8 — Solar Energy

A Technology with Multi-Scale Opportunities to Integrate Wildlife Conservation

Brian B. Boroski

Introduction

Solar energy technologies represent a rapidly developing renewable energy source worldwide (REN21 2016). Technological improvements in efficiency of solar energy are decreasing the time needed to recover initial investments, making solar power a financially competitive renewable energy source (Pherekkis et al. 2009, Dincer 2011). In 2016, for the first time in the United States, solar energy represented the largest new source of electricity-generating capacity, exceeding both natural gas and wind (Wood Mackenzie and SEIA 2016). While California, Georgia, and Utah collectively led solar energy installation within the United States in 2016, a total of 22 additional states each added more than 100 megawatts$_{DC}$ (MW, direct current) of photovoltaic (PV) solar (Wood Mackenzie and SEIA 2016). China, Germany, and Japan documented increased growth in solar energy, with each installing greater solar photovoltaic capacity in 2015 than the United States (REN21 2016). Utility scale (i.e., ≥1 MW) solar energy development is expected to grow worldwide with the strong international consensus to transition away from fossil fuels. Such growth will require large quantities of land for development, which could degrade or destroy habitat for some wildlife (REN21 2016). Nationally total installed solar PV capacity is expected to nearly triple the current capacity between 2018 and 2022, and more than 18 gigawatts$_{DC}$ (GW) of solar PV capacity is predicted to be installed annually (Wood Mackenzie and SEIA 2016); given current technologies and practices, this growth is estimated to require an additional 36,422 to 72,844 ha per year (BLM/DOE 2012, Ong et al. 2013). The US Department of Energy (DOE) SunShot Initiative envisions that utility-scale solar electricity will affect approximately 849,775 to 2,509,181 ha of land by 2050 (US DOE 2012). Because of the broad geographical extent of utility-scale solar energy, development is occurring in many areas with high biodiversity and rare animal species. Consequently, understanding the interface between utility-scale solar energy development and wildlife conservation is increasingly important as utility-scale solar facilities continue to be constructed worldwide.

Construction and operation of solar energy facilities can have direct and indirect effects on wildlife, which may be negative or positive depending on existing landscape conditions at the time of construction, and may affect multiple trophic levels as well as trophic-level interactions (Hernandez et al. 2014b, Grodsky et al. 2017). Positive effects are most likely to occur on previously altered (e.g., marginalized)

landscapes with limited wildlife habitat value. Negative effects are most likely to occur and be most severe in landscapes with previously intact biological communities, especially those characterized by relatively high plant and animal diversity. Examples of negative effects may include direct mortality, broad-scale habitat modification and fragmentation, changes to microclimate within solar arrays, increased levels of light and noise, invasion of non-native plant or animal species, and increased risk of wildfire (Grodsky et al. 2017, Lovich and Ennen 2011, Moore-O'Leary et al. 2017). Landscape connectivity may be reduced or enhanced as a result of siting and development of solar facilities, depending on species involved, existing conditions and location of the site selected for development, operation and maintenance activities during the life of the project, and policy decisions regarding the long-term use of the property. Few peer-reviewed studies on effects of utility-scale solar energy on wildlife exist, making assessments of effects of these systems on wildlife challenging (Lovich and Ennen 2011).

More information on potential effects of utility-scale solar development on wildlife is critically needed and may assist in proactive wildlife conservation. In this chapter, I describe the process for siting, constructing, and operating utility-scale solar energy facilities, summarize the literature on effects of solar energy development on wildlife, and suggest multi-scale measures to enhance potential positive effects and mitigate potential negative effects of solar energy development on wildlife. I provide a Deep Dive that illustrates how topics discussed in the chapter related to a project in California—a state with an ambitious renewable energy goal of 50% renewable electricity generation by 2030 and that is home to 154 animals listed under state and federal Endangered Species Acts (California Department of Fish and Wildlife 2017).

Solar Energy Technologies

Two basic types of solar energy technologies are deployed at the utility scale: PV and concentrating solar power (CSP). Photovoltaic systems use cells to convert sunlight to electric current, whereas CSP systems use reflective surfaces to concentrate sunlight to heat a receiver. Utility-scale CSP systems may comprise CSP trough, CSP tower, parabolic dish, or linear Fresnel reflector technologies (Mendelsohn et al. 2012). Photovoltaic systems usually include either crystalline silicon or thin film technologies. In 2015, global operating capacity of CSP systems was approximately 4.8 GW compared with approximately 227 GW from PV systems (REN21 2016). Because utility-scale PV systems represent the majority of solar energy generation facilities (Mendelsohn et al 2012), they are the primary focus of this chapter. However, many of the topics discussed herein pertain to PV and CSP systems alike.

Photovoltaic technology comprises individual solar panels, referred to as PV modules, which are joined together in a series of increasing voltage to form an array (California Energy Commission 2001). Photovoltaic modules encompass the direct current power side of the overall solar power system, absorbing energy from the sun and converting it to electrical energy. PV modules may be fixed to a stationary rack or a moveable racking system, known as single-axis or dual-axis trackers, that enable panels to rotate to follow the sun. Because a variety of technologies are used (e.g., monocrystalline silicon, thin film), with different rated efficiencies and different variables for performance calculations, the size of arrays used to generate the same electrical output varies. Multiple arrays are connected together (i.e., in parallel) through a combiner box, and multiple combiner boxes feed into an inverter (California Energy Commission 2001). Inverters change the direct current unidirectional flow of electrons to alternating current (AC), and then a single transformer can convert the voltage to different levels. Multiple inverters can supply a transformer that is joined to a substation. From the substation, the electricity travels to the regional grid system.

Siting

Utility-scale solar energy development is projected to affect up to several million ha of land in the United States by 2050 (US DOE 2012). With PV systems, row spacing is important to maximize power density—kilowatt (KW)/ha—while minimizing panel shading, because power output can be greatly diminished by partial shading of a cell, panel, or array (Deline et al. 2011). Ong et al. (2013) reported that capacity-weighted averages for utility-scale solar energy ranged from a direct land-use requirement of approximately 3 ha/MW_{AC} (i.e., land directly occupied by solar arrays, access roads, substations, service buildings, and other infrastructure) to a total land-use area requirement of 3.6 ha/MW_{AC}, where total calculated area corresponds to all land enclosed by the solar site boundary. Moreover, suitability of a location to support a utility-scale solar energy facility depends on solar energy resources, topography, land cost, available transmission interconnections and capacity, and engagement and needs of utilities, among other factors (Hernandez et al. 2014a, Hartmann et al. 2016). Consequently, much effort has been allocated to studying siting of solar power facilities from an industry perspective, including development of software for siting tools (Macknick et al. 2014, Hernandez et al. 2015). A growing number of publications address solar facility siting from a broader land-use perspective, including identifying potential effects on wildlife habitat and areas of "least conflict" from a multidisciplinary perspective (Brown and Whitney 2011, BLM/DOE 2012, Hernandez et al. 2014a, 2015, BLM 2016, Pearce et al. 2016).

A fundamental principle for integration of wildlife conservation and utility-scale solar development is to avoid siting facilities in ecologically sensitive areas (Hernandez et al. 2015). Development of sites without functionally linked to ecologically sensitive areas is likely to be less compatible with conservation objectives and requires more mitigation. Although the definition of what represents an ecologically sensitive area is broad, existing designations can aid in selection of sites that avoid conflicts with regional and national conservation goals, including designations of critical habitat (https://www.fws.gov/endangered/what-we-do/critical-habitat.html), special protected areas (http://jncc.defra.gov.uk/page-167), and important bird and biodiversity areas (http://www.audubon.org/important-bird-areas, http://www.biodiversityia-z.org/content/important-bird-and-biodiversity-areas-iba), to name just a few. Compatibility of utility-scale solar development with conservation objectives should be assessed by ecologists familiar with local natural resource issues, core habitat areas, ecological interactions and functions (e.g., animal movement), and species of conservation concern (Cuéllar et al. 2017).

Co-location is an important concept pertaining to siting of utility-scale solar facilities that can reduce project costs, increase efficiency, and minimize negative effects on wildlife compared with development on more remote and undisturbed landscapes (Hernandez et al. 2014b). Identification of solar energy zones is a co-location strategy designed to encourage energy production and transmission in areas with reduced value for wildlife and natural resource conservation (BLM/DOE 2012). Siting decisions should give priority to previously degraded lands, including abandoned mines, landfills, and other sites where utility-scale solar installation provides an opportunity to increase vegetative cover and conserve soil and water resources (Hernandez et al. 2014b, Hoffacker et al. 2017). Two federal efforts to identify degraded lands appropriate for renewable energy are examples that encourage this type of development: (1)The Restoration Design Energy Project in Arizona uses American Recovery and Reinvestment Act (2009) funds to identify and assess degraded lands, including brownfields, abandoned mines, and landfills; and (2) the US Environmental Protection Agency's RE-Powering America's Land program evaluates the renewable energy potential of brownfields, Resource Conservation and Recovery Act sites, Superfund sites, and abandoned landfills and mines and

describes considerations to address when integrating renewable energy development on such sites (US Environmental Protection Agency 2012). The solar development potential of these sites is estimated to be more than 920,000 MW. Hartmann et al. (2016) suggested that siting solar projects on certain types of previously used lands (e.g., formerly contaminated sites and other ecologically degraded lands) might provide the total land requirements to meet some national renewable energy program goals.

While avoiding impacts to rare species and their associated habitat will remain critical for wildlife conservation, avoidance alone is not likely to be enough to reach conservation goals. Siting criteria and compensatory mitigation offsets will continue to be important considerations (McDonald et al. 2009). A broader, multiple-use perspective of habitat conservation is likely to aid conservation efforts in the face of industrial expansion (Hernandez et al. 2014b, Francis 2015), including utility-scale solar development.

Utility-scale solar facilities possess [illegible] tures that other types of human structures [illegible] Whereas there is variability in the manner [illegible] solar arrays are installed, the posts on which [illegible] are mounted take up less than 5% of the land [illegible] a facility; however, they are spaced apart [illegible] shading of adjoining panels, which results in [illegible] imately 25% to 40% of the ground being [illegible] raised panels (BRE 2014). BRE (2014) [illegible] solar infrastructure, including inverters and [illegible] types of hardscape structures, typically occupy [illegible] than 5% of the ground. Because panels are [illegible] (e.g., up to 2 m in height) and the distance between [illegible] rows of panels can span from approximately [illegible] when the trackers are horizontal to the ground [illegible] proximately 8 m when the trackers are tilted [illegible] degrees, the area between and underneath [illegible] post-construction can sustain plant growth [illegible] ure 8.1). With proper enhancement and management, including through complementary agricultural activities such as grazing, this area has [illegible]

Figure 8.1 A vegetated PV solar array in spring. *H. T. Harvey & Associates*

potential to support habitat for a multitude of species (Hernandez et al. 2014b).

Maintaining electrical productivity and meeting wildlife conservation goals will be greatest when solar facilities are sited in areas with highly degraded habitat conditions. In some cases, even sites with moderate habitat value can be developed and contribute to broader conservation benefits through increasing landscape connectivity and habitat patch size (Guiller et al. 2017). In the San Joaquin Valley of California, where solar development potential is high, habitat for species of conservation concern has been extensively fragmented by agriculture and urban development (USFWS 1998, 2010, Cypher et al. 2013). In situations such as this, potential for improving conditions for species by providing habitat within solar arrays and, thereby, increasing habitat connectivity is high (Phillips and Cypher 2015). Cypher et al. (2007) recommended establishing corridors and improving connectivity for listed species in a portion of the San Joaquin Valley that included salt-impaired farmlands within the Westlands Water District. This area constitutes a large part of the 81,880 ha of "priority least-conflict" lands identified for utility-scale solar development in the San Joaquin Valley (Pearce et al. 2016), highlighting the great potential, in some circumstances, for solar energy development to contribute to regional conservation strategies and recovery efforts (USFWS 1998).

Wildlife Considerations during Construction and Operation

Wildlife professionals and the solar industry have taken actions to ensure that utility-scale solar projects are developed and operated in compliance with local, state, and national regulatory standards pertaining to wildlife. In 2011, Natural England (2011) published a technical information note with recommendations for siting solar projects, their potential impacts on wildlife, mitigation requirements for maintaining the natural environment, and opportunities for environmental stewardship. In 2012, the BLM and DOE published a report, "Final Programmatic Environmental Impact Statement for Solar Energy Development [illegible] Southwestern United States" (BLM/DOE 2012). The Renewable Energy Working Group of the Wildlife Society (www.wildlife.org/rewg) was established to facilitate the synthesis and dissemination of scientific information promoting responsible development of various renewable energy sources that minimize impacts on wildlife through informed siting, project design, construction, operation, and decommissioning stages. More recently, Hartman et al. (2016) summarized emerging environmental impacts related to utility-scale solar development.

Solar projects should look beyond the traditional approach of avoidance, minimization, and mitigation during the preconstruction period to conserve wildlife (Council on Environmental Quality 1993). Through preconstruction surveys, wildlife professionals can help locate activities in less sensitive areas and minimize impacts to biodiversity, thereby integrating wildlife conservation into utility-scale solar development. Along these lines, the BRE National Solar Center in the United Kingdom developed a biodiversity guidance document for solar developers (BRE 2014); the document recommended a management plan be developed for solar facilities to describe site-wide objectives for biodiversity and how those objectives will be achieved throughout the life of the project. The plan should identify potential impacts arising from the site's development and outline mitigation, which often is a regulatory requirement. The management plan also should include land management activities (e.g., control of invasive weeds and vegetation management). A benefit of a management plan is the early consideration that it initiates for all phases of the project (e.g., preconstruction design and mitigation considerations, avoidance measures during construction and operational activities), which facilitates planning and budgeting efforts.

Examples are numerous of site-selection processes that rely on existing databases to identify

elements such as prescreened renewable energy zones and areas that possess higher value for other purposes such as prime farmland or federally designated critical habitat (Macknick et al. 2014, Phillips and Cypher 2015, Pearce et al. 2016). Assorted databases provide different information: for instance, regional databases such as the California Gap Analysis Project and National Wetlands Inventory are often based on remotely derived data that are coarser than what may be obtained on a site-specific basis. Other databases, such as the California Natural Diversity Database, rely on volunteer data and rarely portray recent submittals because of the effort required to manage them. Data for public land might be fairly complete because of focused planning efforts (BLM 2015), whereas data for private lands might be absent because of a lack of prior access.

Conducting on-site baseline surveys in consultation with regulatory agencies is critical during the preconstruction phase of solar development to assess the presence or absence of natural resources, including those necessary for enhancement or restoration. The level of effort needed to establish a sufficient baseline for the purposes of designing the facility to achieve operational goals and avoid and minimize impacts on sensitive wildlife resources will vary. For species with high conservation value, multiyear surveys may be recommended by existing protocols (https://www.fws.gov/sacramento/Survey-Protocols-Guidelines). In the Western United States, however, many recommended protocols were established before utility-scale solar development was commonplace and were not designed with the thought of surveying hundreds to thousands of hectares, which may be necessary should extensive solar energy expansion arise.

During the preconstruction phase, survey data can be used to avoid siting solar in areas with high concentrations of focal wildlife. Multiyear surveys for species with population fluctuations, such as those exhibiting boom-and-bust cycles coincident with rainfall, may be important during the preconstruction phase of the project to capture year-to-year variability. If wildlife populations are suppressed during baseline surveys, survey results can indicate potential areas where expansion could occur post-prior to or during the construction phase and after foreseeable changes in environmental conditions, such as precipitation after a series of drought years (H. T. Harvey & Associates 2017b). Baseline documentation for resources that are relatively fixed, such as availability and extent of wetland resources, may take fewer years to establish.

Basic infrastructure associated with solar arrays and facility construction can have both negative and positive impacts on certain wildlife species. Unlike many forms of human development, PV solar generation facilities have relatively low levels of human activity after construction. During operation of the facility, inspections, testing, maintenance, and repairs are performed continually, with most routine activities occurring only once or twice per year for each tracker or major piece of equipment. Installed infrastructure requires minimal replacement of panels and equipment as a result of breakage or failure, and inverters currently require replacement approximately once every decade (H. T. Harvey & Associates 2015a). Most of this limited operational activity occurs during the day; however, limited nighttime work may occur while the system is de-energized for safety and to maintain energy production during the day. Most sites have a life span of 20 to 35 years or more. In some cases, commitments are made prior to construction to place the lands supporting a facility under a conservation easement, either when the facility becomes operational or after decommissioning, thereby providing the potential for wildlife conservation benefits in perpetuity (EMC Planning Group 2012, Quad Knopf 2014).

Areas underneath arrays are likely to be more heterogeneous than open fields owing to effects of shading and driplines (i.e., areas collecting rain runoff from panels). H. T. Harvey & Associates (2016a) reported establishment of 3 main vegetation zones at a solar facility in California: (1) the area directly beneath the panels; (2) the area along the dripline

and (3) the area between the panels. In areas of the solar facility recovering from construction, H. T. Harvey & Associates (2016a) reported that, 3 years after construction, the vegetation community supported more native plant species than adjacent reference sites, but index values of diversity were similar.

Montag et al. (2016) compared wildlife diversity in solar facilities with nearby areas outside facilities under similar management regimes, such as livestock grazing. Overall, solar facilities had greater levels of plant diversity than other areas (Montag et al. 2016), possibly due to reseeding of species-rich wildflower mixes. Similarly, the study reported that abundance of butterflies and bumblebees was greater in solar facilities than outside solar facilities and that numbers of these pollinators were greatest where botanical diversity also was high. The researchers also documented a greater diversity of birds within the solar facilities and a greater abundance of birds within some of the solar facilities, when compared with paired adjacent areas.

Bird activity may change during and after solar facility construction. In California, development tended to displace most raptors, but establishment of new elevated perches from solar infrastructure in a grassland landscape benefited some raptor species, and use of solar facilities by some raptor species may increase as facilities transition to operational status (H. T. Harvey & Associates 2015b). Responses of other bird species to solar development are mixed. Potential reasons for positive responses of birds to project development may include (1) provision of structures that attract cavity or crevice nesters; (2) installation of solar panels that provide perch substrate and abundant shade in otherwise hot, dry landscapes; (3) provision of refuge for prey from predators (e.g., raptors) that tend to avoid construction activities and developed areas; (4) creation of new microhabitats that favor or concentrate some types of insect prey (e.g., in wind-sheltered areas behind solar panels); and (5) provision of opportunities for various human-adapted species to take advantage of ground-disturbing activities that routinely turn up insects, seeds, and other food resources (H. T. Harvey & Associates 2016a).

Other components of infrastructure can be problematic to wildlife, but solutions exist to minimize harm. Transmission lines often pose risks to wildlife species, a problem that similarly has been documented for other energy sectors. Site-specific assessments are recommended to design electrical infrastructure (Barrientos et al. 2011, APLIC 2012). Without modification, perimeter security fencing can represent a barrier that cause some species, such as the greater roadrunner (*Geococcyx californianus*), to be more prone to predation. Some fence designs are permeable to small and medium-sized wildlife (Cypher and Van Horn Job 2009) and others have been modified to facilitate passage of wildlife by raising the fence or modifying the standard weave to incorporate passageways spaced along the length of the fence (Cypher and Van Horn Job 2009, Cypher et al. 2012). Where solar arrays fragment landscapes used by migrating wildlife or those with large area requirements, arrays can be individually fenced and spaced apart to provide habitat linkages with the surrounding landscape.

Materials used in the construction process can also have a direct effect on wildlife but, similar to the situation with infrastructure described previously, solutions often exist to minimize harm. Hollow spherical piles used in the installation of solar arrays can easily number in the thousands or even tens of thousands, and each represents a potential trap for birds. In such cases, open ends can be capped or open-sided piles can be used to preclude avian mortality from entrapment. Some wildlife, including the San Joaquin kit fox (*Vulpes macrotis mutica*) in California, may use staged materials on the construction site for shelter. Depending on species-specific management goals, staging materials can be stored or stacked in a manner less attractive to wildlife or plugs and barriers can be installed to preclude wildlife use of the materials (Figure 8.2). Evaporation ponds, often used to store effluent from reverse osmosis

Figure 8.2 Example of piles plugged and barricaded to minimize use by wildlife. *H. T. Harvey & Associates.*

systems used to purify ground- or drain-water, may also present a risk to wildlife. Barriers can be designed to restrict access to the ponds by wildlife, and heavy-duty textured pond liners may provide a means of escape for wildlife that become trapped. Basin configuration can be designed so as to deter use of the ponds by birds, bats, and invertebrate prey that may be susceptible to toxins such as selenium.

Protecting critical habitat elements, such as burrows, during the construction period may facilitate wildlife presence within arrays post-construction. Although barriers to and ramps inside open trenches are commonly employed to minimize impacts to wildlife at construction sites, the use of one-way door exclusion devices represents a specialized form of barrier more applicable to solar sites because of the habitat that can be maintained under the arrays for burrowing animals (Figure 8.2). These exclusion devices can be deployed within naturally occurring burrows or atypical dens, such as pipes or culverts, to preclude wildlife from entering the burrow while enabling them to escape. If the burrow occurs in the vicinity of a planned improvement but does not need to be filled to complete the construction process, the one-way door can be left in place during the construction period. When a significant percentage of burrows must be removed because of the installation of hardscape, installation of artificial burrows may facilitate the use of burrows in the solar facility without increased risk of predation while the natural occurrence of burrows is restored (Cypher et al. 2012).

Ongoing human activities during operation and maintenance of solar facilities can benefit or threaten wildlife resources. Solar facilities typically operate 7 days a week during daylight hours. Periodic monitoring and maintenance activities, both planned (e.g., routine inspection, repair, restoration, replacement, washing of solar panels, security surveys and actions, vegetation management, and modification of equipment and facilities) and unplanned (e.g., damage or failure of equipment or facilities), take place during daytime and nighttime hours. Management plans should address planned and unplanned maintenance activities throughout the life of the project. I summa-

Figure 8.3 Example of a one-way door exclusion device for San Joaquin kit fox. *H. T. Harvey & Associates.*

rize general measures that can be applied to minimize impacts on species and habitats from operational activities in Table 8.1.

The degree of habitat restoration or revegetation required following construction of a solar facility will depend on conditions prior to construction, site preparation, the practices used for construction, and desired long-term conservation goals for the site. A habitat restoration and revegetation plan that focuses on soil restoration and revegetation or restoration of areas disturbed during construction and operations is recommended. The plan should describe the quantitative monitoring of revegetation and restoration areas that will be conducted following planting. An annual status report summarizing site conditions and results of monitoring is recommended at the end of each year following implementation of the plan and should describe adaptive management measures to employ if vegetation cover success criteria were not met. The restoration goal should be clearly stated; it can be beneficial to relate the goal to conditions on adjacent undeveloped land that is concurrently sampled. In this way, variability in amount and timing of precipitation and its effect on vegetation growth can be used to inform progress toward meeting the success of [illegible] criteria.

Appropriate vegetation management is vital to ensure habitat maintenance or enhancements achieve conservation goals. It is important to note that different areas within a utility-scale solar installation may be managed to meet different objectives. For instance, lower-growing native grasses and forbs may be managed within arrays whereas taller species, such as some milkweeds (*Asclepias* spp.) that support monarch butterflies (*Danaus plexippus*), are restored around the perimeter of arrays. In fact, establishment of native, pollinator-friendly plants between solar arrays is an increasingly popular approach for integrating conservation with renewable energy development. Wildfire risk is an important consideration within a vegetation management plan. Mowing to reduce or remove vegetative cover can be effective and is commonly used within smaller (less than 20 MW) solar arrays. Mowing can pose greater risk of injury to wildlife than the use of livestock grazing, so application of avoidance and minimization measures as described below are important.

Livestock grazing is a historical land use within many areas selected for solar development, and continued use of livestock grazing can serve as a primary vegetation management tool that enables co-location of solar energy and agricultural production. A grazing management plan should be developed to describe specific grazing approaches that will be used within arrays to manage vegetation, the rationale for these approaches, and how a monitoring program will be implemented within an adaptive management framework to assess the effectiveness of livestock grazing as a management tool.

The vegetation management component of the site management plan should address how to (1) minimize wildfire risk by managing vegetation height to reduce fuel loads while minimizing soil erosion to maintain basic resource values; and (2) maintain habitat

Table 8.2. General measures that can be applied to minimize impacts of operational activities on species and their associated habitat

General operational activities

Provide an education program for site workers to cover the ecology of sensitive species that occur within the facility, how to identify, protect them, and the contact information for communicating when species are located.

Employ rodent control methods, including vegetation management, trapping, fumigation, or other approved rodent baits within observing label and other restrictions mandated by laws and regulations.

Restrict or prohibit use of erosion-control materials potentially harmful to wildlife, such as monofilament netting (erosion control netting) or similar material.

If design specifications allow, stow solar panels flat from sunset to sunrise to minimize the potential risk of bats seeking the panels for roosting, may sometimes perceive more vertically positioned smooth-surfaced panels as a void or open space, which could result in collisions.

Restrict access to the facility to emergency personnel and the operator's designees or employees, composed primarily of the operations and maintenance staff, panel washing staff, environmental compliance specialists, researchers, and security personnel.

If nocturnal threatened or endangered species are present, operational activities should generally occur during daylight hours (sunrise to sunset); exceptions may involve, but are not limited to (1) capacitor bank wiring, connecting, and testing; (2) planned and unplanned maintenance activities that must occur after dark to ensure PV arrays are not energized; (3) interior use of the facility; (4) unanticipated emergencies (defined as an imminent threat to life or to a significant property interest), including forest emergencies; or (5) security patrols, which may occur 24 hours a day.

Transformers within arrays may contain food-grade oils that can be attractive to wildlife. If a transformer is suspected of leaking, the entire power conditioning station where the transformer is located should be enclosed with an exclusion barrier impermeable to wildlife until the leak can be fixed and cleaned up.

Vehicle/equipment operating and fueling procedures

Do not operate vehicles and equipment outside existing access roads within arrays except in compliance with the management plan or in the event of an emergency, and vehicles or equipment traveling between arrays should cross drainages only at improved crossings.

When threatened or endangered wildlife are present, restrict the speed limit on all roads within the facility to approximately 24 km per hour between sunrise and sunset and 16 km per hour between sunset and sunrise.

Stationary and mobile lighting, and fencing

Minimize light sources and keep to the lowest lumen/light intensity level possible, while still meeting minimum safety and security requirements.

Design solar array fencing to allow passage of wildlife compatible with operations. Fencing can be raised or have graduated openings from approximately 7 cm high to 15 or 17 cm high, and be installed with the larger openings at the bottom to allow wildlife passage.

Maintain fencing and gates around evaporation ponds to exclude terrestrial wildlife. The fence should be buried at least 0.6 m in the ground and extend at least 1.8 m above ground. Project personnel should photograph, document, and report to a qualified biologist the discovery of any dead wildlife at the evaporation pond to inform and improve adaptive management.

Weed control activities

Include weed control in the site management plan to prevent the spread of non-native, invasive species within the construction footprint and operational areas of the facility. The weed control plan should describe procedures to avoid the unintentional introduction of invasive species, required monitoring measures to detect invasive species, species-specific control measures that should be implemented if invasive species are detected, and the process by which the weed control plan should be implemented (e.g., the entity responsible for implementing it, funding mechanisms, and reporting procedures). The operator should monitor the facility each year for the presence of invasive weeds pursuant to the weed control plan.

Ground-disturbing or vegetation-disturbing activities

Limit disturbance to the smallest area practicable, schedule activities outside the breeding season, establish avoidance buffers, and thoroughly inspect excavated areas for trapped wildlife each morning before the onset of activities, before covering with plywood at the end of each workday, and before filling.

for wildlife species that may use arrays and respond to annual changes in climate and productivity of the vegetation community. Forb and grass biomass should be managed through grazing or mowing to encourage habitat that supports plant and animal diversity and manage residual dry matter (i.e., herbaceous plant material left standing or on the ground at the beginning of a new growing season). Intensity and duration of grazing, as well as the kinds and classes of livestock used for grazing, should be discussed, as well as when and how mowing may be used to meet vegetation goals, including mitigating

wildfire risk. Numerous factors, including past vegetation management practices, climatic patterns, and wildfire affect the annual amount of grass and forb growth; therefore, monitoring often is required annually to adjust the intensity and duration of livestock grazing and identify areas that require mowing.

The Deep Dive discusses Phillips and Cypher's (2015) cited observations of 2 mammals listed under federal and state endangered species acts—the San Joaquin kit fox and the giant kangaroo rat (*Dipodomys ingens*)—existing utility-scale solar facilities as well as 3 other species that may use solar facilities, given their similar habitat requirements.

Deep Dive: Meeting Wildlife Conservation Goals While Maintaining Electrical Productivity

The Renewable Energy Transmission Initiative is a California planning process to accommodate state renewable energy goals that has identified Competitive Renewable Energy Zones possessing the greatest potential for cost-effective and environmentally responsible development (http://www.energy.ca.gov/reti/). The California Valley Solar Ranch, located in the South Carrizo Competitive Renewable Energy Zone, is a 250 MW solar PV project on an 1,896 ha site in eastern San Luis Obispo County, California. When finalizing the initial site design, the developer had the option of determining where to locate the site within a 2,023 ha area composed of mostly grassland established following the cessation of dryland farming (Holland 1986). Within this area, the developer considered approximately 1,921 ha for siting of the solar facility. Ecological assessments and surveys within the area spanned 4 years and identified 7 plant species of conservation concern considered rare by the California Native Plant Society (http://www.cnps.org/cnps/rareplants/ranking.php). These plant species were broadly distributed across the project area and ranged from small, isolated populations of several plants to large, clearly defined polygons of land cover.

Surveys also identified 3 state and federally listed mammal species: (1) the federally and state-listed endangered giant kangaroo rat; (2) the federally and state-listed threatened San Joaquin kit fox; and (3) the state-listed threatened San Joaquin antelope squirrel (*Ammospermophilus nelsoni*; San Luis Obispo County 2010). Designated critical habitat for vernal pool species, the federally listed endangered longhorn fairy shrimp (*Branchinecta longiantenna*) and threatened vernal pool fairy shrimp (*Branchinecta lynchi*) also occurred within the project area (San Luis Obispo County 2010). Consequently, the initial design was revised through an iterative process to avoid construction near these resources, including the majority of giant kangaroo rat precincts (Figure 8.4).

The sections that follow present an overview of best management practices implemented during construction and operations at the facility from 2011 through 2017 for 2 focal species: San Joaquin kit fox and giant kangaroo rat. To mitigate habitat impacts on these species, permits required the permanent protection and management of approximately 3,706 ha, including a non-wasting endowment to cover the management, maintenance, and monitoring of these lands for the species in perpetuity.

Some giant kangaroo rats were translocated to surrounding on-site conservation lands using "soft release" methods to acclimate the

Figure 3.4. Distribution of giant kangaroo rat precincts relative to position of arrays of the California Valley Solar Ranch prior to construction. *H. T. Harvey & Associates.*

translocated animals to the release sites (H. T. Harvey & Associates 2011, 2013). A total of 427 precincts were mapped and trapped in an attempt to capture and relocated kangaroo rats before the sites were excavated (and, therefore, destroyed). More than 220 giant kangaroo rats were removed from construction areas, nearly all of which were successfully relocated to artificial burrow enclosures located within conservation lands (H. T. Harvey & Associates 2013).

In addition to the extensive redesign, avoidance of giant kangaroo rat precincts occurred during preconstruction and construction phases. Each individual or cluster of precincts identified as occurring within the solar facility was evaluated to identify which could be avoided. Consequently, 261 giant kangaroo rat precincts within planned construction impact areas were avoided through engineered redesign or by modifying construction methods (H. T. Harvey & Associates 2013).

San Joaquin kit fox use of the project site was carefully monitored. Measures for avoiding and protecting dens included restricted-entry buffers and use of one-way doors to protect unoccupied dens in place for future use. Excavation was a last resort for dens that would be directly affected by construction. Biologists closely monitored San Joaquin kit fox activity during construction. In 2013 alone, 416 sightings of San Joaquin kit foxes occurred in the construction area. By adhering to protective measures, no San Joaquin kit fox mortalities were documented during construction activities.

San Joaquin kit fox dens occurred broadly across the site (Figure 8.5). When a den required a one-way door, a minimum of 4 nights of camera data were collected before installation. All one-way doors were checked once per week in January and February and 5 times per week from March through October (i.e., pup rearing and dispersal period) for signs of digging around the boards, for general integrity and functionality, and to ensure that dens remained visible to construction crews. At the end of construction, one-way doors were removed and dens were available for reoccupation. Following one-way-door removal, reuse of dens was common and similar to levels recorded prior to construction.

During operations, sheep grazing was used in arrays to reduce vegetation height and biomass, with some supplemental mowing to reduce wildfire risk. Sheep grazing occurred in spring and usually included at least 1 rotation through each array. Bedding locations for sheep were kept away from sensitive biological resources, such as giant kangaroo rat precincts. Bedding and watering locations were identified by a qualified biologist, and maps of these approved locations were provided in advance to the sheep herder.

During the 2016–2017 rainy season, the project site received an above-average amount of precipitation, resulting in increased vegetation heights and biomass levels that required mowing in arrays, particularly along solar panel driplines. The design of the array fencing allowed passage of San Joaquin kit fox and giant kangaroo rats between solar array areas managed to perpetuate grassland conditions and adjacent conservation lands. Prior to mowing, biologists conducted surveys of kit fox and kangaroo rat activity in each array and within a buffer extending 15 m beyond the perimeter fence. The pre-mowing surveys documented active giant kangaroo rat precincts and San Joaquin kit fox dens.

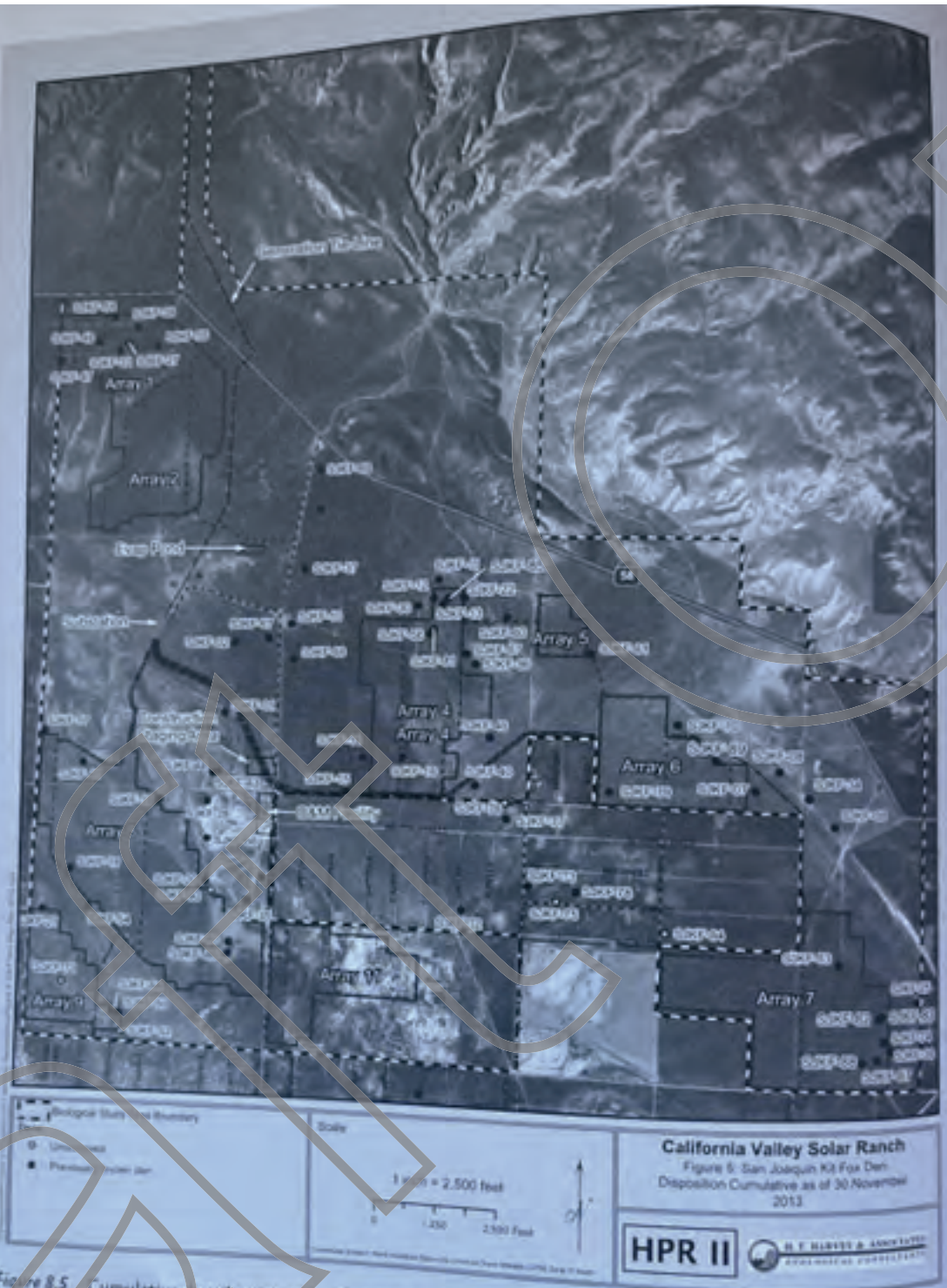

Figure 8.5 Cumulative distribution of San Joaquin kit fox dens between September 2012 and November 30, 2013, on the California Valley Solar Ranch. *H. T. Harvey & Associates.*

Table 8.2. Number of active giant kangaroo rat (*Dipodomys ingens*) precincts by array and in the buffer area of each array during 2017 surveys of California Valley Solar Ranch, San Luis Obispo County, California

Arrays	1	2	4	5	6	7	8	9	11	Total
Precincts	16	72	189	106	149	49	27	0	0	607
15 m buffer around arrays										
Precincts	5	122	106	132	[illegible]	25	23	26	47	551
Total	21	194	295	238	211	74	50	26	47	1,158

Table 8.3. Number of San Joaquin kit fox (*Vulpes macrotis mutica*) dens by array and type of den in 2017 at California Valley Solar Ranch, San Luis Obispo County, California

	Arrays									
Type of Den	1	2	4	5	6	7	8	9	11	Total
Historical	6	0	16	0	1	6	9	2	[illegible]	[illegible]
Natal	0	0	0	0	1	0	[illegible]	2	0	4
Escape	0	1	2	3	0	4	0	[illegible]	0	11
Total	6	1	18	3	2	10	10	5	0	55

The status of giant kangaroo rat precincts was determined using multiple indicators of aboveground activity, including suitably sized vertical shafts and horizontal openings, recently cropped vegetation, haystacks, pit-caching, tail drags, scat, and recent excavation activity. During surveys, biologists identified 1,158 active giant kangaroo rat precincts—607 within arrays and 551 precincts within 15 m buffers around the perimeter of array fencing. Precinct density in the buffer areas, which were not trapped and cleared during the construction period, was 11.54/ha compared with only 1.16/ha in the arrays, which were trapped and cleared of giant kangaroo rats via translocation between September 2009 and July 2013 (Table 8.2).

Fifty-five San Joaquin kit fox dens were located in arrays during surveys in 2017—40 inactive historical dens, 4 active natal dens, and 11 active escape dens (Table 8.3). Den use by San Joaquin kit foxes was identified through signs such as tracks, scat, and suitably sized dens, and by remote-sensing cameras. San Joaquin kit fox natal dens (Figure 8.6) were identified, monitored, and determined to be active within arrays at California Valley Solar Ranch in 5 out of 6 years. Prolonged drought and poor landscape condition appeared to cause low reproductive success for kit foxes in 2014.

The number of natal and escape dens within arrays indicated a stable use of arrays by San Joaquin kit fox, demonstrating the species' ability to use operating solar

Figure 8.6 San Joaquin kit fox adult with pups at a natal den within an array at the California Valley Solar Ranch. *H. T. Harvey & Associates.*

facilities when properly designed, managed, and operated. Preliminary results from a San Joaquin kit fox telemetry study at California Valley Solar Ranch (H. T. Harvey & Associates in prep) support these inferences; radio-collared San Joaquin kit foxes used solar arrays and non-solar array areas.

The impact assessment used to permit the project (San Luis Obispo County 2011) assumed no future use of habitat by giant kangaroo rat within the arrays or within approximately 30.5 m beyond array perimeter fences. Results from the pre-mowing survey, however, demonstrated that giant kangaroo rats occupied some arrays in significant numbers (Table 8.2) and did not avoid areas adjacent to arrays. A one-tailed *t*-test indicated that the estimated number of giant kangaroo rats occupying arrays in 2017 (based on the number of active precincts) was approximately 3 times greater (Table 8.4) than number of animals relocated from arrays during the construction period ($t = 2.28$, $p = 0.03$). Although data used for the *t*-test relied on a comparison of captured individuals versus active precincts, it is important to note that 27% of the animals relocated from the arrays were juveniles (H. T. Harvey & Associates 2013); the assumption is that an active precinct equates to one adult. If relocated juveniles we removed from the

Table 8.4. Comparison of giant kangaroo rat (*Dipodomys ingens*) numbers preconstruction (2011 through 2013) and post-construction (2017) at California Valley Solar Ranch, San Luis Obispo County, California

Array #	Preconstruction (2011 through 2013)	Post-construction (2017)
1	2	16
2	4	72
4	44	189
5	83	106
6	2	149
7	43	48
8	12	27
9	1	0
11	3	0
Total	194	607

analysis, the difference would be even greater.

The increase in number of giant kangaroo rat precincts within [illegible] mean that habitat withi[illegible] arrays was better than the pre-proje[illegible]t conditi[illegible] increase in the numb[illegible]r of gi[illegible]t kangaroo rats likely was in res[illegible]onse [illegible] increased rainfall and vegeta[illegible]on p[illegible]oduc[illegible]ity (Prugh et. al. 2015, H. T. Harve[illegible] & Associ[illegible]tes 2017b). However, arrays did provid[illegible] subst[illegible]ntial habitat and added conservation bene[illegible]ts, supporting an estimated more than 600 in[illegible]dividual giant kangaroo rats not anticipated [illegible] occupy the area post-construction.

Summary

Solar energy represents a rapidly developing and expanding renewable energy source (REN21 2016) that can influence wildlife habitat. Consequently, understanding the interface between utility-scale solar energy development and wildlife conservation is increasingly important. Construction and operation of solar energy facilities modifies wildlife habitat and can have direct and indirect effects on wildlife. Although siting of utility-scale solar facilities potentially affects landscape connectivity, the manner in which a solar facility is operated and maintained may also have positive or negative effects on landscape connectivity, because those activities can directly affect habitat values within the site during the life span of the project.

A fundamental principle for integrating wildlife conservation and utility-scale solar development is siting facilities to avoid ecologically sensitive areas. Facilities within or functionally linked to ecologically sensitive sites are likely to be less compatible with conservation objectives and require more mitigation. Compatibility of utility-scale solar development and conservation objectives should be assessed by ecologists familiar with key biodiversity issues in areas where construction may occur. Co-location of solar energy on marginalized lands is an important concept pertaining to the siting of utility-scale solar facilities and can reduce project costs, increase efficiency, and minimize wildlife conflicts compared with development on more remote and biologically diverse landscapes. Siting decisions should give priority to previously degraded lands, including abandoned mines, landfills, and other sites where utility-scale solar installation provides an opportunity to increase vegetative cover and conserve soil and water resources. However, avoidance is not likely to be enough to reach conservation goals, and a broader, multiple-use perspective of habitat conservation in and around solar facilities is likely to aid conservation efforts.

Utility-scale solar facilities possess unique features that other types of human development affecting wildlife lack; primarily, most of a solar facility site may remain in a condition that can sustain habitat capable of supporting a diverse array of plants and wildlife. Coordinated management of resources

within a solar facility without impairment of electrical generation is a worthy goal. Benefits of approaching siting of utility-scale solar facilities with a goal of supporting multiple uses will be greatest when developments are sited in areas with highly degraded habitat conditions that can be enhanced post-construction and managed during operations.

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