Oregon
Kate Brown, Governor

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Exhibit 5

Crook County
July 12 2022
Planning Dept

July 12, 2022

Crook County Planning Department
Attn: Brent Bybee, Planning Manager
300 NE 3rd Street, Room 12
Prineville, OR 97754

RE: Application 217-21-000438-PLNG
ODFW Response to Applicants updated Powell East Wildlife Mitigation Plan version June 13, 2022, and County Staff Recommendations.

Dear Crook County Planning Department:

The purpose of this letter is to provide formal comments on the Powell East Wildlife Mitigation Plan (revised June 13, 2022) and the Crook County Staff Recommendation (dated July 6, 2022), and to submit the attached documents into the record.

The Oregon Department of Fish and Wildlife (Department) is mandated by the Oregon Legislature to manage fish and wildlife to prevent serious depletion of indigenous species and provided optimum recreational and aesthetic benefits for present and future generations of the citizens of this state (ORS 496.012). The Department recognizes Crook County's authority to approve this application consistent with the County Code provisions and offers the following comments and recommendations regarding the potential impacts to wildlife and their habitats.

BACKGROUND

The Applicant proposes to develop a 320-acre photovoltaic solar power generating facility on lands zoned EFU-3. The project is situated Southeast of Powell Butte and just West of the Millican road, in an area that is becoming increasingly permitted for, and developed with, solar facilities as shown on Exhibit __. The proposed development site is adjacent to the Gala solar facility (320 acres site) to the East and the Hidden Canyon Destination Resort property and proposed Empire solar facility to the West (figure 1). This increasing development is significant for wildlife because the subject property is nearly entirely within the Goal 5 mule deer winter range mapped by the County, and entirely within ODFW-mapped elk winter range.

Because the site boundary of Powell East is within mapped mule deer and elk winter range, pursuant to Department policy it is considered essential and limited habitat **category 2**.[1] ODFW has collected spatial GPS data on annual big game survey flights since 2009. The portion of winter range where the Powell East project is being sited is within the North Paulina wildlife

[1] 2013 ODFW OREGON BIG GAME WINTER HABITAT (exhibit 2)

management unit (WMU). Intensive survey flights were completed in the area between the years 2011-2014 (Quadrat method) and last winter 2022 (sight-rat method). Figure 2 illustrates the locations of wintering deer that have been detected throughout those survey years. Research and monitoring of the mule deer West of Millican road is still in the early phase, but the evidence shows that mule deer GPS collared East of Millican road tend to migrate South and West of their winter range and summer South of Newberry Caldera in Deschutes County (38 miles from the proposed site). Collared mule deer also exhibited resident behavior East of Millican road. This data indicates that mule deer that spend their winter in and around Powell Butte Mt. and are expressed as data points on Figure 2 will exhibit similar migratory and non-migratory behavior. Therefore, to effectively mitigate for impacts to winter range at the proposed site, mitigation efforts should be focused in the areas described above.

ODFW has GPS radio collar data from one individual pronghorn antelope that was captured and collared on the winter range (Figure 3). While this pronghorn does not utilize the site boundaries of the existing or proposed solar facilities, it is worthwhile to illustrate the habitat use of this pronghorn in winter months. Recent research out of Wyoming documents pronghorn antelope avoiding areas near solar developments after construction (Hall Sawyer, 2022). Key takeaways from the authors of this study, and likely to be realized in Crook County[2] for mule deer, elk and pronghorn, is the need for thoughtful layout designs that accommodate animal movements that can minimize barrier effects and retain the landscape connectivity needed for migratory ungulates. "Depending on the size of the Utility scale solar energy (USSE), this may require one or more corridors through the project, possibly splitting the USSE into multiple smaller units to allow ungulate movement in between (5)."

APPROVAL CRITERIA

The Applicant has noted in their letter submitted on June 13, 2022 that the approval criteria must meet compliance with Crook County Code ("CCC") Sections 18.16 and 18.161, and is not subject to compliance with ORS 215.446 (HB 2329). As long as the proposed facility and its related and supporting facilities occupy less than 320 acres, the Department agrees. Therefore, the Department's comments are focused on the applicable mitigation standard, which is to "offset the potential adverse effects of the facility." CCC 18.16.060(3)h)(vi).

It is worth noting that the term "offset" related to wildlife habitat mitigation is defined and explained in great detail in "A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale". *Biodiversity offsets, the last step in the mitigation hierarchy (avoid, minimize, restore, offset), are conservation actions that seek to counterbalance residual impacts resulting from development with measurable conservation outcomes, with the aim of no net loss for biodiversity*. (Joseph M. Kiesecker, 2009).[3] The paper is discussing surface habitat impacted by the Jonah natural gas field and the attempt to offset impacts using a 3:1 ratio of on-site impact to offset from that development(78). The authors detail the importance of site selection and spatial scale, and this can be found in the Discussion section of the paper (82-83).

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[2] 9 solar projects pdf. (attached)

[3] A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale. attached

STAFF RECOMMENDATIONS

ODFW has reviewed the updated mitigation plan (June 13,2022) as well as the staff report and has the following comments and recommendations.

- **Option 1 - Conservation of Like Habitat with Juniper Removal Uplift**

ODFW appreciates the County's effort to for strengthen Option 1 with proposed conditions of approval, including that the mitigation project will need to be completed prior to site clearing or development. ODFW is willing to accept the responsibility of reviewing the results of the mitigation option, reviewing monitoring activities and retreatment actions. ODFW will work with the Applicant to assure this activity is completed and the mitigation site continues to trend in the positive direction with respect to habitat function. If the site's habitat becomes degraded or trends in the negative direction, ODFW will work with the Applicant and the County to correct the deficiency. Since this is rather subjective, ODFW, the Applicant and the County will work together prior to initiating Option 1 to develop performance measures that will guide that process. ODFW recommends that the County require the performance measures be completed at the same time of plan development listed in proposed Condition 3(c).

Proposed Condition 3(c) requires that Applicant apply for an "Administrative Determination" from the Planning Director addressing the number of acres the solar facility is proposed to be, the number of acres to be mitigated, the location of the mitigated site, and the submittal of a durability assurance. ODFW recommends that the adopted condition make explicit the phrase "Administrative Determination" refers to the "Administrative Decisions" process in CCC 18.172.060(1), and that ODFW and all persons that participated in the initial hearing be entitled to notice and participatory rights. ODFW recognizes that invoking the process in CCC 18.172.060(1) may have been the staff's intent, and appreciates the clarification. If, on the other hand, the "Administrative Determination" contemplated by proposed condition 3(c) is not a public process, ODFW disagrees this approach is consistent with the fundamental tenets of land use law and disagrees that there is substantial evidence in this record for the Planning Commission to approve mitigation pursuant to Option 1.

At this point, with the mitigation site location unknown, the mitigation ratio of either 1:1 or 1:1 with a failure buffer of between 1-3% to 30% as proposed by the Applicant does not provide sufficient acreage to demonstrate that implementing Option 1 mitigation will achieve the applicable standard. ODFW has consistently recommended a ratio of 2:1 in Category 2 habitat such as this, and maintains that recommendation for this project.

With respect to location, ODFW recommends the mitigation site be located on a site that is mapped by the County or ODFW (or both) as winter range habitats for mule deer and rocky mountain elk since those are the species that would be impacted. This species-specific approach is necessary to achieve the mitigation goal, and is also consistent with the definition of "mitigation" in CCC 18.08.130 which requires that mitigation have a reasonable relationship to the impact. In addition, ODFW supports Condition 6 that mitigation for either option will occur in Crook County, since the evidence demonstrates that mitigating there will benefit the impacted wildlife.

With respect to the durability assurance, ODFW recommends the instrument restrict both development and conflicting uses on the mitigation site. Examples of conflicting uses that should be restricted are:(i) increased grazing above levels approved under existing grazing management plans unless approved in writing by ODFW (ii) all nonagricultural uses (including but not limited to motorized and nonmotorized recreation) (Michael J Wisdom, 2004) (iii) grading, mowing, blading, or expansion of impervious surfaces or access road networks, and (iv) divisions of the mitigation site.

To capture these recommendations, ODFW recommends the following revisions shown in bold to proposed Condition 3:

3. Mitigation Option 1 Conditions

a. Prior to any site clearing or development, the Applicant shall provide proof to the Planning Department that the mitigation option has been completed. ODFW shall provide a certifying letter stating that the mitigation has been completed in accordance with the approved wildlife mitigation plan.

b. ODFW shall be the authority who shall review the results of the mitigation option after it is completed, shall review monitoring activities every 12 years, and shall review any retreatment actions.

c. Prior to initiating Option 1, the Applicant shall apply for an Administrative ~~Determination~~ **Decision (CCC 18.172.060(1))** from the Planning Director addressing the number of acres the solar facility is proposed to be, the number of acres to be mitigated **which shall be at least 2:1 (mitigation acres : impacted acres)**, the location of the mitigated site, and the submittal of a durability assurance. The determination shall verify that the project **is in mule deer and elk winter range mapped by the County or ODFW (or both),** will create edge habitats with areas of high canopy coverage and open areas for foraging to replicate or improve upon the habitat functions of the solar facility site. **ODFW and other parties that participated at the local hearing, and those entitled to notice under CCC 18.172.060(1), shall be given notice of the hearing and the opportunity to participate, including to appeal the Administrative Decision.**

d. Any durability assurances utilized shall be in effect until decommissioning of the solar facility has occurred, and reclamation of the facility site has been completed. **Durability assurances shall restrict development and other uses that conflict with the habitat purpose of the mitigation site, including: (i) increased grazing above levels approved under existing grazing management plans unless approved in writing by ODFW (ii) all nonagricultural uses (including but not limited to motorized and nonmotorized recreation) (iii) grading, mowing, blading, or expansion of impervious surfaces or access road networks, and (iv) divisions of the mitigation site.** The type of assurance provided shall also be verified and approved by the county prior to initiation of Option 1.

e. If Option 1 is utilized, the sites mitigated shall be designed to contain edge habitats with areas of high canopy coverage and open areas for foraging to replace or improve upon the habitat functions of the solar facility site**, and shall be in mule deer and elk winter range mapped by the County, ODFW, or both**. Compliance shall be determined by the Oregon Department of Fish and Wildlife.

- **Option 2 - One-Time Fee-In-Lieu Payment**

ODFW supports mitigation pursuant to Option 2 with Condition 4 as proposed in the Staff Recommendation. ODFW can support using the CPI index as a way to update the mitigation formula in instances the project is not built immediately after County approval. However, as costs change over time, the formula should updated accordingly. Without Condition 4, there is not substantial evidence in the record that the mitigation payment will fund a mitigation project that will achieve the mitigation goal.

- **Option 3 - Alternative Mitigation Project Approved by ODFW or Cooperative Mitigation Agreement with ODFW**

ODFW supports the Staff Recommendation to not utilize Option 3 as a viable mitigation option because there is no evidence in the record that an unknown approach to mitigation will achieve the mitigation standard.

SUMMARY

ODFW supports this mitigation plan with a few recommended changes to the conditions shown above.

ODFW would also like to start the discussion of cumulative impacts from the increased land use pressure in this part of the County. While one single project mitigated properly can offset the wildlife habitat impacts, the risk of cascading wildlife habitat loss due to multiple project impacts can have increasingly serious consequences. ODFW would like to work with the County and future applicants to identify a fair and balanced solution to this problem that we will face if solar build out occurs on the Millican Plateau. ODFW envisions this as conditioning approval with additional mitigation requirements based on current and future development. So developers that build first don’t avoid this standard, it should be discussed and settled on soon.

Thank you for the opportunity to comment and if you have any questions, please feel free to reach out.

Sincerely

Greg Jackle

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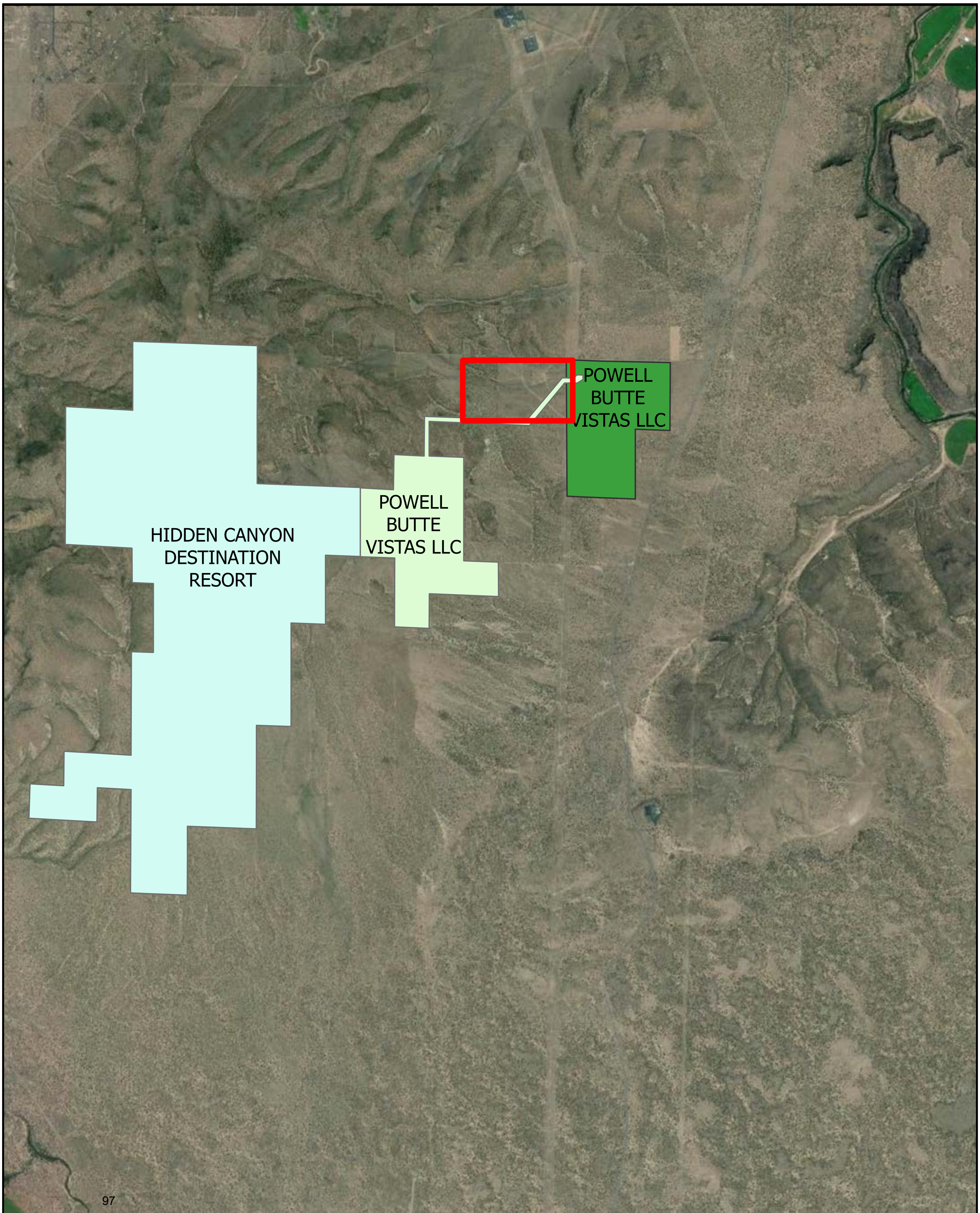
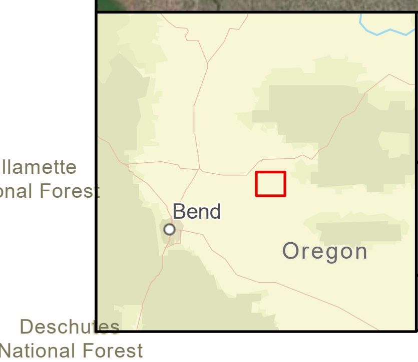
References

Hall Sawyer, N. K. (2022). Trade-offs between utility-scale solar development and ungulates on western rangelands. *Frontiers in Ecology and the Environment*, 1-7.

Joseph M. Kiesecker, H. C. (2009). A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale. *Bioscience*, 77-84.

Michael J Wisdom, A. A. (2004). Effects of Off-road Recreation on Mule Deer and ELk. *North American Wildlife and Natural Resources Conference* (pp. 531-550). Spokane, WA: Wildlife Management Institute.





Powell East - figure 1

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Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

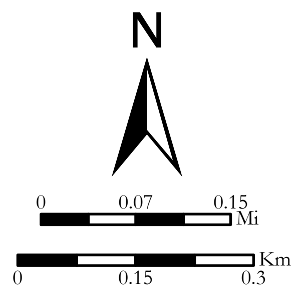
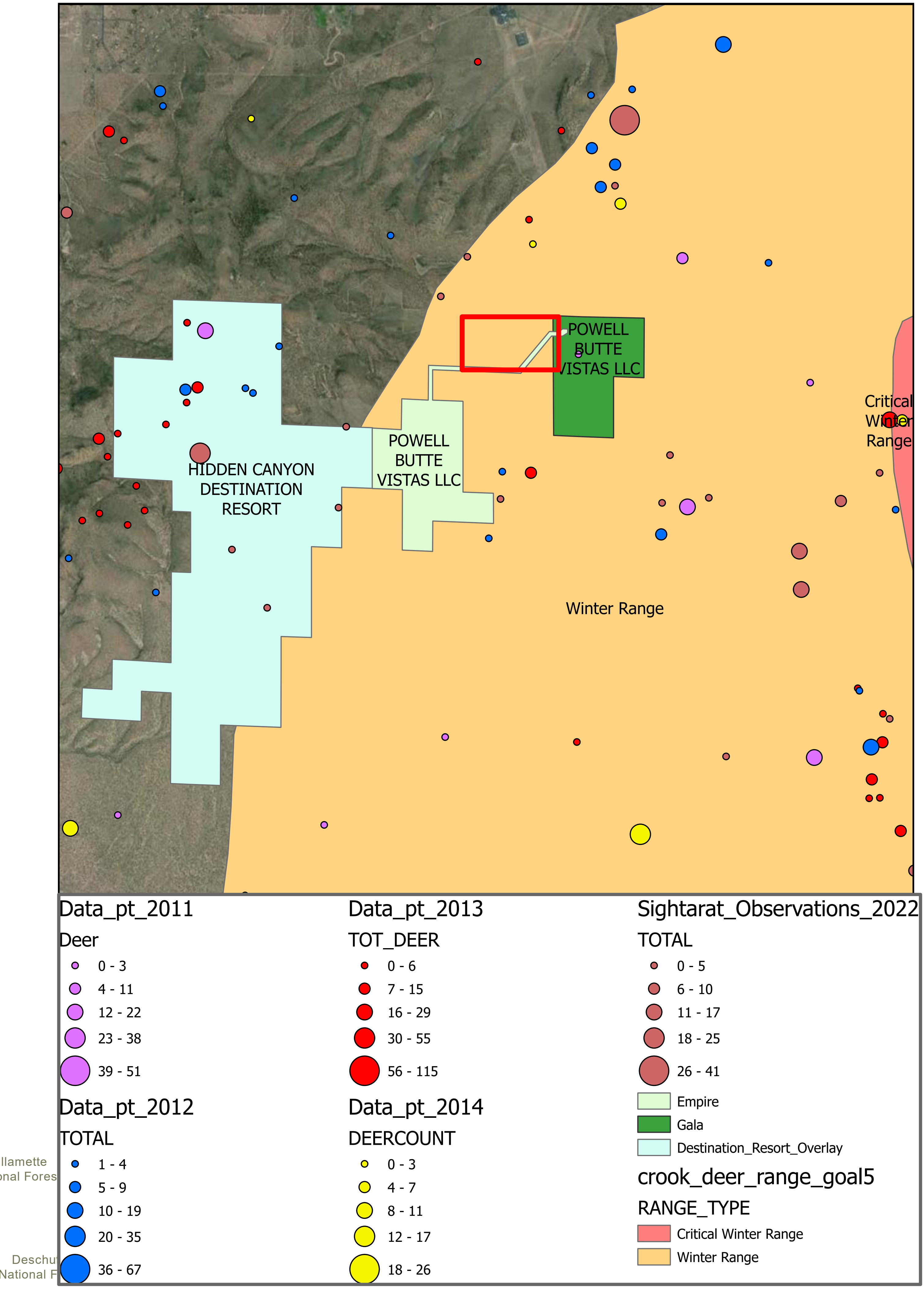


Figure 2



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20 - 35
36 - 67
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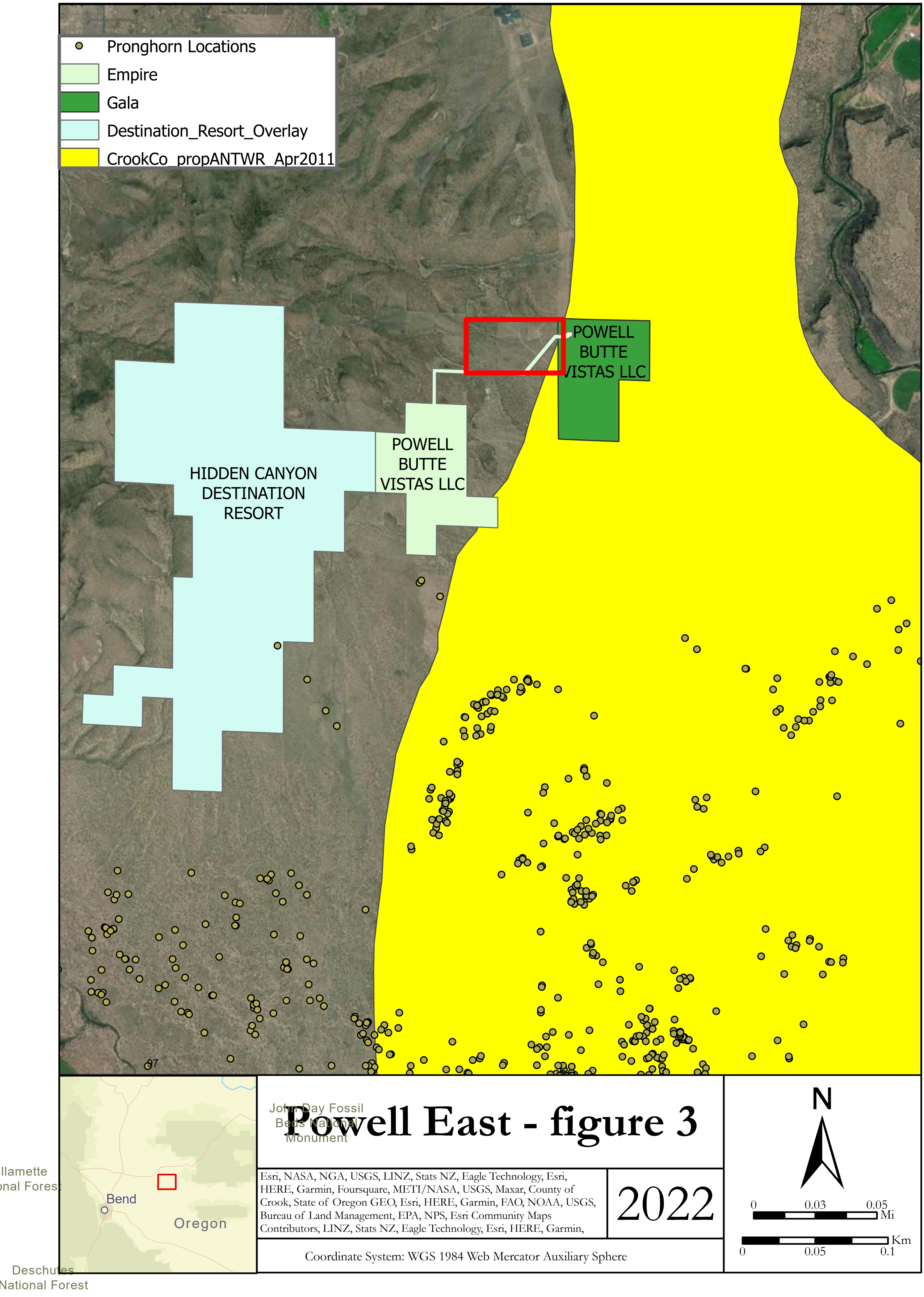

Powell East - figure 3

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Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

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A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale

JOSEPH M. KIESECKER, HOLLY COPELAND, AMY POCEWICZ, NATE NIBBELINK, BRUCE McKENNEY, JOHN DAHLKE, MATT HOLLORAN, AND DAN STROUD

Biodiversity offsets provide a mechanism for maintaining or enhancing environmental values in situations where development is sought despite detrimental environmental impacts. They seek to ensure that unavoidable negative environmental impacts of development are balanced by environmental gains, with the overall aim of achieving a net neutral or positive outcome. Once the decision has been made to offset, multiple issues arise regarding how to do so in practice. A key concern is site selection. In light of the general aim to locate offsets close to the affected sites to ensure that benefits accrue in the same area, what is the appropriate spatial scale for identifying potential offset sites (e.g., local, ecoregional)? We use the Marxan site-selection algorithm to address conceptual and methodological challenges associated with identifying a set of potential offset sites and determining an appropriate spatial scale for them. To demonstrate this process, we examined the design of offsets for impacts from development on the Jonah natural gas field in Wyoming.

Keywords: biodiversity offsets, mitigation hierarchy, no net loss, Marxan site selection

Between one-third and one-half of Earth's land surface has been altered by human action (Vitousek et al. 1997), resulting in an unprecedented loss of biodiversity. As a result, some 10 to 30 percent of all mammal, bird, and amphibian species are threatened with extinction (Levin and Levin 2004, Kiesecker et al. 2004). Looking forward, such impacts could increase dramatically: the global economy is expected to double by 2030 (World Bank 2007), and unprecedented investments are being made in resource development to support this growth, especially in developing countries (IEA 2007). Given the importance of economic development for improving human well-being, there is greater pressure to find ways to balance the needs of development with those of biodiversity conservation.

Biodiversity offsets are one important tool for maintaining or enhancing environmental values in situations where development is sought despite detrimental environmental impacts (ten Kate et al. 2004, McKenney 2005, Gibbons and Lindenmayer 2007). Offsets are intended to be an option for addressing environmental impacts of development after efforts have been undertaken to minimize impacts on-site through application of the three other steps of the mitigation hierarchy: avoid, minimize, restore (40 C.F.R. 1500.2). They seek to ensure that inevitable negative environmental impacts of development are balanced by environmental gains, with the overall aim of achieving a net neutral or positive outcome (see figure 1).

Offset policies for environmental purposes have gained attention in recent years (e.g., Environmental Defense Fund 1999, Government of New South Wales 2003; see McKenney 2005 for a review). Although the use of offset activity remains relatively limited, offsets are increasingly employed to achieve environmental benefits, including pollution control, mitigation of wetland losses, and protection of endangered species (ten Kate et al. 2004, McKenney 2005). Offset activity is most active for US wetlands, where methods and programs have been under development for the past two decades. Wetland offsets in the United States have increased dramatically, with 6000 hectares (ha) per year in the early 1990s growing to an average of more than 16,000 ha per year since 1995 (Environmental Law Institute 2002). Offset programs have also been established or are developing in other parts of the world, including Australia, Brazil, and the European Union (McKenney 2005, Gibbons and Lindenmayer 2007).

Offsets offer potential benefits for industry, government, and conservation groups alike (ten Kate et al. 2004). Benefits for industry include a higher likelihood that permission will be granted from regulators for new operations, greater

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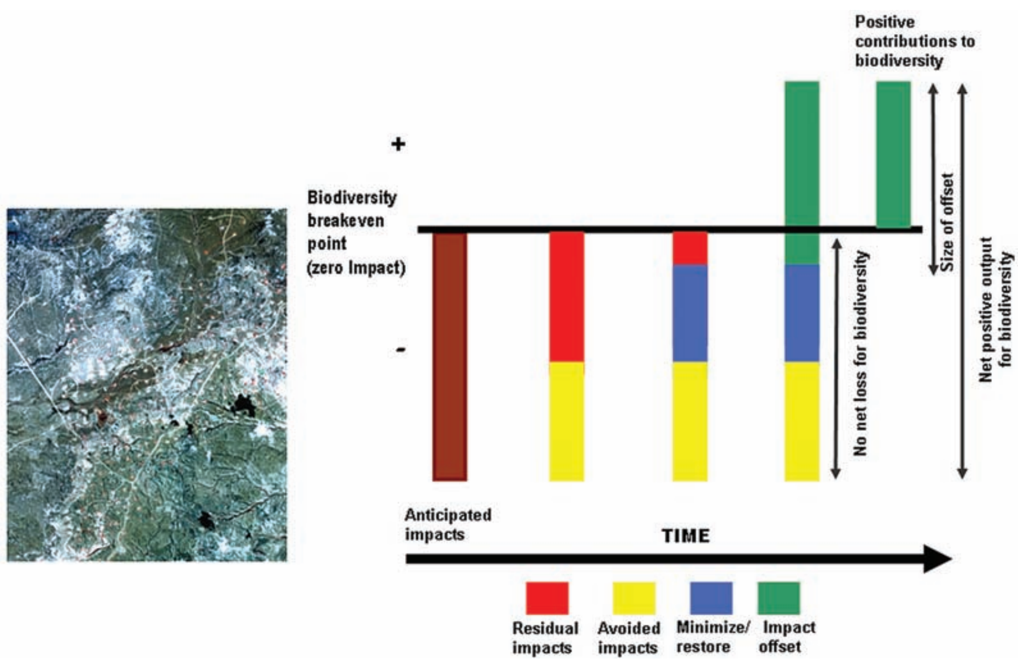

Figure 1. The role of offsets in achieving no net loss (or better) for biodiversity. Impacts to biodiversity are represented here as surface disturbance. Avoided impacts to the project area are in accord with the surface disturbance cap of 5677 hectares (ha), or 46 percent of the project area. Additional surface disturbance will be minimized through the use of drilling mats on 25 percent of the 3100 wells. Wells in the Jonah Field are projected to result in approximately 1.6 ha of surface disturbance per well. Drilling mats reduce approximately 0.81 ha of surface disturbance, resulting in a reduction in approximately 627 ha or about 5 percent reduced surface disturbance. We estimated about 5 percent residual surface disturbance would remain after production activities ceased and restoration was completed in 30 to 50 years. The size of the offset (17,031 hectares) was based on an estimated 3 to 1 ratio of on-site impact to offset (USDOI 2006). The inset is an aerial view of the Jonah Field taken before the infill project that prompted the offset requirement (image courtesy of NASA/GSFC/METI/ERSDAC/JAROS and the US/Japan ASTER Science Team).

societal support for development projects, and the opportunity to more effectively manage environmental risks. Offsets provide governmental regulators with the opportunity to encourage companies to make significant contributions to conservation, particularly when legislation does not require mandatory offsets. Conservation organizations can use biodiversity offsets to move beyond piecemeal mitigation, securing larger-scale, more effective conservation projects. Offsets can also be a mechanism ensuring that regional conservation goals are integrated into governmental and business planning.

Although offsets have great potential as a conservation tool, their establishment requires overcoming a number of conceptual and methodological challenges (Burgin 2008). One of the key questions is how offsets should be located relative to the affected site. When on-site impacts warrant the use of offsets, there is often a tension between choosing sites as close to the impact site as possible (ensuring that benefits accrue to the same area) and choosing sites likely to provide the greatest conservation benefit (with less regard to spatial position). To date, no one has found a way to determine appropriate distances for offsets. Here we propose a framework to address this need. Our proposed framework for offset site selection includes two major components. First, we develop a series of rules (offset goals) for selecting offset sites that meet the conservation needs of potentially affected biological targets (i.e., size, condition, landscape context). Next, we use a site-selection algorithm developed for Marxan (Ball 2000, Ball and Possingham 2000, Possingham et al. 2000) to search for sites at increasing spatial extents. Offset sites can then be chosen from the closest extent at which impact goals are met.

Our objective is to design an approach ensuring that offsets are ecologically equivalent to impact sites and will persist at least as long as on-site impacts, and that they will achieve net neutral or positive outcomes. We propose five steps for this approach: (1) assemble a working group, (2) compile a list of representative biological targets, (3) gather spatial data for biological targets, (4) set impact goals for each biological target, and (5) use the Marxan algorithm at increasing spatial extents to identify potential offset sites. To demonstrate the approach, we present a case study from the Jonah natural gas field located in southwestern Wyoming. British Petroleum, one of the principal operators on the field, expressed the need for a structured framework to guide the disbursement of mitigation funds and invited the Nature Conservancy to design such a plan.

Study area description: Jonah natural gas field

Located in Wyoming's Upper Green River Valley, the 24,407-ha Jonah natural gas field is considered one of the most significant natural gas discoveries in the United States in recent times, with an estimated 7 trillion to 10 trillion cubic feet of natural gas (USDOI 2006). During the last 10 years, the field has become one of the nation's richest gas fields, currently with approximately 500 wells. The Bureau of Land Management (BLM) granted regulatory approval in 2006 to infill the existing 12,343-ha developed portion of the field with an additional 3100 wells (USDOI 2006). As a requirement of the infill project, an off-site mitigation fund of $24.5 million dollars was established (USDOI 2006).

The Jonah Field is located in a high-desert sagebrush ecosystem that provides critical habitat for migratory big game, songbirds, and raptors, within the southern reaches of the Greater Yellowstone Ecosystem. Some of the world's largest herds of large game species (pronghorn antelope, *Antilocarpa americana*) winter here, relying on the valley's snow-free forage to get them through harsh winter weather. Migratory pathways lace the area, connecting the winter range with alpine terrain in five nearby mountain ranges. This area is also a stronghold for the greater sage-grouse (*Centrocercus urophasianus*), an emblematic native game bird now being considered for listing under the Endangered Species Act. Because wildlife in the field had already incurred significant impacts before the infill (TRC Mariah Associates Inc. 2004), off-site mitigation was considered an appropriate tool for the anticipated additional disturbance.

Assembling a working group

A mitigation-design working group was formed to guide development of the process of offset designation and integration of spatial data into the site selection process. All participants had expertise and involvement with the biological systems affected by the Jonah Field development; the group included representatives from state agencies (Wyoming Game and Fish Department, Wyoming Department of Environmental Quality), federal agencies (BLM, US Fish and Wildlife Service), universities, biological consulting firms, and the local agricultural production community. This group helped secure the most current spatial data on species of concern, assessments of the predictive models being developed, and insights into the process being developed. We sought to apply rigorous, objective measures of conservation value whenever possible, recognizing that a quantitative assessment would have to be supplemented by expert opinion.

Compiling a list of representative biological targets

Biological diversity cannot easily be completely and directly measured. Thus, practitioners are forced to select a set of components of biological diversity that can be measured effectively, given existing resources, components that adequately represent the range of biological phenomena in the project area and contribute the most to the overall biological diversity of a project area. Selecting a set of focal targets with sufficient breadth and depth can be done through the coarse-filter/fine-filter approach, as applied, for example, in ecoregional planning by the Nature Conservancy (TNC 2000). "Coarse filter" generally refers to ecosystems; in a more practical sense, it refers to mapped units of vegetation. The basic idea is that conserving a sample of each distinct vegetation type, in sufficient abundance and distribution, is an efficient way to conserve the majority of biological phenomena in the target area. An oft-cited statistic is that coarse-filter conservation will conserve 80 percent of all species in a target area (Haufler et al. 1996). "Fine filter" generally refers to individual species with specific habitat requirements or environmental relationships that are not adequately captured by the coarse filters. Narrow endemic species and extreme habitat specialists, species with restrictive life histories, or those species that have lost significant habitat or are particularly sensitive to human perturbations fall into this category (i.e., IUCN Red List species).

The Nature Conservancy's ecoregional planning uses both coarse- and fine-filter guidelines to identify biological targets. Therefore, for our case study we used the biological target list from the Wyoming Basins Ecoregional Plan (Freilich et al. 2001) crosswalked with information gathered as part of the environmental impact assessment (EIA; USDOI 2006). We selected all ecoregional conservation targets identified within the bounds of the field area as a biological target to be included in the offset design. We selected nine species and one ecological system to represent the biodiversity on the Jonah Field (table 1).

Table 1. Information on targets selected to represent biodiversity on the Jonah natural gas field.

Biological target	Impact goal (hectares)	Data source	Assessment goals met at smaller scale?	Assessment goals met at larger scale?
Burrowing owl	13,690	Deductive model	No	Yes
Cedar-rim thistle	3433	Inductive model	No	Yes
Mountain plover	1390	Deductive model	Yes	Yes
Pronghorn migration routes	7738	Wyoming Game and Fish linear data	Yes	Yes
Pygmy rabbit	7436	Deductive model	Yes	Yes
Sage grouse leks	6	Wyoming Game and Fish point data	Yes	Yes
Sage grouse winter habitat	21,043	Deductive model	Yes	Yes
Sage sparrow	8813	Deductive model	No	Yes
White-tailed prairie dogs	1705	Deductive model	Yes	Yes
Wyoming big sagebrush steppe	22,573	US Forest Service Landfire data	Yes	Yes

Note: Small-scale assessment goals come from analyses for the Pinedale Bureau of Land Management Field Office Boundary; larger-scale assessment goals come from analyses for the Wyoming Landscape Conservation Initiative Boundary.

Spatial data for biological targets

Spatial data were used to quantify impacts associated with development on the Jonah Field and to guide selection of offset sites. We used a combination of point survey data, vegetation cover estimations, and predictive model estimations (table 1). If survey data were sufficient for estimating occurrence patterns, we relied on these data. For example, for pronghorn, we created one-kilometer buffers (Berger et al. 2006) around linear pronghorn migration routes from the Wyoming Game and Fish Department (WGFD 2006). To estimate occurrence patterns of the Wyoming Big Sagebrush Steppe community, we relied on the US Forest Service's Landfire project data of existing vegetation height, type, and percentage cover (USFS 2006).

If survey data were insufficient to estimate occurrence patterns across the study area, we developed predictive models based on species occurrence, observation, and survey data from the Wyoming Natural Diversity Database, Wyoming Wildlife Consultants, Wyoming Game and Fish Department, and the BLM. We initially tried using an inductive modeling approach by developing a CART (classification and regression tree) model (Breiman et al. 1984) with the random forests algorithm through a GIS (geographic information system) tool developed at the University of Georgia called the EDM (element distribution modeling) Tools for ArcGIS (Nibbelink 2006), but our expert biologists were dissatisfied with the models we produced—the models lacked sufficient survey data to generate adequate models. As an alternative, we settled on a simpler approach using deductive models, wherein we identified each species' habitat preferences and created binary models of suitable habitat through a series of GIS overlays based on slope; aspect; topographic roughness; elevation (digital elevation models); stream buffers; and vegetation type, height, and percentage cover. The topographic features (elevation, aspect, slope, roughness) were all derived from the 30-meter National Elevation Dataset assembled by the US Geological Survey (USGS). Vegetation data were obtained from Landfire (USFS 2006), and streams data were based on the National Hydrologic Dataset (USGS 1997). To convert aspect to a continuous linear data set, we calculated the cosine of the aspect multiplied by –100 to produce values ranging from –100 to 100. Topographic roughness was calculated using a 3-by-3 moving-window neighborhood calculation of the standard deviation of the elevation. We validated our habitat models with expert review and survey data. For cedar rim thistle (*Cirsium aridum*), we relied on statewide rare-plant predictive models developed by Fertig and Thurston (2003).

Offset goals for biological targets

Our intention with this analysis was not to reinvent the EIA process, as the literature on this subject is extensive (Sadar et al. 1995, Canter 1996); rather, we intended to provide an approach that could complement existing EIAs. Thus, for this assessment, we used a simple approach to quantify field-level impacts. Spatial data assembled for each of the biological targets were overlaid onto the field boundaries, and estimated acres of habitat within the bounds were included as impacts (table 1). Since it was obvious that impacts associated with development extend beyond areas of surface disturbance, we used the full-field, 24,407-ha boundary, even though the infill project was limited to a 12,343-ha area. These full-field impacts became the input goals for the Marxan algorithm, representing the minimum offset spatial goals.

Selecting potential offset sites with Marxan

When the decision to use offsets is made, there is often a desire to keep them as close as possible to the impact site so benefits accrue to the affected area. The choice of offset location that best balances proximity to the impact site with effectively achieving conservation benefits is often unclear. Here, we used the Marxan (version 1.8.2) site-selection algorithm developed by Ball and Possingham (2000) to illustrate how this tool can be used to determine an appropriate location and spatial extent for offset design. We developed criteria to ensure offsets would serve to mitigate on-site impacts (see below), then we ran analyses at progressively broader spatial extents, with the intention of selecting offsets at the smallest spatial extent at which goals could be met. We chose a nested set of areas in accordance with both biological and political constraints. The first area was limited to the Upper Green River Basin, focusing on the BLM's Pinedale Field Office boundary (figure 2). The second, expanded area included the Wyoming Landscape Conservation Initiative boundary (figure 2) component of the Healthy Lands Initiative of the Department of the Interior.

Marxan, a siting tool for landscape conservation analysis, explicitly incorporates spatial design criteria into the site-selection process. Marxan operates as a stand-alone program and uses an algorithm called "simulated annealing with iterative improvement" as a heuristic method for efficiently selecting regionally representative sets of areas for biodiversity conservation (Possingham et al. 2000). Marxan allows inputs of target occurrences represented as points or polygons in a GIS environment, and makes it possible to state conservation goals in a variety of ways, such as percentage area or numbers of point occurrences. The program also allows the integration of many available spatial data sets on land-use patterns and conservation status, and enables a rapid evaluation of alternative configurations. The ultimate objective is to minimize the cost of the reserve system (i.e., cost = landscape integrity, conservation cost in dollars, size of the reserve, etc.) while still meeting conservation objectives.

For both the fine-scale and broadscale analyses, the working group selected 500-ha hexagons (derived from a uniform grid) as the unit of analysis for running Marxan, because this spatial resolution was sufficient to represent biological targets and also large enough to permit efficient analyses across broad landscape scales. The effectiveness of a contiguous set of hexagonal units for defining natural variability, especially among spatially heterogeneous data sets, is well documented (White et al. 1992). Use of hexagons resulted in 12,159 analysis units (6,079,500 ha) for the larger study area and 1834 analysis units (917,000 ha) for the smaller area. Each hexagon was populated by summing the area of suitable habitat for the targeted community or species.

In addition to the biological information used to select potential offset sites, we incorporated a series of additional rules. First, we guided site selection to areas of high biological integrity (per Copeland et al. 2007). This is equivalent to the "cost" function used by Marxan (Ball and Possingham 2000). Given the difficulty of restoration in this dry sagebrush system (Monsen and Shaw 2000), the team felt it necessary to select areas with high integrity and allow mitigation funding to keep these systems from becoming degraded. Second, we blocked out areas (using status = 3 function; Ball and Possingham 2000) of high oil and gas development potential (based on USGS estimates of undiscovered technically recoverable resources, Energy Information Administration–proved reserve calculations, and a predictive model developed by one of the authors of this article [H. C.]). The team felt that this last rule was critical, given the commitment to maintaining the integrity of the offset for at least as long as impacts are incurred on-site. Because of the high degree of oil and gas activity in this area, we thought it would be prudent to forgo selection of areas with high future development potential for offsets, to prevent the possibility of establishing offset sites that may themselves need to be offset. Moreover, the high cost and regulatory uncertainty associated with working in areas with high resource potential constituted another reason to avoid selecting these areas.

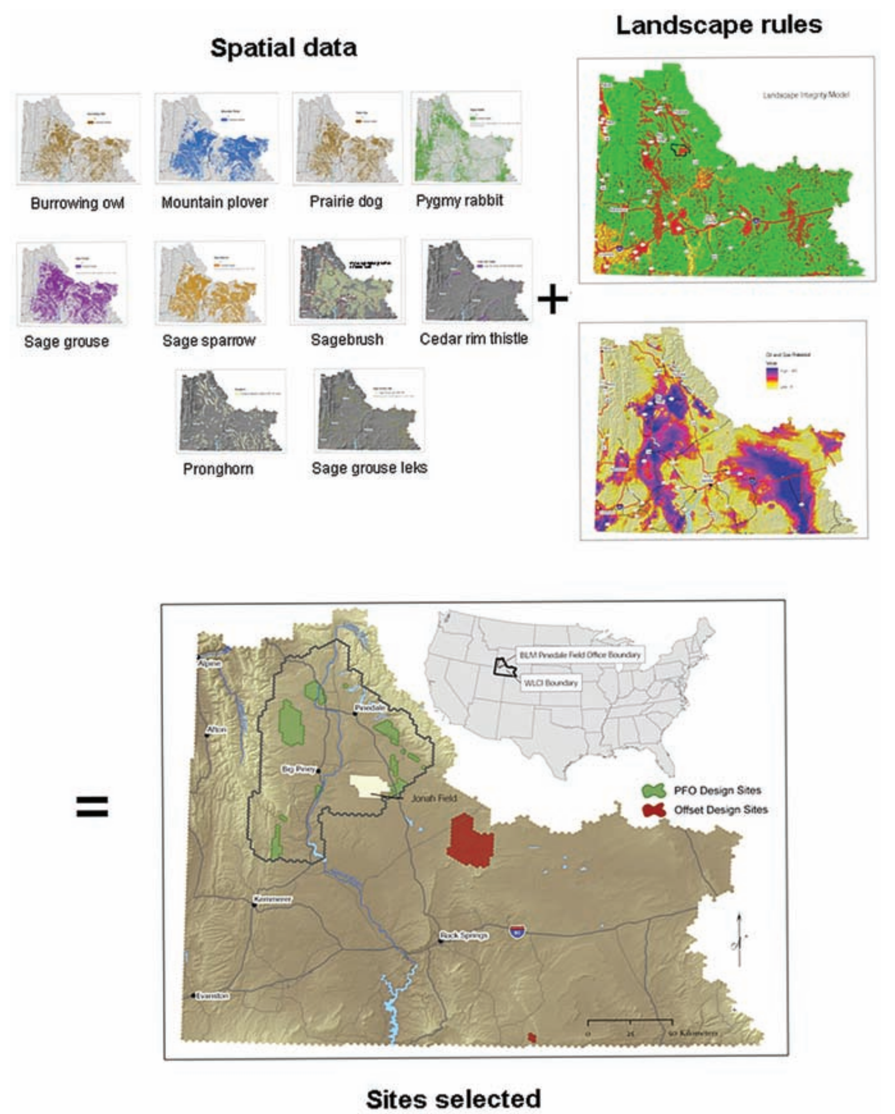

Figure 2. Use of the Marxan algorithm to select suitable offset sites as part of the Jonah natural gas field infill project. Spatial data layers were used both for assessing impacts resulting from development on the field and for selecting suitable offset sites. Landscape rules: "Intactness" (Copeland et al. 2007) and "Oil and Gas Potential" (based on US Geological Survey estimates of undiscovered technically recoverable resources, Energy Information Administration–proved reserve calculations, and a predictive model developed by H. C.) guided the selection of sites to areas of high habitat quality and low oil and gas development potential. Areas in green (smaller spatial extent) and red (larger spatial extent) represent the best fit of the Marxan algorithm based on these specific targets and specified rules. The inset map shows the location of Wyoming within the conterminous United States, as well as the location of the Wyoming Landscape Conservation Initiative and the Pinedale Bureau of Land Management Field Office Boundaries.

Goals achieved

At the smaller spatial extent, we selected 76,517 ha that were consistent with our offset goals. However, for several targets we were unable to meet even the minimum offset goals at the smaller extent (table 1). To achieve no net loss at this smaller spatial extent, given the constraints our team placed on selecting off-site sites (e.g., high intactness, low oil and gas potential), it would be necessary to reduce offset goals by mitigating impacts on-site using a step higher up the mitigation hierarchy. For example, on-site impacts and, in turn, the needs for offsets could be reduced by further avoiding or minimizing the footprint associated with development. Although the selected areas would not be sufficient to achieve no net loss because of the scope of on-site impacts, the selected areas could still be used as offsets when combined with areas from the larger spatial extent. At the larger spatial extent, we selected 62,499 ha, and in contrast to the smaller spatial extent, we found ample opportunity to meet offset goals for all targets (table 1, figure 2). Both the small and larger spatial extents sites selected included a mix of public and private land, and a mix of potential restoration and protection offsets.

Discussion

Biodiversity offsets, the last step in the mitigation hierarchy (avoid, minimize, restore, offset), are conservation actions that seek to counterbalance residual impacts resulting from development with measurable conservation outcomes, with the aim of no net loss for biodiversity. Our study illustrates some general principles in offset design and site selection for mitigating impacts from development on the Jonah natural gas field in southwestern Wyoming. Offsets are intended to provide an additional tool to achieve the no-net-loss goal after efforts have been made to avoid and minimize impacts. To achieve no net loss, offsets—in addition to having a systematic selection process—must ensure that offset actions are genuinely new and additional contributions to conservation, and they will have to quantify ecological quality rather than simply use acreage units. The selection process we have outlined can incorporate these additional requirements.

To trade project impacts for offset benefits, we need to develop an appropriate currency (i.e., area, habitat quality) to ensure that offsets are sufficient. The framework we have developed starts this process by selecting a set of sites that have value for their ability to meet the biologically based offset goals within a landscape context, including consideration of landscape integrity and future potential impacts. As on-the-ground projects are considered, practitioners can establish a finer currency that incorporates the size of the impact and offset, as well as values associated with ecological functions, quality, and integrity. However, most offset programs methods for assessing currency are in their infancy. The exception is wetland offsets, for which methodological developments have been ongoing for more than two decades. Indeed, estimates of the number of available wetland assessment methods range upward of 100 individual tools (Bartoldus 1999). Despite the proliferation of assessment methods, all are subject to criticism, and few are actually used because of the high cost and complexity of application (Kusler 2003). In a study of more than 200 wetland mitigation banks throughout the United States, more than 60 percent of the banks defined credits simply by acreage (Environmental Law Institute 2002).

The framework we have developed will be integrated with the use of an assessment tool, although such a tool is not a key component of our current analysis. For the sagebrush ecosystem, several site assessment tools are available for use (i.e., USFWS 1980, habitat evaluation procedures; USNRCS 1997, ecological site descriptions; Parkes et al. 2003, habitat hectares approach). However, the lessons of wetland mitigation banking show that assessment tools will need to balance time and cost with scientific rigor. By incorporating a valuation process into a site selection framework, we streamline the assessment process. Moreover, if mitigation replacement ratios are adopted, as they are in wetland mitigation banking (see King and Price 2004), then our framework can easily incorporate this by adjusting the goals that are put into the Marxan algorithm.

The majority of offset policies (McKenney 2005) agree that compensatory actions must result in benefits that are additional to any existing values. For our offset design, we guided site selection toward areas with high-quality habitats. These areas may require minimal or no restoration, but they are at risk from future impacts (i.e., residential subdivision, invasive weeds). For example, since the 1970s, rural areas with desirable natural amenities and recreational opportunities throughout the United States have experienced a surge in rural development (Brown et al. 2005), with growth in the mountainous West during the 1990s occurring faster than in any other region of the country (Hansen et al. 2002). Home building in our project area reflected these national trends in the period between 1990 and 2001 (Gude et al. 2007).

We recommend the use of mitigation funds to maintain habitat quality by abating future impacts (i.e., residential development) as well as standard habitat improvements. Although this is different from the emphasis on habitat restoration or creation associated with wetland mitigation (Federal Interagency Mitigation Workgroup 2002), we feel that as long as mitigation action prevents the decline of habitat quality, the averted decline can be measured; and offset planning provides for adaptive management, should conditions or threats change, which can be a practical use of mitigation funds. Given the flexibility of our site-selection framework, offset projects conducted in different ecological or political settings can easily use it to adjust site selection toward areas with more potential for restoration, if that is desired.

Reaching no net loss will come from on-site actions that minimize impacts or restore habitat, combined with off-site actions that provide additional benefits. The appropriate temporal scale should be used when valuing the role of offsets in achieving no net loss. Offsets will need to persist for at least as long as impacts persist on-site, and their value will have to be assessed within a similar temporal framework. For our case study, we use a 30- to 50-year time frame to assess on-site impacts and value on-site restoration and offset value. We recognize, however, that without requiring offset benefits to precede impacts on-site, there may be a temporal lag in achieving no net loss. Offset projects associated with impacts on the Jonah Field will consist of both restoration and protection projects. Valuing restoration projects as a function of habitat improvement is a relatively straightforward process. Valuing protection projects intended to maintain existing quality will involve assessing the background rate of change that necessitates protection (e.g., residential subdivision) and asking what the quality of habitat would be during the time on-site impacts persist if the protection did not exist.

Moving forward, we hope that our study prompts offset practitioners to think strategically about site selection, and to develop practical guidelines for when and how to guide this process. Site selection for offsets will obviously be an exercise in landscape analysis. Quantitative site selection tools (e.g., Arponen et al. 2007) such as Marxan provide a transparent, flexible, and rule-based approach to guide site selection. Where political pressures constrain practitioners to some extent, site-selection algorithms will allow them to determine whether it is possible to meet goals within those constraints. The framework we have developed can be applied if offsets have been selected as an appropriate tool; failure to systematically select suitable sites could reduce the potential benefits for conservation. Moreover, knowing when and how offsets can be applied—and knowing where they cannot—can be difficult to determine; offset use must be complemented by a rigorous process that ensures the mitigation hierarchy has been followed.

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04-200be

Effects of Off-road Recreation on Mule Deer and Elk

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Introduction

Off-road recreation is increasing rapidly in the United States, especially on public land (Havlick 2002, U.S. Department of Agriculture Forest Service 2004). An expansive network of roads provides easy access to much public land, which facilitates off-road uses in the form of all-terrain vehicles (ATVs), horses, mountain bikes and foot traffic. No research, however, has evaluated effects of these off-road activities on vertebrate species in a comparative and experimental manner (see review by Gaines et al. 2003). One recent study (Taylor and Knight 2003a) evaluated bison (*Bison bison*), pronghorn (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) responses to mountain biking and hiking. This study, however, did not include ATV or horseback riding, nor did it include experimental controls needed to assess cause-effect relations.

To address these knowledge gaps, we initiated a manipulative, landscape experiment in 2002 to measure effects of off-road recreation on mule deer and elk (*Cervus elaphus*), two charismatic species of keen recreational, social and economic interest across western North America. Our objectives were to (1) document cause-effect relations of ATV, horseback, mountain bike and hiking activities on deer and elk, using these off-road activities as experimental treatments and periods of no human activity as experimental controls; (2) measure effects with response variables that index changes in animal or population performance, such as movement rates, flight responses, resource selection, spatial distributions and use of foraging versus security areas; (3) use these response variables to estimate the energetic and nutritional costs associated with each activity and the resultant effects on deer and elk survival; and (4) interpret results for recreation management.

Our research began in 2002 and ended in 2004. In this paper, we present findings from 2002 to address parts of objectives 1, 2 and 4. We specifically focus on changes in movement rates and flight responses of mule deer and elk in relation to the off-road activities, compared to periods of no human activity. We then describe potential uses of the results for recreation management.

We present findings from our first year of study because of the urgent need for timely management information to address the rapid growth in off-road recreation (U. S. Department of Agriculture, Forest Service 2004). For example, ATV use on public land has increased seven-fold during the past 20 years, and many conservation groups are calling for widespread restrictions on ATV travel (U. S. Department of Agriculture, Forest Service 2004). Yet, no studies have evaluated the role of ATVs compared to other off-road activities, such as mountain biking and horseback riding, which also are increasing rapidly. Without comprehensive studies of ATV effects in relation to other recreation, the debate over ATV use is likely to intensify. Our study was designed to measure a variety of ungulate responses to address this debate, so results can be used to identify compatible mixes of different off-road recreational opportunities in relation to deer and elk management.

Throughout our paper, we refer to off-road recreation, both motorized and nonmotorized, that occurs on trails, primitive (unpaved) roads, or areas without trails or roads. This definition complements the phrase off-highway vehicle (OHV) use, which refers to motorized vehicle use on any surface beyond highways (U. S. Department of Agriculture, Forest Service 2004), but which does not include other forms of nonwinter recreation that typically occur on primitive roads and trails, such as hiking, horseback riding, and mountain biking.

Study Area and Technologies

We conducted our research in northeastern Oregon at the Starkey Experimental Forest and Range (Starkey, Figure 1), a facility equipped to evaluate real-time and landscape-level responses of deer and elk to human activities under controlled experimentation (Rowland et al. 1997, Wisdom et al. 2004a). The facility encompasses spring, summer and fall ranges typical of those used by mule deer and elk in the western United States. Timber harvest, livestock grazing, motorized traffic, hunting, camping and other public uses of Starkey also are managed like those on national forests in the western United States, providing a large inference space for research findings (Rowland et al. 1997, Wisdom et al. 2004a).

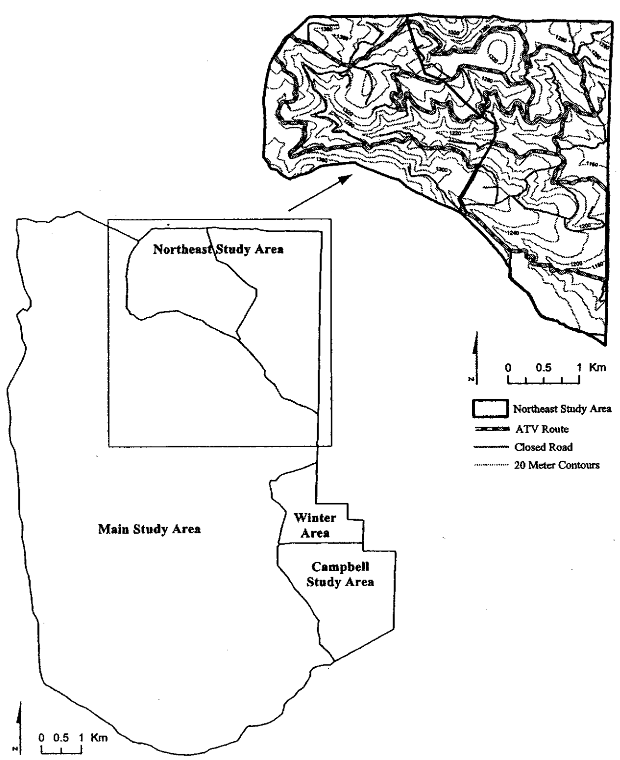


Figure 1. Boundaries of ungulate-proof enclosures at the Starkey Experimental Forest and Range in northeastern Oregon (bottom left) and location of transects used for ATV activities in the 3,590-acre (1,453-ha) Northeast Study Area (upper right), the site of the off-road recreation study. Transects were similar in length and location for mountain biking, hiking and horseback riding as those shown here for ATV activities.

An essential research component at Starkey is the ungulate-proof enclosure, one of the largest in the world, which allows scientists to evaluate ungulate responses to human activities over large areas and under controlled conditions (Bryant et al. 1993, Rowland et al. 1997). Another key technology is the automated tracking system (ATS), which can generate up to one animal location every 20 seconds, 24 hours a day, from April through December each year (Rowland et al. 1997, Kie et al. 2004). Additional technologies include maps and databases of more than 100 environmental variables to relate animal movements to the landscape experiments, as well as supporting methods and software to analyze these data (Rowland et al. 1997, 1998).

Implementing the Recreation Treatments

To meet our objectives, a network of off-road transects was established and run in 2002, using ATV, horseback, mountain bike and hiking activities as experimental treatments in the 3,590-acre (1,453-ha) Northeast Study Area (Figure 1). Approximately 20 miles (32 km) of transects were established (Figure 1), over which ATV, horseback, mountain bike and foot traffic was experimentally applied from mid-April through October. Locations of each transect were established with global positioning system (GPS) units (Figure 1). Transects were located on flat or moderate terrain typically used by off-road activities. Primitive roadbeds, like those often established by off-road vehicles (U. S. Department of Agriculture, Forest Service 2004), were included in the transects. Use of roadbeds and trails to implement human activities is referred to as a tangential experimental approach because animals are not targeted directly by the activities (Taylor and Knight 2003b). This is in contrast to a direct experimental approach, such as testing the reaction of nesting birds to designed encounters with humans at nest sites.

A sufficient number and length of transects were established to encompass all portions of the Northeast Study Area (Figure 1). Each off-road activity was run on a given transect twice daily, once in the morning and once in the afternoon, during a 5-day period; this daily frequency of activity corresponds to traffic frequency on Starkey roads that produced an avoidance response by elk in earlier research (Wisdom 1998, Wisdom et al. 2004b).

A particular activity for a given morning or afternoon was completed by one to three people who rode ATVs (four-wheelers or quads), mountain bikes, or horses, or who hiked as a group. On most days, group size consisted of two people moving as a pair; that is, by two people hiking or each riding ATVs, mountain bikes or horses. A group size of two, with a range of one to three people, often is typical for these recreation activities in nonwilderness portions of national forests (D. Barrett, personal communication 2002). Group size can vary substantially, however, with larger groups of 5 to 10 ATV riders or horseback riders, for instance. We had neither the resources nor the experimental options to include these larger groups as treatments in our study. Moreover, group size of mountain bikers and hikers often does not approach 5 to 10 people, and we wanted to maintain approximately the same group size across all four activities. A group size of two people, with a range of one to three people, provided this consistency.

For ATV travel, a pair of riders could easily cover the 20 miles (32 km) of transects during a given morning or afternoon. A pair of mountain bike riders, however, could cover about 50 percent of the 20 miles (32 km) in a morning or afternoon. Horseback riders and hikers could cover about 30 percent. Because we wanted to standardize the experiment by the same number of transect runs or passes (twice daily) among all four off-road activities, two different groups of mountain bikers and three groups of horseback riders or hikers were used to obtain complete coverage of transects for a given morning or afternoon. For mountain biking, the transects were divided in half, with each of the two groups assigned to ride a different half of the 20 miles (32 km) in a morning or afternoon. Similarly, three groups of horseback riders or hikers, each assigned to travel a different third of the transect length, were used for each morning and afternoon to obtain complete coverage of transects.

Each of the four off-road activities was implemented under an interrupted movement design, where humans were allowed to momentarily stop to view animals for less than 1 minute when animals were observed. This is in contrast to a continuous movement design, where human activities are not delayed or stopped when animals are observed (Taylor and Knight 2003b).

Each 5-day period of off-road activity was followed by a 9-day control period, during which no human activities occurred in the study area. This pattern was followed from mid-April through October, resulting in three replicates of each of the four off-road activities. Each 5-day replicate of an off-road activity thus was paired with a 9-day control period that immediately followed the replicate. Only one type of off-road activity (ATV, horseback, mountain bike or hiking) occurred on transects during a given 5-day replicate. The chronological order of each off-road activity, in terms of which activity occurred during the first 5-day replicate in late April, versus the next 5-day replicate in early May, and so on, was randomly chosen.

Throughout the experiment, all human entry beyond the four off-road activities, including administrative use of roads, was prohibited to eliminate the confounding effects of other human activities with animal response to the off-road activities. Consequently, human activities such as timber harvest, road traffic, camping and hunting did not occur during the study because of their confounding effects.

Measuring Animal Responses

To monitor animal responses, 12 female mule deer and 12 female elk were radio-collared among a larger population of approximately 25 female deer and 100 female elk present in the Northeast Study Area in early April. Movements of these radio-collared animals were monitored with the ATS (Rowland et al. 1997). During periods of off-road activity, locations of each radio-collard deer or elk were generated at approximately 10-minute intervals. Locations of humans engaged in each off-road activity were generated at approximately 1-minute intervals, using GPS units carried by one of the persons in each group of hikers or riders of ATVs, horses or mountain bikes. Use of the automated telemetry system to track animal movements, combined with the use of GPS units to track human movements, provided real-time, unbiased estimates of the distances between each ungulate and group of humans.

Our method of estimating distances between ungulates and humans contrasts strongly with the use of direct observation, using rangefinders or other devices, to measure distances. Direct observation as a means of estimating distances between ungulates and humans is likely to be biased by the proportion of deer or elk whose reactions to human activities cannot be observed because such reactions are different than those of animals that can be observed. For example, some animals may run from human activity at distances beyond the view of observers, while other animals may react at close distances to, and in view of, observers. This bias in observed distances would result in underestimation of the true distance at which animals react to the human activity. In other cases, animals may flee from humans at close distances but not be viewed because such animals seek dense cover during flight; this bias would result in overestimation of distances. We avoided such biases with the use of our automated telemetry system and GPS units to continuously monitor the movements of ungulates and humans throughout our study.

We also located radio-collared animals during the 9-day periods of no human activity, or control period. Approximately two locations of each radio-collared animal were obtained every hour during control periods, to establish baseline information about areas of deer and elk use, habitat selection, movement rates, and flight responses in the absence of human activities. For this paper, we analyzed two types of animal reactions: (1) movement rate and (2) probability of flight response. We evaluated movement rate and probability of flight response because both can ultimately be used to estimate the energetic costs of animal reactions to off-road activities (see Conclusions and Interpretations).

Estimating Movement Rates

We defined movement rate as the speed of animal movement (yards moved per minute), estimated hourly, 24 hours per day, for a given species, treatment and control period. We calculated the speed of animal movement for each radio-collared deer or elk for each pair of successive locations; that is, the horizontal distance between two successive locations divided by the elapsed time between locations (Ager et al. 2003). Each measurement of animal speed for a given radio-collared animal was assigned to the time recorded for the first location of each pair of animal locations used in the calculation.

Only successive locations with consistent elapsed times were included in the calculation of movement rates to eliminate the bias of excessively short and long elapsed times. Short elapsed times (e. g., fewer than 5 minutes) between locations falsely inflate the movement rate because of random location errors in the ATS over such short time periods (Findholt et al. 1996, 2002). Long elapsed times (e .g., more than 35 minutes) between locations allow animals to move back and forth between the documented locations, thus biasing the estimate of movement rate downward (Ager et al. 2003).

To estimate overall patterns of movement rates for each species, rates calculated for each individual radio-collared animal were averaged among all animals, for mule deer and for elk, by hourly interval, for each off-road treatment and the paired control period that immediately followed that treatment. For this analysis, we minimized random variation by summarizing results across each 5-

day treatment and across each subsequent 9-day control. We did this after exploratory plots of data provided no evidence of change in movement rates of animals from day 1 through day 5 of each treatment period, or for day one through nine of each control period, as examined on an hourly basis. We then pooled hourly results for each species across the three replicates of each off-road activity, and across control periods, after finding no evidence of differences in like replicates across time, or in control periods across time.

Estimating Probabilities of a Flight Response

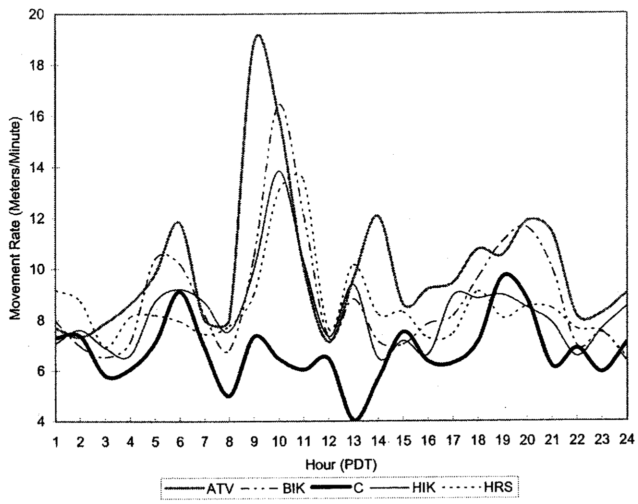
We used a stimulus response model to estimate the probability of a flight response by a deer or elk with changing distance between each animal and off-road activity. We defined a flight response as the speed of animal movement, or movement rate, that exceeded the 95th percentile of all deer or elk speeds calculated for each hour from data collected during the control periods. Specifically, a flight response was any animal movement for a given hour of day that exceeded the 95th percentile of all deer or elk speeds calculated for that same hour of day during the paired 9-day control period that immediately followed a given 5-day period of off-road activity. Thus by definition, when no stimulus was present (no human activity), a deer or elk would register a response (i. e., travel at speeds greater than the 95th percentile of all deer or elk speeds for that hour during the control period) 5 percent of the time. Probabilities of response were estimated using logistic regression within the generalized additive model framework (Hastie and Tibshirani 1990).

Each estimated probability of a flight response for a given radio-collared animal was linked to the estimated distance between that animal and each group of humans conducting an off-road activity, allowing an examination of how probabilities changed with distance between animals and humans. As with our analyses of movement rates, we pooled the probability data for each species across the three replicates of each off-road activity and across control periods. We pooled data after initial analyses showed that results for deer and elk were similar across the three replicates of each off-road activity and across all control periods.

Movement Rates of Elk

Movement rates of elk were substantially higher during periods of all four off-road activities, compared to periods of no human activity (Figure 2). Responses of elk to the morning and afternoon runs were clearly evident, with

Figure 2. Mean movement rate (speed, meters per minute) of elk, estimated hourly on a 24-hour basis, Pacific Daylight Time (PDT), during periods of no human activity (C) versus periods of ATV activity (ATV), hiking (HIK), mountain bike riding (BIK) and horseback riding (HRS), from April through October, 2002, in Northeast Study Area of Starkey.



the most pronounced increase in movement rates observed during the hours when each off-road activity occurred (Figure 2). For example, our morning pass on transects began between 0830 and 0930 Pacific Daylight Time (PDT), and highest movement rates for elk occurred in the hours immediately after, from 0900 to 1100, during all four activities (Figure 2). Moreover, lunch break for participants in the experiment occurred at or near noon, and movement rates for elk dipped to their lowest level at noon during all activities. Finally, we resumed each activity at 1230 to 1300 PDT, and movement rates for elk substantially increased immediately after (Figure 2).

Movement rates were substantially higher for elk during the morning pass, compared to the afternoon pass, for all four activities (Figure 2). Movement rates of elk during the afternoon pass, however, stayed well above the rates observed during the periods of no human activity (control period, Figure 2). Movement rates during the afternoon pass declined after 1500 PDT, when afternoon activities ended.

For the morning pass, movement rates of elk were highest during ATV riding, second-highest during mountain-bike riding and lowest during hiking and horseback riding (Figure 2). Movement rates of elk also stayed higher, over a longer period, during the afternoon ATV run, compared to rates during afternoon horseback riding, mountain-bike riding and hiking. Peak movement rates of elk during the morning pass were highest for ATV riding (21 yards per minute [19 m/min]), followed by mountain bike riding (17 yards per minute [16 m/min]) and horseback riding and hiking (both about 15 yards per minute [14 m/min]). For the afternoon run, movement rates of elk again were highest during ATV riding (13 yards per minute [12 m/min]), followed by horseback riding (about 11 yards per minute [10 m/min]) and hiking and mountain bike riding (about 10 yards per minute [9 m/min]).

By contrast, peak movement rates of elk during the control periods did not exceed 9 yards per minute (8 m/min). Moreover, peak movement rates during the control periods stayed below 8 yards per minute (7 m/min) during daylight hours of 0800 to 1500, the comparable period of each day when off-road treatments were implemented.

Interestingly, movement rates of elk also were higher than control periods at times encompassing sunrise and sunset for the days in which an off-road activity occurred, even though humans were not present at these times of day (Figure 2). These higher movement rates near sunrise and sunset suggest that elk were displaced from preferred security and foraging areas as a result of flight behavior during the daytime off-road activities. In particular, movement rates of elk at or near sunrise and sunset were higher during the 5-day treatments of mountain bike and ATV activity (Figure 2). This finding will be studied in detail in future analyses.

Flight Responses of Elk

The estimated probability of elk flight from a human disturbance was highly dependent on distance. When elk and humans were close to one another, the maximum probability of a flight response was approximately 0.65 during ATV, mountain bike and hiking activity, and 0.55 during horseback riding (Figure 3). Higher probabilities of flight response occurred during ATV and mountain bike activity, in contrast to lower probabilities observed during hiking and horseback riding (Table 1). Probability of a flight response declined most rapidly during hiking, with little effect when hikers were beyond 550 yards (500 m) from an elk. By contrast, higher probabilities of elk flight continued beyond 820 yards (750 m) from horseback riders and 1,640 yards (1,500 m) from mountain bike and ATV riders (Figure 3).

Movement Rates of Deer

In contrast to elk, mule deer showed less change in movement rates during the four off-road activities compared to the control periods (Figure 4).

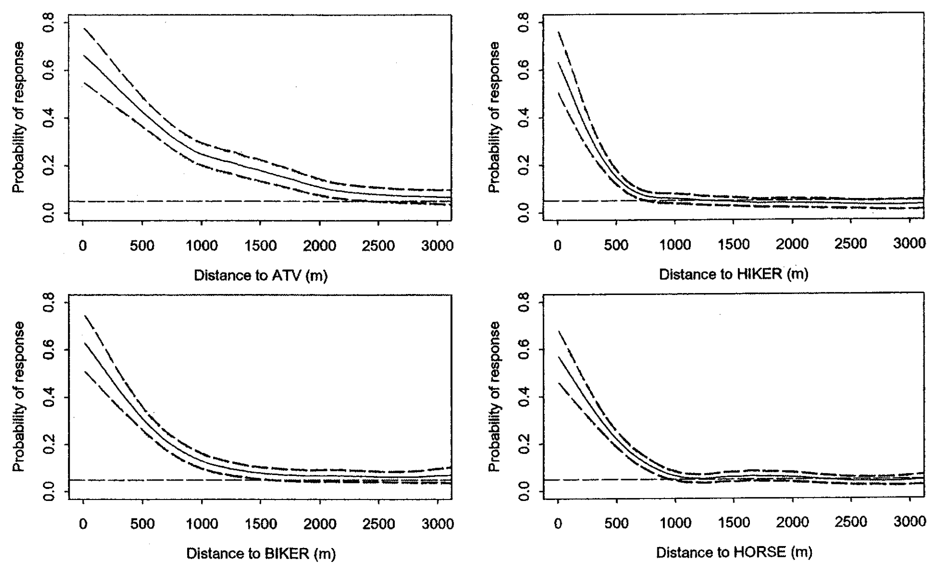


Figure 3. Estimated probability (solid line encompassed by dashed lines of the approximate 95 percent pointwise confidence interval) of a flight response by elk during 2002 in relation to distance (meters) from humans riding ATVs, mountain bikes, horses or hiking. A flight response is defined as an animal movement with a speed exceeding the 95th percentile of speeds observed during periods of no human activity (control period). The horizontal dashed line at the bottom of each graph is the probability of a flight response by elk during periods of no human activity, and this line represents the background, or the null condition, above which significant elk response to the off-road activities exists.

During the period of day from 0800 to1500 when off-road activities occurred, movement rates of deer during ATV riding were similar to rates during control periods. By contrast, daytime movement rates of deer were higher, compared to control periods, during mountain bike riding, horseback riding and hiking, especially in the morning (Figure 4).

Interestingly, the increased movement rates observed for elk near sunrise and sunset also were evident for mule deer. Movement rates at these times were particularly high during all four activities as well as during the control periods, suggesting that these times were peak foraging periods (Ager et al. 2003).

Flight Responses of Deer

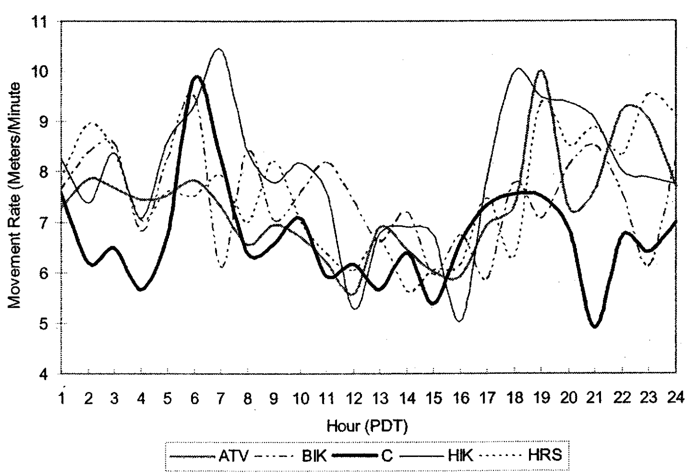
Estimated probabilities of flight response for mule deer were similar among all four activities versus control periods (Table 1, Figure 5). These

Table 1. Estimated probabilities (and approximate 95 percent confidence limits) of a flight response by elk and mule deer as a function of distance between animals and humans riding all-terrain vehicles (ATV), mountain bikes (BIKE), horses (HORSE) or hiking (HIKE). On average there were 128 deer or elk locations obtained during a given day of each off-road activity (treatment periods). During periods of no human activity (control periods), the null probability of a flight response is 0.05. Thus, any values greater than 0.05 reflect an increased probability of a flight response in relation an off-road activity.

Distance[1]	ATV	Bike	Horse	Hike
109 yards (100 m)	0.62	0.58	0.50	0.52
from elk	(0.52–0.73)	(0.46–0.68)	(0.40–0.59)	(0.42–0.64)
545 yards (500 m)	0.43	0.31	0.22	0.15
from elk	(0.36–0.49)	(0.26–0.35)	(0.19–0.26)	(0.12–0.18)
1,090 yards (1,000 m)	0.25	0.13	0.07	0.06
from elk	(0.20–0.30)	(0.10–0.16)	(0.05–0.08)	(0.04–0.08)
All distances	0.19	0.14	0.11	0.08
from elk	(0.17–0.21)	(0.12–0.16)	(0.09–0.12)	(0.07–0.10)
109 yards (100 m)	0.06	0.08	0.11	0.10
from deer	(0.01–0.11)	(0.02–0.14)	(0.03–0.19)	(0.04–0.17)
545 yards (500 m)	0.05	0.07	0.05	0.04
from deer	(0.02–0.07)	(0.04–0.10)	(0.03–0.07)	(0.02–0.05)
1,090 yards (1,000 m)	0.03	0.06	0.04	0.04
from deer	(0.01–0.06)	(0.03–0.08)	(0.02–0.06)	(0.02–0.06)
All distances	0.03	0.05	0.04	0.04
from deer	(0.02–0.05)	(0.04–0.07)	(0.03–0.05)	(0.03–0.06)

[1] Distance between an animal and human during each off-road activity.

Figure 4. Mean movement rate (speed, meters/minute) of mule deer, estimated hourly on a 24-hour basis, Pacific Daylight Time (PDT), during periods of no human activity (C) versus periods of ATV activity (ATV), hiking (HIK), mountain bike riding (BIK) and horseback riding (HRS) during 2002 in the Northeast Study Area of Starkey.



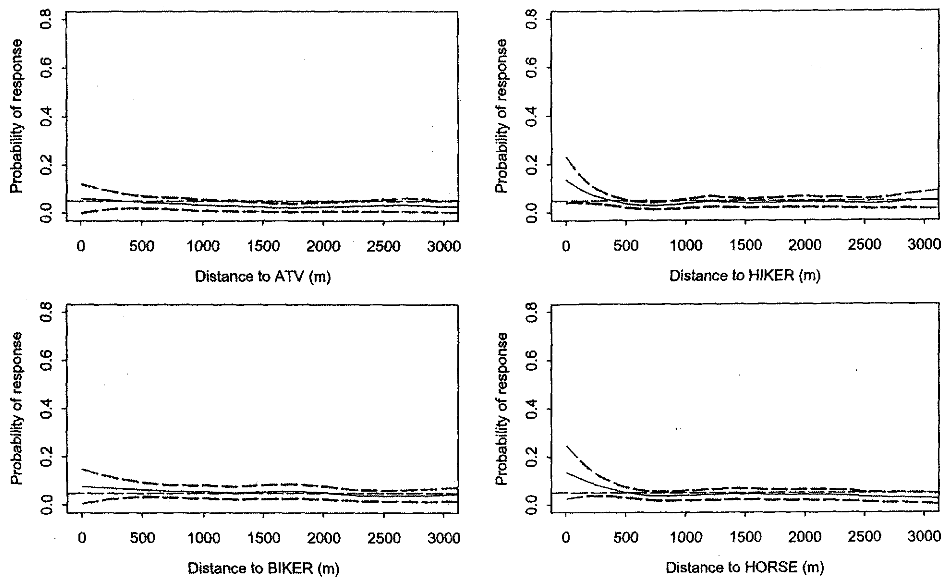


Figure 5. Estimated probability (solid line encompassed by dashed lines of the approximate 95 percent pointwise confidence interval) of a flight response by mule deer during 2002 in relation to distance (meters) from humans riding ATVs, mountain bikes, horses or hiking. A flight response is defined as an animal movement with a speed exceeding the 95th percentile of speeds observed during periods of no human activity (control period). The horizontal dashed line at the bottom of each graph is the probability of a flight response by deer during periods of no human activity, and this line represents the background, or null, condition, above which significant deer response to the off-road activities exists.

probabilities were nearly identical among all four activities and not significantly different than the null probability of 0.05 set for control periods, suggesting that deer were not exhibiting the same tendency for flight as shown by elk in relation to off-road activities (Table 1).

Conclusions and Interpretations

Elk

Movement rates and probabilities of flight response for elk were substantially higher during all four off-road activities, compared to control periods of no human activity. Consequently, off-road recreational activities like those evaluated in our study appear to have a substantial effect on elk behavior. The energetic costs associated with these treatments deserve further analysis to assess potential effects on elk survival. For example, if the additional energy required to flee from an off-road activity reduces the percent body fat of elk below 9 percent as animals enter the winter period, the probability of surviving the winter is reduced (Cook et al. 2004). Animal energy budgets also may be adversely affected by the loss of foraging opportunities while animals respond to off-road activities, both from increased movements and from displacement from foraging habitat. These potential effects will be evaluated as part of future analyses.

Our results from 2002 also show clear differences in elk responses to the four off-road activities. Elk reactions were more pronounced during ATV and mountain bike riding, and they were less so during horseback riding and hiking. Both movement rates and probabilities of flight responses were higher for ATV and mountain bike riding than for horseback riding and hiking.

Interestingly, the maximum probability of flight was approximately 0.65 for the treatments, meaning that, about 35 percent of the time, elk did not exhibit a flight response when close to an off-road activity. Most likely the response depends on local topography, cover and other factors that we have not yet analyzed as part of our flight response model. Future work will include terrain and vegetation measures as covariates in the probability models to examine whether these effects can be detected and quantified (see Taylor and Knight 2003b).

It is important to note that designing our study to maintain the same number of daily passes on transects among all four activities required the most effort for hiking and horseback riding, and the least effort for ATV riding. Specifically, to accomplish two runs per day required three groups of hikers or horseback riders (with each group hiking approximately 33 percent of transect length) but only one group of ATV riders. By contrast, accomplishing two runs per day required two groups of mountain bikers (with each group covering approximately 50 percent of transect length).

Our results for elk might have been different had we designed the study to test animal response to an equal number of groups, or equal density, of people engaged in the four off-road activities (i. e., the same number of groups of people engaged in each activity, regardless of the number of passes that could be accomplished), rather than testing for effects of equal saturation of the study area (i. e., two daily passes on transects for all four activities). In future analyses, we plan to explore the use of the amount of time spent by each off-road activity as a covariate and possibly weight the movement rates and probabilities of flight response by the inverse of time spent by each of the four off-road activities. This weighting would help account for differences in effort required among the four activities to achieve equal saturation of the study area.

Our results may also change if elk eventually become habituated to some or all of the off-road activities. We will evaluate this possibility in future analyses by formally testing for replicate and year effects under a random effects model, with repeated measures taken on radio-collared animals over time (Kirk 1982). Analyses to test for animal habituation to the off-road activities will be possible when all three years of data are collected.

Mule Deer

In contrast to elk, mule deer showed little measurable response to the off-road treatments. Movement rates increased slightly, however, during periods of all four-off road activities except ATV riding. Deer may well be responding to the treatments with fine-scale changes in habitat use, rather than substantial increases in movement rates and flight responses.

For example, it is possible that deer may respond to an off-road activity by seeking dense cover, rather than running from the activity. If mule deer are spending more time in dense cover, in reaction to any of the off-road activities, this could result in reduced foraging opportunities and a subsequent reduction in opportunities to put on fat reserves during summer that are needed for winter survival. Such potential responses will be evaluated as part of future analyses.

Utility of Response Variables

Taylor and Knight (2003b) defined a variety of terms for measuring animal responses to human activity. Neither movement rate nor probability of a flight response was defined, however, because these types of animal responses apparently have not been measured in past research. We measured these two responses to human activity because both variables can ultimately be used to estimate the energetic costs of animal reactions to human activities. For example, movement rate can be used as a background index of the rate of animal speed without human activities, versus periods of human activities, to estimate the additional energetic costs of increased movement, if any, in relation to human activities (Ager et al. 2003).

Similarly, the probability of a flight response indicates how likely an animal is to move at high speed in relation to its distance from a human. This probability indicates how likely an animal is to run from a human activity, and thereby disrupt the animal's activities related to energy acquisition (foraging) or energy conservation (resting). Any movement away from an area in relation to human activity has the potential to disrupt these foraging and resting patterns and, thereby, to cost energy (Johnson et al. 2004).

Future analyses will focus on the energetic costs, if any, to mule deer and elk from exposure to each off-road activity. Additional analyses also will include estimates of (1) the distance moved by an animal, given a flight response; (2) the time required for an animal that exhibits a flight response to return within a specified distance of the animal's location before the flight; (3) the change in space use by an animal, during or following periods of human activity, which may suggest or reflect an animal seeking greater refuge from the human activity, as compared to background, or null, use of space during periods of no human activity; and (4) the degree to which animals spend time in forage areas, gaining energy, versus time spent in nonforaging areas, during each off-road activity versus control periods.

Implications for Recreation Management

Laws and policies of public land management emphasize multiple resource uses. Management of timber, grazing, roads, minerals, and wilderness are examples of traditional uses on lands administered by the U. S. Department of Agriculture, Forest Service (Forest Service) and U. S. Department of Interior, Bureau of Land Management (BLM), the two largest federal landowners in the United States. Public land managers now face the additional challenge of serving a variety of off-road recreational uses that are increasing rapidly, and that can be difficult to accommodate on the same land area at the same time (Taylor and Knight 2003a).

New planning approaches are underway in the Forest Service to accommodate increasing off-road recreational demands while mitigating the negative effects on species like elk (U.S. Department of Agriculture Forest Service 2004). These approaches could consider two related concepts: (1) off-road use rates and (2) off-road recreational equivalents. We define off-road use rates as the number of passes per unit of time on a given linear route (primitive road or trail that we referred to as transects) traveled by an off-road activity. Our results show that one pass per day by any of the four off-road activities causes increased movement rates and flight responses by elk.

We define off-road recreational equivalents as the ratio of ATV riders, mountain bikers, horseback riders and hikers that results in approximately the same effect on a given resource, given the same off-road use rate. In the case of elk, movement rates and probabilities of flight were highest during ATV riding and lowest during horseback riding and hiking. These effects were a result of one group of ATV riders, two groups of mountain bikers and three groups of horseback riders or hikers required to complete one pass on the transects each morning or afternoon. Consequently, the stronger effects posed by ATV riding, combined with differences in the number of groups required of each activity to achieve one pass on the transects, suggest that recreational equivalents would exceed three groups of horseback riders or hikers to every one group of ATV riders, and exceed two groups of mountain bike riders to every group of ATV riders.

Although the formal methods of calculating the specific recreational equivalents could be a subject of lengthy debate, the idea that different levels of each off-road activity are required to approximate the same effect on a given resource is logical and defensible. Accordingly, off-road use rates and recreational equivalents could be tested as potential concepts in helping allocate recreational activities within and across watersheds on a given national forest or BLM field office. These concepts may be particularly relevant when derived from a combination of response variables or resource uses. For example, effects of each off-road activity on water quality, soil productivity, invasion of exotic plants and species sensitive to human activities could be considered in deriving use rates and recreational equivalents.

Such an approach would demand a substantial increase in research on effects of off-road activities. For management of elk, results from our study will be most useful when estimates of the energetic costs, if any, are derived for each of the four off-road activities in terms of use rates and recreational equivalents. Energetic costs to elk from one pass per day on a given linear route traveled by a given off-road activity could be estimated, and the equivalent energetic costs, given the same use rates, could be estimated among all off-road activities.

Although these details are not yet available, managers could begin to consider holistic management strategies for all off-road activities based on our current findings. Some watersheds might feature opportunities for ATV or mountain bike riding, for example, while other watersheds might focus on opportunities for horseback riding or hiking. Importantly, the watersheds identified for horseback riding or hiking could accommodate a substantially higher number of groups engaged in these off-road activities before realizing the same effects on elk as would be expected in watersheds where ATV or mountain bike riding are featured. This type of holistic management of different mixes of all off-road activities contrasts with management approaches that focus on a single off-road activity, without consideration of all off-road uses and their cumulative effects.

Other strategies for watershed planning might simply focus on restricting each recreational activity to specified trails or roads. In this case, our results suggest that the effectiveness of such a strategy would depend on how much area is affected by the network of trails or roads allowed for use. If the linear distance of trails or roads open to recreation is small, relative to the total area of the watershed, the effect on elk is likely to be minor or negligible. If the linear distance is large, relative to the size of the watershed, the negative effect on elk could increase substantially. The specific effects could be analyzed in the same manner as outlined for estimating effects of motorized road traffic on elk, as done with distance band models (Rowland et al. 2004).

Effective and defensible strategies to meet off-road recreation demands, while also mitigating negative resource effects, are likely to require a substantial increase in budgets of public land agencies for research, management and monitoring of these activities. Managers currently have little knowledge with which to develop effective strategies in partnership with the many public recreation users. Without such knowledge, the debate about off-road recreation is likely to intensify, with few scientifically based options for resolution in relation to mitigating potential negative effects on species like elk that are sensitive to human activities.

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Trade-offs between utility-scale solar development and ungulates on western rangelands

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Utility-scale solar energy (USSE) has become an efficient and cost-effective form of renewable energy, with an expanding footprint into rangelands that provide important habitat for many wild ungulate populations. Using global positioning system data collected before and after construction, we documented the potential impacts of USSE on pronghorn (*Antilocapra americana*), including direct habitat loss, indirect habitat loss, and barrier effects to both resident and migratory population segments. Our case study highlights the challenges that USSE poses to ungulate conservation, including (1) impermeable security fencing that blocks access to and reduces connectivity between formerly available habitats, and (2) the lack of guidelines for minimizing USSE impacts on ungulates. Improved siting and ungulate-specific best management practices would help to minimize habitat loss and retain landscape connectivity. Ungulate biodiversity and ecosystem services (for example, services provided by long-distance migratory species) in arid rangelands are important considerations when balancing the global benefits of renewable energy with local wildlife impacts.

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Renewable energy can help mitigate global climate change but can also cause localized environmental impacts (Moore-O'Leary *et al*. 2017), including habitat loss and fragmentation (Lovich and Ennen 2011). The growing demand for renewable energy in the US is propelled by renewable portfolio standards (Barbose 2019) and wide-ranging policies that support transitioning to a "green economy" (Gasparatos *et al*. 2017). Solar energy comprises an increasing proportion of the growing US renewable energy market and is predicted to provide 40% of the US electric supply by 2035 (US Department of Energy 2021).

As compared to other renewables, solar energy has the lowest life-cycle greenhouse-gas emissions (Hernandez *et al*. 2015b), and in some cases can have high land-use efficiency (that is, amount of energy generated by area) (Hernandez *et al*. 2014). Yet the impacts associated with utility-scale solar energy (USSE; ≥1 megawatt [MW]) are evident in the amount of land these installations require, and can be exacerbated in arid landscapes where plant and wildlife communities are especially sensitive to disturbance (Grodsky and Hernandez 2020). With the exception of several avian (Kosciuch *et al*. 2020) and sensitive (Agha *et al*. 2020) species, the potential impacts of solar development on wildlife, and specifically ungulates, are largely undocumented (Lovich and Ennen 2013). As USSE installations expand in size and distribution, understanding the potential effects on ungulates is needed to inform siting and layout design, and to weigh the broader trade-offs of mitigating climate change against impacts on local wildlife and ecosystem services.

Pronghorn (*Antilocapra americana*) occupy the open plains and arid rangelands of the Intermountain West, an area heavily impacted by fossil-fuel extraction in recent decades (Jones *et al*. 2015). Such habitats are now also hotspots for USSE because of their excellent solar energy potential (Lovich and Ennen 2011) and proximity to states with renewable energy portfolio standards (Barbose 2019). Pronghorn appear especially vulnerable to USSE impacts because they prefer flat, open habitats ideal for solar development. Furthermore, as a wide-ranging species, pronghorn are more susceptible to linear barriers (such as roads and fences) and fragmentation effects than other ungulates (Jones *et al*. 2019; Xu *et al*. 2021).

Unlike other forms of energy development (eg wind or natural gas) that remain permeable to ungulates (Sawyer *et al*. 2013), safety regulations require USSE perimeters be surrounded by 2-m-tall, chain-link fencing (NFPA 2017), making habitat within solar projects inaccessible to pronghorn and other ungulates. In addition to habitat loss, USSE may also alter or block ungulate movements or migrations, depending on site location, size, and layout design. Given the rapid expansion of USSE, it is critical to understand the consequences of habitat loss and identify ways to make USSE more permeable to wide-ranging ungulates to inform stakeholder decisions regarding project siting and design.

We used global positioning system (GPS) data collected from 30 pronghorn before and after the first USSE constructed in the US state of Wyoming to evaluate habitat loss and barrier effects to resident and migratory animals. Our study provided a unique opportunity to quantify impacts from USSE by comparing high-use areas before and after construction. We also used fine-scale movement data to estimate

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the extent of barrier effects and we discuss the potential ramifications to resident and migratory ungulates. We use this case study to highlight planning and policy considerations needed to inform USSE siting, layout designs, and the broader trade-offs between reducing global emissions and creating localized impacts on ungulates in western rangelands.

Methods

Study area

Our study area was located in southwestern Wyoming (41.628°N, –109.683°W), adjacent to Highway 372 (Figure 1). With flat and rolling topography, this region is characterized by high-elevation (1920–2030 m above sea level) sagebrush (*Artemisia* spp) communities. High irradiance values, relatively low snowfall, and existing electricity transmission infrastructure make the region attractive for solar development (BLM 2018). The Sweetwater Solar Facility, the first USSE (80 MW) in Wyoming, was built during the autumn of 2018 on native rangelands managed by the US Bureau of Land Management (BLM). In response to concerns from the Wyoming Game and Fish Department (WGFD) about the facility's proposed square layout potentially blocking pronghorn migration and diverting animals onto Highway 372 (BLM 2018), the developer modified the southwest corner to an angled layout (WebFigure 1) to accommodate pronghorn movements on flat terrain around the west side of the facility (BLM 2018). Following construction in October 2018, the 2.3-km^2 facility was enclosed with a 2-m-tall chain-link fence topped with three-strand barbed wire.

The project sits in an area designated as crucial pronghorn winter range by the WGFD. The study area south to Interstate 80 supports hundreds of resident pronghorn year-round and hundreds more during the winter, when migratory animals return from their respective summer ranges. In severe winters, the area is also used by >1000 pronghorn from the Opal herd that normally spend winters 20–40 km northwest of the USSE.

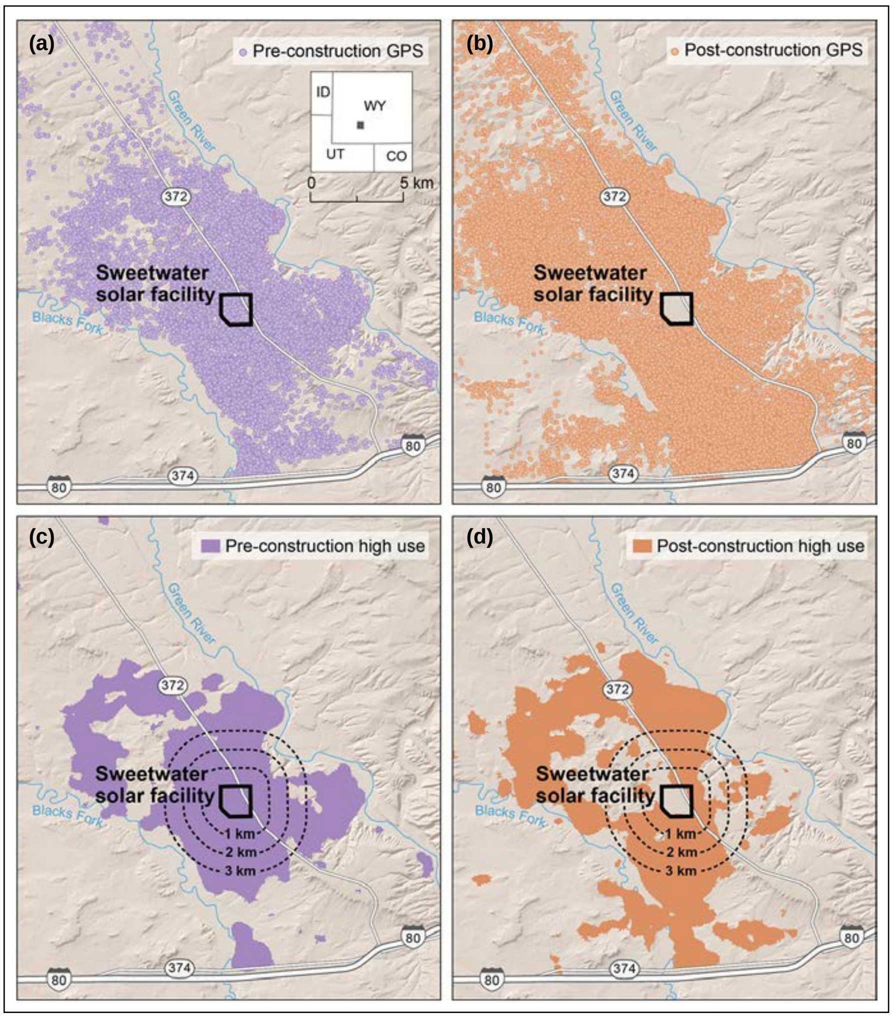

Figure 1. Global positioning system (GPS) locations of resident pronghorn (*Antilocapra americana*; *n* = 11) (a) before and (b) after construction of the Sweetwater Solar Facility, a utility-scale solar energy (USSE) project in southwestern Wyoming. High-use range of resident pronghorn (c) before (01 May–30 Sep 2018) and (d) after (01 May–30 Sep 2019 and 2020) the USSE facility was built.

Data collection

We used helicopter net-gunning to capture 20 adult female pronghorn in February 2018 and an additional three females in November 2018. We fitted each pronghorn with a GPS collar programmed to collect locations every 2 hours through October 2020. Overall, we collected 198,278 locations from 23 individuals, of which 70% (*n* = 16) were non-migratory and 30% (*n* = 7) were migratory. As part of a separate study, we also captured seven pronghorn in March 2017 from the larger Opal herd. Our capture coincided with one of the periodic migrations of this herd through the study area, allowing us to document their migratory movements relative to the USSE site during the spring of 2017, approximately 18 months prior to construction.

Habitat loss and barrier effects

We used several complementary maps and metrics to quantify habitat loss. First, we mapped pre-construction (01 Apr–30 Sep 2018) GPS locations (*n* = 25,881) to visually compare with post-construction (01 Nov 2018–30 Oct 2020) locations (*n* = 67,967). We restricted this analysis to resident animals that had at least one location in, or moved through, the project area prior to USSE construction (*n* = 10). We then used Brownian bridge movement models (Horne *et al.* 2007) to estimate utilization distributions (UDs) from GPS location data. We calculated UDs for each individual and then averaged across individuals to estimate pre- and post-construction population-level UDs (Sawyer *et al*. 2009). We restricted the post-construction UD analyses from 2019 and 2020 to the same date range as pre-construction (01 Apr–30 Sep) to facilitate comparison. We then used the 30% contour of the UDs (that is, the highest 30% of UD values) to identify high-use areas relative to the USSE before and after construction. To identify potential changes in habitat use adjacent to the USSE, we compared the amount of high-use areas within 1-km, 2-km, and 3-km buffers around the USSE before and after construction. We limited our buffer analysis to 3 km because barrier effects were unlikely to extend farther, and pronghorn movements were restricted by a railroad 3 km to the west and the Green River 3 km to the east. We also used Brownian bridge movement models to estimate the average high-use winter (01 Dec–15 Mar) and summer (01 Jun–01 Sep) range size of all pronghorn from the study area (n = 23). On the basis of the average winter and summer range sizes, we then calculated what proportion of each the USSE habitat loss of 2.3 km^2 represented.

To estimate the extent of barrier effects, we determined the proportion of resident and migratory animals whose movements were affected by the USSE. We identified individual animals as affected by barrier effects if their pre-construction movements (represented by lines connecting GPS locations) were inside of the area or within 500 m of where the USSE installation was subsequently constructed and fenced. The 500-m buffer was based on average step length (454 ± 12 m, mean ± standard error [SE]) and intended to account for uncertainty in movement between successive GPS locations.

Results

Analysis of the UDs revealed that the USSE was constructed within a high-use seasonal range of resident pronghorn (Figure 1). Following construction, pronghorn were unable to access habitat within the USSE, losing 2.3 km^2 of year-round habitat. Pre-construction, high-use areas totaled 110.5 km^2, including 11.7 km^2, 26.6 km^2, and 43.9 km^2 within the 1-km, 2-km, and 3-km buffers, respectively. Post-construction, high-use areas totaled 106.8 km^2, including 7.0 km^2, 15.8 km^2, and 27.3 km^2 within the 1-km, 2-km, and 3-km buffers, respectively. Overall, the amount of high-use areas adjacent to the USSE was reduced by 40% within 1–2 km and by 34% within 3 km following construction (Figure 1). Reduced use was most apparent northwest and southeast of the USSE installation (Figure 1). The average high-use pronghorn summer range size was 18.78 ± 2.41 km^2 (mean ± SE), whereas the average high-use winter range was 22.05 ± 2.15 km^2. The 2.3-km^2 loss of habitat due to the USSE represented 12% of the average summer range and 10% of the average winter range.

Prior to construction, 69% (n = 11) of resident pronghorn used the USSE site and were subsequently forced to alter their year-round movements to accommodate the USSE (Table 1). Only 31% (n = 5) of resident pronghorn did not overlap with the USSE and were presumably unaffected by barrier effects. Within the migratory segment, 86% of pronghorn (n = 6) moved through the USSE before construction and could no longer migrate through that specific area after construction (Table 1). Most of these migratory movements were to summer ranges approximately 30 km northwest, but some extended up to 225 km (Figure 2). Of the migratory pronghorn sampled from the larger Opal herd that periodically migrates southeasterly and northwesterly through the study area, 57% (n = 4) migrated through the USSE site before its construction (Table 1; Figure 3).

Discussion

Solar energy offers an efficient and cost-effective source of renewable energy that plays a growing role in reducing global atmospheric carbon emissions (Moore-O'Leary *et al*. 2017). However, with USSE expansion into western rangelands comes a new set of challenges for managing and conserving ungulates. Other forms of energy development (eg natural gas, wind, oil) typically remain permeable to ungulates (Sawyer *et al*. 2013), and their impacts can often be minimized by consolidating infrastructure and reclaiming disturbed sites (Northrup and Wittemyer 2013). In contrast, habitat within USSE is completely lost because the required security fencing is impermeable to large mammals. Our case study demonstrates that the first USSE constructed in Wyoming was sited on important seasonal pronghorn range that resulted in habitat loss inside and possibly adjacent to the project,

Table 1. Summary of solar development habitat loss and barrier effects to resident and migratory pronghorn (*Antilocapra americana*) in southwestern Wyoming, 2018–2020

Herd segment	Proportion of animals affected	Habitat loss	Barrier effect
Residents	69%	Year-round habitat	Daily and seasonal movements
Local migrants	86%	Migratory habitat	Annual spring and autumn migratory movements
Opal herd migrants	57%	Migratory habitat	Periodic migratory movements

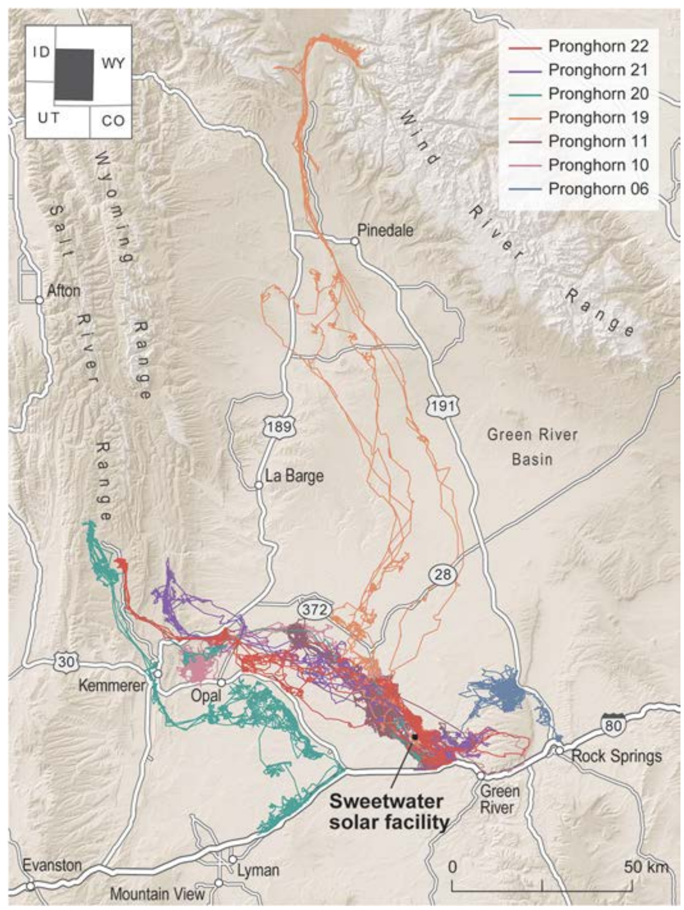

Figure 2. Year-round (2018–2020) movements of migratory pronghorn (*n* = 7) captured in or near the Sweetwater Solar Facility. Most (86%) of these animals migrated through the site's footprint prior to its construction. Pronghorn #19 migrated 225 km to summer range each year: in 2018, 2019, and 2020.

and introduced barrier effects to both resident and migratory herd segments – distinct impacts that other ungulate populations may be exposed to as solar development expands.

Pronghorn directly lost 2.3 km^2 of high-use habitat, an area equivalent to 10% and 12% the size of the average pronghorn winter and summer core ranges, respectively. Furthermore, the proportion of high-use habitat up to 2 km beyond the USSE declined by 40% following construction. This degree of indirect habitat loss was unexpected because of the relatively low levels of human disturbance (eg traffic, noise, lights) associated with the USSE. Nonetheless, our GPS data collected from the same animals and date ranges before and after construction revealed reduced levels of use to the northwest and southeast of the USSE. We recognize that – relative to other ungulates – pronghorn can be more plastic with respect to movement and site fidelity (Morrison *et al.* 2021), and thus pronghorn possibly shifted habitat use patterns in subsequent years due to factors unrelated to the USSE. However, because no obvious environmental or land-use change occurred following construction of the facility, we speculate that the indirect habitat loss was related to barrier effects or behavioral responses that modified pronghorn movements beyond the USSE boundary. Indirect habitat loss from avoidance behavior is well documented for ungulates living near conventional forms of energy development (Sawyer *et al.* 2017), including pronghorn (Sawyer *et al.* 2019). Our results suggest that indirect habitat loss associated with USSE may also occur and additional study is warranted.

Although relatively small, the 80-MW Sweetwater USSE was sited where it impacted 69% of resident and 86% of migratory pronghorn, adding to the cumulative effects of existing highways, gravel pits, trona mines (mineral from which soda ash is refined), railroads, and other anthropogenic disturbances. Resident pronghorn lost year-round habitat and had to modify their movements accordingly, and migratory pronghorn could no longer move through the USSE during migration, affecting migrations that extended up to 225 km away. The biological cost of barrier effects on ungulate movements is unclear but is of broad conservation concern and growing research interest (Xu *et al.* 2021). Likewise, more than half the pronghorn we sampled from the Opal herd also lost migratory habitat. Anecdotal evidence suggests that these animals, which only move through the area periodically, currently lack the knowledge or perceptual range to move around the west side of the project area and instead follow the USSE fence east to Highway 372. During one of the Opal herd migration events, several hundred pronghorn encountered the north boundary of the USSE and subsequently moved onto Highway 372, on which they traveled south for several miles (https://bit.ly/3L7CHA5). The WGFD opened several right-of-way fence gates and attempted to haze the animals off the highway. Although collisions with vehicles were averted, it was dangerous for both motorists and pronghorn, and several pronghorn that became entangled in fences died. Snow trails indicated that several hundred other pronghorn had indeed moved around the west side of the USSE as intended with the angled-fence layout design. However, given the strong propensity for pronghorn to move parallel to the highway, agencies and industry made the post-hoc decision to create a 50-m-wide corridor between the solar panels and highway right-of-way fencing for the 1.5-km length of the USSE, although at the time of publication this modification had yet to be completed.

Our case study reveals clear impacts of the USSE on resident and migratory pronghorn, raising the question of whether this project could have been sited or designed to better accommodate pronghorn. Ideally, USSE projects are sited in disturbed areas ("brownfields") or agricultural fields where environmental impacts are largely avoided (Cameron *et al.* 2012; Hernandez *et al.* 2015a,b) and, in some instances, improved with native plant restoration to benefit soils, water quality, pollinators, small mammals, and birds (Semeraro *et al.* 2018; Sinha *et al.* 2018). However, brownfield site

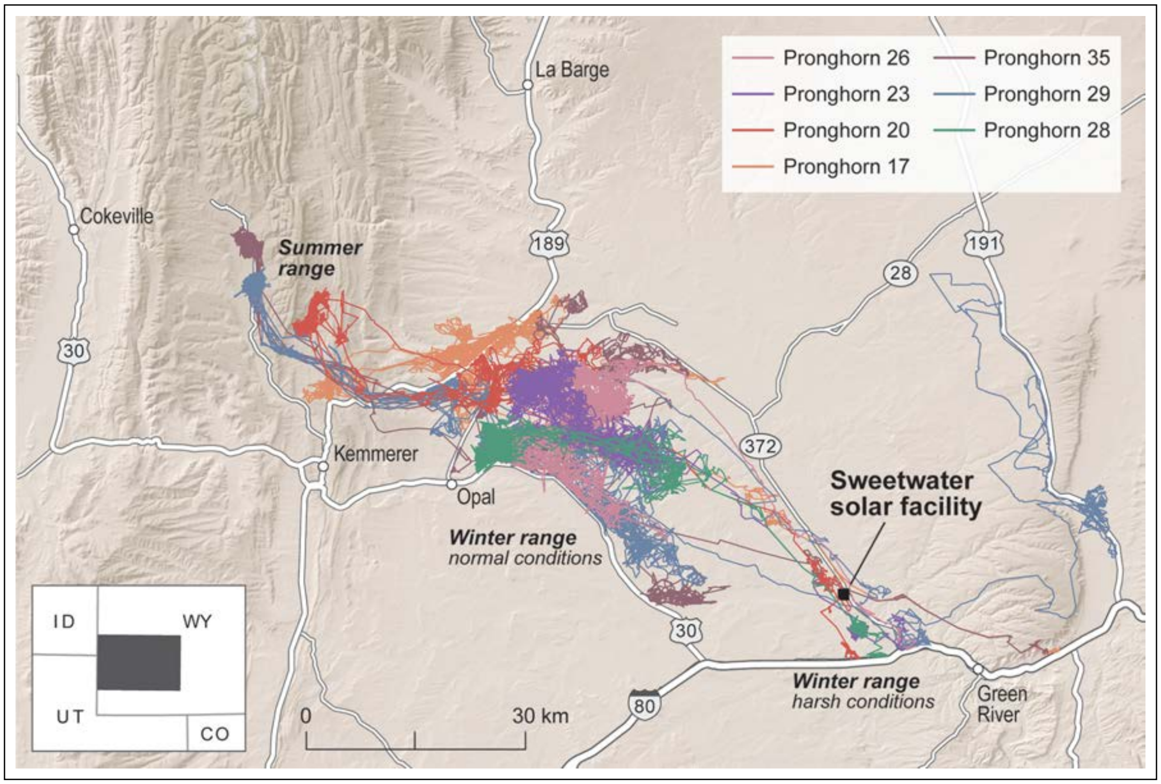

Figure 3. Year-round (2017–2019) movements of migratory pronghorn captured from the Opal herd, which migrates through the study area periodically in response to harsh winter conditions. Several thousand pronghorn utilize winter ranges 10–30 km north of the project area. Most (57%) of these animals migrated through the site of the Sweetwater Solar Facility prior to its construction.

availability varies regionally, brownfields may not be located close to transmission lines or other necessary infrastructure, and brownfields can have unique permitting challenges. Our study area contained no alternate sites that were previously disturbed and available for surface occupancy, and therefore any new development would disrupt native sagebrush grasslands and incur greater environmental costs. Our project relied on federal (National Environmental Policy Act), state (eg industrial siting process), and local (eg county commission) planning to minimize environmental impacts. We suggest these multiple planning levels would benefit from a unified strategy for siting and designing USSE installations to accommodate ungulates.

Regardless of the regulatory framework that a particular project undertakes, planning would benefit from greater access to wildlife movement and distribution data. Widespread use of GPS collars, through programs like those associated with the US Department of the Interior Secretarial Order 3362, has made ungulate migration routes and key seasonal ranges widely available. For example, the US Geological Survey is now collaborating with state wildlife agencies to collate and provide access to ungulate migration and winter range data for the western US (Kauffman *et al*. 2020). Armed with these types of data, solar developers and regulators could improve USSE siting and design layouts to minimize impacts to ungulates. Another challenge for managers is the short duration of USSE construction; unlike other energy development projects, which often take years to construct, USSE projects can be built within several months, making it difficult to collect sufficient ecological baseline data. Here, agencies and developers were proactive in implementing a pronghorn study immediately after project approval, yet that allowed us only 6 months of baseline data collection prior to construction, a limitation that may have masked or missed important patterns in seasonal use. Given how quickly USSE projects can be constructed, we suggest that state and federal agencies preemptively monitor ungulate movement and distribution in regions where solar development is anticipated.

Although habitat loss due to USSE installations may be unavoidable, thoughtful layout designs that accommodate animal movements can minimize barrier effects and retain the landscape connectivity needed for migratory ungulates. Depending on the size of the USSE, this may require one or more corridors through the project, possibly by splitting the USSE into multiple smaller units to allow ungulate movement in between. Unlike oil and gas development projects, in which managers often consolidate infrastructure (eg drilling multiple wells from a single pad) to minimize impacts (Northrup and Wittemyer 2013), solar arrays may need to be dispersed to accommodate ungulate movements. To date, there are no best management practices (BMPs) or standard corridor widths available to developers and regulators to inform layout design; consequently, we encourage experimentation with fence angles and corridor widths (even if they are relatively small [eg <50 m]), associated monitoring (eg GPS collars, trail cameras), and consolidation of information to help establish corridor guidelines and BMPs.

The global environmental benefits of renewable energy come at a cost of localized impacts that include loss of habitat, movement options, and possibly ecosystem services associated with affected species (including long-distance migrants). Although it can be argued that impacts to local wildlife from renewable energy are necessary to reduce the far greater risks to global biodiversity incurred from climate change (Allison *et al*. 2014), it is also clear that improved coordination and consideration of local and regional plans to protect wildlife could reduce the local impacts of green energy and climate policies (Jackson 2011). As increasing effort is put into reconciling trade-offs and minimizing local impacts (Santangeli *et al*. 2016; Gasparatos *et al*. 2017), we emphasize the need to consider ungulates – both migratory and resident populations – in future planning and design of USSE facilities. Arid western rangelands are generally not considered biodiversity hotspots, but the unique biological value of these ecosystems is critically important (Durant *et al*. 2012), and they support some of the longest ungulate migrations in the world (Middleton *et al*. 2020).

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Data Availability Statement

Utilization distributions and migration route data are available on the Dryad Digital Repository website (https://doi.org/10.5061/dryad.djh9w0w14).

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2498/suppinfo