CHAPTER 6 | LANDSCAPE-LEVEL SOLAR DEVELOPMENT AND ECOLOGICAL IMPACTS

Although there are many ecological impacts that can occur at the site-level, there is also the potential for even greater landscape-level impacts, especially when considering the cumulative effects of multiple facilities across the California desert. These impacts have implications for the functioning of ecological processes and the status of species well beyond the boundaries of the facility site, and can result in fundamental changes to the ecology and biology of the region. Landscape-level impacts could result from disruptions of or alterations to ecological processes including habitat connectivity, sand transport systems, carbon sequestration, and surface albedo. The extent and type of impacts are dependent on the geographic placement of the facilities within the context of the CDCA, the total amount of land and water consumed, and the nature or intensity of the impact. To the extent that these landscape-level impacts may disrupt ecological functions and species interactions, the sum of these impacts may determine if, where, and what biodiversity can persist in the face of utility-scale solar development. Therefore, an analysis of the likely landscape-level ecological impacts is a critical component in understanding the potential cumulative environmental effects of these projects.

In addition to ample amounts of sunlight, the most important resource needs of a solar energy facility are land and water. Given this, we developed a method of analysis that can be used to quantify the relationship between the benefit of the renewable electricity generated by these projects and their relative impacts on the surrounding land and water resources. We refer to these analyses as land and water use efficiencies. The quantity of land and water consumed, as well as the facility locations, will determine the type, intensity, and extent of ecological impact. The following section includes our land use efficiency analysis and an examination of how facility size combined with geographic location may affect surrounding wildlife populations and ecological processes. Next we include our water use efficiency analysis and a discussion of the landscape-level impacts of groundwater use and surface water diversion. Finally, using species as indicators of larger-scale ecosystem health, we illustrate how solar development may affect population-level dynamics in three important desert species: the desert tortoise, the desert bighorn sheep, and native pollinators.

LAND USE EFFICIENCY

A land use efficiency analysis was performed by calculating the amount of renewable electricity a facility expected to produce in a year and dividing this number by the total acreage that the facility expected to disturb. This served as our metric for the land use efficiency of a given project. Table 6.1 summarizes the results. By using this analysis tool to quantify the relationship between the technology type, size of facility footprint, and the amount of energy being produced, we are able to compare the

Table 6.1 Analysis of Land Use Efficiency by Project Size (in MW) and Technology Type.

Proposal Name	Nameplate Capacity	MWh Produced Per Acre Disturbed	CSP or PV	Technology Type
Solar Millennium - Blythe	1,000	352.11	CSP	Parabolic Trough
Solar Millennium - Ridgecrest	250	283.90	CSP	Parabolic Trough
Solar Millennium - Palen	484	336.50	CSP	Parabolic Trough
Beacon Solar Energy Project	250	455.95	CSP	Parabolic Trough
Abengoa Mojave	250	409.60	CSP	Parabolic Trough
Genesis Solar	250	407.00	CSP	Parabolic Trough
City of Palmdale - Hybrid Gas-Solar	62	356.46	CSP	Parabolic Trough
Parabolic Trough Average	*364*	*371.65*		
Calico (formerly Solar One)	850	1,000.20	CSP	Dish/Engine
Imperial Valley (formerly Solar Two)	750	845.20	CSP	Dish/Engine
Dish/Engine Average	*800*	*922.70*		
Chevron Lucerne Valley	60	211.55	PV	Thin-Film
FirstSolar's Desert Sunlight	550	226.90	PV	Thin-Film
PV Average	*305*	*219.23*		
Ivanpah	400	991.70	CSP	Power Tower

relative land use efficiencies of the proposals on both a project-by-project basis as well as on a technology-versus-technology basis. In a project-by-project comparison, this analysis shows which proposed facility is making relatively better use of the land by producing a greater quantity of energy per unit of area. In short, the project with the best ratio, in this case the *highest* amount of megawatt-hours of electricity produced per acre of land disturbed, could be viewed as the most efficient project in terms of land use. This is a simplified way of determining which project will have a relatively "smaller" environmental footprint while still maximizing the amount of electricity that is produced by the facility.

As can be seen in Table 6.1, there is a substantial range of land use efficiencies, with the Solar Millennium Ridgecrest project having the lowest efficiency at 284 MWh of electricity produced per acre of land disturbed, and the Tessera Calico project having the highest efficiency at 1,000 MWh of electricity produced per acre of land disturbed.

An analysis across technology types was also performed. Although the majority of applications are for parabolic trough systems, there are also other types of solar technologies being proposed, including power tower, dish/engine, and thin film PV. Each of these technologies has its own distinct set of advantages and disadvantages, including relative operating efficiencies, land requirements, and cooling system needs. By calculating the average land use efficiency for each technology type, we are able to

see which technologies appear to have higher land use needs, and thus a greater ecological impact. A breakdown of the average land use efficiencies by technology type, as well as an average across technology types and the maximum and minimum values, is shown below in Figure 6.1.

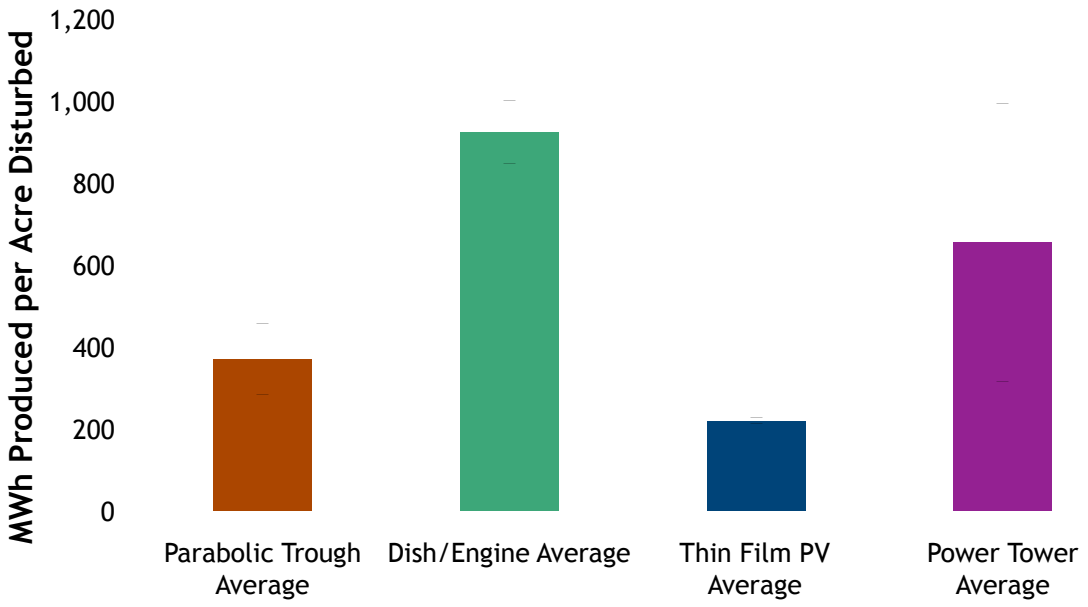

Figure 6.1 Average, Maximum, and Minimum Land Use Efficiencies for Four Solar Technologies.

This analysis shows the effect that technology type has on the overall facility footprint. The above results indicate that thin film PV and parabolic trough systems have the lowest average land use efficiency of these four technologies. For parabolic trough and thin film PV systems, this is likely due to the fact that these systems require long, contiguous rows of panels or mirrors to be constructed on a three percent grade or less. This requirement means that a greater portion of the site must be graded to accommodate the technology. In contrast, technology types that have fewer land constraints have higher land use efficiencies. An example is the dish/engine system, which can be placed in non-contiguous configurations and can tolerate slopes up to six percent. Since dish/engines can be anchored to the ground independently of one another, this eliminates the need to grade the entire solar field to a consistent level, which results in a lower overall grading requirement. In turn, this means there will be fewer disturbances to soil crusts, native vegetation, and wildlife species, which may contribute to the high average land use efficiency of this technology type.

This analysis can serve as a preliminary dataset for stakeholders to determine which technologies appear to be maximizing energy production while keeping facility footprint and related ecological

impacts relatively low. Yet, it is important to keep in mind that these averages are currently based on only 13 projects, with some technology types only having two projects to draw data from.

Ecological Impacts Dependent on Size of Facility Footprint

The land use efficiencies for proposed projects are directly related to the size of the facility footprint. The total amount of land disturbed has implications for dust emissions related to aeolian wind processes, carbon sequestration by biological soil crust, and regional albedo.

Aeolian Wind Processes: Dust Emission

Solar development may release large amounts of dust if a facility is particularly large, if it is constructed in a location where a large quantity of dust is currently sequestered, or if multiple facilities are constructed in relative proximity to one another. Dust release could have indirect impacts to both the facility site as well as off-site areas downwind. Dust plays a role in nutrient cycling; since much of the plant-essential nutrients are stored in the top few millimeters of soil, excess dust release may significantly deplete nutrients on site.[1] This may limit availability in an already nutrient-starved ecosystem, deliver excess nutrients to the deposition area, and alter the overall nutrient balance of the system. Additionally, dust storms may result in a "sandblast" effect downwind of a solar development-induced dust release, causing increased wind erosion and disturbance in adjacent areas, and triggering larger dust emissions in the dust storm's path.[2] Large dust depositions could also bury landscapes in a layer of dust, halting photosynthetic activity and reducing fertility if plants and soil crusts are covered.[3] Finally, at a global scale, far reaching dust could increase snowmelt (by decreasing snow albedo), alter nutrient load in aquatic ecosystems, or have other impacts to distant ecosystems.[4]

Aeolian Wind Processes: Human Health

Any process or activity, whether it is natural wind movement or vehicles driving on unpaved roads, can resuspend dust particles and contribute to PM10 pollution. For example, in the Mojave Desert and Salton Sea Air Basins, dust emissions from paved and unpaved roads and construction contribute to PM10 pollution concentrations.[5] Therefore the construction of solar facilities is likely to contribute to PM10 pollution, but the potential relative contribution of facilities to the overall PM10 concentrations in the California desert region remains unknown. How dust emissions are managed on site, such as the application of water to suppress construction dust, will also influence the contribution of a facility to overall PM10 pollution concentrations. Addressing potential increases in PM10 pollution is crucial to the health and well-being of residents in desert communities.

Biological Soil Crusts: Carbon Sequestration

Solar development could affect the carbon sequestration potential of the California desert; the extent of this impact may be dependent on total size of disturbed area (in other words, the facility footprint), in addition to the carbon sequestration potential at the specific facility location. In the 2004 article "Carbon Sequestration in Dryland Ecosystems," author Lal states that the worlds arid land ecosystems have a large potential to sequester carbon, and that degradation of these lands often results in emission of carbon dioxide, CO_2, into the atmosphere.[6] In a two-year study of the Mojave Desert published in 2008, Wohlfahrt et al. found the ecosystem to be a significant net sink for CO_2. The authors attribute a significant portion of the desert soil's carbon sequestration capabilities to the expansion and growth of cryptobiotic soil crust organisms.[7] In a 2008 review of the Wohlfahrt et al. paper, author Stone wrote:

> "The effect could be huge: About 35 percent of Earth's land surface, or 5.2 billion hectares, is desert and semiarid ecosystems. If the Mojave readings represent an average CO_2 uptake, then deserts and semiarid regions may be absorbing up to 5.2 billion tons of carbon a year – roughly half the amount emitted globally by burning fossil fuels, says John 'Jay'Arnone…a co-author of the Mojave paper."[8]

However, assertions about desert soils as carbon sinks have been met with skepticism by some scientists. In Stone's 2008 article in *Science*, Jayne Belnap, an ecologist for the USGS and world renowned authority on soil crusts, says: "There is no way that all the CO_2 absorption observed in these studies is due to biological crusts, as there are not enough of them active long enough to account for such a large sink."[9]

Despite the controversy, the potential for desert soils to act as long-term carbon sinks has important implications for solar development in the California desert. The grading of land necessary for facility construction could eliminate the ability of the soil to sequester carbon and might result in the release of large amounts of carbon into the atmosphere. Whether developing large swaths of desert for solar energy production or leaving the desert soil intact has greater potential for reducing carbon emissions warrants further study.

Biological Soil Crusts: Carbon Uptake and Avoided Carbon Emissions

Because of the potential for biological soil crusts to fix carbon across the California desert landscape, we examine potential carbon uptake by desert soils compared with the range of potential avoided carbon emissions that would result from the construction of solar facilities in the California desert. Our calculations indicate that potential carbon taken up by biological soil crusts is far less than the amount of carbon offset by the production of solar energy. This calculation does not take into account the amount of carbon emitted by the solar panel manufacturing process, which can be a significant portion of the life-cycle carbon emitted by this product, and is only intended to provide a rough comparison of

whether desert soils or solar energy production are more effective at reducing overall carbon emission. Our results must be understood within the context of our assumptions and parameters, which are as follows:

- Rates of carbon uptake determined by the 2008 Wohlfahrt et al. paper are average for the California desert and that rates can be applied to the entire California desert.
- If these utility-scale solar facilities were not built, the carbon that would have been produced by conventional energy sources can be estimated by using CO_2 emitted per MWh of electricity produced, using a statewide average coefficient of 0.138 metric tons CO_2 per MWh for California's grid.[10]
- Average nameplate capacity of proposed solar facilities in California = 427 MW
- Average number of acres for proposed solar facilities in California = 3,797 acres
- Highest average operating efficiency for proposed solar technologies = 39.9 percent (dish/engines)
- Lowest average operating efficiency for proposed solar technologies = 11 percent (Thin Film PV)

Wohlfahrt et al. found that their study sites in the Mojave Desert took up 102 and 110 g C m^{-2} during 2005 and 2006, respectively. We used the average of the two years to calculate the annual rate of carbon uptake per acre of undisturbed desert at 428,967 g C/acre/yr.[a] Operating efficiencies for Thin Film PV at 11 percent efficiency and dish/engine at 39.9 percent efficiency were used to calculate a lower and upper range of avoided emissions: 4,081,211 to 14,803,667 g C/acre/yr.[b, c] A comparison of carbon uptake to avoided emissions is shown in Figure 6.2.

The estimated range of avoided carbon emissions from use of solar energy is 4 to 14.8 million grams carbon per acre per year, depending on the operating efficiency of the solar technology, while the amount of annual carbon uptake is much smaller at approximately 429,000 grams carbon per acre per year. Under these assumptions and parameters, solar facilities are much more effective at reducing overall atmospheric carbon than desert soils.

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[a] Calculating the amount of carbon uptake by desert soils:
(106 g C / m^2) * (1 m^2 / 0.000247105 acre) = 428,967.443 g C/acre/yr
[b] Calculation for Thin Film PV:
(427 MW) * (0.138 t CO_2/MWh) * (0.11) * (8,766 hr/yr) = 56,819.98 mt CO_2/yr
(56,819.98 mt CO_2/yr) * (10^6 g / mt) * (12g C / 44g CO_2) = 1.55 * 10^{10} g C/yr
(1.55 * 10^{10} g C/yr) ÷ (3,797 acres) = 4,081,211 g C/acre/yr
[c] Calculation of Dish/Engine
(427 MW) * (0.138 t CO_2/MWh) * (0.399) * (8,766 hr/yr) = 206,101.58 mt CO_2/yr
(206,101.58 mt CO_2/yr) * (10^6 g / mt) * (12g C / 44g CO_2) = 5.62 * 10^{10} g C/yr
(5.62 * 10^{10} g C/yr) ÷ (3,797 acres) = 14,803,666.6 g C/acre/yr

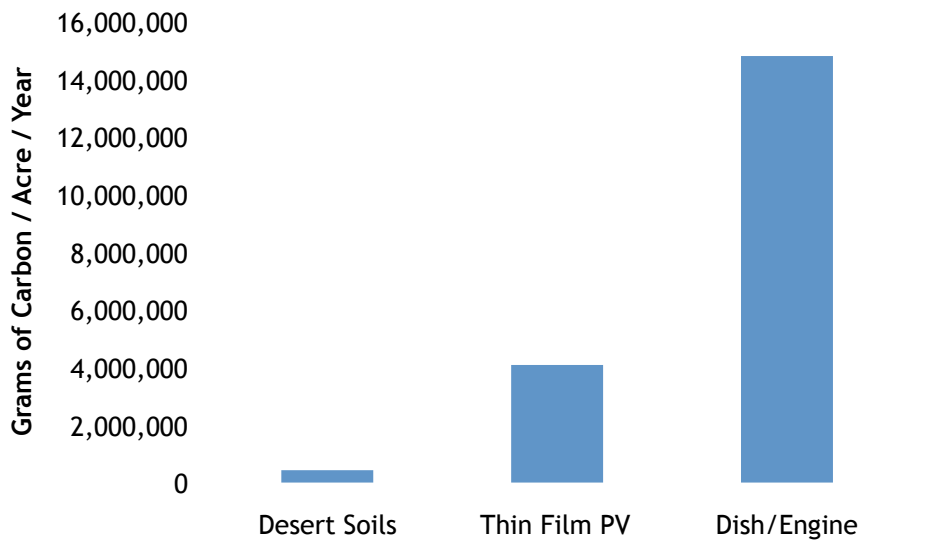


Figure 6.2. Comparison of Carbon Uptake by California Desert Soils and Avoided Carbon Emissions by Solar Energy Production.

Biological Soil Crusts: Albedo

Another unanticipated consequence of solar development might be its effect on regional climate through alteration of soil albedo. Albedo is a measure of how reflective a surface is to the sun's radiation.[11] A surface that is more reflective to this radiation (e.g. a light-colored surface) would have a higher albedo than a surface that absorbs more of the sun's radiation (e.g. a dark-colored surface). In a 2003 paper by Belnap and Eldridge, the authors state that the trampling of dark-colored biological soil crusts exposes lighter soils and can increase albedo; they also caution that *large-scale* changes in surface color may lead to changes in regional climate patterns.[12] There is concern that eliminating the soil crusts, which are dark in color, over several thousand acres of desert and replacing those dark surfaces with reflective panels and mirrors, could also affect regional climate. Jayne Belnap of the USGS said:

> "You've now taken a pretty dark surface and made it reflective. And so you've vastly changed the albedo of that surface. Probably not a big deal in terms of a small solar installation, but in terms of a large one, there are studies that indicate that you can change the regional climate by having large reflective surfaces. And 250,000 acres is a large reflective surface. It could end up decreasing rainfall in the region where the reflective surface is."[13]

The effect that modifying several thousand acres of surface albedo will have on the regional climate of the California desert warrants further study.

Water Use Efficiency

The impacts to groundwater and surface water availability from solar development will vary by project, and will depend on amount of water used as well as water source. Water obtained by surface water diversion and groundwater pumping can have implications for desert ecosystems. However, hydrology in the California desert is a complex system, and impacts to water levels are sometimes difficult to predict. After having analyzed the relative land use efficiencies of individual projects as well as averages by technology type, it was determined that a similar analysis for water would be a useful step in understanding the implications that solar development may have for desert water resources. Due to the limited amount of water resources in the California desert, the issue of water use by utility-scale solar energy facilities is highly contentious in the views of environmentalists, communities, developers, politicians, and land managers. In order to investigate the impact of the various projects on water resources, an analysis was conducted based on information gathered from the publicly available AFC for each project (Table 6.2). On a project-by-project basis, a clear comparison can be made based on absolute water consumption among the various technology types (Table 6.2 and Figure 6.3).

Table 6.2 Annual Average Water Consumption per Project.[14]

Proposal Name	Technology Type	Cooling System Type	Annual Water Usage (AFY)
Solar Millennium - Blythe	Parabolic Trough	Dry	600
Solar Millennium - Ridgecrest	Parabolic Trough	Dry	150
Solar Millennium - Palen	Parabolic Trough	Dry	300
Parabolic Trough Average			350
Beacon Solar Energy Project	Parabolic Trough	Wet	1,600
Abengoa Mojave	Parabolic Trough	Wet	1,077
Genesis Solar	Parabolic Trough	Wet	1,644
Parabolic Trough Average			1,440
Ivanpah	Power Tower	Dry	100
Rice Solar Energy Project	Power Tower	Dry	150
Power Tower Average			125
Calico (formerly Solar One)	Dish/Engine	N/A	36
Imperial Valley (formerly Solar Two)	Dish/Engine	N/A	33
Dish/Engine Average			35
Chevron Lucerne Valley	Thin-Film PV	N/A	0.14[15]
Notes: "N/A" stands for not applicable in this table.			

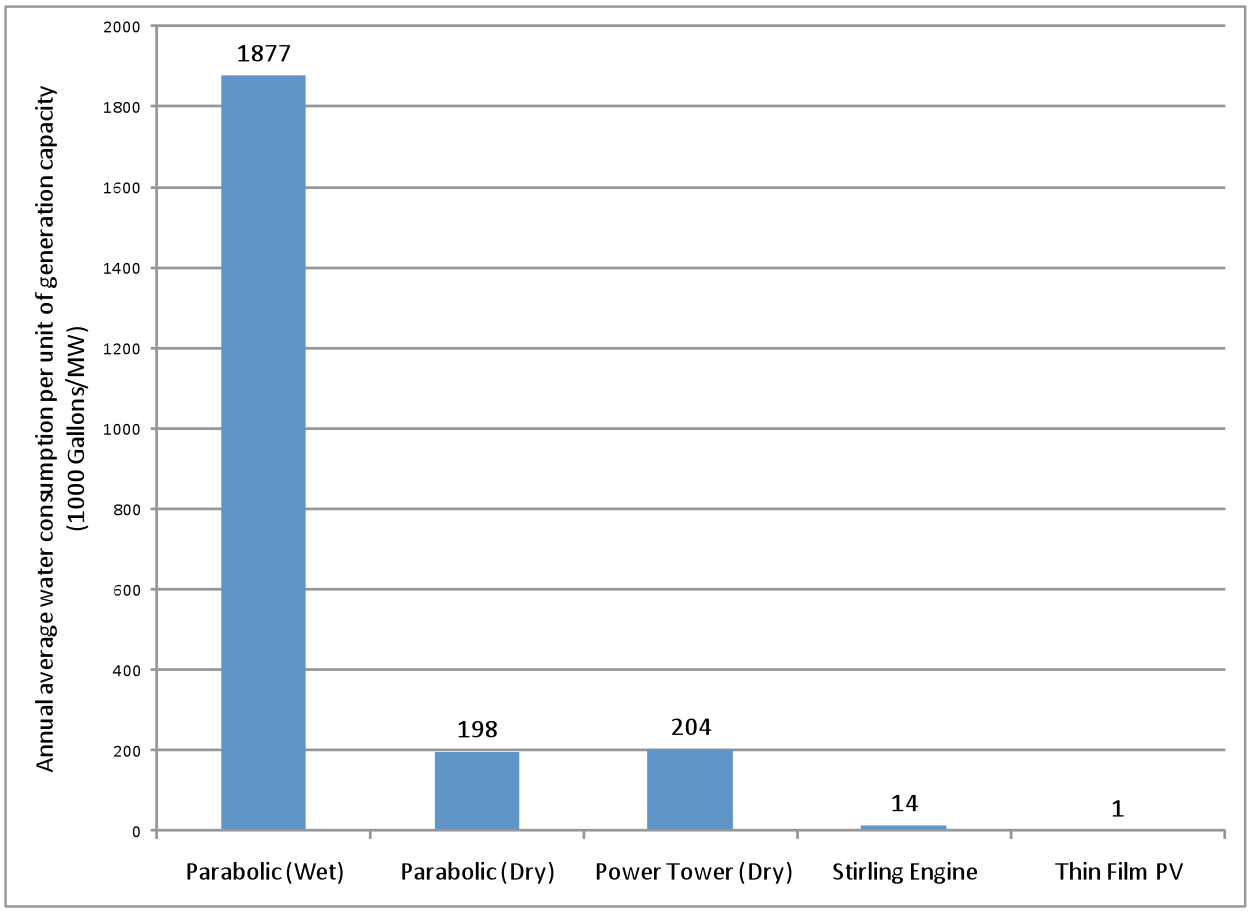


Figure 6.3 Average Annual Water Consumption of Solar Technology Types with Wet and Dry Cooling Systems.

On an absolute scale, thin film photovoltaic facilities appear to consume much less water than other solar thermal based technologies. This is mainly because the water that is used during operation of these types of facilities is only for washing the modules and is not needed as part of the electricity generation process. It should be noted, however, that the water use value for thin film PV technology in this study is based on only one project and the size of the facility is approximately one fifth the size of an average parabolic trough system. Therefore, for a more accurate comparison, the amount of water used by the thin film PV facility would need to be increased by five times. Yet, even with a five-fold increase, the absolute consumption of water by thin film PV systems is still the lowest of all the technologies analyzed. In contrast, in terms of total annual water consumption, wet-cooled parabolic trough systems are clearly the most water-intensive technology type, consuming an average of close to 1.9 million gallons of water per mega-watt of installed capacity.

Total water consumption is often used as a metric to measure impact on water resources; however, these values do not accurately represent how *efficiently* the various technology types use water. In order to quantify this efficiency, a separate analysis was conducted using the water consumption values in conjunction with each project's electricity generation capability, similar to the land use

efficiency analysis above. The analysis was based on average annual water consumption rates and average annual electricity production of each facility. The total electricity production value (in MWh) was chosen over the nameplate capacity (in MW) of the facility because it inherently takes into consideration the operating efficiencies of various solar technology types and is a more accurate representation of the facilities' power producing capabilities.

Based on this analysis, it was determined that on a per MWh basis, thin film PV facilities actually appear to be the least water efficient technology with an average efficiency of 6,912 gallons of water used per MWh of electricity produced (Table 6.3). In contrast, dish/engine systems appear to be the most water efficient technology type, requiring only an average of four gallons of water consumed per MWh of electricity produced. In other words, a thin film PV facility would use approximately 1,700 times more water than a dish/engine facility to produce the same megawatt of electricity. This was a surprising result since PV facilities have the lowest overall water consumption due to the fact that they do not utilize cooling systems and the only water used during operation is attributed to washing the modules. Upon further investigation, it was determined that the reason why thin film PV facilities appear so unfavorable in this analysis is because of the low module efficiency of this type of technology. This leads to two important consequences that affect the analysis. First, the low module efficiency effectively lowers the overall operating efficiency of the facility, thereby reducing the total

Table 6.3 Water Efficiency Analysis Based on Annual Water Consumption per Project.[14]

Proposal Name	Technology Type	Cooling System Type	Water Consumption per Unit of Electricity Produced (Gal/MWh)
Solar Millennium – Blythe	Parabolic Trough	Dry	93
Solar Millennium – Ridgecrest	Parabolic Trough	Dry	98
Solar Millennium – Palen	Parabolic Trough	Dry	98
Parabolic Trough Average			96
Beacon Solar Energy Project	Parabolic Trough	Wet	869
Abengoa Mojave	Parabolic Trough	Wet	557
Genesis Solar	Parabolic Trough	Wet	1,786
Parabolic Trough Average			1,071
Ivanpah	Power Tower	Dry	34
Rice Solar Energy Project	Power Tower	Dry	109
Power Tower Average			71.52
Calico (formerly Solar One)	Dish/Engine	N/A	3.94
Imperial Valley (formerly Solar Two)	Dish/Engine	N/A	4.10
Dish/Engine Average			4.02
Chevron Lucerne Valley	Thin Film PV	N/A	6,912[16]

amount of electricity produced. Second, because less power is produced per unit area, installation of more solar modules would be necessary to produce a fixed amount of electricity. As a result of this increase of installed units, more water would be necessary to clean these additional modules. For comparison, water efficiency rates among various solar and conventional power plant types such as coal, natural gas or nuclear is shown in Figure 6.4.

It should be noted that PV technology companies are continuously working on improving water capture and reuse methods as well as developing systems that would not require module washing. Advances in this area would greatly improve the water use efficiency values of these systems and should be monitored and analyzed on an ongoing basis.

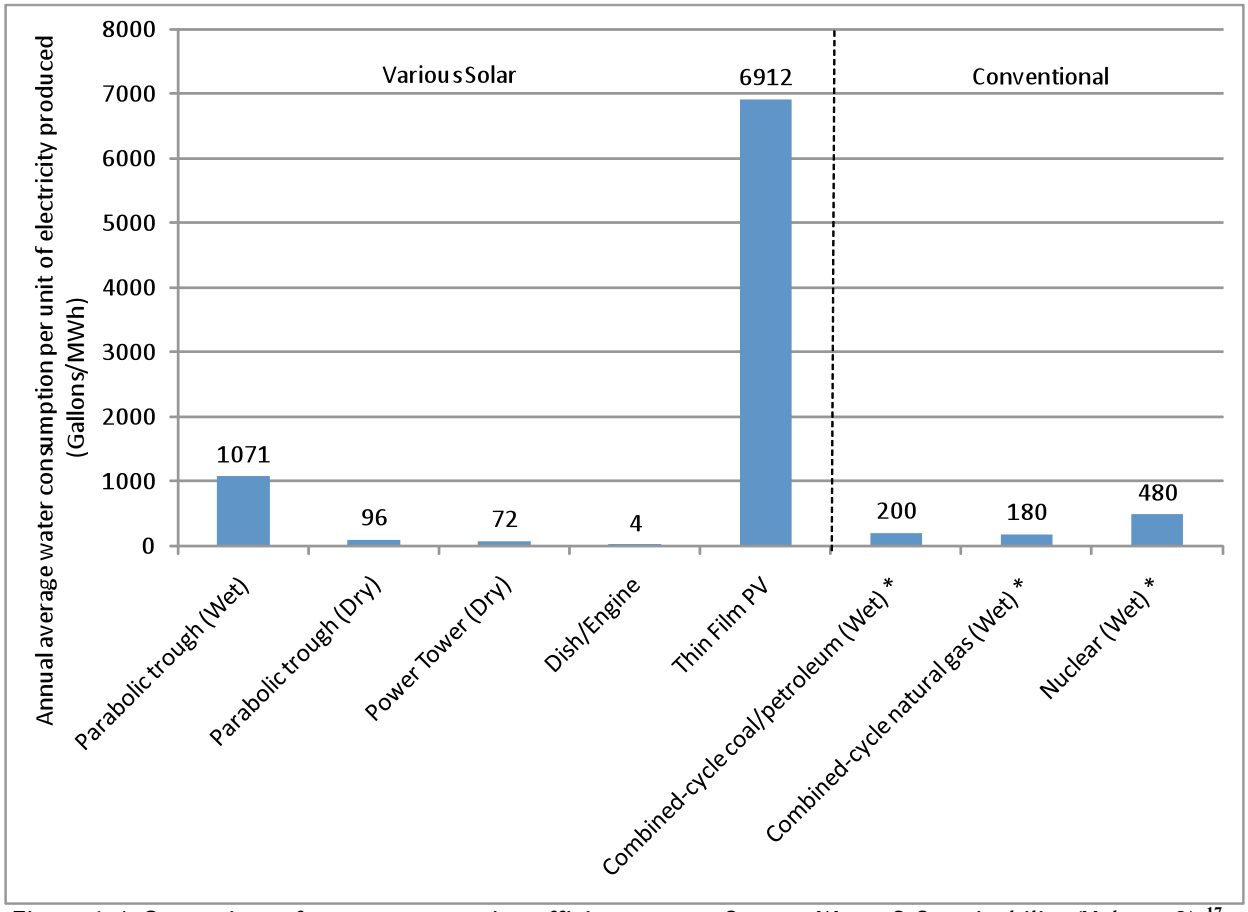


Figure 6.4 Comparison of water consumption efficiency rates. Source: Water & Sustainability (Volume 3).[17]

Ecological Impacts from Groundwater Withdrawal or Surface Water Diversion

The total amount of water used by solar facilities across the landscape, how efficiently that water is used, and the source of the water has consequences for the hydrology of the California desert. Terrestrial, riparian, and aquatic habitats are likely to be affected. The desert pupfish (*Cyprinodon macularius*) and the Owens Valley are used as examples to demonstrate potential impacts.

Hydrology: Impacts to Terrestrial Habitats

Long-term sustainability of groundwater-dependent ecosystems in arid regions is particularly sensitive to anthropogenic alterations of subterranean water systems.[18] Groundwater withdrawals for solar development that lower an already shallow water table may lead to reduction or even elimination of spring discharge. Some plant species in arid regions are more dependent on groundwater resources than precipitation because groundwater is less subject to annual variability than precipitation.[19] If pumping water for solar development reduces groundwater to a level below the root zones, these groundwater-dependent plants could be adversely affected.[20] The result may include reduced plant species richness, reduction of plant cover, or shift in vegetation type.[21] Vegetation response to groundwater pumping is dependent on several factors, including but not limited to the magnitude of change in spring discharge, amount of groundwater decline, spring size, soil characteristics that affect salt percolation, and distance from extraction site.[22] Additionally, water obtained for solar development could alter the ratio of surface water and groundwater availability, which could induce changes to vegetation community composition.[23] Alteration in plant communities can, in turn, affect animal species through habitat loss or decreased habitat connectivity. Similar impacts to desert species may occur if solar development requires surface water diversions that decrease water supply to riverine systems and riparian corridors.[24] In addition to habitat loss, decreased vegetation resulting from water extraction or diversion may result in increased erosion and sediment production since plant assemblages protect against wind and water scraping.[25] Reduced soil moisture that may result from vegetation removal has the potential to cause localized and long-term increases in dust emission.

Habitat Connectivity: Impacts to Riparian Corridors

Riparian habitats, which are assemblages of plant communities characterized by their associations with surface or subsurface water, often function as migration corridors.[26] Both the water and the plants associated with these corridors provide important resources for the species that rely on these riparian habitats. In the Mojave in particular, many bird species are supported by these riparian habitats.[27] These habitats can be patchy, but they provide connectivity for species as they move across the landscape. If gaps between patches become too wide along the corridor, they may no longer be useful for migration. Solar development that limits water supply to these corridors, through either channel diversion or withdrawal, may impact the health of these habitats. Riparian habitats that suffer a loss of water may not be able to support as many plant communities, or water availability for animals may be depleted.

Hydrology: Impacts to Aquatic Habitats

Aquatic habitats, while relatively limited in arid regions, are susceptible to impacts from solar development in the California desert if groundwater and surface water sources are affected. Desert springs are just one example of a rare aquatic habitat; they are seldom encountered in arid ecosystems

and their distribution is scattered.[28] Though they may occur as single springs or a cluster of springs, distances between spring habitats are often too far to allow migration between them.[29] If the vitality of a spring is compromised by groundwater extraction for solar development, species dependent on the spring may suffer loss of habitat that cannot be mitigated.[30]

However, impacts to water supply as the result of groundwater extraction (for solar development or otherwise) can be difficult to predict both spatially and temporally; aquifers in the California desert are structurally complex, impacts may occur at great distances from extraction sites, and there may be a lag time between extraction and identifiable impacts.[31] This complexity also makes cumulative effects difficult to predict. An agency hydrologist notes:

> "It's not enough to just monitor withdrawal effects, since even if you stop pumping, effects may be slow to reach the site… Every time you start pumping an aquifer, something's got to give. Either there is going to be a decline in spring discharge or water levels down gradient; it could increase recharge from up-gradient areas - but something's got to give. The aquifer is in equilibrium with natural conditions as far as recharge rates and discharge rates, and when you start sticking more straws in the glass, each one of these actions - not the individual actions but the cumulative effects of these incremental increases in water withdrawals from that aquifer – are going to result in decreased water levels, aquifer levels and decreased spring discharge."[32]

While impacts to groundwater- and surface water-dependent species and habitats from solar development may be difficult to predict or monitor, water extraction that exceeds groundwater recharge or replenishment from precipitation has potential long-term consequences. Additionally, impacts may be difficult to assign to specific projects, as they often occur at great distances from the extraction source and/or after significant time has passed.

Case Study: The Desert Pupfish

The desert pupfish (*Cyprinodon macularius*) serves as one example of a sensitive aquatic species that may be affected by reduction in water availability, as their habitat includes warm pools, marshes, springs, seeps. The species is listed as federally endangered, and NatureServe Explorer gives the species a global status of G1 (Critically Imperiled).[33] Populations have been drastically reduced as a result of several threats, including habitat loss from water extraction and encroachment by invasive plant species, introduction of predator and competitor species, and water contamination by pesticides.[34] Though not widely distributed, they are considered an indicator species for water availability and stability in some areas of the California desert.[35] Generally considered a fairly hearty species, the desert pupfish can tolerate wide ranges of salinity and temperature.[36] However, they have an upper limit for temperature tolerance, and like many other species in the California desert, the desert pupfish is already living at its upper limits of these tolerances.[37] Groundwater pumping that limits water supply to pupfish habitat can increase water temperatures and put a physiological stress

on the species.[38] Specifically, when the upper temperature limit is crossed, either egg-hatching success dwindles close to zero or survival of newly hatched larvae is limited.[39] Paired with climate change predictions for decreased precipitation and increased temperatures, these changes could have a devastating effect on the species.

The desert pupfish, therefore, is an illustration of aquatic species sensitivity to reductions in water availability. Climate change will likely continue to put stress on aquatic species, with increased water temperatures, intensified pollutant toxicity, and a reduction in dissolved oxygen levels.[40] In 2006, Carveth et al. showed that increasing water temperatures may provide more suitable habitat for introduced fish species, adding another potential threat to native fish in the form of competition.[41] Consideration of these species interactions should be given to hydrologically connected aquatic habitats if groundwater is pumped for solar development needs.

Case Study: Water Extraction and Diversion in Owens Valley, CA

The depletion of surface and groundwater by solar development may have unexpected consequences, as illustrated by the impacts of both surface water diversion and groundwater pumping in Owens Valley, California. The Owens Valley, located in the Great Basin Desert in California's Inyo County, provides a good example of terrestrial impacts that can result from reduced flows of surface and groundwater. In 1913, Los Angeles opened an aqueduct that diverted surface water from the Owens River, which runs through the Owens Valley, down to the city. Los Angeles began pumping groundwater in 1918, and opened a parallel aqueduct that pumped additional groundwater out of the valley in 1970.[42] Surface water diversion and groundwater pumping have induced measurable changes in vegetation composition and cover of the Owens Valley, including increased shrub cover replacing grass cover.[43] Preliminary evaluations of vegetation change found that from 1906 to 1968, major vegetation cover declined by 38 percent, and from 1968 to 1981, major vegetation cover declined by 67 percent.[44] It has been estimated that approximately 25,000 acres of groundwater-dependent vegetation in the valley have been negatively affected by groundwater pumping.[45]

The water table served as a buffer for vegetation to adjust to annual fluctuations in precipitation, but diversion and pumping have resulted in fluctuations in the water supply that negatively affects native plants such as willow (*Salix* spp.), saltgrass (*Distichlis spicata*), greasewood (*Sarcobatus vermiculatus*), and favors weed species such as Russian thistle (*Salsola* spp.) and bassia (*Bassia hysopifolia*).[46] Saltcedar (*Tamarix ramosissima*) has colonized riparian habitats below the aqueduct intake because intermittent surface water flow creates disturbance that harms native vegetation and favors saltcedar.[47] Nevada saltbush scrub (*Atriplex torreyi*), saltgrass meadow, and alkali marsh communities around the Little Black Rock Spring have declined because of groundwater pumping.[48]

Conclusion

The information on site engineering processes (such as grading and fire prevention) combined with the results of the subsequent land and water use analyses, indicate that technology type and facility footprint have a number of implications for the effect of a project on the surrounding ecosystem. This analysis has yielded a variety of interesting results that help us to better understand how and to what degree these two variables act on the local environment. The analyses have demonstrated that certain technology types, such as dish/engine systems, show the promise of having both high land and water use efficiencies, which could make this technology type one of the most productive forms of solar development while also suggesting that it may incur a relatively lower amount of ecological impact. Likewise, these analyses demonstrated that one of the most effective design changes a facility can make to reduce its environmental impact is to utilize a dry-cooled system rather than a wet-cooled system.

However, it is important to note that the land use analysis also has some limitations. First, it constructs the disturbance ratio based on the amount of area that will be covered completely by various forms of infrastructure, such as roads, buildings, and the solar field. It does not include other types of disturbance or environmental disruption that may arise from other forms of infrastructure, which may still result in ecological impacts on the surrounding area and wildlife. Second, this form of analysis utilizes the area of disturbance as the key variable in assessing the relative land use efficiency of a project proposal. Caution should be applied with this approach as these project proposals are still in the permitting process and are therefore subject to design change. Should certain design changes occur, the relative land use efficiency ratio of a project might change as well. Third, although this tool primarily focuses on the relationship between the facility footprint and the amount of electricity generated by the facility, users should keep in mind that the size of the facility footprint also contains its own set of ecological and efficiency trade-offs. For example, solar energy facilities that utilize a dry-cooling system will inherently operate at a lower efficiency, and therefore developers will frequently expand the footprint accordingly to generate the same amount of energy as a smaller wet-cooled facility. For some users of this tool, the consideration of the amount of water use may be of greater concern than area of land use, in which case, they may weigh the results of the water use efficiency analysis more heavily. And finally, users of this tool should refrain from extrapolating the total environmental impact of a project from these ratios. Although land use efficiencies are undoubtedly helpful for comparisons among different projects and even various technologies, they remain a snapshot of the proposed development and are certainly not comprehensive in their scope of environmental assessment.

Regardless of a technology type's relative land-use and water-use efficiency, the geographic location of facilities, as well as the biological resources associated with sites, will directly determine the type,

intensity, and extent of landscape-level impacts from development. Case studies of potential impacts to desert wildlife offer an illustration of how landscape-level impacts resulting from the construction of multiple facilities may affect species at the population level; to that end, we developed case studies of potential impacts to three desert species, discussed below.

SOLAR DEVELOPMENT IMPACTS: SPECIES CASE STUDIES

In addition to our analysis on the potential impacts of solar development on ecological processes, many of the sensitive species found in the California desert are also at risk. Individual species as well as populations may be affected by site-level and/or landscape-level impacts. To illustrate this, we discuss the potential impacts that solar development may have on: the desert tortoise (*Gopherus agassizii)*, the desert bighorn sheep (*Ovis canadensis nelsoni*), and pollinators in the California desert. Though we chose to focus on just three examples to illustrate the potential impacts utility-scale solar development may have on desert species, similar concerns could be relevant for any species that may suffer from habitat loss, habitat fragmentation, water depletion, migration corridor blockage, or the indirect impacts associated with increased human presence in the region. Species that are most at risk include species with limited ranges, in particular those species with primary habitat in the flat, low-lying desert areas where solar development is most likely to occur.

Desert Tortoise (Gopherus agassizii)

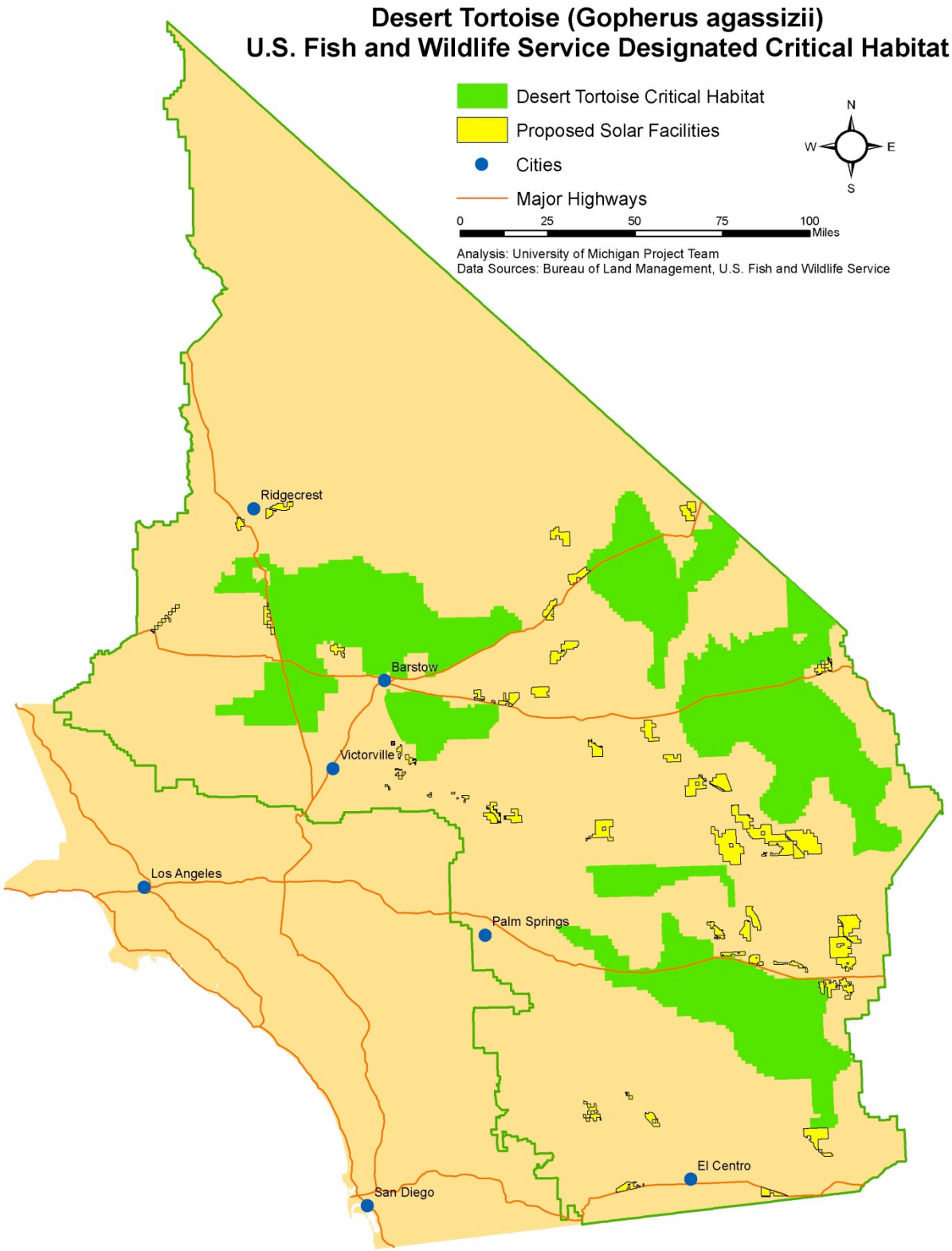
Status/Listing

The desert tortoise, a flagship species in the California desert, has been listed as threatened under the California Endangered Species Act since 1989 and the Mojave population has been listed under the Federal Endangered Species Act since 1990 (Figure 6.5).[49] The Sonoran population of tortoises is currently under review for listing by the FWS.[50] NatureServe Explorer gives the tortoise a global status of G4 (apparently secure) and a state status of S2 (imperiled) for California.[51] The International Union for Conservation of Nature lists the desert tortoise as Vulnerable.[52] Despite the listing and attention the species receives for recovery and conservation efforts, populations continue to experience dramatic decline.[53]

Figure 6.5 Desert Tortoise. Image Credit: Beth Jackson/FWS.

Habitat Loss

Many solar facilities have proposed siting in or near desert tortoise habitat (Map 6.1). Development of the these facilities will result in a direct loss of habitat for the desert tortoise because proposed solar facilities plan to use fencing specifically designed to exclude desert tortoises from a project site.



Map 6.1 Desert Tortoise Critical Habitat and Proposed Facilities.

Tortoises will be excluded from project sites in order to prevent them from being accidentally killed by machinery during construction, killed by vehicles during operation, or otherwise trapped within the facility. While fencing the entire disturbance area of a facility may prevent the direct mortality of individual tortoises, the total area of habitat that is lost could have negative impacts on tortoise populations, depending on habitat quality within proposed sites.

Surveys of one proposed (2,012 acre) solar facility found zero desert tortoise within the project disturbance area, and five tortoises about 600 feet outside of the proposed disturbance area.[54] The low numbers of tortoises found at this site may be due in part to past agricultural activities that left the site heavily disturbed and low in native vegetation. However, surveys of another proposed (1,760 acre) solar facility found 40 desert tortoise within the project disturbance area, and 10 tortoises within the one-mile buffer zone.[55] Surveys of the project site and buffer zone also found over 200 tortoise burrows, where 36 active burrows were within the disturbance area and 12 were in the one-mile buffer zone.[56] Though the project is not located in designated desert tortoise critical habitat or in a designated desert tortoise Desert Wildlife Management Area (DWMA), the estimated density of adult tortoises within the disturbance area was greater than that of a nearby DWMA: 9.8 desert tortoise per km^2 within the proposed solar site, compared with 5.3 to 7.6 desert tortoise per km^2 within the nearby DWMA.[57] Projects that are built in areas of high desert tortoise density will permanently eliminate large swaths of high quality habitat.

Habitat Fragmentation and Connectivity

Increased habitat fragmentation caused by new facilities, roads, ground disturbance under transmission lines, and other linear corridors (e.g., pipelines), will create barriers to movement that could negatively affect population dynamics. Roads and other linear corridors subdivide contiguous habitat, creating smaller and more isolated tortoise populations. These smaller, isolated populations are more susceptible to decline or local extinction due to drought or other stochastic events, as well as the negative effects of inbreeding. Recovery by small, isolated populations may rely heavily on immigration of new individuals from adjacent habitat, but these inter-population movements are often prevented by the very things that fragmented the habitat in the first place (i.e. roads, development).[58]

The development of barriers between desert tortoise critical habitats is especially problematic. In a 2009 study, Bare et al. found that solar development in the West Mojave could inhibit movement between certain desert tortoise critical habitats.[59] Conserving habitats that allow movement of individuals between critical habitat units is essential to the long-term viability of the Mojave population of the desert tortoise.[60,61] Solar development, in addition to eliminating several thousands of acres of occupied and potential desert tortoise habitat per project, may also eliminate or fragment

habitats that serve as crucial habitat corridors between conservation areas, which may compromise recovery of the species.

Linear Corridors

New roads constructed to service solar facilities and/or an increase in traffic on existing roads will increase mortality of desert tortoises. Desert tortoises are vulnerable to being run over by automobiles, and the proliferation of new roads through tortoise habitat will likely increase the risk of roadkill mortality.[62] Increased OHV access to previously undisturbed natural areas via these new roads could also increase the chances of tortoises being run over by OHVs. In addition to increased OHV access, an increase in human access to tortoise habitat has several other negative implications.

Increased human access to and presence in the California desert due to new solar facilities could benefit the common raven (*Corvus corax*), considered to be a "subsidized predator" of juvenile desert tortoise.[63] Ravens are able to travel long distances to take advantage of human-provided food and water sources at a solar facility, such as trash generated on-site, roadkill created by increased vehicle traffic, and standing water created by dust suppression techniques.[64] Raven populations, elevated by human-provided food supplies, venture far beyond developments and into natural areas where they prey on juvenile desert tortoises.[65] Says Jody Fraser, a biologist with the FWS:

> "Ravens may travel more than 40 kilometers to forage and will take advantage of subsidies, such as food, water, and perch and nest substrates provided, often inadvertently, by humans. Large solar facilities in remote areas of the desert will likely attract ravens to these sites, and the transmission infrastructure will provide a corridor along which they can travel."[66]

Solar facility infrastructure, such as fencing, buildings, or transmission lines, could create elevated perches that could be used by ravens to hunt tortoises more effectively. Predation by ravens is a serious threat to desert tortoise populations. In a 2003 study by Kristan and Boarman, the authors state that "anthropogenic resources for ravens could indirectly lead to the suppression, decline, or even extinction of desert tortoise populations."[67] More recently, coyote (*Canis latrans*) predation on desert tortoise has become a problem especially in light of the prolonged drought being experienced in the region and a decline in prey species, such as jack rabbits and ground squirrels.[68] A proliferation of solar development in desert tortoise habitat could supplement existing human-provided resources for ravens and coyotes, and lead to further decline of tortoise populations.

The proliferation of new roads in or near tortoise habitat has the potential to negatively affect tortoise populations via increased trash or litter, collection, disease, and vandalism. For example, one proposed solar facility would be sited about seven miles from a desert tortoise DWMA. Increased human access to desert areas in the proximity of tortoise habitat could lead to an increase in the amount of trash or

litter in tortoise habitat. Tortoises have been known to eat balloons, plastic, and other pieces trash, which can become lodged in the digestive tract, eventually causing death.[69] Other human activities that endanger tortoise populations are collection of tortoises (i.e. for pets), release of previously-collected tortoises from captivity that can spread diseases to wild tortoises, and vandalism.[70, 71] Disease in wild desert tortoise populations is responsible for increased stress and mortality in tortoises, likely contributing to population declines.[72,73] Acts of vandalism include shooting, beheading, severing of body parts, and overturning (which immobilizes the tortoises).[74] In 1996, Berry found a higher percentage of desert tortoise gunshot deaths in the Western Mojave, compared to the Eastern Mojave or Colorado Deserts, and attributed this to a higher number of human visitors and greater vehicular access in the Western Mojave.[75]

Invasive Plants

Roads and other transportation corridors necessary for solar development could facilitate the colonization of natural areas by invasive plants.[76] The spread of invasive plants is problematic for the desert tortoise because of its effect on the frequency of fire. Invasive grasses increase the frequency of fire by increasing the amount of vegetative fuel and by reducing the space between plants, allowing fire to spread to a larger area.[77] Wildfires have both direct and indirect effects on tortoises. The slow-moving tortoises might not be able to escape a fast-moving wildfire, and could therefore suffer direct mortality in a fire.[78] If a tortoise does survive a fire, the loss of vegetation from the fire could leave large areas devoid of food for the tortoise and lead to starvation. In addition, loss of vegetative cover leads to loss of protection from predators (i.e. places to hide) and temperature extremes (i.e. loss of shade).[79]

The effect that non-native grasses have on tortoise diet is less clear. Non-native annual grasses compete with native annual plants in the Mojave Desert, potentially reducing the amount of acceptable/useable food plants for the tortoise.[80] However, desert tortoise may include non-native plants in their diet.[81] Despite a possible increase in the availability of tortoise forage, positive effects from non-native plant species are far outweighed by the serious negative effects from higher fire potential and subsequent habitat destruction.[82]

Implications for the Ecosystem

To escape from harsh environmental conditions, tortoises will utilize a wide variety and number of burrows that they have either excavated on their own or modified from another animal.[83] Excavation and construction of burrows by tortoises can provide habitat for several other species, including, but not limited to: antelope ground squirrel (*Ammospermophilus lecurus*), blacktailed jackrabbit (*Lepus californicus*), kangaroo rat (*Dipodomys* spp.), kit fox (*Vulpes macrotis*), burrowing owl (*Athene cunicularia*), Gambel's quail (*Callipepla gambelii*), roadrunner (*Geococcyx californianus*), desert spiny

lizard (*Sceloporus magister*), western rattlesnake (*Crotalus viridis*), ground beetle (*Tenbrionidae*), and tarantula (*Aphonopelma* spp.).[84] Because the tortoise creates microhabitats for numerous other species, it could be considered a keystone species of the California desert.[85] Extirpation or continued decline of the desert tortoise in the California desert from the impacts discussed above may have implications for species that currently benefit from tortoise burrows.

Ecological Implications for Facility Location and Design

The magnitude of impact that the development of a single solar facility or multiple facilities will have on the desert tortoise is dependent on the facility design variables and location as discussed in Table 6.4. These variables will influence the magnitude of the cumulative impact of solar development on the desert tortoise populations in the California desert.

Table 6.4 Solar Facility Design Variables Affecting Desert Tortoise.

Facility Design Variable	Implications for the Desert Tortoise
Location of Facility	Determines the quality of desert tortoise habitat that is eliminated (some areas are better quality tortoise habitat than others). Determines magnitude of habitat fragmentation (some areas are more heavily used by tortoises for movement and migration).
Size of facility	Larger facility has a greater probability of eliminating desert tortoise habitat.
Proximity to other development	The closer a facility is to developed areas, the more likely it is that desert tortoise habitat is already degraded and populations are depressed from predation and other human impacts.
New and existing roads to access the facility	More roads increase the probability of roadkill mortality.
Number of construction and operation personnel	More vehicles increase the probability of roadkill mortality.
Speed limits	Lower speed limits reduce the probability of roadkill mortality.
Length of new transmission line(s)	Longer transmission lines create a larger disturbance area and increased habitat fragmentation.
On-site Raven Management Plan	An effective raven management plan might prevent the establishment of ravens at the facility site and could reduce predation of ravens on desert tortoise.
On-site trash and standing water BMPs	Secured trash and minimization of standing water on-site reduces attractiveness of the facility to predators (e.g. ravens, coyotes) and reduces predation on desert tortoise.
Invasive plant and fire management plans	Plans that minimize the establishment and spread of invasive plants and contain fires reduce direct and indirect mortality of tortoises from fire.

Nelson's (or Desert) Bighorn Sheep (Ovis canadensis nelsoni)

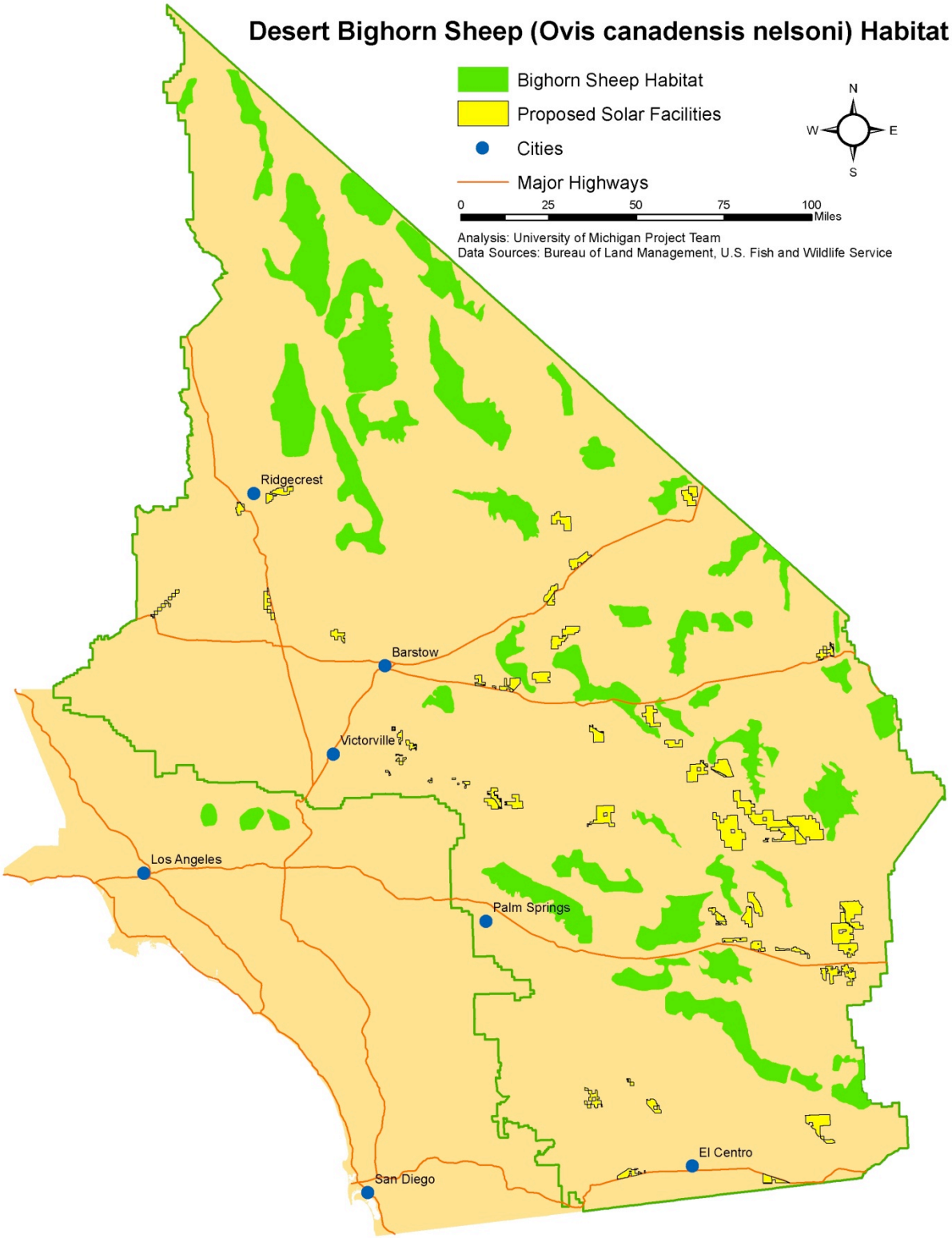
Status/Listing

There are three subspecies of bighorn sheep (*Ovis canadensis*) within or in proximity to the California desert: Nelson's bighorn sheep (*O. c. nelsoni*), peninsular bighorn sheep (*O. c. nelsoni DPS*), and Sierra Nevada bighorn sheep (*O. c. sierrae*).[86] Historical population and distribution data shows a substantial decline in California's bighorn sheep populations over the last 60 years due to human pressures that include habitat degradation and disease introduction from domestic livestock.[87] Nelson's bighorn sheep (or desert bighorn sheep) is the only subspecies of the three that thrives in the California desert, and is the largest native vertebrate in the bioregion (Figure 6.6).[88] The desert bighorn sheep is not federally listed; the BLM and the USFS, however, both list the subspecies as Sensitive.[89] NatureServe Explorer gives the desert bighorn sheep subspecies a global status of G4T4 (apparently secure), and a California state status of S3 (vulnerable).[90] The International Union for Conservation of Nature (IUCN) lists *Ovis canadensis* as Least Concern, but NatureServe indicates the IUCN's historic listing for the desert bighorn sheep subspecies as Conservation Dependent.[91,92]

Figure 6.6 Desert Bighorn Sheep. Image Credit: Lynn B. Starnes/USFWS

Habitat Fragmentation: Loss of Connectivity and Barriers to Migration

Habitat loss and fragmentation are major contributors to the declining bighorn sheep population in the California desert.[93] Metapopulations need to be able to move between mountain ranges and come in contact with one another, in order to maintain genetic diversity through breeding.[94] These intermountain movements also allow for new colonization of available habitat. As connectivity between mountain ranges is essential for the persistence of the population, the addition of solar facilities on the desert floor may have consequences for these mountain-dwelling bighorn sheep (Map 6.2). Fencing and roads associated with these facilities could act as barriers to migration. In a 2005 study of the rapid decline of genetic diversity for the subspecies, Epps et al. found an apparent elimination of gene flow due to anthropogenic barriers that include highways and developed areas. Their results indicate these barriers represent a "severe threat" to the persistence of the populations.[95] Though solar development may not necessitate new highways, even some two-lane roads may deter movement of desert bighorn sheep; heavy traffic and/or sustained human presence may inhibit migration across new or existing roads associated with solar facilities, particularly during construction phase.[96] Paired with the potential impacts of climate change, which could include loss of habitat (as sheep are pushed into higher elevations), and decreased water availability, this added pressure could be detrimental to the metapopulation. As evidenced by the 2005 Epps et al. study:



Map 6.2 Bighorn Sheep Habitat and Proposed Facilities.

> "Our analyses point to the conclusion that human-made barriers may greatly reduce stability of the system as a whole…Extinction risk for many desert bighorn sheep populations in California is high, and may sharply increase in the coming century because of climate warming… if barriers disrupt gene flow and recolonization, genetic diversity may be lost very rapidly from the system as a whole (given that the total number of populations in this instance is not large."[97]

Dr. Clinton Epps, the lead author of that study, offered a follow-up perspective of the desert bighorn sheep metapopulation in the California desert in light of potential solar development. In a personal interview, he expressed concern about maintaining habitat connectivity:

> "When I found out about the solar projects it was pretty shocking frankly. One of the conclusions from my years of working down there is that probably the most critical thing we can do to preserve bighorn over the larger landscape is maintain connectivity between those populations... Well we've seen some of them get recolonized, and so the analysis is, I think, correct in that extinction is more likely in some of those low-lying areas but if you look at it from a metapopulation perspective, the system as a whole will be more stable and more genetically diverse the more those patches are occupied, and the way to keep those patches occupied is to maintain the ability for these animals to move back and forth between those patches.
>
> The developments are mostly slated for the flats – people still regard flats between those mountain ranges as wastelands, but we've got very clear evidence (genetically, directly, radiotelemetry, etc.) that they do move back and forth between these areas and that it's not just a question of inbreeding and genetic diversity although that's part of it; it's also just a simple extinction and recolonization dynamics, and my guess is that's actually more important than the genetic diversity worries."[98]

In 2009, Bare et al. modeled the connectivity of 69 bighorn sheep populations in West Mojave that depend on gene flow between populations facilitated by migration. This study analyzed the potential of utility-scale renewable energy development to obstruct these pathways. Results indicate that extensive development could have serious consequences for desert bighorn sheep, by obstructing movement and gene flow.[99] The authors also caution against siting facilities in areas that are currently unoccupied suitable habitats for bighorn sheep as these areas may be needed for future recolonization.[100]

Water Availability: Groundwater Pumping and Invasive Plants

While severe drought compromises water availability, solar facilities have the potential to affectdesert bighorn sheep populations if groundwater pumping or surface water diversions occur as a direct or indirect consequence of development. Aquifer drawdown that results in the reduction or elimination of surface water used by desert bighorn sheep could negatively affect their ability to survive in the already water-limited desert. Additionally, studies indicate that sustained human presence deters bighorn sheep from accessing relied-upon water sources — this could be problematic during the construction phase when more workers are present on site.[101] Introduced species from new or increased

road access during construction and operation phases can also have an indirect impact on water availability. For example, the well-established non-native shrub tamarisk (*Tamarix* spp.), also known as saltcedar, has already had detrimental effects on water availability; introduction of new invasive plant species could compound this problem, consuming more groundwater and therefore limiting surface water availability for the bighorn sheep.[102]

Ecological Implications for Facility Location and Design

The magnitude of impact that the development of a single solar facility or multiple facilities will have on the desert bighorn sheep is dependent on the facility design variables and location as discussed in Table 6.5. These variables will influence the magnitude of the cumulative impact of solar development on the bighorn sheep metapopulations in the California desert.

Table 6.5 Solar Facility Design Variables Affecting Bighorn Sheep.

Facility Design Variable	Implications for the Desert Bighorn Sheep
Location of Facility	Determines whether facility blocks a migration corridor or impedes bighorn sheep movement. Also determines if resources for sheep are lost due to habitat removal by perimeter fencing.
Size of facility	Larger facility (i.e. greater fenced area) increases probability of blocking migration corridor or impeding bighorn sheep movement, increases amount of habitat loss if sheep relies on fenced area for resources.
Proximity to other development	Determines magnitude of habitat fragmentation or migration corridor blockage.
New and existing roads to access the facility	Determines magnitude of habitat fragmentation or migration corridor blockage. More roads increase probability of impact.
Number of construction and operation personnel	Greater human presence increases probability of impeding species movement (sheep often avoid areas of high human presence).
Water Source and Quantity	Water source (groundwater pumping or surface water diversion) for facility use determines whether a water source has been compromised for the sheep. Greater quantity of water diverted increases likelihood of affecting habitat connectivity for sheep that rely on affected surface water resource for migration.

Pollinators

Despite the importance of pollinators, pollination appears to have been overlooked in the solar debate thus far.[103] Pollinators provide an essential ecosystem service – pollination – to wild plants and crops worldwide. In addition to valuable crops, pollinators sustain plants that are important to natural resource-based tourism. The Mojave National Preserve, Death Valley National Park, and Joshua Tree National Park are popular tourist destination for colorful springtime wildflower blooms (Figure 6.7). Both Joshua Tree National Park and Mojave National Preserve attract visitors from around the world who come to see the distinctive Joshua tree (*Yucca brevifolia*). The loss of pollination services to

natural ecosystems is difficult to predict. One potential impact from the loss or disruption of this service could be severe limitation of flowering plant reproduction, which could have cascading effects throughout an ecosystem.[104]

Figure 6.7 Pollinator in Mojave National Preserve. Image Credit: Sarah Tomsky.

Cumulative Effects from Solar Development

Utility-scale solar development could significantly contribute to habitat loss and fragmentation for pollinators in the California desert. A 2009 study by Brown and Paxton cites habitat loss as the "most universal and high impact factor driving bee declines"; second on their list is habitat fragmentation.[105] Without the services of reliable pollinators, flowering plant populations in habitat fragments may experience reduced seed production and lower genetic diversity.[106] Solar development, at the scale that it has been proposed, would likely result in habitat loss and fragmentation for pollinators. Because most solar technologies require a zero to six percent rise in slope (a few can tolerate seven to 11 percent), much of the habitat loss will occur in lower elevation areas. The creosote bush (*Larrea tridentata*) that dominates these lowland areas attracts over 120 species of bees, one of the richest bee faunas of any plant in North America.[107] Additionally, areas of the California desert along the Colorado River contain a high number of endemic bee species that specialize on the creosote bush.[108] The loss and fragmentation of several thousands of acres of a relatively common plant species could seriously affect a much wider array of pollinator biodiversity.

Habitat loss and fragmentation are not the only threats to pollinators; climate change and the invasion of non-native honeybees (*Apis mellifera*) that compete with native bees for pollen resources also threaten native desert pollinators.[109] Even if pollinators could survive a single threat relatively unscathed, the cumulative effect of these threats compounded by solar development, could result in a decline in pollinator populations and biodiversity, with unknown effects for the rest of the California desert ecosystem.

Climate Change and Pollinators

Pollination mutualisms exist between pollinators and the plants that provide them with food or other services. For example, several moth species have co-evolved a mutualistic relationship with the plant genus *Yucca* (family Agavaceae), including the distinctive Joshua tree (*Yucca brevifolia*) (Figure 6.8).[110] Moths simultaneously pollinate yucca flowers and lay eggs within them and the yucca seeds nourish the moth larvae once they hatch. In the Sonoran

Figure 6.8 Joshua Trees (*Yucca brevifolia*). Image Credit: Sarah Tomsky.

Desert, the senita cactus (*Lophocereus schottii*) and senita moth (*Upiga virescens*) have also evolved a mutualistic relationship.[111,112]

Global climate change could affect pollination mutualisms by disrupting the synchrony between flowering plants and pollinators.[113] Shifts in phenology (i.e. flowering time) induced by climate change could reduce or eventually eliminate the temporal overlap between pollinator activity and plant flowering, potentially causing local extinction of pollinators whose activity periods no longer overlap with any of their food plants.[114] Climate change could also disrupt pollination mutualisms by altering desert plant communities. Climate models show a slow warming of the Mojave and Sonoran Desert regions, and climate change is also likely to alter precipitation regimes.[115,116] Changes in temperature and precipitation patterns could result in a greater production of invasive grasses and/or increased mortality of native plants; elevated fire frequencies and shifts in the distribution of plant communities are also concerns.[117] Pollinator species with narrow habitat requirements and/or specialized diets may decline if certain plant species or communities become locally extinct.[118]

Ecological Implications for Facility Location and Design

The magnitude of impact that the development of a single solar facility or multiple facilities will have on the desert pollinators is dependent on the facility design variables and location as discussed in Table 6.6. These variables will influence the magnitude of the cumulative impact of solar development on the important but not well-understood role of these pollinators.

Table 6.6 Solar Facility Design Variables Affecting Desert Pollinators.

Facility Design Variable	Implications for Desert Pollinators
Location of Facility	Determines the quality of pollinator habitat that is eliminated (some areas are better quality habitat than others).
Size of facility	Larger facility increases probability of eliminating pollinator habitat.
Proximity to other development (solar and other)	Determines magnitude of habitat fragmentation.
Land-Use Efficiency	Determines facility's contribution to off-setting net carbon emissions and reducing the impacts of climate change on pollinators while minimizing impacts to pollinators from habitat loss and fragmentation.

CITATIONS

Chapter 6

[1] Jayne Belnap, "Biological Soil Crusts and Wind Erosion," in *Biological Soil Crusts: Structure, Function, and Management*, eds. J. Belnap and O.L. Lange, *Ecological Studies*, Vol. 150 (Berlin Heidelberg: Springer-Verlag, 2001).
[2] Jayne Belnap, "Biological Soil Crusts and Wind Erosion," in *Biological Soil Crusts: Structure, Function, and Management*, eds. J. Belnap and O.L. Lange, *Ecological Studies*, Vol. 150 (Berlin Heidelberg: Springer-Verlag, 2001).
[3] Jayne Belnap, "Biological Soil Crusts and Wind Erosion," in *Biological Soil Crusts: Structure, Function, and Management*, eds. J. Belnap and O.L. Lange, *Ecological Studies*, Vol. 150 (Berlin Heidelberg: Springer-Verlag, 2001).
[4] J.P. Field, J. Belnap, D.D. Breshears, J.C. Neff, G.S. Okin, J.J. Whicker, T.H. Painter, S. Ravi, M.C. Reheis, R.L. Reynolds, "The ecology of dust," *Frontiers in Ecology and the Environment,* The Ecological Society of America, 2009.
[5] California Environmental Protection Agency, *Characterization of Ambient PM10 and PM2.5 in California Technical Report June 2005,* 2005, California Air Resources Board, http://www.arb.ca.gov/pm/pmmeasures/pmch05/pmch05.htm.
[6] R. Lal, "Carbon Sequestration in Dryland Ecosystems," *Environmental Management* 33, no. 4 (2004): 528-544.
[7] Wohlfahrt, G., L.F. Fenstermaker, and J.A. Arnone III. 2008. "Large annual net ecosystem CO2 uptake of a Mojave Desert ecosystem." *Global Change Biology* 14: 1475-1487.
[8] R. Stone, "Have Desert Researchers Discovered a Hidden Loop in the Carbon Cycle?," *Science* 320 (2008): 1409-1410.
[9] R. Stone, "Have Desert Researchers Discovered a Hidden Loop in the Carbon Cycle?," *Science* 320 (2008): 1409-1410.
[10] Energy Information Administration, U.S. Department of Energy, *Updated State-level Greenhouse Gas Emission Factors for Electricity Generation*, 2001, Office of Integrated Analysis and Forecasting.
[11] D. Budikova, M. Hall-Beyer, and G. Hussein, "Albedo." In *Encyclopedia of Earth*, ed. Cutler J. Cleveland. (Washington, DC: Environmental Information Coalition, National Council for Science and the Environment, 2010), http://www.eoearth.org/article/Albedo.
[12] J. Belnap and D. Eldridge. 2003. "Disturbance and recovery of biological soil crusts," in *Biological Soil Crusts: Structure, Function, and Management*, eds. J. Belnap and O.L. Lange, *Ecological Studies*, Vol. 150 (Berlin Heidelberg: Springer-Verlag, 2001), 363-383.
[13] Jayne Belnap, *Research Ecologist, U.S. Geological Survey*, Personal Communication, November 4, 2010.
[14] California Energy Commission, *Large Solar Energy Projects,* California Energy Commission Home Page, http://www.energy.ca.gov/siting/solar/index.html.
[15] U.S. Bureau of Land Management, *Solar Energy Projects - California Desert District, Bureau of Land Management California*, BLM National Home Page, http://www.blm.gov/ca/st/en/fo/cdd/alternative_energy/SolarEnergy.html.
[16] U.S. Bureau of Land Management, *Solar Energy Projects - California Desert District, Bureau of Land Management California*, BLM National Home Page, http://www.blm.gov/ca/st/en/fo/cdd/alternative_energy/SolarEnergy.html.
[17] R. Myhre, *Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century,* (Palo Alto: Electric Power Research Institute, 2002), http://www.epriweb.com/public/000000000001006786.pdf
[18] D.T. Patten, L. Rouse, J.C. Stromberg, "Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: potential response of vegetation to groundwater withdrawal," *Environmental Management* 41 (2008): 398-413.
[19] A.J. Elmore, S.J. Manning, J.F. Mustard, J.M. Craine, "Decline in alkali meadow vegetation cover in California: the effects of groundwater extraction and drought," *Journal of Applied Ecology* 43 (2006): 770-779.
[20] A.J. Elmore, S.J. Manning, J.F. Mustard, J.M. Craine, "Decline in alkali meadow vegetation cover in California: the effects of groundwater extraction and drought," *Journal of Applied Ecology* 43 (2006): 770-779.
[21] D.T. Patten, L. Rouse, J.C. Stromberg, "Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: potential response of vegetation to groundwater withdrawal," *Environmental Management* 41 (2008): 398-413.
[22] D.T. Patten, L. Rouse, J.C. Stromberg, "Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: potential response of vegetation to groundwater withdrawal," *Environmental Management* 41 (2008): 398-413.
[23] J.P. Brunel, "Sources of water used by natural mesquite vegetation in a semi-arid region of northern Mexico," *Hydrological Sciences Journal* 54, no. 2 (2009): 375-381.
[24] D.T. Patten, L. Rouse, J.C. Stromberg, "Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: potential response of vegetation to groundwater withdrawal," *Environmental Management* 41 (2008): 398-413.
[25] J. Laity, "Aeolian destabilization along the Mojave River, Mojave Desert, California: Linkages among fluvial, groundwater, and aoelian systems," *Physical Geography* 24, no. 3 (2003): 196-221.
[26] K.L. Penrod, E.S. Rubin, C. Paulman, *Mojave Desert Habitat Connectivity ~ Phase 1: A Brief Overview of the Mojave Desert's Previously Identified Areas of Ecological Significance*, (Fair Oaks, CA: SC Wildlands, 2009).
[27] K.L. Penrod, E.S. Rubin, C. Paulman, *Mojave Desert Habitat Connectivity ~ Phase 1: A Brief Overview of the Mojave Desert's Previously Identified Areas of Ecological Significance*, (Fair Oaks, CA: SC Wildlands, 2009).
[28] W.D. Shepard, "Desert springs – both rare and endangered," *Aquatic Conservation: Marine and Freshwater Ecosystems* 3 (1993): 351-359.
[29] W.D. Shepard, "Desert springs – both rare and endangered," *Aquatic Conservation: Marine and Freshwater Ecosystems* 3 (1993): 351-359.
[30] W.D. Shepard, "Desert springs – both rare and endangered," *Aquatic Conservation: Marine and Freshwater Ecosystems* 3 (1993): 351-359.
[31] Agency Hydrologist 1, Personal Communication, October 29, 2009.
[32] Agency Hydrologist 1, Personal Communication, October 29, 2009.

[33] NatureServe. *NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1*, (Arlington, VA: NatureServe, 2009), http://www.natureserve.org/explorer.
[34] NatureServe. *NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1*, (Arlington, VA: NatureServe, 2009), http://www.natureserve.org/explorer.
[35] National Park Service Staff Member 1, Personal Communication, November 6, 2009.
[36] National Park Service Staff Member 1, Personal Communication, November 6, 2009.
[37] National Park Service Staff Member 1, Personal Communication, November 6, 2009.
[38] National Park Service Staff Member 1, Personal Communication, November 6, 2009.
[39] National Park Service Staff Member 1, Personal Communication, November 6, 2009.
[40] A.D. Ficke, C.A. Myrick, L.J. Hansen, "Potential impacts of global climate change on freshwater fisheries," *Rev Fish Biol Fisheries* 17 (2007): 581-613.
[41] C.M. Carveth, A.M. Widmer, S.A. Bonar, "Comparison of upper thermal tolerances of native and nonnative fish species in Arizona," *Transactions of the American Fisheries Society* 135 (2006): 1433–1440.
[42] Robert A. Sauder, *The Lost Frontier: Water Diversion in the Growth and Destruction of Owens Valley Agriculture,* (Tucson: The University of Arizona Press, 1994).
[43] D.P. Groeneveld, "Owens Valley, California, Plant Ecology: Effects from Export Groundwater Pumping and Measures to Conserve the Local Environment," in *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* ed. C.A. Hall Jr., V. Doyle-Jones, and B. Widawski, (CA: White Mountain Research Station Symposium, 1992), 128-155.
[44] D. Jaques, "Preliminary Evaluation of Vegetation Changes from 1906 to 1968 to 1981 in the Southern Half of the Owens Valley, California," in *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* ed. C.A. Hall Jr., V. Doyle-Jones, and B. Widawski, (CA: White Mountain Research Station Symposium, 1992), 444-445.
[45] Robert A. Sauder, *The Lost Frontier: Water Diversion in the Growth and Destruction of Owens Valley Agriculture,* (Tucson: The University of Arizona Press, 1994).
[46] D.P. Groeneveld, "Owens Valley, California, Plant Ecology: Effects from Export Groundwater Pumping and Measures to Conserve the Local Environment," in *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* ed. C.A. Hall Jr., V. Doyle-Jones, and B. Widawski, (CA: White Mountain Research Station Symposium, 1992), 128-155.
[47] D.P. Groeneveld, "Owens Valley, California, Plant Ecology: Effects from Export Groundwater Pumping and Measures to Conserve the Local Environment," in *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* ed. C.A. Hall Jr., V. Doyle-Jones, and B. Widawski, (CA: White Mountain Research Station Symposium, 1992), 128-155.
[48] M. DeDecker, "The Death of a Spring," in *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* ed. C.A. Hall Jr., V. Doyle-Jones, and B. Widawski, (CA: White Mountain Research Station Symposium, 1992), 223-226.
[49] U.S. Fish & Wildlife Service, *Desert tortoise (Gopherus agassizii),* 2010, U.S. Fish & Wildlife Service Species Profile, http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=C04L.
[50] U.S. Fish & Wildlife Service, *Desert tortoise (Gopherus agassizii),* 2010, U.S. Fish & Wildlife Service Species Profile, http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=C04L.
[51] D.J. Morafka and G. Hammerson, "*Gopherus agassizzi*," NatureServe Explorer: An online encyclopedia of life [web application]m, 2009, http://www.natureserve.org/explorer.
[52] International Union for Conservation of Nature, "*Gopherus agassizii*," IUCN Red List of Threatened Species, 2009, http://www.iucnredlist.org/apps/redlist/details/9400/0
[53] California Department of Fish and Game, *California Wildlife: Conservation Challenges*, prepared by the UC Davis Wildlife Health Center for the California Department of Fish and Game, 2005.
[54] California Energy Commission, *Application for Certification [project and applicant name withheld],* 2010, http://www.energy.ca.gov/sitingcases.
[55] California Energy Commission, *Application for Certification [project and applicant name withheld],* 2010, http://www.energy.ca.gov/sitingcases.
[56] California Energy Commission, *Application for Certification [project and applicant name withheld],* 2010, http://www.energy.ca.gov/sitingcases.
[57] California Energy Commission, *Application for Certification [project and applicant name withheld],* 2010, http://www.energy.ca.gov/sitingcases.
[58] T.E. Edwards, C.R. Schwalbe, D.E. Swann, and C.S. Goldberg, "Implications of Anthropogenic Landscape Change on Inter-Population Movements of the Desert Tortoise (*Gopherus agassizii*)," *Conservation Genetics* 5, no. 4 (2004): 485-499.
[59] L. Bare, T. Bernhardt, T. Chu, M. Gomez, C. Noddings, and M. Viljoen, "Cumulative Impacts of Large-scale Renewable Energy Development in the West Mojave," (Santa Barbara, CA: Donald Bren School of Environmental Science & Management, University of California, Santa Barbara, 2009), http://fiesta.bren.ucsb.edu/~westmojave/proposal.html.
[60] T.E. Edwards, C.R. Schwalbe, D.E. Swann, and C.S. Goldberg, "Implications of Anthropogenic Landscape Change on Inter-Population Movements of the Desert Tortoise (*Gopherus agassizii*)," *Conservation Genetics* 5, no. 4 (2004): 485-499.
[61] U.S. Fish and Wildlife Service Staff Member 3, Personal Communication, April 6, 2010.
[62] M.C. Grover and L.A. DeFalco, "Desert Tortoise (*Gopherus agassizii*): Status-of-Knowledge Outline With References," U.S. Department of Agriculture Intermountain Research Station, 1995.
[63] W.B. Kristan and W.I. Boarman, "Spatial Pattern of Risk of Common Raven Predation on Desert Tortoises," *Ecology* 84, no. 9 (2003): 2432-2443.
[64] W.I. Boarman, "Managing a subsidized predator population: Reducing common raven predation on desert tortoises," *Environmental Management* 32, no. 2 (2003): 205-217.
[65] W.I. Boarman, "Managing a subsidized predator population: Reducing common raven predation on desert tortoises," *Environmental Management* 32, no. 2 (2003): 205-217.
[66] Jody Fraser, *Desert Tortoise Recovery Biologist, U.S. Fish & Wildlife Service*, Personal Communication, January 22, 2010.
[67] W.B. Kristan and W.I. Boarman, "Spatial Pattern of Risk of Common Raven Predation on Desert Tortoises," *Ecology* 84, no. 9 (2003): 2432-2443.

[68] U.S. Fish and Wildlife Service Staff Member 3, Personal Communication, April 6, 2010.
[69] U.S. Fish & Wildlife Service, *Desert Tortoise (Mojave Population) Recovery Plan*, 1994, U.S. Fish & Wildlife Service, Portland, OR.
[70] U.S. Fish & Wildlife Service, *Desert Tortoise (Mojave Population) Recovery Plan*, 1994, U.S. Fish & Wildlife Service, Portland, OR.
[71] Jody Fraser, *Research Biologist, U.S. Fish & Wildlife Service*, Personal Communication, January 22, 2010.
[72] B.L. Homer, K.H. Berry, M.B. Brown, G. Ellis, and E.R. Jacobson, "Pathology of diseases in wild desert tortoises from California," *Journal of Wildlife Diseases* 34, no. 3 (1998): 508-523.
[73] M.M. Christopher, K.H. Berry, B.T. Henen, and K.A. Nagy, "Clinical disease and laboratory abnormalities in free-ranging desert tortoises in California (1990-1995)," *Journal of Wildlife Diseases* 39, no. 1 (2003): 35-56.
[74] U.S. Fish & Wildlife Service, *Desert Tortoise (Mojave Population) Recovery Plan*, 1994, U.S. Fish & Wildlife Service, Portland, OR.
[75] K.H. Berry, "Incidence of gunshot deaths in desert tortoise populations in California," *Wildlife Society Bulletin* 14, no. 2 (1986): 127-132.
[76] M.L. Brooks, "Spatial and Temporal Distribution of Nonnative Plants in Upland Areas of the Mojave Desert," in *The Mojave Desert: Ecosystem Processes and Sustainability*, ed. R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, (Reno: The University of Nevada Press, 2009), 101-124.
[77] M.L. Brooks and J.R. Matchett, "Spatial and temporal patterns of wildfires in the Mojave Desert, 1980-2004," *Journal of Arid Environments* 67 (2006): 148-164.
[78] T.C. Esque, C.R. Schwalbe, L.A. DeFalco, R.B. Duncan, and T.J. Hughes, "Effects of Desert Wildfires on Desert Tortoise (*Gopherus agassizii*) and Other Small Vertebrates," *The Southwestern Naturalist* 48, no. 1 (2003): 103-111.
[79] T.C. Esque, C.R. Schwalbe, L.A. DeFalco, R.B. Duncan, and T.J. Hughes, "Effects of Desert Wildfires on Desert Tortoise (*Gopherus agassizii*) and Other Small Vertebrates," *The Southwestern Naturalist* 48, no. 1 (2003): 103-111.
[80] M.L. Brooks, "Competition between alien annual grasses and native annual plants in the Mojave Desert," *American Midland Naturalist* 144 (2000): 92-108.
[81] M.C. Grover and L.A. DeFalco, "Desert Tortoise (*Gopherus agassizii*): Status-of-Knowledge Outline With References," U.S. Department of Agriculture Intermountain Research Station, 1995.
[82] U.S. Fish & Wildlife Service, *Desert Tortoise (Mojave Population) Recovery Plan*, 1994, U.S. Fish & Wildlife Service, Portland, OR.
[83] M.C. Grover and L.A. DeFalco, "Desert Tortoise (*Gopherus agassizii*): Status-of-Knowledge Outline With References," U.S. Department of Agriculture Intermountain Research Station, 1995.
[84] M.C. Grover and L.A. DeFalco, "Desert Tortoise (*Gopherus agassizii*): Status-of-Knowledge Outline With References," U.S. Department of Agriculture Intermountain Research Station, 1995.
[85] Mark Massar, *Wildlife Biologist, Bureau of Land Mangement*, Personal Communication, November 5, 2009.
[86] California Department of Fish and Game, *Special Animals*, 2009, California Natural Diversity Database, http://www.dfg.ca.gov/biogeodata/cnddb/plants_and_animals.asp
[87] W.F. Laudenslayer, Jr., K.B. Buckingham, T.A. Rado, "Mammals of the deserts of California," in Latting, J., Rowlands, P. G., eds. *The California Desert: An Introduction to Natural Resources and Man's Impact, Vol. II*. (Riverside, CA: June Latting Books, 1995).
[88] B.M. Pavlik, *The California Deserts: an ecological rediscovery*, (Berkeley and Los Angeles: University of California Press, 2008).
[89] California Department of Fish and Game, *Special Animals*, 2009, California Natural Diversity Database, http://www.dfg.ca.gov/biogeodata/cnddb/plants_and_animals.asp
[90] NatureServe, *NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1*, NatureServe, (Arlington, Virginia: NatureServe, 2009), http://www.natureserve.org/explorer.
[91] IUCN, *IUCN Red List of Threatened Species*, Version 2009.2, 2009, http://www.iucnredlist.org.
[92] NatureServe, *NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1*, NatureServe, (Arlington, Virginia: NatureServe, 2009), http://www.natureserve.org/explorer.
[93] K.L. Penrod, E.S. Rubin, C. Paulman, *Mojave Desert Habitat Connectivity ~ Phase 1: A Brief Overview of the Mojave Desert's Previously Identified Areas of Ecological Significance*, (Fair Oaks, CA: SC Wildlands, 2009).
[94] J.D. Wehausen, "Nelson Bighorn Sheep." Found online: *BLM California Desert District West Mojave Habitat Conservation Plan Species Accounts, Mammals page*, http://www.blm.gov/ca/st/en/fo/cdd/wemo_species_mammals.html
[95] C.W. Epps, P.J. Palsboll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II, D.R. McCullough, "Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep," *Ecology Letters* 8 (2005): 1029-1038.
[96] Clint W. Epps, *Assistant Professor, Oregon State University, Dept. of Fish & Wildlife*, Personal Communication, December 8, 2009.
[97] C.W. Epps, P.J. Palsboll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II, D.R. McCullough, "Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep," *Ecology Letters* 8 (2005): 1029-1038.
[98] Clint W. Epps, *Assistant Professor, Oregon State University, Dept. of Fish & Wildlife*, Personal Communication, December 8, 2009.
[99] L. Bare, T. Bernhardt, T. Chu, M. Gomez, C. Noddings, and M. Viljoen, "Cumulative Impacts of Large-scale Renewable Energy Development in the West Mojave," (Santa Barbara, CA: Donald Bren School of Environmental Science & Management, University of California, Santa Barbara, 2009), http://fiesta.bren.ucsb.edu/~westmojave/proposal.html.
[100] L. Bare, T. Bernhardt, T. Chu, M. Gomez, C. Noddings, and M. Viljoen, "Cumulative Impacts of Large-scale Renewable Energy Development in the West Mojave," (Santa Barbara, CA: Donald Bren School of Environmental Science & Management, University of California, Santa Barbara, 2009), http://fiesta.bren.ucsb.edu/~westmojave/proposal.html.
[101] D.Thompson and K. Longshore, *The impact of human disturbance on desert bighorn sheep (Ovis Canadensis nelsoni) in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California*, 2007, prepared by U. S. Geological Survey, Las Vegas Field Station, 2007.

[102] California Department of Fish and Game, *California Wildlife: Conservation Challenges*, prepared by the UC Davis Wildlife Health Center. (Sacramento, CA: California Department of Fish and Game, 2005).
[103] Robert Fulton, *Manager, California State University Desert Studies Center*, Personal Communication, October 20, 2010.
[104] J.C. Biesmeijer, S.P.M. Roberts, M. Reemer, R. Ohlemueller, M. Edwards, T. Peeters, A.P. Schaffers, S.G. Potts, R. Kleukers, C.D. Thomas, J. Settele, and W.E. Kunin, "Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands," *Science* 313, no. 5785 (2006): 351-354.
[105] M.J.F. Brown and R.J. Paxton, "The conservation of bees: a global perspective," *Apidologie* 40, no. 3 (2009): 410-416.
[106] J.H. Cane, J.H., R.L. Minckley, L.J. Kervin, T.H. Roulston, and N.M. Williams, "Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation," *Ecological Applications* 16, no. 2 (2006): 632-644.
[107] J.H. Cane, J.H., R.L. Minckley, L.J. Kervin, T.H. Roulston, and N.M. Williams, "Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation," *Ecological Applications* 16, no. 2 (2006): 632-644.
[108] R.L. Minckley, J.H. Cane, and L. Kervin, "Origins and ecological consequences of pollen specialization among desert bees," *Proceedings of The Royal Society of London Series B-Biological Sciences* 267, no. 1440 (2000): 265-271.
[109] Robert Fulton, *Manager, California State University Desert Studies Center*, Personal Communication, October 20, 2010.
[110] J.A. Powell, "Interrelationships of Yuccas and Yucca Moths," *Trends in Ecology & Evolution* 7, no. 1 (1992): 10-15.
[111] J.N. Holland and T.H. Fleming, "Mutualistic interactions between Upiga virescens (Pyralidae), a pollinating seed-consumer, and Lophocereus schottii (Cactaceae)," *Ecology* 80, no. 6 (1999): 2074-2084.
[112] J.N. Holland, J.N. and T.H. Fleming, "Geographic and population variation in pollinating seed-consuming interactions between senita cacti (Lophocereus schottii) and senita moths (Upiga virescens)," *Oecologia* 121, no. 3 (1999): 405-410.
[113] M.A. Wall, M. Timmerman-Erskine, and R.S. Boyd, "Conservation impact of climatic variability on pollination of the federally endangered plant, Clematis socialis (Ranunculaceae)," *Southeastern Naturalist* 2, no. 1 (2003): 11-24.
[114] J. Memmott, P.G. Craze, N.M. Waser, and M.V. Price, "Global warming and the disruption of plant-pollinator interactions," *Ecology Letters* 10, no. 8 (2007): 710-717.
[115] K.T. Redmond, "Historic Climate Variability in the Mojave Desert," in *The Mojave Desert: Ecosystem Processes and Sustainability*, ed. R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, (Reno: The University of Nevada Press, 2009), 11-30.
[116] S.D. Smith, T.N. Charlet, L.F. Fenstermaker, and B.A. Newingham, "Effects of Global Change on Mojave Desert Ecosystems," in *The Mojave Desert: Ecosystem Processes and Sustainability*, ed. R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, (Reno: The University of Nevada Press, 2009), 31-56.
[117] S.D. Smith, T.N. Charlet, L.F. Fenstermaker, and B.A. Newingham, "Effects of Global Change on Mojave Desert Ecosystems," in *The Mojave Desert: Ecosystem Processes and Sustainability*, ed. R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, (Reno: The University of Nevada Press, 2009), 31-56.
[118] J.C. Biesmeijer, S.P.M. Roberts, M. Reemer, R. Ohlemueller, M. Edwards, T. Peeters, A.P. Schaffers, S.G. Potts, R. Kleukers, C.D. Thomas, J. Settele, and W.E. Kunin, "Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands," *Science* 313, no. 5785 (2006): 351-354.