pipe Line Company
NIS	New Israeli Shekel
NGP	Nevada Geothermal Power Inc.
NV Energy	NV Energy, Inc.
NYSE	New York Stock Exchange
OEC	Ormat Energy Converter
OFC	Ormat Funding Corp., a wholly owned subsidiary of the Company
OFC Senior Secured Notes	8.25% Senior Secured Notes Due 2020 issued by OFC
OFC 2	OFC 2 LLC, a wholly owned subsidiary of the Company
OFC 2 Senior Secured Notes	Senior Secured Notes Due 2034 issued by OFC 2

Olkaria Loan	Initial $105,000,000 in aggregate principal amount borrowed by OrPower 4 from a group of European DFIs
OMPC	Ormat Momotombo Power Company, a wholly owned subsidiary of the Company
OPIC	Overseas Private Investment Corporation

Term	Definition
OPC	OPC LLC, a consolidated subsidiary of the Company
OPC Transaction	Financing transaction involving four of our Nevada power plants in which institutional equity investors purchased an interest in our special purpose subsidiary that owns such plants.
OrCal	OrCal Geothermal Inc., a wholly owned subsidiary of the Company
OrCal Senior Secured Notes	6.21% Senior Secured Notes Due 2020 issued by OrCal
Organic Rankine Cycle	A process in which an organic fluid such as a hydrocarbon or fluorocarbon (but not water) is boiled in an evaporator to generate high pressure vapor. The vapor powers a turbine to generate mechanical power. After the expansion in the turbine, the low pressure vapor is cooled and condensed back to liquid in a condenser. A cycle pump is then used to pump the liquid back to the vaporizer to complete the cycle. The cycle is illustrated in the figure below:



Ormat International	Ormat International Inc., a wholly owned subsidiary of the Company
Ormat Nevada	Ormat Nevada Inc., a wholly owned subsidiary of the Company
Ormat Systems	Ormat Systems Ltd., a wholly owned subsidiary of the Company
OrPower 4	OrPower 4 Inc., a wholly owned subsidiary of the Company
Ortitlan	Ortitlan Limitada, a wholly owned subsidiary of the Company
Orzunil	Orzunil I de Electricidad, Limitada, a wholly owned subsidiary of the Company
Parent	Ormat Industries Ltd.
PGV	Puna Geothermal Venture, a wholly owned subsidiary of the Company

PLN	PT Perusahaan Listrik Negara
Power plant equipment	Interconnection equipment, cooling towers for water cooled power plant, etc.
PPA	Power purchase agreement
ppm	Part per million

Term	Definition
PTC	Production tax credit
PUA	Israeli Public Utility Authority
PUCH	Public Utilities Commission of Hawaii
PUCN	Public Utilities Commission of Nevada
PUHCA	U.S. Public Utility Holding Company Act of 1935
PUHCA 2005	U.S. Public Utility Holding Company Act of 2005
PURPA	U.S. Public Utility Regulatory Policies Act of 1978
Qualifying Facility(ies)	Certain small power production facilities are eligible to be "Qualifying Facilities" under PURPA, provided that they meet certain power and thermal energy production requirements and efficiency standards. Qualifying Facility status provides an exemption from PUHCA 2005 and grants certain other benefits to the Qualifying Facility.
REC	Renewable Energy Credit
REG	Recovered Energy Generation
RGGI	Regional Greenhouse Gas Initiative
RPM	Revolutions Per Minute
RPS	Renewable Portfolio Standards
SCPPA	Southern California Public Power Authority
SEC	U.S. Securities and Exchange Commission
Senior Unsecured Bonds	7% Senior Unsecured Bonds Due 2017 issued by the Company
Securities Act	U.S. Securities Act of 1933, as amended
SOX Act	Sarbanes-Oxley Act of 2002
Solar PV	Solar photovoltaic
Southern California Edison	Southern California Edison Company
SPE(s)	Special purpose entity(ies)
SRAC	Short Run Avoided Costs
Sunday Energy	Sunday Energy Ltd.
TGL	Tikitere Geothermal Power Limited
Union Bank	Union Bank, N.A.
U.S.	United States of America
U.S. Treasury	U.S. Department of the Treasury
W&M	Watts & More Ltd.

Table of Contents

Cautionary Note Regarding Forward-Looking Statements

This annual report includes "forward-looking statements" within the meaning of the Private Securities Litigation Reform Act of 1995. All statements, other than statements of historical facts, included in this report that address activities, events or developments that we expect or anticipate will or may occur in the future, including such matters as our projections of annual revenues, expenses and debt service coverage with respect to our debt securities, future capital expenditures, business strategy, competitive strengths, goals, development or operation of generation assets, market and industry developments and the growth of our business and operations, are forward-looking statements. When used in this annual report, the words "may", "will", "could", "should", "expects", "plans", "anticipates", "believes", "estimates", "predicts", "projects", "potential", or "contemplate" or the negative of these terms or other comparable terminology are intended to identify forward-looking statements, although not all forward-looking statements contain such words or expressions. The forward-looking statements in this report are primarily located in the material set forth under the headings Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" contained in Part II, Item 1A — "Risk Factors" contained in Part I, and "Notes to Financial Statements" contained in Part II, Item 8 — "Financial Statements and Supplementary Data" contained in Part II of this annual report, but are found in other locations as well. These forward-looking statements generally relate to our plans, objectives and expectations for future operations and are based upon management's current estimates and projections of future results or trends. Although we believe that our plans and objectives reflected in or suggested by these forward-looking statements are reasonable, we may not achieve these plans or objectives. You should read this annual report completely and with the understanding that actual future results and developments may be materially different from what we expect due to a number of risks and uncertainties, many of which are beyond our control. We will not update forward-looking statements even though our situation may change in the future.

Specific factors that might cause actual results to differ from our expectations include, but are not limited to:

- significant considerations, risks and uncertainties discussed in this annual report;
- operating risks, including equipment failures and the amounts and timing of revenues and expenses;
- geothermal resource risk (such as the heat content of the reservoir, useful life and geological formation);
- financial market conditions and the results of financing efforts;
- the impact of fluctuations in natural gas prices on the energy price component under certain of our PPAs;
- environmental constraints on operations and environmental liabilities arising out of past or present operations, including the risk that we may not have, and in the future may be unable to procure, any necessary permits or other environmental authorizations;
- construction or other project delays or cancellations;
- political, legal, regulatory, governmental, administrative and economic conditions and developments in the United States and other countries in which we operate;
- the enforceability of the long-term PPAs for our power plants;
- contract counterparty risk;
- weather and other natural phenomena;
- the impact of recent and future federal, state and local regulatory proceedings and changes, including legislative and regulatory initiatives regarding deregulation and restructuring of the electric utility industry incentives for the production of renewable energy at the federal and state level in the United States and elsewhere, and carbon-related legislation;
- changes in environmental and other laws and regulations to which our company is subject, as well as changes in the application of existing laws and regulations;

- current and future litigation;

- our ability to successfully identify, integrate and complete acquisitions;
- competition from other similar geothermal energy projects, including any such new geothermal energy projects developed in the future, and from alternative electricity producing technologies;
- the effect of and changes in economic conditions in the areas in which we operate;
- market or business conditions and fluctuations in demand for energy or capacity in the markets in which we operate;
- the direct or indirect impact on our company's business resulting from the threat or occurrence of terrorist incidents or cyber-attacks or responses to such threatened or actual incidents or attacks, including the effect on the availability of and premiums on insurance;
- the effect of and changes in current and future land use and zoning regulations, residential, commercial and industrial development and urbanization in the areas in which we operate;
- other uncertainties which are difficult to predict or beyond our control and the risk that we may incorrectly analyze these risks and forces or that the strategies we develop to address them may be unsuccessful; and
- development and construction of the Solar PV projects may not materialize as planned.

PART I

ITEM 1. *BUSINESS*

Certain Definitions

Unless the context otherwise requires, all references in this annual report to "Ormat", "the Company", "we", "us", "our company", "Ormat Technologies", or "our" refer to Ormat Technologies, Inc. and its consolidated subsidiaries. A glossary of certain terms and abbreviations used in this annual report appears at the beginning of this report.

Overview

We are a leading vertically integrated company primarily engaged in the geothermal and recovered energy power business. We design, develop, build, own, and operate clean, environmentally friendly geothermal and recovered energy-based power plants, usually using equipment that we design and manufacture. Our geothermal power plants include both power plants that we have built and power plants that we have acquired, while all of our recovered energy-based plants have been constructed by us. We conduct our business activities in two business segments, which we refer to as our Electricity Segment and Product Segment. In our Electricity Segment, we develop, build, own and operate geothermal and recovered energy-based power plants in the United States and geothermal power plants in other countries around the world and sell the electricity they generate. We have expanded our activities in the Electricity Segment to include the ownership and operation of power plants that produce electricity generated by Solar PV systems that we do not manufacture. In our Product Segment, we design, manufacture and sell equipment for geothermal and recovered energy-based electricity generation, remote power units and other power generating units and provide services relating to the engineering, procurement, construction, operation and maintenance of geothermal and recovered energy-based power plants.

The map below shows our current worldwide portfolio of operating geothermal power plants and recovered energy plants, as well as the geothermal and recovered energy-based power plants and a Solar PV power plant that are under construction, and countries with projects under development and exploration.

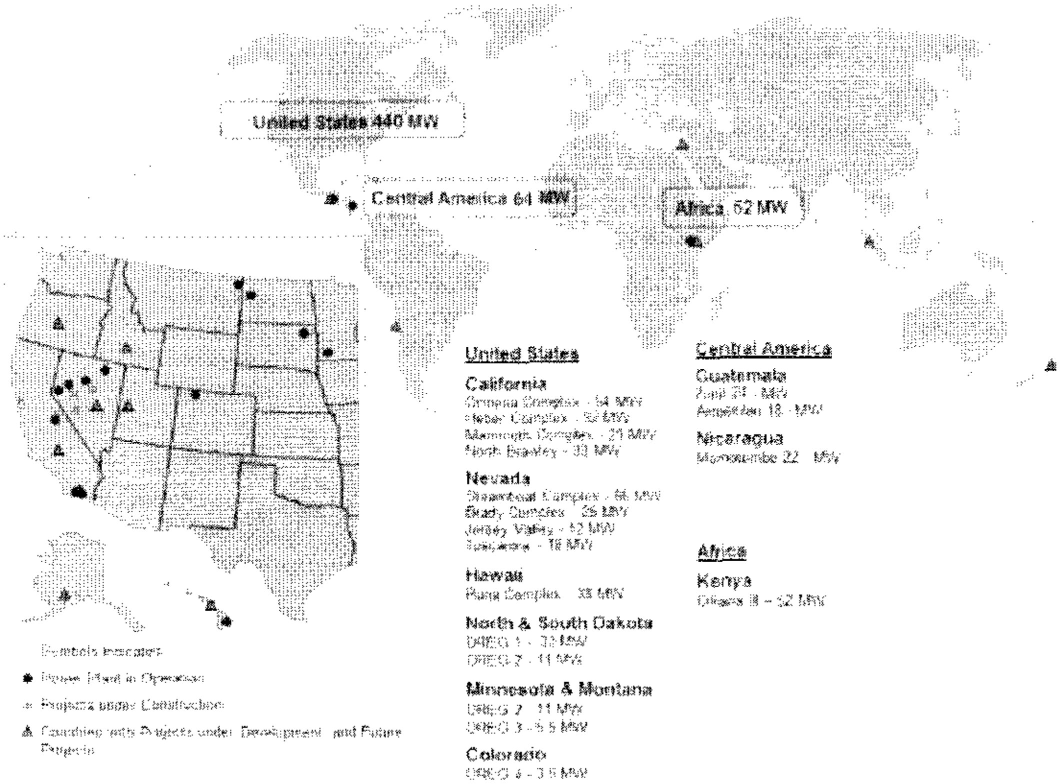
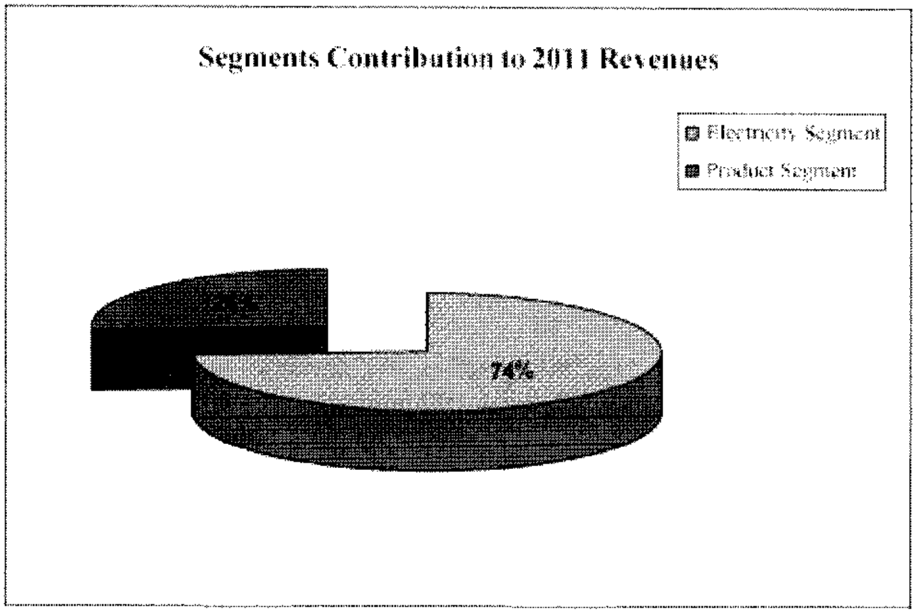


Table of Contents

The charts below show the relative contributions of the Electricity Segment and the Product Segment to our consolidated revenues and the geographical breakdown of our segment revenues for our fiscal year ended December 31, 2011. Additional information concerning our segment operations, including year-to-year comparisons of revenues, the geographical breakdown of revenues, cost of revenues, results of operations, and trends and uncertainties is provided below in Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" and Item 8 — "Financial Statements and Supplementary Data".

The following chart sets forth a breakdown of revenues for the year ended December 31, 2011:



The following chart sets forth the geographical breakdown of the revenues attributable to our Electricity Segment for the year ended December 31, 2011:

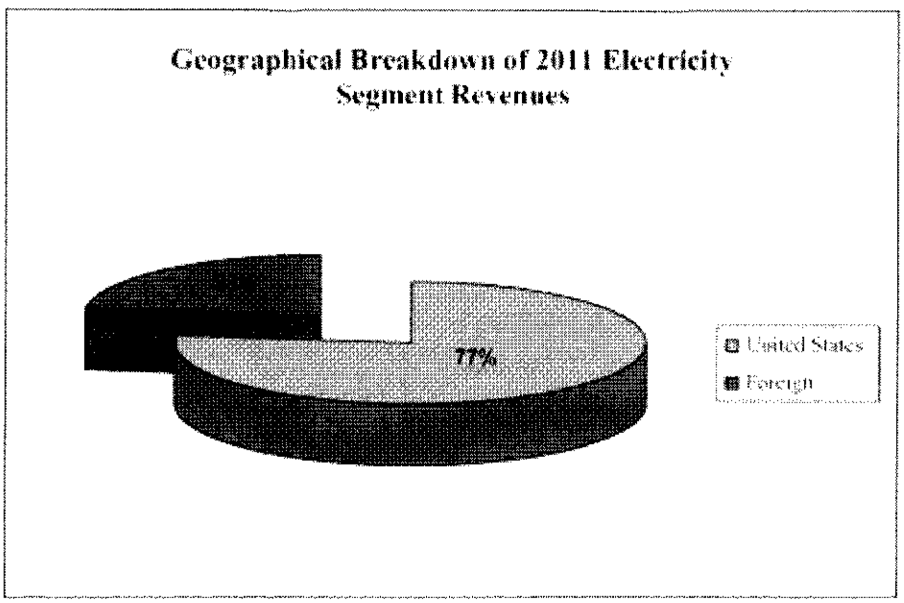


Table of Contents

All of our revenues attributable to our Product Segment for the year ended December 31, 2011 were from foreign operations.

Most of the power plants that we currently own or operate produce electricity from geothermal energy sources. Geothermal energy is a clean, renewable and generally sustainable form of energy derived from the natural heat of the earth. Unlike electricity produced by burning fossil fuels, electricity produced from geothermal energy sources is produced without emissions of certain pollutants such as nitrogen oxide, and with far lower emissions of other pollutants such as carbon dioxide. Therefore, electricity produced from geothermal energy sources contributes significantly less to local and regional incidences of acid rain and global warming than energy produced by burning fossil fuels. Geothermal energy is also an attractive alternative to other sources of energy as part of a national diversification strategy to avoid dependence on any one energy source or politically sensitive supply sources.

In addition to our geothermal energy business, we manufacture products that produce electricity from recovered energy or so-called "waste heat". We also construct, own, and operate recovered energy-based power plants. Recovered energy represents residual heat that is generated as a by-product of gas turbine-driven compressor stations, solar thermal units and a variety of industrial processes, such as cement manufacturing. Such residual heat, which would otherwise be wasted, may be captured in the recovery process and used by recovered energy power plants to generate electricity without burning additional fuel and without additional emissions.

We have expanded our activity to the Solar PV industry. We are constructing a new utility-scale Solar PV project near our Heber complex in California and we are developing other Solar PV projects in Israel.

Company Contact and Sources of Information

We file annual, quarterly and periodic reports, proxy statements and other information with the SEC. You may obtain and copy any document we file with the SEC at the SEC's Public Reference Room at 100 F Street, N.E., Room 1580, Washington D.C. 20549. You may obtain information on the operation of the SEC's Public Reference Room by calling the SEC at 1-800-SEC-0330. The SEC maintains an internet website at http://www.sec.gov that contains reports, proxy and other information statements, and other information regarding issuers that file electronically with the SEC. Our SEC filings are accessible via the internet at that website.

Our reports on Form 10-K, 10-Q and 8-K, and amendments to those reports filed or furnished pursuant to Section 13(a) or 15(d) of the Exchange Act are available through our website at www.ormat.com for downloading, free of charge, as soon as reasonably practicable after these reports are filed with the SEC. Our Code of Business Conduct and Ethics, Code of Ethics Applicable to Senior Executives, Audit Committee Charter, Corporate Governance Guidelines, Nominating and Corporate Governance Committee Charter, Compensation Committee Charter, and Insider Trading Policy, as amended, are also available at our website address mentioned above. If we make any amendments to our Code of Business Conduct and Ethics or Code of Ethics Applicable to Senior Executives or grant any waiver, including any implicit waiver, from a provision of either code applicable to our Chief Executive Officer, Chief Financial Officer or principal accounting officer requiring disclosure under applicable SEC rules, we intend to disclose the nature of such amendment or waiver on our website. The content of our website, however, is not part of this annual report.

You may request a copy of our SEC filings, as well as the foregoing corporate documents, at no cost to you, by writing to the Company address appearing in this annual report or by calling us at (775) 356-9029.

Table of Contents

Our Power Generation Business (Electricity Segment)

Power Plants in Operation

The table below summarizes certain key non-financial information relating to our power plants as of February 24, 2012. The generating capacity of certain of our power plants listed below has been updated to reflect changes in the resource temperature and other factors that impact resource capabilities:

Power Plant	Location	Ownership[1]	Generating Capacity in MW[2]
Domestic Geothermal			
Brady Complex	Nevada	100%	25.0
Heber Complex	California	100%	92.0
Jersey Valley[3]	Nevada	100%	12.0

Mammoth Complex	California	100%	29.0
North Brawley[(4)]	California	100%	33.0
Ormesa Complex	California	100%	54.0
Puna Complex	Hawaii	100%	38.0
Steamboat Complex	Nevada	100%	86.0
Tuscarora[(5)]	Nevada	100%	18.0
REG			
OREG 1	North and South Dakota	100%	22.0
OREG 2	Montana, North Dakota and Minnesota	100%	22.0
OREG 3	Minnesota	100%	5.5
OREG 4	Colorado	100%	3.5
Total for domestic power plants			**440.0**
Foreign			
Geothermal			
Amatitlan	Guatemala	100%	18.0
Momotombo	Nicaragua	100%	22.0
Olkaria III Complex	Kenya	100%	52.0
Zunil	Guatemala	100%	24.0
Total for foreign power plants			**116.0**
Total for all power plants			**556.0**

(1) We own and operate all of our power plants other than the Momotombo power plant in Nicaragua, which we do not own but which we control and operate through a concession arrangement with the Nicaraguan government. Two financial institutions hold equity interests in one of our consolidated subsidiaries (OPC) that owns the Desert Peak 2 power plant in our Brady complex and the Steamboat Hills, Galena 2 and Galena 3 power plants in our Steamboat complex. In the above table, we show these power plants as being 100% owned because all of the generating capacity is owned by OPC and we control the operation of the power plants. The nature of the equity interests held by the financial institution is described in Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations under the heading "OPC Transaction".

(2) References to generating capacity generally refer to the gross capacity less auxiliary power, in the case of all of our existing domestic and foreign power plants, except for the Zunil power plant. We determine the generating capacity figures in these power plants by taking into account resource capabilities. In the case of

the Zunil power plant, the energy output of the power plant was sold, until September 2011, under a "take or pay" arrangement, under which the revenues are calculated based on 24 MW capacity unrelated to the actual performance of the reservoir. This column represents our net ownership in such generating capacity.

In any given year, the actual power generation of a particular power plant may differ from that power plant's generating capacity due to variations in ambient temperature, the availability of the resource, and operational issues affecting performance during that year. The Capacity Factor of the geothermal power plants in commercial operation in 2011, excluding the North Brawley power plant, which operates at partial load, was approximately 88%. The Capacity Factor of the REG power plants in 2011 was approximately 85%.

(3) The Jersey Valley power plant is not operating at full capacity. Detailed information on the Jersey Valley power plant is provided under "Description of our Power Plants" below.

(4) The North Brawley power plant is not operating at full capacity. Detailed information on the North Brawley power plant is provided under "Description of our Power Plants" below.

(5) The Tuscarora power plant commenced commercial operation on January 11, 2012.

Substantially all of the revenues that we currently derive from the sale of electricity are pursuant to long-term PPAs. Approximately 53.2% of our total revenues in the year ended December 31, 2011 from the sale of electricity by our domestic power plants were derived from power purchasers that currently have investment grade credit ratings. The purchasers of electricity from our foreign power plants are either state-owned or private entities.

New Power Plants

We are currently in various stages of development of new power plants, construction of new power plants and expansion of existing power plants. Our growth plan includes our share of approximately 175 MW in generating capacity from geothermal power plants in the United States and Kenya that are expected to come on-line in the next two years. In addition, we expect to add, in three phases, a total of approximately 42 MW, which is our share in the Sarulla project in Indonesia.

In addition, we are constructing a 10 MW Solar PV project in the U.S. and are developing approximately 18 ground-mounted and roof-top Solar PV projects in Israel. Our share of the expected generation capacity of these projects is 130 MW. However, due to the competition in the Solar PV market in Israel, combined with a relatively low cap on the feed-in-tariff, we expect that only a portion of the Solar PV projects in our Israeli development pipeline will be ultimately constructed.

We have a substantial land position that is expected to support future geothermal development on, which we have started or plan to start exploration activity. This land position is approximately 675,000 acres in 42 sites. This is comprised of various leases and concessions, exploration concessions for geothermal resources and an option to enter into geothermal leases. We have started or plan to start exploration activity at a number of these sites.

Our Product Business (Product Segment)

We design, manufacture and sell products for electricity generation and provide the related services described below. Generally, we manufacture products only against customer orders and do not manufacture products for our own inventory.

Power Units for Geothermal Power Plants. We design, manufacture and sell power units for geothermal electricity generation, which we refer to as OECs. Our customers include contractors and geothermal power plant owners and operators.

Power Units for Recovered Energy-Based Power Generation. We design, manufacture and sell power units used to generate electricity from recovered energy, or so-called "waste heat." This heat is generated as a residual by-product of gas turbine-driven compressor stations, solar thermal units and a variety of industrial processes, such as cement manufacturing, and is not otherwise used for any purpose. Our existing and target customers include interstate natural gas pipeline owners and operators, gas processing plant owners and operators, cement plant owners and operators, and other companies engaged in other energy-intensive industrial processes.

EPC of Power Plants. We engineer, procure, and construct, as an EPC contractor, geothermal and recovered energy power plants on a turnkey basis, using power units we design and manufacture. Our customers are geothermal power plant owners as well as the same customers described above that we target for the sale of our power units for recovered energy-based power generation. Unlike many other companies that provide EPC services, we have an advantage in that we are using our own manufactured equipment and thus have better control over the timing and delivery of required equipment and its related costs.

Remote Power Units and Other Generators. We design, manufacture and sell fossil fuel powered turbo-generators with a capacity ranging between 200 watts and 5,000 watts, which operate unattended in extreme climate conditions, whether hot or cold. Our customers include contractors installing gas pipelines in remote areas. In addition, we design, manufacture, and sell generators for various other uses, including heavy duty direct-current generators.

History

We were formed as a Delaware corporation in 1994 by Ormat Industries Ltd. (also referred to in this annual report as the "Parent", "Ormat Industries", "the parent company", or "our parent"). Ormat Industries was one of the first companies to focus on the development of equipment for the production of clean, renewable and generally sustainable forms of energy. Ormat Industries owns approximately 60% of our outstanding common stock.

Industry Background

Geothermal Energy

Most of our power plants in operation produce electricity from geothermal energy. There are several different sources or methods to obtain geothermal energy, which are described below.

Hydrothermal geothermal-electricity generation — Hydrothermal geothermal energy is derived from naturally occurring hydrothermal reservoirs that are formed when water comes sufficiently close to hot rock to heat the water to temperatures of 300 degrees Fahrenheit or more. The heated water then ascends toward the surface of the earth where, if geological conditions are suitable for its commercial extraction, it can be extracted by drilling geothermal wells. The energy necessary to operate a geothermal power plant is typically obtained from several such wells which are drilled using established technology that is in some respects similar to that employed in the oil and gas industry. Geothermal production wells are normally located within approximately one to two miles of the power plant as geothermal fluids cannot be transported economically over longer distances due to heat and pressure loss. The geothermal reservoir is a renewable source of energy if natural ground water sources and reinjection of extracted geothermal fluids are adequate over the long-term to replenish the geothermal reservoir following the withdrawal of geothermal fluids and if the well field is properly operated. Geothermal energy power plants typically have higher capital costs (primarily as a result of the costs attributable to well field development) but tend to have significantly lower variable operating costs (principally consisting of maintenance expenditures) than fossil fuel-fired power plants that require ongoing fuel expenses. In addition, because geothermal energy power plants produce 24hr/day weather independent power, the variable operating costs are lower.

EGS — An EGS has been broadly defined as a subsurface system that may be artificially created to extract heat from hot rock where the characteristics required for a hydrothermal system, i.e., permeability and aquifers,

are non-existent. A geothermal power plant that uses EGS techniques recovers the thermal energy from the subsurface rocks by creating or accessing a system of open fractures in the rock through which water can be injected, heated through contact with the hot rock, returned to the surface in production wells and transferred to a power unit.

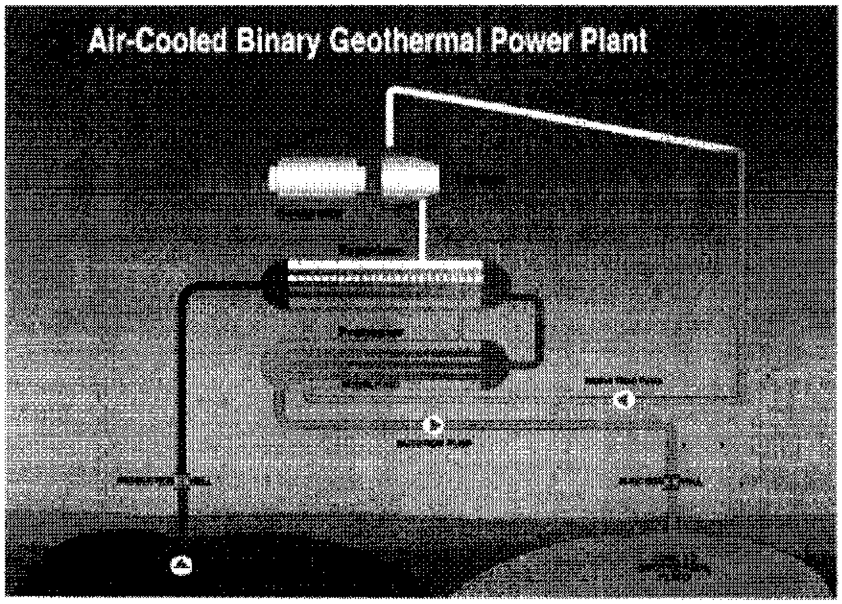
Co-produced Geothermal from Oil and Gas fields, geo-pressurized resources — Another source of geothermal energy is hot water produced from oil and gas production. This application is referred to as "Co-produced Fluids". In some oil and gas fields, water is produced as a by-product of the oil and gas extraction. When the wells are deep the fluids are often at high temperatures and if the water volume is significant, the hot water can be used for power generation in equipment similar to a geothermal power plant.

Geothermal Power Plant Technologies

Geothermal power plants generally employ either binary systems or conventional flash design systems, as described below. In our geothermal power plants, we also employ our proprietary technology of combined geothermal cycle systems.

Binary System

In a geothermal power plant using a binary system, geothermal fluid, either hot water (also called brine) or steam or both, is extracted from the underground reservoir and flows from the wellhead through a gathering system of insulated steel pipelines to a heat exchanger, which heats a secondary working fluid which has a low boiling point. This is typically an organic fluid, such as isopentane or isobutene, which is vaporized and is used to drive the turbine. The organic fluid is then condensed in a condenser which may be cooled by air or by water from a cooling tower. The condensed fluid is then recycled back to the heat exchanger, closing the cycle within the sealed system. The cooled geothermal fluid is then reinjected back into the reservoir. The binary technology is depicted in the graphic below.

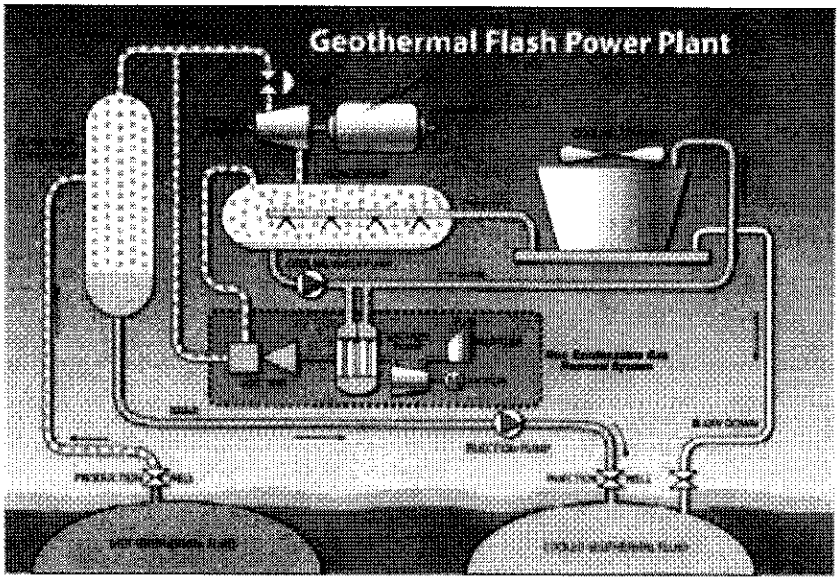


Flash Design System

In a geothermal power plant using flash design, geothermal fluid is extracted from the underground reservoir and flows from the wellhead through a gathering system of insulated steel pipelines to flash tanks and/or separators. There, the steam is separated from the brine and is sent to a demister in the plant, where any

Table of Contents

remaining water droplets are removed. This produces a stream of dry saturated steam, which drives a turbine generator to produce electricity. In some cases, the brine at the outlet of the separator is flashed a second time (dual flash), providing additional steam at lower pressure used in the low pressure section of the steam turbine to produce additional electricity. Steam exhausted from the steam turbine is condensed in a surface or direct contact condenser cooled by cold water from a cooling tower. The non-condensable gases (such as carbon dioxide) are removed through the removal system in order to optimize the performance of the steam turbines. The condensate is used to provide make-up water for the cooling tower. The hot brine remaining after separation of steam is injected back into the geothermal resource through a series of injection wells. The flash technology is depicted in the graphic below.

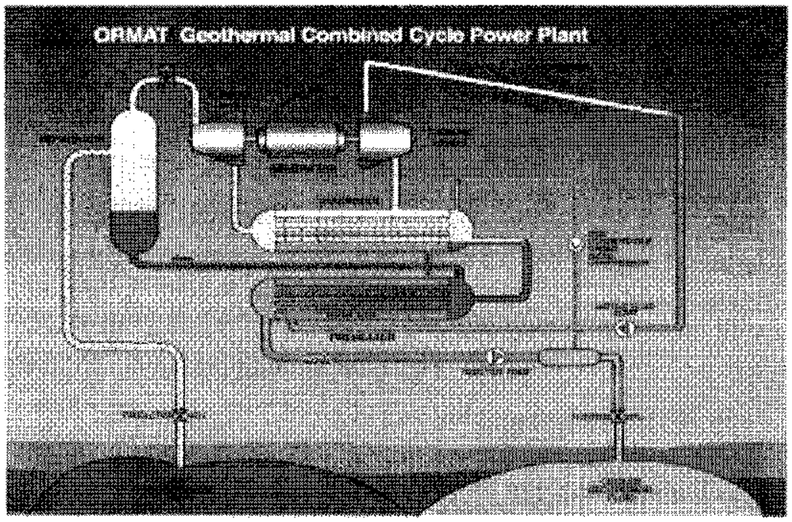


In some instances, the wells directly produce dry steam (the flashing occurring underground). In such cases, the steam is fed directly to the steam turbine and the rest of the system is similar to the flash power plant described above.

Ormat's Proprietary Technology

Our proprietary technology may be used in power plants operating according to the Organic Rankine Cycle, only or in combination with, various other commonly used thermodynamic technologies that convert heat to mechanical power. It can be used with a variety of thermal energy sources, such as geothermal, recovered energy, biomass, solar energy and fossil fuels. Specifically, our technology involves original designs of turbines, pumps, and heat exchangers, as well as formulation of organic motive fluids. All of our motive fluids are non-ozone-depleting substances. Using advanced computerized fluid dynamics and other computer aided design software as well as our test facilities, we continuously seek to improve power plant components, reduce operations and maintenance costs, and increase the range of our equipment and applications. In particular, we are examining ways to increase the output of our plants by utilizing evaporative cooling, cold reinjection, performance simulation programs, and topping turbines. In the geothermal as well as the recovered energy (waste heat) areas, we are examining two-level recovered energy systems and new motive fluids.

We also construct combined cycle geothermal power plants in which the steam first produces power in a backpressure steam turbine and is subsequently condensed in a vaporizer of a binary plant, which produces additional power. Our combined cycle technology is depicted in the graphic below.



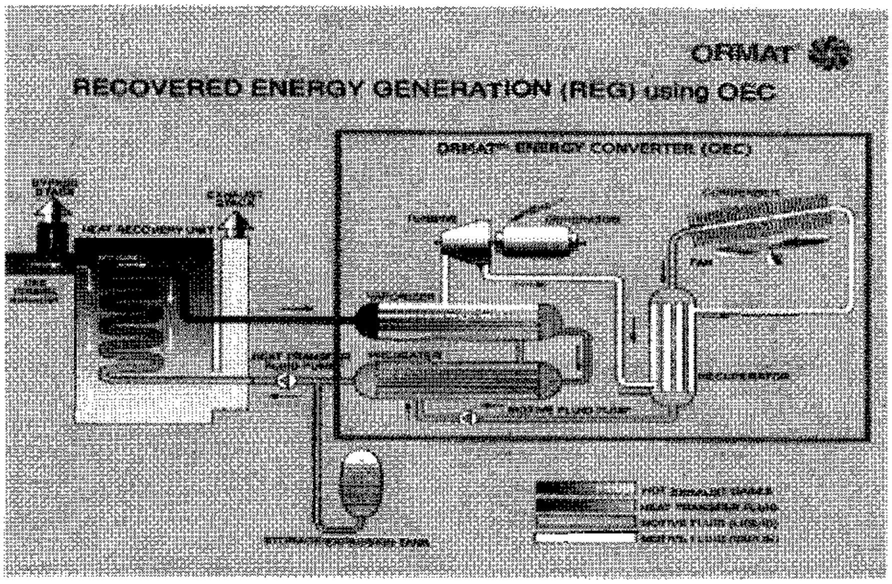
In the conversion of geothermal energy into electricity, our technology has a number of advantages compared with conventional geothermal steam turbine plants. A conventional geothermal steam turbine plant consumes significant quantities of water, causing depletion of the aquifer, and also requires cooling water treatment with chemicals and thus a need for the disposal of such chemicals. A conventional geothermal steam turbine plant also creates a significant visual impact in the form of an emitted plume from the cooling tower during cold weather. By contrast, our binary and combined cycle geothermal power plants have a low profile with minimum visual impact and do not emit a plume when they use air cooled condensers. Our binary and combined cycle geothermal power plants reinject all of the geothermal fluids utilized in the respective processes into the geothermal reservoir. Consequently, such processes generally have no emissions.

Other advantages of our technology include simplicity of operation and easy maintenance, low RPM, temperature and pressure in the OEC, a high efficiency turbine, and the fact that there is no contact between the turbine itself and often corrosive geothermal fluids.

We use the same elements of our technology in our recovered energy products. The heat source may be exhaust gases from a simple cycle gas turbine, low pressure steam, or medium temperature liquid found in the process industry. In most cases, we attach an additional heat exchanger in which we circulate thermal oil to transfer the heat into the OEC's own vaporizer in order to provide greater operational flexibility and control. Once this stage of each recovery is completed, the rest of the operation is identical to the OEC used in our geothermal power plants. The same advantages of using the Organic Rankine Cycle apply here as well. In addition, our technology allows for better load following than conventional steam turbines exhibit, requires no water treatment as it is air cooled, and does not require the continuous presence of a steam licensed operator on site.

Table of Contents

Our REG technology is depicted in the graphic below.



Patents

We have been granted 82 U.S. patents (and about 20 pending patents) that cover our products (mainly power units based on the Organic Rankine Cycle) and systems (mainly geothermal power plants and industrial waste heat recovery plants for electricity production). The system-related patents cover not only a particular component but also the overall effectiveness of the plant's systems from the "fuel" (e.g., geothermal fluid, waste heat, biomass or solar) to generated electricity. The duration of such patents ranges from one year to seventeen years. No single patent on its own is material to our business.

The products-related patents cover components which include turbines, heat exchangers, seals and controls. The system patents cover subjects such as waste heat recovery related to gas pipelines compressors, disposal of non-condensable gases present in geothermal fluids, power plants for very high pressure geothermal resources, and use of two-phase fluids as well as processes related to EGS. A number of patents cover the combined cycle geothermal power plants, in which the steam first produces power in a backpressure steam turbine and is subsequently condensed in a vaporizer of a binary plant, which produces additional power.

Research and Development

We are conducting research and development of new EGS technologies and their application to enhance our power plants without using any additional fluid supply. We are undertaking this development effort at our Desert Peak 2 and Brady power plants in Nevada in cooperation with GeothermEx Inc., and a number of universities and national laboratories, with funding support from the DOE.

We are also continuing with our research and development activities intended to improve plant performance, reduce costs, and increase the breadth of product offerings. The primary focus of our research and development efforts includes continued improvements to our evaporative cooling system, condensing equipment with improved performance and lower land usage, developing new turbine products, and specialized power units designed to reduce fuel consumption and associated costs during a project's development phase.

Additionally, we are continuing to evaluate investment opportunities in new companies with product offerings for renewable energy markets, such as our investment in W&M, a company with whom we are engaged for the development of energy harvesting and system balancing solutions for electrical sources and, in particular, Solar PV.

Table of Contents

Market Opportunity

Interest in geothermal energy in the United States remains strong as a result of legislative and regulatory support for renewable energy, and the baseload nature of geothermal energy generation.

Although electricity generation from geothermal resources is currently concentrated mainly in California, Nevada, Hawaii, Idaho and Utah, there are opportunities for development in other states such as Alaska, Arizona, New Mexico, Washington and Oregon due to the availability of geothermal resources and, in some cases, a favorable regulatory environment in such states.

The Western Governors Association estimates that 13,000 MW of identified geothermal resources will be developed by 2025. In a report issued in April 2010 for the World Geothermal Congress, Ruggero Bertani of Enel Green Power forecasted that by 2015 the worldwide installed capacity will increase by approximately 73% from 10,715 MW in 2010 to 18,500 MW in 2015. The report identifies the U.S., Indonesia, the Philippines, New Zealand and Mexico as the main contributors to the forecasted growth.

In a report issued in April 2011, the Geothermal Energy Association identified a total of 146 confirmed and unconfirmed geothermal projects under various phases of consideration or development in 15 U.S. states that have between 4,448 MW and 5,040 MW potential capacity.

The assessments conducted by the Western Governors Association and the Geothermal Energy Association are estimates only. We refer to them only as two possible reference points, but we do not necessarily concur with those estimates.

An additional factor fueling recent growth in the renewable energy industry is global concern about the environment. Power plants that use fossil fuels generate higher levels of air pollution and their emissions have been linked to acid rain and global warming. In response to an increasing demand for "green" energy, many countries have adopted legislation requiring, and providing incentives for, electric utilities to sell electricity generated from renewable energy sources. In the United States, Arizona, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Dakota, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin and the District of Colombia have all adopted RPS, renewable portfolio goals, or similar laws requiring or encouraging electric utilities in such states to generate or buy a certain percentage of their electricity from renewable energy sources or recovered heat sources.

According to the Database of State Incentives for Renewables and Efficiency (DSIRE), twenty nine states (including California, Nevada, and Hawaii, where we have been the most active in our geothermal energy development and in which all of our U.S. geothermal power plants in operation are located) and the District of Columbia define geothermal resources as "renewable."

According to DSIRE, seventeen states have enacted RPS and Alternative Portfolio Standards that include some form of combined heat and power and/or waste heat recovery. The seventeen states are: Arizona, Colorado, Connecticut, Hawaii, Indiana, Maine, Michigan, Nevada, New York, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, and West Virginia.

We believe that these legislative measures and initiatives present a significant market opportunity for us. In California, on April 12, 2011, Governor Jerry Brown signed Senate Bill X1-2 (SBX1-2) to increase California's RPS to 33% by December 31, 2020, among the most aggressive renewable energy goals in the United States. We expect that the additional demand for renewable energy from utilities in states with RPS will outpace a possible reduction in general demand for energy (if any) due to the effect of general economic conditions. We see this increased demand and, in particular, the impact of the increase in California's RPS, as one of the most significant opportunities for us to expand existing projects and build new power plants. In 2010, California's RPS target was to supply at least 20% of the total retail electricity sales from eligible renewable energy resources; California's three large investor-owned utilities collectively served 17% of their 2010 retail electricity sales with renewable power. Due to flexible compliance, California utilities must average 20% through years 2011-2013. The investor-owned utilities have interim targets each year, with a requirement of 25% by 2016. Due to the new 33% target, publicly-owned utilities in California must also procure 33% of retail electricity sales from eligible renewable energy resources by 2020, opening up a significant new market of potential off-takers in years ahead. These utilities do not have interim targets. Nevada's RPS requires NV Energy to supply at least 15% of the total electricity it sells from eligible renewable energy resources by 2013, which will increase to 25% by 2025. In 2010, 14.8% of the electricity retail sales in Nevada were from renewable energy sources. Hawaii's RPS requires each Hawaiian electric utility that sells electricity for consumption in Hawaii to obtain 15% of its net electricity sales from renewable energy sources by December 31, 2015, 20% by December 31, 2020, and 40% by 2030. In 2010, Hawaiian Electric Company and its subsidiaries achieved a consolidated RPS of 20.7%.

In 2006, California passed a state climate change law, AB 32. The goal of AB 32 is to reduce GHG emissions to 1990 levels by the end of 2020. In 2008, CARB approved a Scoping Plan to carry out regulations implementing AB 32. In December 2010, CARB approved cap-and-trade regulations to reduce California's GHG emissions under AB 32. The cap-and-trade regulation, the first phase of which was initiated in January 2012 with compliance obligations commencing in January 2013, will set a statewide limit on emissions from sources responsible for emitting 80% of California's GHGs and, according to CARB, will help establish a price signal needed to drive long-term investment in cleaner fuels and more efficient use of energy. However, implementation of this cap-and-trade program under AB 32 has been the subject of legal challenges that may hinder and/or ultimately thwart its implementation. At the federal level as of 2011, the EPA's Tailoring Rule sets thresholds for when permitting requirements under the Clean Air Act's Prevention of Significant Deterioration and Title V programs apply to certain major sources of GHG emissions. Regional initiatives are also being developed to reduce GHG emissions and to develop trading systems for renewable energy credits. For example, nine Northeast and Mid-Atlantic States are part of the RGGI, a regional cap-and-trade system to limit carbon dioxide. The RGGI is the first mandatory, market-based carbon dioxide emissions reduction program in the United States. The first-in-the-nation auction of carbon dioxide allowances was held in September 2008. Under RGGI, the participating states plan to reduce carbon emissions from power plants by 10%, at a rate of 2.5% per year between 2015 and 2018.

In addition to RGGI, other states have also established the Midwestern Regional Greenhouse Gas Reduction Accord and the Western Climate Initiative. Although individual and regional programs will take some time to develop, their requirements, particularly the creation of any market-based trading mechanism to achieve compliance with emissions caps, should be advantageous to in-state and in-region (and, in some cases, such as RGGI and the State of California, inter-regional) energy generating sources that have low carbon emissions such as geothermal energy. Although it is currently difficult to quantify the direct economic benefit of these efforts to reduce GHG emissions, we believe they will prove advantageous to us.

The federal government also encourages production of electricity from geothermal resources through certain tax subsidies. We are permitted to claim 30% of certain eligible costs of a new geothermal power plant put into service prior to December 31, 2013 in the United States as a one-time credit against our federal income taxes. Projects put into service after that date continue to qualify, but the credit is reduced to 10% (certain tax benefits are impacted by these tax credits as described in the section below). Alternatively, we are permitted to claim a tax credit based on the power produced from a geothermal power plant. These production-based credits, which in 2011 were 2.2 cents per kWh, are adjusted annually for inflation and may be claimed for ten years on the electricity produced by a new geothermal power plant put into service prior to December 31, 2013. The production-based credits are allowed only to the extent the power is sold to a third party. The owner of the power plant must choose between these two types of tax credits described above. In either case, under current tax rules, any unused tax credit has a one-year carry back and a twenty-year carry forward. Another alternative available is a cash grant for Specified Energy Projects in Lieu of Tax Credits from the U.S. Treasury. It is available for certain power plants placed in service by the end of 2011, or on which construction began in 2009, 2010 or 2011 and that are completed by the end of 2013. Please refer to Item 7 — "Management's Discussion and Analysis of Financial Condition and Result of Operations" regarding the valuation allowance we recorded in the year ended December 31, 2011 against deferred tax assets related to the abovementioned tax credits.

Whether we claim tax credits or a cash grant, we are also permitted to depreciate, or write off, most of the cost of the plant. If we claim the one-time 30% (or 10%) tax credit or receive the ITC cash grant, our tax basis in the plant that we can recover through depreciation must be reduced by one-half of the tax credit or cash grant; if we claim other tax credits, there is no reduction in the tax basis for depreciation. For projects that we placed into service after September 8, 2010 and before January 1, 2012, a depreciation "bonus" will permit us to write off 100% of the cost of certain equipment that is part of the geothermal power plant in the year the plant is placed into service, if certain requirements are met. For projects that are placed into service after December 31, 2011 and before January 1, 2013, a similar "bonus" will permit us to write off 50% of the cost of that equipment in the year the power plant is placed into service. After applying any depreciation bonus that is available, we can write off the remainder of our tax basis in the plant, if any, over five years on an accelerated basis, meaning that more of the cost may be deducted in the first few years than during the remainder of the depreciation period.

Collectively, these benefits (to the extent fully utilized) have a present value equivalent to approximately 30% to 40% of the capital cost of a new power plant.

Production of electricity from geothermal resources may also be supported under the "Temporary Program For Rapid Deployment of Renewable Energy and Electric Power Transmission Projects" established with the DOE as part of the DOE's existing Innovative Technology Loan Guarantee Program. The Temporary Program (i) extends the scope of the existing federal loan guarantee program to cover renewable energy projects, renewable energy component manufacturing facilities and electricity transmission projects that embody established commercial, as well as innovative, technologies; and (ii) provides an appropriation to cover the "credit subsidy cost" of such projects (meaning estimated average costs to the federal government from issuing the loan guarantee, equivalent to a lending bank's loan loss reserve). Although the Temporary Program was subject to a September 30, 2011 sunset, Congress has enacted further authorizations and appropriations to provide for a limited amount of subsidized support beyond that date for projects that would have qualified for the Temporary Program. A project supported by the federal guarantee under the new program must pay prevailing federal wages.

Operations outside of the United States may be subject to and/or benefit from requirements under the Kyoto Protocol. In December 2011, the United Nations Climate Change Conference was held in Durban, South Africa. The conference encompassed the 17th Conference of the Parties to the United Nations Framework Convention on Climate Change and the seventh meeting of the Parties to the Kyoto Protocol. Negotiators agreed to start work on a new climate deal that would have legal force and, crucially, require both developed and developing countries to cut their carbon emissions. The terms now need to be agreed by 2015 and will come into effect from 2020. The next Conference of the Parties is scheduled to take place in Qatar in November 2012. Before the Qatar conference in November 2012, the Rio +20 United Nations Conference will take place in Rio de Janeiro in June 2012. The first Rio summit 20 years ago is seen as one of the most ambitious gatherings in the history of the United Nations. More than 100 heads of state signed up to a raft of actions, including efforts to halt the deterioration of the ozone layer, tackle climate change and reduce the loss of biodiversity. These issues have taken center stage in international negotiations over the past two decades.

Outside of the United States, the majority of power generating capacity has historically been owned and controlled by governments. Since the early 1990s, however, many foreign governments have privatized their power generation industries through sales to third parties and have encouraged new capacity development and/or refurbishment of existing assets by independent power developers. These foreign governments have taken a variety of approaches to encourage the development of competitive power markets, including awarding long-term contracts for energy and capacity to independent power generators and creating competitive wholesale markets for selling and trading energy, capacity, and related products. Some countries have also adopted active governmental programs designed to encourage clean renewable energy power generation. Several Latin American countries have rural electrification programs and renewable energy programs. For example, Guatemala, where our Zunil and Amatitlan power plants are located, approved in November 2003 a law which created incentives for power generation from renewable energy sources by, among other things, providing economic and fiscal incentives such as exemptions from taxes on the importation of relevant equipment and various tax exemptions for companies implementing renewable energy projects. Another example is New Zealand, where we (and our Parent before us) have been actively designing and supplying geothermal power solutions since 1986. The New Zealand government's policies to fight climate change include a target for GHG emissions reductions of between 10% and 20% below 1990 levels by 2020 and the target of increasing renewable electricity generation to 90% of New Zealand's total electricity generation by 2025. In Indonesia, the government has implemented policies and regulations intended to accelerate the development of renewable energy and geothermal projects in particular. These include designating approximately 4,000 MW of geothermal projects in its second phase of power acceleration projects to be implemented by 2014, of which the majority is IPP projects and the remaining state utility PLN projects. For the IPP sector, certain regulations for geothermal projects have been implemented providing for incentives such as investment tax credits and accelerated depreciation, and pricing guidelines intended to allow preferential power prices for generators; other regulation are being discussed. In addition, there is a regulation providing feed-in tariffs for small scale renewable energy projects up to 10 MW. On a macro level, the Government of Indonesia committed at the United Nations Climate Change Conference 2009 in Copenhagen to reduce its CO_2 emissions by 20% by 2020, which is intended to be achieved mainly through prevention of deforestation and accelerated renewable energy development. Another example is Chile, where we were recently awarded six exploration concessions. The Chilean Renewable Energy Act of 2008 requires that 5% of electricity sold come from renewable sources beginning in 2010, increasing gradually to 10% by 2024.

We believe that these developments and governmental plans will create opportunities for us to acquire and develop geothermal power generation facilities internationally, as well as create additional opportunities for our Product Segment.

In addition to our geothermal power generation activities, we are pursuing recovered energy-based power generation opportunities in North America and the rest of the world. We believe recovered energy-based power generation may benefit from the increased attention to energy efficiency. For example, in the United States, the FERC has expressed its position that one of the goals of new natural gas pipeline design should be to facilitate the efficient, low-cost transportation of fuel through the use of waste heat (recovered energy) from combustion turbines or reciprocating engines that drive station compressors to generate electricity for use at compressor stations or for commercial sale. FERC has, as a matter of policy, requested natural gas pipeline operators filing for a certificate of approval for new pipeline construction or expansion projects to examine "opportunities to enhance efficiencies for any energy consumption processes in the development and operation" of the new pipeline. We have initially targeted the North American market, where we have built over 20 power plants which generate electricity from "waste heat" from gas turbine-driven compressor stations along interstate natural gas pipelines, from midstream gas processing facilities, and from processing industries in general.

Several states, and to a certain extent, the federal government, have recognized the environmental benefits of recovered energy-based power generation. For example, Colorado, Connecticut, Indiana, Louisiana, Michigan, Nevada, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Utah, and West Virginia allow electric utilities to include recovered energy-based power generation in calculating their compliance with their mandatory or voluntary RPS. In addition, California recently modified the Self Generation Incentive Program (SGIP) which allows recovered energy-based generation to qualify for a per watt incentive. North Dakota, South Dakota, and the U.S. Department of Agriculture (through the Rural Utilities Service) have approved recovered energy-based power generation units as renewable energy resources, which qualifies recovered energy-based power generators (whether in those two states or elsewhere in the United States) for federally funded, low interest loans, but currently do not qualify for an ITC, PTC, or ITC cash grant. Recovery of waste heat is also considered "environmentally friendly" in the western Canadian provinces. We believe that Europe and other markets worldwide may offer similar opportunities in recovered energy-based power generation.

The market for solar power grew significantly in recent years, driven by a combination of favorable government policies and a decline in equipment prices. We are monitoring market drivers in various regions with a view to developing Solar PV power plants in those locations where we can offer competitively priced power generation, particularly where we can develop a Solar PV plant next to one of our existing power plants, and thereby leverage existing infrastructure and otherwise take advantage of operating efficiencies.

Competitive Strengths

Competitive Assets. Our assets are competitive for the following reasons:

- *Contracted Generation.* All of the electricity generated by our geothermal power plants is currently sold pursuant to long-term PPAs.
- *Baseload Generation.* All of our geothermal power plants supply all or a part of the baseload capacity of the electric system in their respective markets. This means they supply electric power on an around-the-clock basis. We have a competitive advantage over other renewable energy sources, such as wind power, solar power or hydro-electric power (to the extent dependent on precipitation), which compete with us to meet electric utilities' renewable portfolio requirements but which cannot serve baseload capacity because of their weather dependence and thus intermittent nature of these other renewable energy sources.
- *Competitive Pricing.* Geothermal power plants, while site specific, are economically feasible to develop, construct, own, and operate in many locations, and the electricity they generate is generally price competitive compared to electricity generated from fossil fuels or other renewable sources under existing economic conditions and existing tax and regulatory regimes.
- *Ability to Finance Our Activities from Internally Generated Cash Flow.* The cash flow generated by our portfolio of operating geothermal and REG power plants provides us with a robust and predictable base for our exploration, development, and construction activities, to a certain level. We believe that this gives us a competitive advantage over certain competitors whose activities are more dependent on external credit and financing sources that may be subject to availability constraints depending on prevailing global credit and market conditions.

Growing Legislative Demand for Environmentally-Friendly Renewable Resource Assets. Most of our currently operating power plants produce electricity from geothermal energy sources. The clean and sustainable characteristics of geothermal energy give us a competitive advantage over fossil fuel-based electricity generation as countries increasingly seek to balance environmental concerns with demands for reliable sources of electricity.

High Efficiency from Vertical Integration.

- Unlike our competitors in the geothermal industry, we are a fully-integrated geothermal equipment, services, and power provider. We design, develop, and manufacture equipment that we use in our geothermal and REG power plants. Our intimate knowledge of the equipment that we use in our operations allows us to operate and maintain our power plants efficiently and to respond to operational issues in a timely and cost-efficient manner. Moreover, given the efficient communications among our subsidiary that designs and manufactures the products we use in our operations and our subsidiaries that own and operate our power plants, we are able to quickly and cost effectively identify and repair mechanical issues and to have technical assistance and replacement parts available to us as and when needed.
- We design, manufacture, and sell to third parties power units and other power generating equipment for geothermal and recovered energy-based electricity generation. Our extensive experience in the development of state-of-the-art, environmentally sound power solutions enables our customers to relatively easily finance their power plants.

Exploration and Drilling Capabilities. We have in-house capabilities to explore and develop geothermal resources. We have established a drilling subsidiary that currently owns nine drilling rigs. We employ an experienced resource group that includes engineers, geologists, and drillers. This resource group executes our exploration and drilling plans for projects that we develop.

Highly Experienced Management Team. We have a highly qualified senior management team with extensive experience in the geothermal power sector. Key members of our senior management team have worked in the power industry for most of their careers and average over 25 years of industry experience.

Technological Innovation. We have been granted 82 U.S. patents (additionally approximately 20 patents are pending) relating to various processes and renewable resource technologies. All of our patents are internally developed. Our ability to draw upon internal resources from various disciplines related to the geothermal power sector, such as geological expertise relating to reservoir management, and equipment engineering relating to power units, allows us to be innovative in creating new technologies and technological solutions.

Limited Exposure to Fuel Price Risk. A geothermal power plant does not need to purchase fuel (such as coal, natural gas, or fuel oil) in order to generate electricity. Thus, once the geothermal reservoir has been identified and estimated to be sufficient for use in a geothermal power plant and the drilling of wells is complete, the plant is not exposed to fuel price or fuel delivery risk apart from the impact fuel prices may have on the price at which we sell power under PPAs that are based on the relevant power purchaser's avoided costs.

Although we are confident in our competitive position in light of the strengths described above, we face various challenges in the course of our business operations, including as a result of the risks described in Item 1A — "Risk Factors" below, the trends and uncertainties discussed under Item 7 — "Management's Discussion and Analysis of Financial Condition and Results of Operations" below, and the competition we face in our different business segments described under "Competition" below.

Business Strategy

Our strategy is to continue building a geographically balanced portfolio of geothermal and recovered energy assets, and to continue to be a leading manufacturer and provider of products and services related to renewable energy. We intend to implement this strategy through:

- *Development and Construction of New Geothermal Power Plants* — continuously seeking out commercially exploitable geothermal resources, developing and constructing new geothermal power plants and entering into long-term PPAs providing stable cash flows in jurisdictions where the regulatory, tax and business environments encourage or provide incentives for such development and which meet our investment criteria;
- *Development and Construction of Recovered Energy Power Plants* — establishing a first-to-market leadership position in recovered energy power plants in North America and building on that experience to expand into other markets worldwide;
- *Acquisition of New Assets* — acquiring from third parties additional geothermal and other renewable assets that meet our investment criteria;
- *Manufacturing and Providing Products and Service Related to Renewable Energy* — designing, manufacturing and contracting power plants for our own use and selling to third parties power units and other generation equipment for geothermal and recovered energy-based electricity generation;
- *Increasing Output from Our Existing Power Plants* — increasing output from our existing geothermal power plants by adding additional generating capacity, upgrading plant technology, and improving geothermal reservoir operations, including improving methods of heat source supply and delivery; and
- *Technological Expertise* — investing in research and development of renewable energy technologies and leveraging our technological expertise to continuously improve power plant components, reduce operations and maintenance costs, develop competitive and environmentally friendly products for electricity generation and target new service opportunities.
- In addition, we are considering various opportunities in the solar energy market and recently commenced construction of the Heber Solar project in Imperial Valley, California. There are several reasons for entering the solar energy market including:
  - the recent decline in the cost of Solar PV technologies;
  - the attractive electricity prices that may be achieved in certain regions;

  - our ability to leverage EPC and development expertise in geothermal and recovered energy power generation facilities; and
  - cost efficiencies we can derive from sharing infrastructure and related facilities, as well as operations and maintenance, with our existing power plants.

- Among other things, we have considered, and expect to continue to consider, a number of different opportunities including:
  - acquisitions and joint ventures;
  - expanding our internal research and development activity, or acquiring other companies engaged in solar research and development activities; and
  - constructing and operating solar electric power generation facilities.

Recent Developments

- On February 16, 2012, Geothermal Development Company (GDC) that is owned by the Government of Kenya, has awarded our subsidiary the first well head power plant project in the Menengai geothermal field in Kenya on a Build-Own-Transfer basis. The award is the result of an international tender for the design, manufacturing, procurement, construction and commissioning of the 6 MW geothermal well head power plant. GDC will supply the steam for conversion to electricity by Ormat's power plant. The Menengai geothermal field is located on the outskirts of the town of Nakuru, about 180 kilometers west of Nairobi.
- On January 30, 2012, the PUCN approved the 20-year PPA that we signed in February 2011 with NV Energy to sell 30 MW from the Dixie Meadows geothermal project that we are developing in Churchill County, Nevada.
- In December 2011, the PUCH approved the 20-year PPA we signed in February 2011 with HELCO to sell to the Hawaii Island grid an additional 8 MW of dispatchable geothermal power. The power is generated from the Puna complex and is sold at a fixed price (subject to escalation) independent of oil prices. Further information on the terms of the PPA is described in "Operation of our Electricity Segment" under "Puna Complex".
- In December 2011, we signed a termination agreement with respect to the PPA and joint operating agreement with NV Energy for the Carson Lake geothermal project in Churchill County, Nevada. Further information is provided under Operation of our Electricity Segment under "Carson Lake Project".
- In December 2011, we signed a 20-year PPA with IID for 10 MW of Solar PV energy from a project located near the Heber geothermal complex in Imperial Valley, California. This will be our first utility- scale Solar PV project. Construction started in 2011 and commercial operation is expected within 18 months, subject to timely completion of the interconnection, for which IID is responsible.
- On December 20, 2011, our subsidiary, Ormat Nevada signed a $21.4 million EPC contract and a credit agreement with Thermo No. 1 BE-01, LLC (Thermo 1), a subsidiary of Cyrq Energy, Inc. (Cyrq), in connection with the construction of an OEC at Thermo 1's existing geothermal power plant in Utah to increase the plant's output and reduce operating costs. Under the credit agreement, we will provide financing in an aggregate principal amount not to exceed $22.7 million that will be used to finance the project construction costs under the EPC contract with Thermo 1. The project is expected to have a relatively short completion schedule and could come online by the middle of 2013.
- On November 22, 2011, our subsidiary, Ormat Nevada, signed a $65.0 million EPC contract and a credit agreement with Lightning Dock Geothermal HI-01, LLC (LDG), a subsidiary of Cyrq, in connection with the construction of LDG's geothermal project in New Mexico. The EPC contract work is scheduled to be released in stages based on LDG's progress in the well field drilling and development necessary to support the project. Early engineering will be released as soon as the basic well field characteristics are

confirmed in order to maintain the project schedule. Further work will be released based on the progress of the well field development. Under the credit agreement we will provide financing in an aggregate principal amount not to exceed $66.0 million that will be used to finance the project construction costs under the EPC contract with LDG. The project is expected to come online by the end of 2013.

- In October 2011, the Chilean Committee on Geothermal Energy Analysis recommended that the Chilean Ministry of Energy award us five exploration concessions in Chile. Under the applicable regulatory framework governing the concessions, in order to maintain the development rights granted under these concessions, we will need to make certain investments in an exploration program over the next two years. Following compliance with these exploration commitments, we may receive an exploitation license, which is the first step toward power plant construction.
- In September 2011, our wholly owned indirect subsidiary, OFC 2, and its project subsidiaries (the Issuers), finalized and signed loan documentation for a 20-year loan for up to $350.0 million aggregate principal amount of OFC 2 Senior Secured Notes due December 31, 2034 under a financing agreement with John Hancock. The transaction will be guaranteed by the DOE's Loan Programs Office in accordance with and subject to the DOE's Loan Guarantee Program under Section 1705 of Title XVII of the Energy Policy Act of 2005. The financing will support power generation from three Nevada-based facilities built in two phases that are expected to generate up to 113 MW of power. The three facilities, Jersey Valley, McGinness Hills, and Tuscarora, will provide baseload power through 20-year PPAs with Nevada Power Company, a subsidiary of NV Energy. The capacity of the first phase is expected to be up to approximately 60 MW. The second phase of development is subject to a feasibility assessment of the geothermal resource, which will be performed following completion of the first phase of each facility and fulfillment of other conditions in the loan documents. On October 31, 2011, OFC 2 and the Issuers completed the sale of $151.7 million aggregate principal amount of Series A of OFC 2 Senior Secured Notes due 2032. The net proceeds from the sale of the Series A of OFC 2 Senior Secured Notes, after deducting transaction fees and expenses, were approximately $141.1 million, and will be used to finance a portion of the construction costs of Phase I of the McGinness Hills and Tuscarora facilities.
- In September 2011, our wholly owned subsidiary, Ormat International, signed a commitment letter with OPIC to provide project financing of up to $310.0 million to refinance and expand our 48 MW Olkaria III geothermal complex located in Naivasha, Kenya. Under the agreed term sheet attached to the commitment letter, the loan will be comprised of a refinancing tranche of up to $85.0 million to prepay the existing loan and fund transaction costs, a construction loan tranche of up to $165.0 million to finance the construction of an additional 36 MW expansion currently underway, and a $60.0 million stand-by facility to finance an additional optional 16 MW capacity expansion, that, if exercised by us, could bring the total capacity of the complex to approximately 100 MW. The maturity dates of the construction tranche and the refinancing tranche are expected to be June 2030 and December 2030, respectively. The maturity date and certain other terms of the stand-by facility will be finalized following our decision, if any, to exercise the option to construct the additional 16 MW expansion.
- We have completed the modification of the 20 MW Burdette (Galena 1) power plant into an evaporative cooling configuration. Evaporative cooling provides increased power generation from air-cooled facilities, compared to regular air-cooled facilities by as much as 30% during the peak heat hours of the day. The implementation of this system in moderate to dry climates, especially in the high desert, generates more energy per year than water-cooled systems, and with a fraction of the water and chemical consumption of traditional water-cooled systems.
- In June 2011, we signed a lease agreement for approximately 300 acres with Kibbutz Revivim in Israel. We plan to use the land to build a Solar PV power plant.
- In June 2011, we entered into a BOT agreement with TGL to explore, develop, supply, construct, own and operate a geothermal power plant in the Tikitere geothermal area near Rotorua, New Zealand. Under the BOT agreement, the parties will jointly develop a geothermal power plant with an estimated capacity of approximately 45 MW. We will own and operate the project for an initial period of 14 years following

commercial operation and then the ownership interests in the project will be transferred to TGL. The project will utilize Ormat's generating units. The BOT agreement is conditional upon receiving regulatory approval and resolution of internal arrangements, such as royalties, between the trusts owning the land. Construction of the power plant will commence following the obtaining of local permits, as well as satisfactory feasibility results following exploration and development activities to be carried out by us.

- In June 2011, two of our subsidiaries signed a supply contract and an EPC contract with Mighty River Power Limited of New Zealand, for the first stage of the Ngatamariki geothermal project valued at a total of approximately $130.0 million. The new power plant is to be constructed on the Ngatamariki Geothermal Field in New Zealand. Construction of the power plant is expected to be completed within 24 months from the contract date. Mighty River Power Limited, a state-owned enterprise, is a New Zealand electricity generation and electricity retailing company.
- In May 2011, we entered into a supply contract with Norske Skog Tasman Limited of New Zealand to supply a new geothermal power plant that is to be constructed in the Kawerau Geothermal Field in New Zealand. The contract is valued at a total of approximately $20.0 million and delivery of the power plant is expected to be completed within 13 months from the contract date.
- In April 2011, we amended and restated the PPA with KPLC, the off-taker of the Olkaria III complex located in Naivasha, Kenya. The amended and restated PPA governs our construction of, and KPLC's purchase of electricity from, a new 36 MW power plant at the Olkaria III complex. The new power plant is scheduled to come online in 2013. The PPA amendment includes an option to increase the combined 84 MW capacity from the new and existing plants to a maximum of 100 MW, subject to monitoring and assessment of the geothermal reservoir capacity.
- In March 2011, we entered into an agreement with the Weyerhaeuser Company granting us an option to enter into geothermal leases covering approximately 264,000 acres of land in Oregon and Washington. Under this agreement we have the exclusive right to explore the land for geothermal resources and may enter into one or more geothermal leases within the optioned land.
- On March 31, 2011, Southern California Edison Company (Southern California Edison) set the demonstrated capacity of the North Brawley power plant at 33 MW. Southern California Edison also agreed to modify the North Brawley PPA to allow us the option of performing an additional capacity demonstration within one year from the first capacity demonstration on March 31, 2011, which may enable us to increase the demonstrated capacity of the plant.

Operations of our Electricity Segment

How We Own Our Power Plants. We customarily establish a separate subsidiary to own interests in each power plant. Our purpose in establishing a separate subsidiary for each plant is to ensure that the plant, and the revenues generated by it, will be the only source for repaying indebtedness, if any, incurred to finance the construction or the acquisition (or to refinance the acquisition) of the relevant plant. If we do not own all of the interest in a power plant, we enter into a shareholders agreement or a partnership agreement that governs the management of the specific subsidiary and our relationship with our partner in connection with the specific power plant. Our ability to transfer or sell our interest in certain power plants may be restricted by certain purchase options or rights of first refusal in favor of our power plant partners or the power plant's power purchasers and/or certain change of control and assignment restrictions in the underlying power plant and financing documents. All of our domestic geothermal and REG power plants, with the exception of the Puna complex, which is an Exempt Wholesale Generator, are Qualifying Facilities under the PURPA, and are eligible for regulatory exemptions from most provisions of the FPA and certain state laws and regulations.

How We Explore and Evaluate Geothermal Resources. Since 2006, we have expanded our exploration activities, particularly in Nevada. These activities generally involve:

- Identifying and evaluating potential geothermal resources using information available to us from public and private resources as described under "Initial Evaluation" below.

- Acquisition of land rights to any geothermal resources our initial evaluation indicates could potentially support a commercially viable power plant, taking into account various factors described under "Land Acquisition" below.
- Conducting geophysical and geochemical surveys on some or all of the sites acquired, as described under "Surveys" below.
- Obtaining permits to conduct exploratory drilling, as described under "Environmental Permits" below.
- Drilling one or more exploratory wells on some or all of the sites to confirm and/or define the geothermal resource where indicated by our surveys, creating access roads to drilling locations and related activities, as described under "Exploratory Drilling" below.
- Drilling a full-size well (as described below) if our exploratory drilling indicates the geothermal resource can support a commercially viable power plant taking into account various factors described under "Exploratory Drilling" below. Drilling a full-size well is the point at which we usually consider a site moves from exploration to construction.

It normally takes us one to two years from the time we start active exploration of a particular geothermal resource to the time we have an operating production well, assuming we conclude the resource is commercially viable.

Initial Evaluation. As part of our initial evaluation, we generally follow the following process, although our process can vary from site to site depending on the particular circumstances involved:

- We evaluate historic, geologic and geothermal information available from public and private databases.
- For some sites, we may obtain and evaluate additional information from other industry participants, such as where oil or gas wells may have been drilled on or near a site.
- We generally create a digital, spatial geographic information systems database containing all pertinent information, including thermal water temperature gradients derived from historic drilling, geologic mapping information (e.g., formations, structure and topography), and any available archival information about the geophysical properties of the potential resource.
- We assess other relevant information, such as infrastructure (e.g., roads and electric transmission lines), natural features (e.g., springs and lakes), and man-made features (e.g., old mines and wells).

Our initial evaluation is usually conducted by our own staff, although we might engage outside service providers for some tasks from time to time. The costs associated with an initial evaluation vary from site to site, based on various factors, including the acreage involved and the costs, if any, of obtaining information from private databases or other sources. On average, our expenses for an initial evaluation of a site range from approximately $20,000 to $100,000.

If we conclude, based on the information considered in the initial evaluation, that the geothermal resource can support a commercially viable power plant, taking into account various factors described below, we proceed to land rights acquisition.

Land Acquisition. For domestic power plants, we either lease or own the sites on which our power plants are located. In our foreign power plants, our lease rights for the plant site are generally contained in the terms of a concession agreement or other contract with the host government or an agency thereof. In certain cases, we also enter into one or more geothermal resource leases (or subleases) or a concession or other agreement granting us the exclusive right to extract geothermal resources from specified areas of land, with the owners (or sublessors) of such land. This documentation will usually give us the right to explore, develop, operate, and maintain the geothermal field, including, among other things, the right to drill wells (and if there are existing wells in the area, to alter them) and build pipelines for transmitting geothermal fluid. In certain cases, the holder of rights in the geothermal resource is a governmental entity and in other cases a private entity. Usually the duration of the lease (or sublease) and concession agreement corresponds to the duration of the relevant PPA, if any. In certain other cases, we own the land where the geothermal resource is located, in which case there are no restrictions on its utilization. Leasehold interests in federal land in the United States are regulated by the BLM and the Minerals Management Service. These agencies have rules governing the geothermal leasing process as discussed under the heading "Description of Our Leases and Lands."

For most of our current exploration sites in Nevada, we acquire rights to use geothermal resource through land leases with the BLM, with various states, or through private leases. Under these leases, we typically pay an up-front non-refundable bonus payment, which is a component of the competitive lease process. In addition, we undertake to pay nominal, fixed annual rent payments for the period from the commencement of the lease through the completion of construction. Upon the commencement of power generation, we begin to pay to the lessors long-term royalty payments based on the use of the geothermal resources as defined in the respective agreements. These payments are contingent on the power plant's revenues. There is a summary of our typical lease terms under the heading "Description of our Leases and Lands."

The up-front bonus and royalty payments vary from site to site and are based, among other things, on current market conditions.

Surveys. Following the acquisition of land rights for a potential geothermal resource, we conduct surface water analyses and soil surveys to determine proximity to possible heat flow anomalies and up-flow/permeable zones and augment our digital database with the results of those analyses. We then initiate a suite of geophysical surveys (e.g., gravity, magnetics, resistivity, magnetotellurics, and spectral surveys) to assess surface and sub-surface structure (e.g., faults and fractures) and develop a roadmap of fluid-flow conduits and overall permeability. All pertinent geophysical data are then used to create three-dimensional geothermal reservoir models that are used to identify drill locations.

We make a further determination of the commercial viability of the geothermal resource based on the results of this process, particularly the results of the geochemical and geophysical surveys. If the results from the geochemical and geophysical surveys are poor (i.e., low derived resource temperatures or poor permeability), we will re-evaluate the commercial viability of the geothermal resource and may not proceed to exploratory drilling.

Exploratory Drilling. If we proceed to exploratory drilling, we generally will use outside contractors to create access roads to drilling sites. After obtaining drilling permits, we generally drill temperature gradient holes and/or slim holes using either our own drilling equipment or outside contractors. However, exploration of some geothermal resources can require drilling a full-size well, particularly where the resource is deep underground. If the slim hole is "dry", it may be capped and the area reclaimed if we conclude that the geothermal resource will not support a commercially viable power project. If the slim hole supports a conclusion that the geothermal resource will support a commercially viable power plant, it may either be:

- Converted to a full-size commercial well, used either for extraction or reinjection of geothermal fluids (Production Well).
- Used as an observation well to monitor and define the geothermal resource.

The costs we incur for exploratory drilling vary from site to site based on various factors, including market demand for drilling contractors and equipment (which may be affected by on-shore oil and gas exploration activities, etc.), the accessibility of the drill site, the geology of the site, and the depth of the resource, among other things. However, on average, exploration drilling costs are approximately $5 million for each site.

At various points during our exploration activities, we re-assess whether the geothermal resource involved will support a commercially viable power plant. In each case, this re-assessment is based on information available at that time. Among other things, we consider the following factors:

- New information obtained concerning the geothermal resource as our exploration activities proceed, and particularly the expected MW capacity power plant the resource can be expected to support.

- Current and expected market conditions and rates for contracted and merchant electric power in the market(s) to be serviced.
- Anticipated costs associated with further exploration activities.
- Anticipated costs for design and construction of a power plant at the site.
- Anticipated costs for operation of a power plant at the site, particularly taking into account the ability to share certain types of costs (such as control rooms) with one or more other power plants that are, or are expected to be, operating near the site.

If we conclude that the geothermal resource involved will support a commercially viable power plant, we proceed to constructing a power plant at the site.

How We Construct Our Power Plants. The principal phases involved in constructing one of our geothermal power plants are as follows:

- Drilling Production Wells.
- Designing the well field, power plant, equipment, controls, and transmission facilities.
- Obtaining any required permits.
- Manufacturing (or in the case of equipment we do not manufacture ourselves, purchasing) the equipment required for the power plant.
- Assembling and constructing the well field, power plant, transmission facilities, and related facilities.

It generally takes approximately two years from the time we drill a Production Well, until the power plant becomes operational.

Drilling Production Wells. As noted above, we consider drilling the first Production Well as the beginning of our construction phase for a power plant. The number of Production Wells varies from plant to plant depending, among other things, on the geothermal resource, the projected capacity of the power plant, the power generation equipment to be used and the way geothermal fluids will be re-injected to maintain the geothermal resource and surface conditions. The Production Wells are normally drilled by our own drilling equipment. In some cases we use outside contractors, generally firms that service the on-shore oil and gas industry.

The cost for each Production Well varies depending, among other things, on the depth and size of the well and market conditions affecting the supply and demand for drilling equipment, labor and operators. On average, however, our costs for each Production Well range from $3 million to $5 million.

Design. We use our own employees to design the well field and the power plant, including equipment that we manufacture. The designs vary based on various factors, including local laws, required permits, the geothermal resource, the expected capacity of the power plant and the way geothermal fluids will be re-injected to maintain the geothermal resource and surface conditions.

Permits. We use our own employees and outside consultants to obtain any required permits and licenses for our power plants that are not already covered by the terms of our site leases. The permits and licenses required vary from site to site, and are described below under the heading "Environmental Permits."

Manufacturing. Generally, we manufacture most of the power generating unit equipment we use at our power plants. Multiple sources of supply are available for all other equipment we do not manufacture.

Construction. We use our own employees to manage the construction work. For site grading, civil, mechanical, and electrical work we use subcontractors.

Table of Contents

During the year ended December 31, 2011, one site (Olkaria III Phase III) moved to construction, and during each of the years ended December 31, 2010 and 2009, two sites moved to construction. In 2010 the sites were CD4 at the Mammoth complex and Wild Rose (formerly DH Wells), and in 2009, the sites were Carson Lake and McGinness Hills. During the years ended December 31, 2010 and 2009, we discontinued exploration activities at one site each year. Those sites were Gabbs Valley and Rock Hills, in Nevada. After conducting exploratory drilling in those sites, we concluded that the geothermal resource at those sites would not support commercially viable power plants at this time. The costs associated with exploration activities at those sites were expensed during the years ended December 31, 2010 and 2009, respectively, (see "Write-off of Unsuccessful Exploration Activities" under Item 7 — "Management Discussion and Analysis of Financial Condition and Results of Operations"). Thirteen new sites were added to our exploration and development activities in the year ended December 31, 2011, compared with seven sites in the year ended December 31, 2010 and with six sites in the year ended December 31, 2009.

How We Operate and Maintain Our Power Plants. In the U.S. we usually employ our subsidiary, Ormat Nevada, to act as operator of our power plants pursuant to the terms of an operation and maintenance agreement. Operation and maintenance of our foreign projects are generally provided by our subsidiary that owns the relevant project. Our operations and maintenance practices are designed to minimize operating costs without compromising safety or environmental standards while maximizing plant flexibility and maintaining high reliability. Our operations and maintenance practices for geothermal power plants seek to preserve the sustainable characteristics of the geothermal resources we use to produce electricity and maintain steady-state operations within the constraints of those resources reflected in our relevant geologic and hydrologic studies. Our approach to plant management emphasizes the operational autonomy of our individual plant or complex managers and staff to identify and resolve operations and maintenance issues at their respective power plants; however, each power plant or complex draws upon our available collective resources and experience, and that of our subsidiaries. We have organized our operations such that inventories, maintenance, backup, and other operational functions are pooled within each power plant complex and provided by one operation and maintenance provider. This approach enables us to realize cost savings and enhances our ability to meet our power plant availability goals.

Safety is a key area of concern to us. We believe that the most efficient and profitable performance of our power plants can only be accomplished within a safe working environment for our employees. Our compensation and incentive program includes safety as a factor in evaluating our employees, and we have a well-developed reporting system to track safety and environmental incidents, if any, at our power plants.

How We Sell Electricity. In the United States, the purchasers of power from our power plants are typically investor-owned electric utility companies. Outside of the United States, the purchaser is either a state-owned utility or a privately-owned entity and we typically operate our facilities pursuant to rights granted to us by a governmental agency pursuant to a concession agreement. In each case, we enter into long-term contracts (typically called PPAs) for the sale of electricity or the conversion of geothermal resources into electricity. A power plant's revenues under a PPA used to consist of two payments — energy payments and capacity payments; however our recent PPAs provide for energy payments only. Energy payments are normally based on a power plant's electrical output actually delivered to the purchaser measured in kilowatt hours, with payment rates either fixed or indexed to the power purchaser's "avoided" power costs (i.e., the costs the power purchaser would have incurred itself had it produced the power it is purchasing from third parties, such as us) or rates that escalate at a predetermined percentage each year. Capacity payments are normally calculated based on the generating capacity or the declared capacity of a power plant available for delivery to the purchaser, regardless of the amount of electrical output actually produced or delivered. In addition, most of our domestic power plants located in California are eligible for capacity bonus payments under the respective PPAs upon reaching certain levels of generation.

How We Finance Our Power Plants. Historically we have funded our power plants with a combination of non-recourse or limited recourse debt, lease financing, parent company loans, and internally generated cash,

Table of Contents

which includes funds from operation, as well as proceeds from loans under corporate credit facilities, sale of securities, and other sources of liquidity. Such leveraged financing permits the development of power plants with a limited amount of equity contributions, but also increases the risk that a reduction in revenues could adversely affect a particular power plant's ability to meet its debt obligations. Leveraged financing also means that distributions of dividends or other distributions by plant subsidiaries to us are contingent on compliance with financial and other covenants contained in the financing documents.

Non-recourse debt or lease financing refers to debt or lease arrangements involving debt repayments or lease payments that are made solely from the power plant's revenues (rather than our revenues or revenues of any other power plant) and generally are secured by the power plant's physical assets, major contracts and agreements, cash accounts and, in many cases, our ownership interest in our affiliate that owns that power plant. These forms of financing are referred to as "project financing." Project financing transactions generally are structured so that all revenues of a power plant are deposited directly with a bank or other financial institution acting as escrow or security deposit agent. These funds are then payable in a specified order of priority set forth in the financing documents to ensure that, to the extent available, they are used to first pay operating expenses, senior debt service (including lease payments) and taxes, and to fund reserve accounts. Thereafter, subject to satisfying debt service coverage ratios and certain other conditions, available funds may be disbursed for management fees or dividends or, where there are subordinated lenders, to the payment of subordinated debt service.

In the event of a foreclosure after a default, our affiliate that owns the power plant would only retain an interest in the assets, if any, remaining after all debts and obligations have been paid in full. In addition, incurrence of debt by a power plant may reduce the liquidity of our equity interest in that power plant because the interest is typically subject both to a pledge in favor of the power plant's lenders securing the power plant's debt and to transfer and change of control restrictions set forth in the relevant financing agreements.

Limited recourse debt refers to project financing as described above with the addition of our agreement to undertake limited financial support for our affiliate that owns the power plant in the form of certain limited obligations and contingent liabilities. These obligations and contingent liabilities may take the form of guarantees of certain specified obligations, indemnities, capital infusions and agreements to pay certain debt service deficiencies. To the extent we become liable under such guarantees and other agreements in respect of a particular power plant, distributions received by us from other power plants and other sources of cash available to us may be required to be used to satisfy these obligations. To the extent of these limited recourse obligations, creditors of a project financing of a particular power plant may have direct recourse to us.

We have also used a financing structure to monetize PTCs and other favorable tax benefits derived from the financed power plants and an operating lease arrangement for one of our power plants.

How We Mitigate International Political Risk. We generally purchase insurance policies to cover our exposure to certain political risks involved in operating in developing countries, as described below under the heading "Insurance". To date, our political risk insurance contracts are with the Multilateral Investment Guaranty Agency (MIGA), a member of the World Bank Group, and Zurich Re, a private insurance and re-insurance company. Such insurance policies generally cover, subject to the limitations and restrictions contained therein, 80% to 90% of our revenue loss derived from a specified governmental act such as confiscation, expropriation, riots, the inability to convert local currency into hard currency, and, in certain cases, the breach of agreements. We have obtained such insurance for all of our foreign power plants in operation.

Description of Our Leases and Lands

We have domestic leases on approximately 481,000 acres of federal, state, and private land in California, Nevada, Utah, Alaska, Hawaii, Oregon, and Idaho. The approximate breakdown between federal, state, and private leases is as follows:

- 72% are leases with the U.S. government, acting through the BLM;

- 15% are leases with various states, none of which is currently material; and
- 13% are leases with private landowners and/or leaseholders.

Each of the leases within each of the categories has standard terms and requirements, as summarized below. We own approximately 6,700 acres of land in Nevada and California. Internationally, our land position includes approximately 365,000 acres, most of which are geothermal exploration licenses in six prospects in Chile. In addition, we own land, a portion of which is used for our Heber Solar PV project.

Bureau of Land Management Geothermal Leases

Certain of our domestic project subsidiaries have entered into geothermal resources leases with the U.S. government, pursuant to which they have obtained the right to conduct their geothermal development and operations on federally-owned land. These leases are made pursuant to the Geothermal Steam Act and the lessor under such leases is the U.S. government, acting through the BLM.

BLM geothermal leases grant the geothermal lessee the right and privilege to drill for, extract, produce, remove, utilize, sell, and dispose of geothermal resources on certain lands, together with the right to build and maintain necessary improvements thereon. The actual ownership of the geothermal resources and other minerals beneath the land is retained in the federal mineral estate. The geothermal lease does not grant to the geothermal lessee the exclusive right to develop the lands, although the geothermal lessee does hold the exclusive right to develop geothermal resources within the lands. The geothermal lessee does not have the right to develop minerals unassociated with geothermal production and cannot prohibit others from developing the minerals present in the lands. The BLM may grant multiple leases for the same lands and, when this occurs, each lessee is under a duty to not unreasonably interfere with the development rights of the other. Because BLM leases do not grant to the geothermal lessee the exclusive right to use the surface of the land, BLM may grant rights to others for activities that do not unreasonably interfere with the geothermal lessee's uses of the same land; such other activities may include recreational use, off-road vehicles, and/or wind or solar energy developments.

Certain BLM leases issued before August 8, 2005 include covenants that require the projects to conduct their operations under the lease in a workmanlike manner and in accordance with all applicable laws and BLM directives and to take all mitigating actions required by the BLM to protect the surface of and the environment surrounding the land. Additionally, certain leases contain additional requirements, some of which concern the mitigation or avoidance of disturbance of any antiquities, cultural values or threatened or endangered plants or animals, the payment of royalties for timber, and the imposition of certain restrictions on residential development on the leased land.

BLM leases entered into after August 8, 2005 require the geothermal lessee to conduct operations in a manner that minimizes impacts to the land, air, water, to cultural, biological, visual, and other resources, and to other land uses or users. The BLM may require the geothermal lessee to perform special studies or inventories under guidelines prepared by the BLM. The BLM reserves the right to continue existing leases and to authorize future uses upon or in the leased lands, including the approval of easements or rights-of-way. Prior to disturbing the surface of the leased lands, the geothermal lessee must contact the BLM to be apprised of procedures to be followed and modifications or reclamation measures that may be necessary. Subject to BLM approval, geothermal lessees may enter into unit agreements to cooperatively develop a geothermal resource. The BLM reserves the right to specify rates of development and to require the geothermal lessee to commit to a communalization or unitization agreement if a common geothermal resource is at risk of being overdeveloped.

Typical BLM leases issued to geothermal lessees before August 8, 2005 have a primary term of ten years and will renew so long as geothermal resources are being produced or utilized in commercial quantities, but cannot exceed a period of forty years after the end of the primary term. If at the end of the forty-year period geothermal steam is still being produced or utilized in commercial quantities and the lands are not needed for other purposes, the geothermal lessee will have a preferential right to renew the lease for a second forty-year term, under terms and conditions as the BLM deems appropriate.

BLM leases issued after August 8, 2005 have a primary term of ten years. If the geothermal lessee does not reach commercial production within the primary term the BLM may grant two five-year extensions if the geothermal lessee: (i) satisfies certain minimum annual work requirements prescribed by the BLM for that lease, or (ii) makes minimum annual payments. Additionally, if the geothermal lessee is drilling a well for the purposes of commercial production, the primary term (as it may have been extended) may be extended for five years and as long thereafter as steam is being produced and used in commercial quantities (meaning the geothermal lessee either begins producing geothermal resources in commercial quantities or has a well capable of producing geothermal resources in commercial quantities and is making diligent efforts to utilize the resource) for thirty-five years. If, at the end of the extended thirty-five year term, geothermal steam is still being produced or utilized in commercial quantities and the lands are not needed for other purposes, the geothermal lessee will have a preferential right to renew the lease for fifty-five years, under terms and conditions as the BLM deems appropriate.

For BLM leases issued before August 8, 2005, the geothermal lessee is required to pay an annual rental fee (on a per acre basis), which escalates according to a schedule described therein, until production of geothermal steam in commercial quantities has commenced. After such production has commenced, the geothermal lessee is required to pay royalties (on a monthly basis) on the amount or value of (i) steam, (ii) by-products derived from production, and (iii) commercially de-mineralized water sold or utilized by the project (or reasonably susceptible to such sale or use).

For BLM leases issued after August 8, 2005, (i) a geothermal lessee who has obtained a lease through a non-competitive bidding process will pay an annual rental fee equal to $1.00 per acre for the first ten years and $5.00 per acre each year thereafter; and (ii) a geothermal lessee who has obtained a lease through a competitive process will pay a rental equal to $2.00 per acre for the first year, $3.00 per acre for the second through tenth year and $5.00 per acre each year thereafter. Rental fees paid before the first day of the year for which the rental is owed will be credited towards royalty payments for that year. For BLM leases issued, effective, or pending on August 5, 2005 or thereafter, royalty rates are fixed between 1-2.5% of the gross proceeds from the sale of electricity during the first ten years of production under the lease. The royalty rate set by the BLM for geothermal resources produced for the commercial generation of electricity but not sold in an arm's length transaction is 1.75% for the first ten years of production and 3.5% thereafter. The royalty rate for geothermal resources sold by the geothermal lessee or an affiliate in an arm's length transaction is 10% of the gross proceeds from the arm's length sale. The BLM may readjust the rental or royalty rates at not less than twenty year intervals beginning thirty-five years after the date geothermal steam is produced.

In the event of a default under any BLM lease, or the failure to comply with any of the provisions of the Geothermal Steam Act or regulations issued under the Geothermal Steam Act or the terms or stipulations of the lease, the BLM may, 30 days after notice of default is provided to the relevant project, (i) suspend operations until the requested action is taken, or (ii) cancel the lease.

Private Geothermal Leases

Certain of our domestic project subsidiaries have entered into geothermal resources leases with private parties, pursuant to which they have obtained the right to conduct their geothermal development and operations on privately owned land. In many cases, the lessor under these private geothermal leases owns only the geothermal resource and not the surface of the land.

Typically, the leases grant our project subsidiaries the exclusive right and privilege to drill for, produce, extract, take and remove from the leased land water, brine, steam, steam power, minerals (other than oil), salts, chemicals, gases (other than gases associated with oil), and other products produced or extracted by such project subsidiary. The project subsidiaries are also granted certain non-exclusive rights pertaining to the construction and operation of plants, structures, and facilities on the leased land. Additionally, the project subsidiaries are granted the right to dispose of waste brine and other waste products as well as the right to reinject into the leased

Table of Contents

land water, brine, steam, and gases in a well or wells for the purpose of maintaining or restoring pressure in the productive zones beneath the leased land or other land in the vicinity. Because the private geothermal leases do not grant to the lessee the exclusive right to use the surface of the land, the lessor reserves the right to conduct other activities on the leased land in a manner that does not unreasonably interfere with the geothermal lessee's uses of the same land, which other activities may include agricultural use (farming or grazing), recreational use and hunting, and/or wind or solar energy developments.

The leases provide for a term consisting of a primary term in the range of five to 30 years, depending on the lease, and so long thereafter as lease products are being produced or the project subsidiary is engaged in drilling, extraction, processing, or reworking operations on the leased land.

As consideration under most of our project subsidiaries' private leases, the project subsidiary must pay to the lessor a certain specified percentage of the value "at the well" (which is not attributable to the enhanced value of electricity generation), gross proceeds, or gross revenues of all lease products produced, saved, and sold on a monthly basis. In certain of our project subsidiaries' private leases, royalties payable to the lessor by the project subsidiary are based on the gross revenues received by the lessee from the sale or use of the geothermal substances, either from electricity production or the value of the geothermal resource "at the well".

In addition, pursuant to the leases, the project subsidiary typically agrees to commence drilling, extraction or processing operations on the leased land within the primary term, and to conduct such operations with reasonable diligence until lease products have been found, extracted and processed in quantities deemed "paying quantities" by the project subsidiary, or until further operations would, in such project subsidiary's judgment, be unprofitable or impracticable. The project subsidiary has the right at any time within the primary term to terminate the lease and surrender the relevant land. If the project subsidiary has not commenced any such operations on said land (or on the unit area, if the lease has been unitized), or terminated the lease within the primary term, the project subsidiary must pay to the lessor, in order to maintain its lease position, annually in advance, a rental fee until operations are commenced on the leased land.

If the project subsidiary fails to pay any installment of royalty or rental when due and if such default continues for a period of fifteen days specified in the lease, for example, after its receipt of written notice thereof from the lessor, then at the option of the lessor, the lease will terminate as to the portion or portions thereof as to which the project subsidiary is in default. If the project subsidiary defaults in the performance of any obligations under the lease, other than a payment default, and if, for a period of 90 days after written notice is given to it by the lessor of such default, the project subsidiary fails to commence and thereafter diligently and in good faith take remedial measures to remedy such default, the lessor may terminate the lease.

We do not regard any property that we lease as material unless and until we begin construction of a power plant on the property, that is, until we drill a production well on the property.

Exploration Concessions in Chile

We have been awarded six exploration concessions in Chile, under which we have the rights to start exploration work with an original term of two years. Prior to the last six months of the original term of each exploration concession, we can request its extension for an additional period of two years. According to applicable regulations, the extension of the exploration concession is subject to the receipt by the Ministry of Energy of evidence that at least 25% of the planned investments for the execution of the project, as reflected in the relevant proposal submitted during the tender process, has been invested. Following submission of the request, the Ministry of Energy has three months in which it may grant or deny the extension.

Description of Our Power Plants

Domestic Power Plants

The following descriptions summarize certain industry metrics for our domestic power plants:

Brady Complex

Location	Churchill County, Nevada
Generating Capacity	25 MW
Number of Power Plants	2 (Brady and Desert Peak 2 power plants).
Technology	The Brady complex utilizes binary and flash systems. The complex uses air and water cooled systems.
Subsurface Improvements	12 production wells and 6 injection wells are connected to the plants through a gathering system.
Major Equipment	Three OEC units and three steam turbines along with Balance of Plant equipment.
Age	The Brady power plant commenced commercial operations in 1992 and a new OEC unit was added in 2004. The Desert Peak 2 power plant commenced commercial operation in 2007.
Land and Mineral Rights	The Brady complex area is comprised of mainly BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases, and the Brady power plant holds right of ways from the BLM and from the private owner that allows access to and from the plant.
Resource Information	The resource temperature at Brady is 278 degrees Fahrenheit and at Desert Peak 2 is 370 degrees Fahrenheit. The Brady and Desert Peak geothermal systems are located within the Hot Springs Mountains, approximately 60 miles northeast of Reno, Nevada, in northwestern Churchill County. The dominant geological feature of the Brady area is a linear NNE-trending band of hot ground that extends for a distance of two miles. The Desert Peak geothermal field is located within the Hot Springs Mountains, which form part of the western boundary of the Carson Sink. The structure is characterized by east-titled fault blocks and NNE-trending folds. Geologic structure in the area is dominated by high-angle normal faults of varying displacement.

Resource Cooling	Approximately 4 degrees Fahrenheit per year was observed at Brady during the past 15 years of production. The temperature decline at Desert Peak is less than 1 degree Fahrenheit per year.
Sources of Makeup Water	Condensed steam is used for makeup water.

Power Purchaser	Brady power plant — Sierra Pacific Power Company. Desert Peak 2 power plant — Nevada Power Company.
PPA Expiration Date	Brady power plant — 2022. Desert Peak 2 power plant — 2027.
Financing	OFC Senior Secured Notes (Brady) and OPC Transaction (Desert Peak 2).

Heber Complex

Location	Heber, Imperial County, California
Generating Capacity	92 MW
Number of Power Plants	5 (Heber 1, Heber 2, Heber South, G-1 and G-2).
Technology	The Heber 1 plant utilizes dual flash and the Heber 2, Heber South, G-1 and G-2 plants utilize binary systems. The complex uses a water cooled system.
Subsurface Improvements	31 production wells and 34 injection wells connected to the plants through a gathering system.
Major Equipment	17 OEC units and 1 steam turbine with the Balance of Plant equipment.
Age	The Heber 1 plant commenced commercial operations in 1985 and the Heber 2 plant in 1993. The G-1 plant commenced commercial operation in 2006 and the G-2 plant in 2005. The Heber South plant commenced commercial operation in 2008.
Land and Mineral Rights	The total Heber area is comprised of mainly private leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The resource supplying the flash flowing Heber 1 wells averages 350 degrees Fahrenheit. The resource supplying the pumped Heber 2 wells averages 318 degrees Fahrenheit.

Heber production is from deltaic sedimentary sandstones deposited in the subsiding Salton Trough of California's Imperial Valley. Produced fluids rise from near the magmatic heated basement rocks (18,000 feet) via fault/fracture zones to the near surface. Heber 1 wells produce directly from deep (4,000 to 8,000 feet) fracture zones. Heber 2 wells

	produce from the nearer surface (2,000 to 4,000 feet) matrix permeability sandstones in the horizontal outflow plume fed by the fractures from below and the surrounding ground waters. Scale deposition in the flashing Heber 1 producers is controlled by down hole chemical inhibition supplemented with occasional mechanical cleanouts and acid treatments. There is no scale deposition in the Heber 2 production wells.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Sources of Makeup Water	Water is provided by condensate and by the IID.
Power Purchaser	2 PPAs with Southern California Edison and 1 PPA with SCPPA.
PPA Expiration Date	Heber 1 — 2015, Heber 2 — 2023, and Heber South — 2031. The output from the G-1 and G-2 power plants is sold under the PPAs of Southern California Edison and SCPPA.
Financing	OrCal Senior Secured Notes.
Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues. We plan to enhance the complex and add 6 MW, if negotiation on new PPA will succeed.

Jersey Valley Power Plant

Location	Pershing County, Nevada
Generating Capacity	12 MW (See supplemental information below)
Number of Power Plants	1
Technology	The Jersey Valley power plant utilizes an air cooled binary system.
Subsurface Improvements	2 production wells and 4 injection wells are connected to the plant through a gathering system. The drilling of the third production well was completed and will be used in the future as required. Drilling of additional injection wells is currently under development.
Major Equipment	2 OEC units together with the Balance of Plant equipment.

Table of Contents

Age	Construction of the power plant was completed at the end of 2010 and the off-taker approved commercial operation status under the PPA effective on August 30, 2011.
Land and Mineral Rights	The Jersey Valley area is comprised of BLM leases. The leases are held

	by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants.
	The power plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from leased property and access across leased property under surface rights granted in leases from BLM.
Resource Information	The Jersey Valley geothermal reservoir consists of a small high-permeability area surrounded by a large low-permeability area. The high-permeability area has been defined by wells drilled along an interpreted fault trending west-northwest. Static water levels are artesian; two of the wells along the permeable zone have very high productivities, as indicated by Permeability Index (PI) values exceeding 20 gpm/psi.

The average temperature of the resource is 330 degrees Fahrenheit.

Power Purchaser	Nevada Power Company.
PPA Expiration Date	January 1, 2032
Financing	Corporate funds.
	Once the Jersey Valley power plant reaches certain operational targets and meets other conditions precedent we have the ability to borrow additional funds under the OFC 2 Senior Secured Notes.
	We have submitted an application for the ITC cash grant for the power plant.
Supplemental Information	The Jersey Valley power plant is currently operating below its designed capacity. This is primarily due to the need to shut down one of the injection wells that was rendered unusable by old mining wells that we believe were not adequately plugged when abandoned by the mining operator that previously operated on the land.
	We have drilled an additional injection well, which is being connected to the plant.
	We have identified targets for additional wells and will continue to drill to improve injection capacity.

Mammoth Complex

Location	Mammoth Lakes, California

Generating Capacity	29 MW
Number of Power Plants	3 (G-1, G-2, and G-3).
Technology	The Mammoth complex utilizes air cooled binary systems.

Subsurface Improvements	11 production wells and 5 injection wells connected to the plants through a gathering system.
Major Equipment	8 Rotoflow expanders together with the Balance of Plant equipment.
Age	The G-1 plant commenced commercial operations in 1984 and G-2 and G-3 commenced commercial operation in 1990.
Land and Mineral Rights	The total Mammoth area is comprised mainly of BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands." We recently purchased land at Mammoth that was owned by a third party. This purchase will reduce royalty expenses for the Mammoth complex.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The average resource temperature is 339 degrees Fahrenheit. The Casa Diablo/Basalt Canyon geothermal field at Mammoth lies on the southwest edge of the resurgent dome within the Long Valley Caldera. It is believed that the present heat source for the geothermal system is an active magma body underlying the Mammoth Mountain to the northwest of the field. Geothermal waters heated by the magma flow from a deep source (> 3,500 feet) along faults and fracture zones from northwest to southeast east into the field area. The produced fluid has no scaling potential.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Power Purchaser	Southern California Edison.
PPA Expiration Date	G-1 — 2014, G2 and G-3 — 2020.
Financing	50% — OFC Senior Secured Notes and 50% — corporate funds.

Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues.

We are in the process of repowering the Mammoth complex by replacing part of the old units with new Ormat-manufactured equipment. The replacement of the equipment will optimize generation and add approximately 3 MW of generating capacity to the complex..

North Brawley Power Plant

Location	Imperial County, California
Generating Capacity	33 MW (See supplemental information below)
Number of Power Plants	1
Technology	The North Brawley power plant utilizes a water-cooled binary system.
Subsurface Improvements	16 production wells and 21 injection wells are currently connected to the plant through a gathering system. An additional production well is currently being completed.
Major Equipment	5 OEC units together with the Balance of Plant equipment.
Age	The power plant was placed in service on January 15, 2010 with commercial operation having commenced on March 31, 2011.
Land and Mineral Rights	The total North Brawley area is comprised of private leases. The leases are held by production. The scheduled expiration date for all of these leases is after the end of the expected useful life of the power plant. The plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	North Brawley production is from deltaic and marine sedimentary sands and sandstones deposited in the subsiding Salton Trough of the Imperial Valley. Based on seismic refraction surveys the total thickness of these sediments in the Brawley area is over 15,000 feet. The shallow production reservoir (1,500 – 4,500 feet) that was developed is fed by fractures and matrix permeability and is

conductively heated from the underlying fractured reservoir which convectively circulates magmatically heated fluid. Produced fluid salinity ranges from 20,000 to 50,000 ppm, and the moderate scaling and corrosion potential is chemically inhibited. The temperature of the deeper fractured reservoir fluids exceed 525 degrees Fahrenheit, but the fluid is not yet developed because of severe scaling and corrosion potential. The deep reservoir is not dedicated to the North Brawley power plant.

The average produced fluid resource temperature is 335 degrees Fahrenheit.

Sources of Makeup Water	Water is provided by IID.
Power Purchaser	Southern California Edison
PPA Expiration Date	2031
Financing	Corporate funds and ITC cash grant from the U.S. Treasury.
Supplemental Information	The ramp up of the field has been slow and expensive. While we believe that the reservoir is large enough to support the originally designed generation capacity of 50 MW, the operation of the production wells, injection wells and the handling of the geothermal fluid has been a challenge. On March 31, 2011, Southern California Edison set the demonstrated capacity of the power plant at 33MW. Southern California Edison also agreed to modify the PPA to allow us the option of performing an additional capacity demonstration until March 31, 2012. There is ongoing work to increase the generation of the power plant. We have set new targets for production wells and identified improvements that we can make to the injection wells, all in parallel with our effort to reduce the operating expenses, mostly through modifications that would extend the service time of the production pumps. The power plant currently has an interim transmission agreement with IID. A transmission study that is in progress will allow IID to enter into a permanent transmission agreement. To date the study has been delayed due to extensive analysis by the utility and maintenance activity on the transmission corridor.

OREG 1 Power Plant

Location	Four gas compressor stations along the Northern Border natural gas pipeline in North and South Dakota
Generating Capacity	22 MW
Number of Units	4

Technology	The OREG 1 power plant utilizes our air cooled OEC units.
Major Equipment	4 WHOH and 4 OEC units together with the Balance of Plant equipment.
Age	The OREG 1 power plant commenced commercial operations in 2006.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Basin Electric Power Cooperative.

PPA Expiration Date	2031
Financing	Corporate funds.

OREG 2 Power Plant

Location	Four gas compressor stations along the Northern Border natural gas pipeline; one in Montana, two in North Dakota, and one in Minnesota
Generating Capacity	22 MW
Number of Units	4
Technology	The OREG 2 power plant utilizes our air cooled OEC units.
Major Equipment	4 WHOH and 4 OEC units together with the Balance of Plant equipment.
Age	The OREG 2 power plant commenced commercial operations during 2009.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Basin Electric Power Cooperative.
PPA Expiration Date	2034
Financing	Corporate funds.

OREG 3 Power Plant

Location	A gas compressor station along Northern Border natural gas pipeline in Martin County, Minnesota
Generating Capacity	5.5 MW
Number of Units	1

Technology	The OREG 3 power plant utilizes our air cooled OEC units.
Major Equipment	One WHOH and one OEC unit along with the Balance of Plant equipment.
Age	The OREG 3 power plant commenced commercial operations during 2010.
Land	Easement from NBPL.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Great River Energy
PPA Expiration Date	2029
Financing	Corporate funds.

OREG 4 Power Plant

Location	A gas compressor station along natural gas pipeline in Denver, Colorado
Generating Capacity	3.5 MW
Number of Units	1
Technology	The OREG 4 power plant utilizes our air cooled OEC units.
Major Equipment	2 WHOH and 1 OEC unit together with the Balance of Plant equipment.
Age	The OREG 4 power plant commenced commercial operations during 2009.
Land	Easement from Trailblazer Pipeline Company.
Access to Property	Direct access to the plant from public roads.
Power Purchaser	Highline Electric Association
PPA Expiration Date	2029
Financing	Corporate funds.

Ormesa Complex

Location	East Mesa, Imperial County, California
Generating Capacity	54 MW
Number of Power Plants	4 (OG I, OG II, GEM 2 and GEM 3).
Technology	The OG plants utilize a binary system and the GEM plants utilize a flash system. The complex uses a water cooling system.

Subsurface Improvements	32 production wells and 52 injection wells connected to the plants through a gathering system.
Material Major Equipment	32 OEC units and 2 steam turbines with the Balance of Plant equipment.
Age	The various OG I units commenced commercial operations between 1987 and 1989, and the OG II plant commenced commercial operation in 1988. Between 2005 and 2007 a significant portion of the old equipment in the OG plants was replaced (including turbines through repowering). The GEM plants commenced commercial operation in 1989, and a new bottoming unit was added in 2007.
Land and Mineral Rights	The total Ormesa area is comprised of BLM leases. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants. The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The resource temperature is an average of 307 degrees Fahrenheit. Production is from sandstones. Productive sandstones are between 1,800 and 6,000 feet, and have only matrix permeability. The currently developed thermal anomaly was created in geologic time by conductive heating and direct outflow from an underlying convective fracture system. Produced fluid salinity ranges from 2,000 ppm to 13,000 ppm, and minor scaling and corrosion potential is chemically inhibited.
Resource Cooling	1 degree Fahrenheit per year was observed during the past 20 years of production.
Sources of Makeup Water	Water is provided by the IID.
Power Purchaser	Southern California Edison under a single PPA.
PPA Expiration Date	2018
Financing	OFC Senior Secured Notes.
Supplemental Information	As a result of the significant decrease in natural gas price forecasts for 2012 and 2013 and the delay of California's GHG cap-and-trade program that is now scheduled to begin in 2013, each of which is uncertain and subject to changes, we are currently looking at alternative contractual solutions to the PPAs. However, using the January 2012 estimates for gas prices in 2012 and 2013, it is expected that the new SRAC price formulas will reduce our revenues.

Puna Complex

Location	Puna district, Big Island, Hawaii
Generating Capacity	38 MW
Number of Power Plants	2
Technology	The Puna plants utilize our geothermal combined cycle and binary systems. The plants use an air cooled system.
Subsurface Improvements	5 production wells and 4 injection wells connected to the plants through a gathering system. We are preparing to drill a sixth production well.
Major Equipment	One plant consists of 10 OEC units consisting of 10 binary turbines, 10 steam turbines and two bottoming units along with the Balance of Plant equipment. The second plant consists of 2 OEC units along with Balance of Plant equipment.
Age	The first plant commenced commercial operation in 1993. The second plant was placed in service in 2011, but has not yet reached commercial operation.

Land and Mineral Rights	The Puna area is comprised of a private lease. The private lease is between PGV and KLP and it expires in 2046. PGV pays annual rental payment to KLP, which is adjusted every 5 years based on the CPI.
	The state of Hawaii owns all mineral rights (including geothermal resources) in the state. The state has issued a Geothermal Resources Mining Lease to KLP, and KLP in turn has entered into a sublease agreement with PGV, with the state's consent. Under this arrangement, the state receives royalties of approximately 3% of the gross revenues.
Access to Property	Direct access to the leased property is readily available via county public roads located adjacent to the leased property. The public roads are at the north and south boundaries of the leased property.
Resource Information	The geothermal reservoir at Puna is located in volcanic rock along the axis of the Kilauea Lower East Rift Zone. Permeability and productivity are controlled by rift-parallel subsurface fissures created by volcanic activity. They may also be influenced by lens-shaped bodies of pillow basalt which have been postulated to exist along the axis of the rift at depths below 7,000 feet.
	The distribution of reservoir temperatures is strongly influenced by the configuration of subsurface fissures and temperatures are among the hottest of any geothermal field in the world, with maximum measured temperatures consistently above 650 degrees Fahrenheit.
Resource Cooling	The resource temperature is stable.
Power Purchaser	3 PPAs with HELCO (see "Supplemental Information" below).

PPA Expiration Date	December 31, 2027.
Financing	Operating Lease.
	We have submitted an application for an ITC cash grant for the new 8 MW power plant.
Supplemental Information	The construction of the new 8 MW power plant has been completed and it was placed in service.
	We signed a new PPA with HELCO that was recently approved by the PUCH, under which the Puna power plant will deliver to the HELCO grid an additional dispatchable 8 MW and will revise the pricing for the energy that is sold from the Puna complex as follows:
	For the first on-peak 25 MW, the energy price has not changed from HELCO avoided cost.
	For the next on-peak 5 MW, the price has changed from a diesel-based price to a flat rate of 11.8 cents per kWh escalated by 1.5% per year.
	For the new on-peak 8 MW, the price is 9 cents per kWh for up to 30,000 MWh/year and 6 cents per kWh above 30,000 MWh/year, escalated by 1.5% per year.
	• For the first off-peak 22 MW the energy price has not changed from avoided cost.

The off-peak energy above 22 MW is dispatchable:

- For the first off-peak 5 MW, the price has changed from diesel-based price to a flat rate of 11.8 cents per kWh escalated by 1.5% per year.
- For the energy above 27 MW (up to 38 MW) the price is 6 cents per kWh, escalated by 1.5% per year.

The capacity payment for the first 30 MW remains the same ($160 kW/year for the first 25 MW and $100.95 kW/year for the additional 5 MW). For the new 8MW power plant the annual capacity payment is $2 million.

Steamboat Complex

Location

Steamboat, Washoe County, Nevada

Generating Capacity

86 MW

Number of Power Plants

7 (Steamboat 1A, Steamboat 2 and 3, Burdette (Galena 1), Steamboat Hills, Galena 2 and Galena 3).

Technology

The Steamboat complex utilizes a binary system (except for Steamboat Hills, which utilizes a single flash system). The complex uses air and water cooling systems.

Subsurface Improvements

23 production wells and 8 injection wells connected to the plants through a gathering system.

Major Equipment

12 individual air cooled OEC units and one steam turbine together with the Balance of Plant equipment.

Age

The Steamboat 1A plant commenced commercial operation in 1988 and the other plants commenced commercial operation in 1992, 2005, 2007 and 2008. During 2008, the Rotoflow expanders at Steamboat 2 and 3 were replaced with four turbines manufactured by us and we repowered Steamboat 1A.

Land and Mineral Rights

The total Steamboat area is comprised of 41% private leases, 41% BLM leases and 18% private land owned by us. The leases are held by production. The scheduled expiration dates for all of these leases are after the end of the expected useful life of the power plants.

The complex's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

We have easements for the transmission lines we use to deliver power to our power purchasers.

Resource Information

The resource temperature is an average of 292 degrees Fahrenheit.

The Steamboat geothermal field is a typical basin and range geothermal reservoir. Large and deep faults that occur in the rocks allow circulation of ground water to depths exceeding 10,000 feet below the surface. Horizontal zones of permeability permit the hot water to flow eastward in an out-flow plume.

Steamboat Hills and Galena 2 power plants produce hot water from fractures associated with normal faults. The rest of the power plants acquire their geothermal water from the horizontal out-flow plume.

The water in the Steamboat reservoir has a low total solids concentration. Scaling potential is very low unless the fluid is allowed to flash which will result in calcium carbonate scale. Injection of cooled water for reservoir pressure maintenance prevents flashing.

Resource Cooling	2 degrees Fahrenheit per year was observed during the past 20 years of production.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Sources of Makeup Water	Water is provided by condensate and the local utility.
Power Purchaser	Sierra Pacific Power Company (for Steamboat 1A, Steamboat 2 and 3, Burdette, Steamboat Hills, and Galena 3) and Nevada Power Company (for Galena 2).
PPA Expiration Date	Steamboat 1A — 2018, Steamboat 2 and 3 — 2022, Burdette — 2026, Steamboat Hills — 2018, Galena 3 — 2028, and Galena 2 — 2027.

Financing	OFC Senior Secured Notes (Steamboat 1A, Steamboat 2 and 3, and Burdette) and OPC Transaction (Steamboat Hills, Galena 2, and Galena 3).

Tuscarora Power Plant

Location	Elko County, Nevada
Projected Generating Capacity	18 MW
Number of Power Plants	1
Technology	The Tuscarora power plant utilizes a water cooled binary system.
Subsurface Improvements	3 production and 5 injection wells are connected to the power plant. A fourth production well is under development.
Major Equipment	2 water cooled OEC units with the Balance of Plant equipment.
Age	The power plant commenced commercial operation on January 11, 2012.
Land and Mineral Rights	The Tuscarora area is comprised of private and BLM leases.

The leases are currently held by payment of annual rental payments, as described in "Description of Our Leases and Lands."

The plant's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Resource Information	The Tuscarora geothermal reservoir consists of an area of approximately 2.5 square miles. The reservoir is contained in both Tertiary and Paleozoic (basement) rocks. The Paleozoic section consists primarily of sedimentary rocks, overlain by Tertiary volcanic rocks. Thermal fluid in the native state of the reservoir flows upward and to the north through apparently southward-dipping, basement formations. At an elevation of roughly 2,500 feet with respect to mean sea level, the upwelling thermal fluid enters the Tertiary volcanic rocks and flows directly upward, exiting to the surface at Hot Sulphur Springs. The resource temperature averages 346 degrees Fahrenheit.
Resource Cooling	Will be established in the future.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Sources of Makeup Water	Water is provided from two water makeup wells. A third makeup well will be added.
Power Purchaser	Nevada Power Company

Table of Contents

PPA Expiration Date	2032
Financing	OFC 2 Senior Secured Notes. We plan to file an application for an ITC cash grant for the power plant.

Foreign Power Plants

The following descriptions summarize certain industry metrics for our foreign power plants:

Amatitlan Power Plant (Guatemala)

Location	Amatitlan, Guatemala
Generating Capacity	18 MW
Number of Power Plants	1
Technology	The Amatitlan power plant utilizes an air cooled binary system and a small back pressure steam turbine (1MW).
Subsurface Improvements	5 production wells and 2 injection wells connected to the plants through a gathering system.
Major Equipment	1 steam turbine and 2 OEC units together with the Balance of Plant equipment.
Age	The plant commenced commercial operation in 2007.
Land and Mineral Rights	Total resource concession area (under usufruct agreement with INDE) is for a term of 25 years from April 2003. Leased and company owned property is approximately 3% the of concession area. Under the

	agreement with INDE, the power plant company pays royalties of 3.5% of revenues up to 20.5 MW and 2% of revenues exceeding 20.5 MW.
	The generated electricity is sold at the plant fence. The transmission line is owned by INDE.
Resource Information	The resource temperature is an average of 530 degrees Fahrenheit.
	The Amatitlan geothermal area is located on the north side of the Pacaya Volcano at approximately 5,900 feet above sea level.
	Hot fluid circulates up from a heat source beneath the volcano, through deep faults to shallower depths, and then cools as it flows horizontally to the north and northwest to hot springs on the southern shore of Lake Amatitlan and the Michatoya River Valley.
Resource Cooling	Approximately 2 degrees Fahrenheit per year.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.

Power Purchasers	INDE and another local purchaser.
PPA Expiration Date	Contract with INDE expires in 2028.
Financing	Senior secured project loan from TCW Global Project Fund II, Ltd.
Supplemental Information	The power plant was registered by the United Nations Framework Convention on Climate Change as a Clean Development Mechanism. It is expected to offset emissions of approximately 83,000 tons of CO_2 per year.
	The power plant has a long-term contract to sell all of its emission reduction credits to a European buyer.

Momotombo Power Plant (Nicaragua)

Location	Momotombo, Nicaragua
Generating Capacity	22 MW
Number of Power Plants	1
Technology	The Momotombo power plant utilizes single flash and binary systems. The plant uses air and water cooled systems.
Subsurface Improvements	10 production wells and 7 injection wells connected to the plants through a gathering system.
Major Equipment	1 steam turbine and 1 OEC unit together with the Balance of Plant equipment.
Age	The plant commenced commercial operation in 1983 and was already in existence when we signed the concession agreement in 1999.
Land and Mineral Rights	The total Momotombo area is under a concession agreement which

	expires in 2014. We sell the generated electricity at the boundary of the plant. The transmission line is owned by the utility.
Resource Information	The resource temperature is an average of 466.5 degrees Fahrenheit. The Momotombo geothermal reservoir is located within sedimentary and andesitic volcanic formations that relate to the Momotombo volcano. Main flow paths in the geothermal system are a hot reservoir layer. The shallow layer conducted deep fluids that eventually will be discharged at surface at the eastern edge of the geothermal system at the shore of the Lake Managua.
Resource Cooling	Approximately 3.5 degrees Fahrenheit per year was observed during the past 10 years of production.

Access to Property	Direct access to public roads and access across the property are provided under surface rights granted pursuant to the concession assignment agreement.
Sources of Makeup Water	Condensed steam is used for makeup water.
Power Purchaser	DISNORTE and DISSUR
PPA Expiration Date	2014
Financing	A loan from Bank Hapoalim B.M, which was repaid in full in 2010.

Olkaria III Complex (Kenya)

Location	Naivasha, Kenya
Generating Capacity	52 MW
Number of Power Plants	2 (Olkaria III Phase 1 and Olkaria III Phase 2).
Technology	The Olkaria III complex utilizes an air cooled binary system.
Subsurface Improvements	10 production wells and 3 injection wells connected to the plants through a gathering system.
Major Equipment	6 OEC units together with the Balance of Plant equipment.
Age	Phase I plant commenced commercial operation in 2000 and was incorporated into the phase II plant in January 2009.
Land and Mineral Rights	The total Olkaria III area is comprised of government leases. A license granted by the Kenyan government provides exclusive rights of use and possession of the relevant geothermal resources for an initial period of 30 years, expiring in 2029, which initial period may be extended for two additional five-year terms. The Kenyan Minister of Energy has the right to terminate or revoke the license in the event work in or under the license area stops during a period of six months, or there is a failure to

comply with the terms of the license or the provisions of the law relating to geothermal resources. Royalties are paid to the Kenyan government monthly based on the amount of power supplied to the power purchaser and an annual rent.

The power generated is purchased at the metering point located immediately after the power transformers in the 220 kV sub-station within the power plant, before the transmission lines which belong to the utility.

Resource Information

The resource temperature is an average of 570 degrees Fahrenheit.

The Olkaria III geothermal field is on the west side of the greater Olkaria geothermal area located at approximately 6,890 feet above sea level within the Rift Valley.

Hot geothermal fluids rise up from deep in the northeastern portion of the concession area, penetrating a low permeability zone below 3280 feet ASL to a high productivity, two-phase zone identified between 3,280 and 4,270 feet ASL.

Resource Cooling

The resource temperature is stable.

Access to Property

Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.

Power Purchaser

KPLC

PPA Expiration Date

2029

Financing

Senior secured project finance loan from a group of European DFIs.

Supplemental Information

See "Projects under Construction — Olkaria III Phase III (Kenya)."

We have signed a commitment letter issued by OPIC to provide up to $310 million to refinance and expand the Olkaria III complex. See "New Financing of our Project" in Item 7.

If the Phase III of Olkaria III is completed by November 2015, the expiration date of the PPA will be extended until 2033.

Zunil Power Plant (Guatemala)

Location

Zunil, Guatemala

Generating Capacity

24 MW

Number of Power Plants

1

Technology

The Zunil power plant utilizes an air cooled binary system.

Major Equipment

7 OEC units together with the Balance of Plant equipment.

Age	The plant commenced commercial operation in 1999.
Land and Mineral Rights	The land owned by the plant includes the power plant, workshop and open yards for equipment and pipes storage. Pipelines for the gathering system transit through a local agricultural area's right of way acquired by us. The geothermal wells and resource are owned by INDE. Our produced power is sold at our property line; power transmission lines are owned and operated by INDE.
Access to Property	Direct access to public roads.
Power Purchaser	INDE

PPA Expiration Date	2019
Financing	Senior Secured project loan from IFC and CDC that was repaid in full in November 2011.
Supplemental Information	Through August 2011, the energy output of the power plant was sold under a "take or pay" arrangement, under which the revenues were calculated based on 24 MW capacity regardless of the actual performance of the power plant. From September 2011, the energy portion of revenues is paid based on the actual generation of the power plant, while the capacity portion remains the same. The actual generation of the power plant is based on a capacity of approximately 13 MW. In 2011, the energy revenues were approximately 21% of the total revenues of the power plant.

Projects under Construction

We are in varying stages of construction or enhancement of domestic and foreign projects. Based on our current construction schedule, we have new generating capacity of approximately 145 MW under construction in California, Nevada, and Hawaii (including Mammoth expansion described above).

The following is a description of the projects currently undergoing construction:

Carson Lake Project (U.S.)

Location	Churchill County, Nevada
Projected Generating Capacity	20 MW
Projected Technology	The Carson Lake power plant will utilize a binary system.
Condition	Received the approval of the BLM for the required EIS and for the permitting required to start the drilling of additional wells.
Subsurface Improvements	Awaiting drilling permits.
Land and Mineral Rights	The Carson Lake area is comprised of BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands."

	Unless steam is produced in commercial quantities, the primary term for these leases will expire commencing August 31, 2016.
	The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.

Financing	Corporate funds.
Projected Operation	To be determined.
Supplemental Information	Permitting delays have prevented substantial progress on the project site and on transmission until late last year and have had a significant impact on the development plan and the economics of the project. As a result, in December 2011, we terminated the project's PPA and joint operating agreement with NV Energy. We are continuing to work on the project.

CD4 Project (Mammoth Complex) (U.S.)

Location	Mammoth Lakes, California
Projected Generating Capacity	30 MW
Projected Technology	The CD4 power plant will utilize an air cooled binary system.
Condition	Drilling activity.
Subsurface Improvements	We have completed 1 production well and 1 injection well. Continued drilling is subject to receipt of additional permits.
Land and Mineral Rights	The total Mammoth area is comprised mainly of BLM leases, several of which are held by production and the remainder of which are the subject of a unitization agreement that is pending BLM approval. The expiration date of the leases (assuming approval of the unitization agreement) is after the end of the expected useful life of the power plant.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the leases.
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Power Purchaser	We have not executed a PPA.
Financing	Corporate funds.

Projected Operation	To be determined.
Supplemental Information	As part of the process to secure a transmission line, we are participating in the Southern California Edison Wholesale Distribution Access Tariff Transition Cluster Generator Interconnection Process to deliver energy into the Southern California Edison system at the Casa Diablo Substation.

Table of Contents

Heber Solar PV Project (U.S.)

Location	Imperial County, California
Projected Generating Capacity	10 MW (24,500 MWh per year)
Projected Technology	Solar PV.
Condition	Procurement.
Land	The Heber Solar area is comprised of land that we own.
Access to Property	Direct access to public roads from the leased property and access across the leased property.
Power Purchaser	IID
PPA Expiration Date	20 years after date of COD.
Financing	Corporate funds.
Projected Operation	2013
Supplemental Information	Commercial operation is expected within 18 months from the signing of the PPA, subject to timely completion of the interconnection that is to be provided by IID.

McGinness Hills Project (U.S.)

Location	Lander County, Nevada
Projected Generating Capacity	30 MW
Projected Technology	The McGinness Hills power plant will utilize an air cooled binary system.
Subsurface Improvements	5 production wells and 3 injection wells have been drilled.
Material Equipment	Power plant equipment on site.
Condition	Field development is still in process and construction is in an advanced stage.
Land and Mineral Rights	The McGinness Hills area is comprised of private and BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands." Unless steam is produced in commercial quantities, the primary term for

these leases will expire commencing September 30, 2017.

The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."

Table of Contents

Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Power Purchaser	Nevada Power Company
PPA Expiration Date	20 years after date of COD.
Financing	OFC 2 Senior Secured Notes.
	We plan to file an application for an ITC cash grant for the project.
Projected Operation	Third quarter of 2012.
Supplemental Information	Commercial operation of the power plant is expected in the second half of 2012.

Olkaria III – Phase III (Kenya)

Location	Naivasha, Kenya
Projected Generating Capacity	36 MW
Technology	The phase III of the Olkaria III complex will utilize an air cooled binary system.
Condition	Field development and manufacturing of the power plant is in progress.
Subsurface Improvement	Two production wells have been drilled.
Land and Mineral Rights	The total Olkaria III area is comprised of government leases. See description above under "Olkaria III complex."
Resource Information	The Olkaria III geothermal field is on the west side of the greater Olkaria geothermal area located within the Rift Valley at approximately 6,890 feet above sea level.
	Hot geothermal fluids rise up from deep in the northeastern portion of the concession area through low permeability at a shallow depth to a high productivity two-phase region from 3,280 to 4,270 feet above sea level.
	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted pursuant to the lease agreement.

Table of Contents

Power Purchaser	KPLC
PPA Expiration Date	20 years from COD.
Financing	Corporate funds.
Projected Operation	2013
Supplemental Information	We amended and restated the existing PPA with KPLC. The amended and restated PPA provides for the construction of a new 36 MW power plant at the Olkaria III complex. The PPA amendment includes an option for additional capacity up to 100 MW. We have signed a commitment letter with OPIC to provide up to $310 million to refinance and expand the Olkaria III complex. See description in Item 7 under "New Financing of our Projects."

Wild Rose (formerly DH Wells) Project (U.S.)

Location	Mineral County, Nevada
Projected Generating Capacity	15-20 MW
Projected Technology	The Wild Rose power plant will utilize a binary system.
Material Equipment	Drilling equipment for wells.
Condition	Field development is in progress.
Subsurface Improvement	3 wells have been drilled. We are continuing with the drilling activity.
Land and Mineral Rights	The Wild Rose area is comprised of BLM leases. The leases are currently held by the payment of annual rental payments, as described in "Description of Our Leases and Lands." Unless steam is produced in commercial quantities, the primary term for these leases will expire commencing September 30, 2017. The project's rights to use the geothermal and surface rights under the leases are subject to various conditions, as described in "Description of Our Leases and Lands."
Resource Information	The expected average temperature of the resource cannot be estimated as field development has not been completed yet.
Access to Property	Direct access to public roads from the leased property and access across the leased property are provided under surface rights granted in leases from BLM.
Power Purchaser	We have not executed a PPA yet for this power plant.
Financing	Corporate funds.
Projected Operation	2013

Comment Letter 10

ORMAT®

March 26, 2012

Dan Lyster
Director
Mono County Economic Development Department
P.O. Box 2415
Mammoth Lakes, CA 93546

Scott Burns
Director
Mono County Community Development Department
P.O. Box 347
Mammoth Lakes, CA 93546

Subject: Mammoth Pacific I Replacement Project
Comment on Revised Draft EIR – Project Benefits

Dear Director Lyster and Director Burns:

The purpose of this letter is to provide a brief summary of the Mammoth Pacific, L.P. I Replacement Project (Project) as well as a summary of the environmental (and economic and social) benefits to help ensure the Planning Commission and Board of Supervisors have an understanding of the purposes of the Project as they study the Draft Environmental Impact Report (DEIR). The DEIR, of course, includes a complete project description under the "project description" section and more specifically as needed in the following sections of that document. Some of the project benefits are also
10-01 mentioned in the DEIR, but this letter concisely lists some of the benefits.

Ormat representatives will appear at the Planning Commission and Board of Supervisor (if needed) hearing(s) to provide an overview of the Project and to answer any questions that may arise.

We respectfully request that you include this letter in the Final EIR on the project so that it will be available to Mono County officials and the general public.

PURPOSE AND DESCRIPTION OF THE M-1 PROJECT

Mammoth Pacific, L.P. is a wholly owned subsidiary of Ormat Technologies, Inc. Ormat is a pure-play clean energy company that has 500 employees in the United States. Its operations are consistent with policies at various levels of government, including Mono County, that encourage the safe development of alternative energy resources as a means of reducing the country's dependence on fossil fuels.

ORMAT Nevada
6225 Neil Road, Reno, NV, 89511-1163 • Telephone (775) 356-9029 • Facsimile (775) 356-9039

ORMAT®

As described in the DEIR, Ormat, by and through its subsidiary Mammoth Pacific, L.P. (MPLP), proposes to replace the existing MP-1 (also called G-1) power plant at the Casa Diablo geothermal complex with an advanced generation plant called M-1. The MP-I plant will be torn down, de-commissioned and the site reclaimed after the new plant is on-line. The new plant will be constructed on land owned by MPLP immediately adjacent to and on the same parcel as the existing plant.

The MP-I plant was the first geothermal plant constructed at Casa Diablo. It commenced operations in 1984 after receiving a conditional use permit from Mono County. It has been in continuous operation since that time. It was one of the first geothermal plants in the United States utilizing binary cycle technology. It was therefore *first generation* technology. Geothermal technology has advanced significantly in the last 28 years.

10-01 Cont.

As a result of *advanced generation* technologies, the new M-1 plant will utilize the geothermal resource in a manner that will result in the production of approximately 15 percent more energy with the same amount of resource used by the existing plants. There will be no increase in the amount of the geothermal fluid used in the process. The plant will consist of one Ormat Energy Converter (OEC). An OEC is proprietary modular binary geothermal power generation equipment manufactured by Ormat that includes a vaporizer, turbines, generators, an air-cooled condenser (the cooling system), a pre-heater, pumps and piping. There will be no additional wells drilled. The only new pipelines will consist of pipes on the MPLP property to connect with existing pipes connected to the well-field. The expected life of the new plant is 30 years.

PROJECT BENEFITS

Mono County's alternative energy policies state that the County may request the applicant to provide information on economic benefits to the community of a geothermal development project. Pursuant to the County's request, that information was provided in the form of a study by the independent economic consulting firm of Wahlstrom and Associates. Wahlstrom's report, which has been submitted for the record, is entitled "*Economic Benefits of proposed M-1 Geothermal Power Replacement Plant, Mono County, California*." It shows that the project will provide some $46.1 million of new investment in materials, equipment and services. Ormat submitted for the record an additional analysis entitled "*Supplemental Economic and Societal Benefits Report: Geothermal Operations in the Casa Diablo Area*." This report summarizes the economic, technologic and other benefits of geothermal development generally at Casa Diablo.

The benefits of the replacement project include, but are not limited to, the following:

- More efficient production of renewable, clean green energy from the same resource without significant environmental effects.

ORMAT Nevada

6225 Neil Road, Reno, NV, 89511-1163 • Telephone (775) 356-9029 • Facsimile (775) 356-9039

10-01 Cont.

- Construction jobs utilizing local contractors to the extent possible.
- Continuation of stable, long-term well-paying energy/green jobs in Mono County.
- Increased revenues to state and local governments in the form of property, sales, income and employment taxes, generated both by the new plant's increased efficiencies and its longer life span.
- Quieter operations as a result of the advanced generation technologies.
- Substantially less fugitive emissions that with the existing plant.
- The working pressure of the OEC is lower than with the existing system, resulting in reduced leakage of the working fluid and increased safety.
- Substantially less lubricating oil because the new design requires less oil, is more leak-resistant, and has fewer moving parts.
- Substantially reduced fire hazard for the reasons listed in the DEIR, including a reduced on-site need for flammable working fluid and up-graded fire protection system utilized in the project design.
- To the extent electricity production is increased and sent to the grid, it will offset emissions of pollutants and green-houses gases that would otherwise be produced by conventional fossil fuel plants elsewhere on the grid.
- There have been no documented significant adverse environmental effects from the existing geothermal operation at Casa Diablo. A more efficient and safe plant utilizing advanced generation technologies has also not been shown to have any potential effects.

As requested above, please include this letter in the Final EIR on the project so that it will be available to Mono County officials and the general public, and also please place a copy of this in the administrative record for the M-1 project.

Very truly yours,

Ron Leiken

Ron Leiken, QEP
Environmental/Regulatory Affairs Administrator