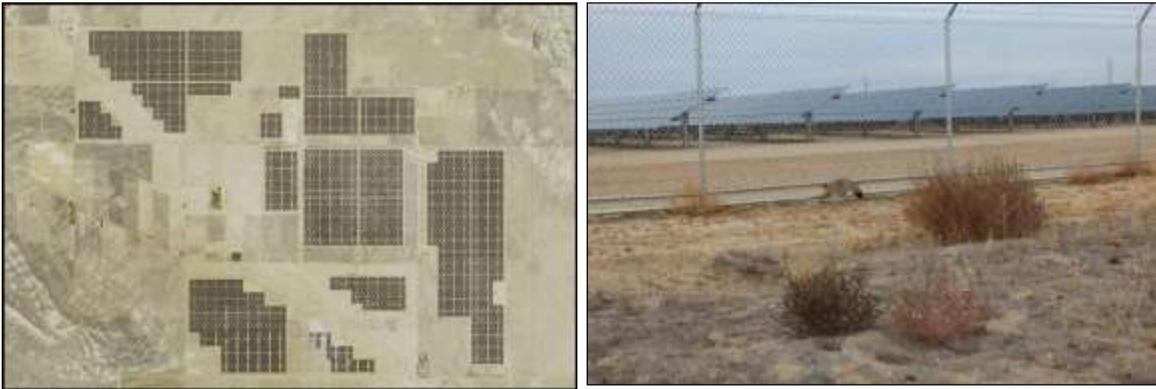


SOLAR ENERGY DEVELOPMENT AND ENDANGERED UPLAND SPECIES OF THE SAN JOAQUIN VALLEY: IDENTIFICATION OF CONFLICT ZONES



PREPARED FOR: THE CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE
AGREEMENT: P1440003 00

Prepared by:
Scott E. Phillips and Brian L. Cypher
*California State University, Stanislaus
Endangered Species Recovery Program
One University Circle
Turlock, CA 95382*

August 8th, 2015

SOLAR ENERGY DEVELOPMENT AND ENDANGERED UPLAND SPECIES OF THE SAN JOAQUIN VALLEY: IDENTIFICATION OF CONFLICT ZONES

Prepared By:
Scott E. Phillips and Brian L. Cypher

California State University, Stanislaus
Endangered Species Recovery Program
One University Circle
Turlock, CA 95382

CONTENTS

Introduction.....	1
Methods	3
Suitability for Solar Development.....	3
Habitat Quality.....	7
Results.....	13
Discussion	16
Recommendations.....	17
References.....	19
Appendix A. Data Model.....	1
Appendix B. Analysis categories applied to NASS 2014 cropland layer and FMMP 2012 land use layer.	1

TABLES

Table 1. Five listed animal species associated with the arid western and southern San Joaquin Valley.....	3
Table 2. Land use classification used to evaluate solar and habitat potential	4
Table 3. Criteria used to evaluate suitability for large-scale solar development.....	5
Table 4. Criteria used to evaluate habitat quality.....	11
Table 5. Cross-tabulation of area for zones of suitability for solar development and habitat quality zones.	13

FIGURES

Figure 1. The San Joaquin Valley region in California.	2
Figure 2. Criteria used to evaluate suitability for large-scale solar development.	5
Figure 3. Estimated solar potential based on land use, protected land status, slope, and insolation.	6
Figure 4. Estimated historical land cover in the San Joaquin Valley.....	8
Figure 5. Estimated historical ranges for Giant kangaroo rats (<i>Dipodomys Ingens</i>), short-nosed kangaroo rats (<i>D. nitratoides brevinasus</i>), Fresno kangaroo rats (<i>D.n. exils</i>), Tipton kangaroo rat (<i>D.n. nitratoides</i>), San Joaquin antelope squirrel (<i>Ammospermophilus nelsoni</i>), blunt-nosed leopard lizard (<i>Gambelia sila</i>), San Joaquin kit fox (<i>Vulpes macrotis mutica</i>) and total of overlapping ranges.	9
Figure 6. Estimated historical habitat value and contemporary land use showing current rangeland or non-rangeland.....	11
Figure 7. Estimated habitat value based on historical species ranges, land use, and slope.	12
Figure 8. Combined suitability for solar development with contemporary habitat conditions.....	14
Figure 9. Closer view of combined suitability for solar development with contemporary habitat conditions in the southwestern San Joaquin Valley.....	15

EXECUTIVE SUMMARY

A number of endemic and rare animal and plant species occur in the San Joaquin Valley (SJV) in central California. Profound habitat loss and degradation is the primary cause of endangerment for these species. Unfortunately, a significant portion of the remaining habitat for these species also has high potential for solar energy generation. Indeed, a number of facilities have already been constructed and many more have been proposed. We conducted a spatially-explicit GIS analysis of lands in the SJV to identify areas of potential conflict between listed species and solar energy development, and also to identify areas where such conflict would be minimized. We modeled solar energy generation potential based on land use, terrain, protected land status, and insolation rates. We also modeled habitat suitability for 5 federally listed animal species whose habitat requirements and distribution ranges encompass those of numerous co-occurring rare species. We then layered the model results to identify areas of greater or lesser conflict. Approximately 4,145 km² (1,601 mi²) have moderate to high potential for solar energy development and constitute moderate to high quality habitat for listed species. These lands comprise the highest potential for conflict. These lands are particularly concentrated in the southwestern portion of the SJV from Kern County up into southwestern Fresno County, private lands in the northern and eastern Carrizo Plain, valley floor lands in northern Kern and southern Tulare counties, and the Panoche Valley region in eastern San Benito County. Approximately 8,436 km² (3,257 mi²) have moderate to high potential for solar energy development but no to moderate value quality habitat for listed species. These lands are the optimal sites for solar energy generation projects. These lands are scattered throughout the southern SJV with particular concentrations in western Fresno County, southern Kings County, southern Kern County a small concentration on the east side of the valley on the Kern-Tulare County boundary. Siting solar projects in areas with high habitat value should be strongly discouraged whereas siting projects in areas with low habitat value should be strongly encouraged, possibly with by offering incentives. Furthermore, siting projects in areas with no or marginal habitat value actually might increase the value of these lands for listed species. In particular, strategic siting of solar facilities in low value habitat adjacent to occupied lands might actually increase the amount and patch size of useable habitat while siting facilities on low value lands between higher quality habitat might create linkages between occupied areas. Our analysis did not consider all possible factors that could influence the selection of a proposed site for solar facility. However, our results should be useful for identifying general areas and even specific locations where siting such facilities would result in minimal or no impacts to listed arid-adapted species and potentially could even provide a benefit by expanding or linking areas with suitable habitat.

ACKNOWLEDGMENTS

This project was funded by the California Department of Fish and Wildlife (CDFW) with funds from the U.S. Fish and Wildlife Service, State Wildlife Grant Program. We thank Krista Tomlinson at CDFW for administrative assistance and project support.

INTRODUCTION

The San Joaquin Valley (SJV) floor in central California extends about 415 km from north to south, and encompasses approximately 3.44 million hectares below the 152-m (500-ft) contour (U.S. Fish and Wildlife Service [USFWS] 1998). The SJV is bounded on the east by the Sierra Nevada, on the west by the Coast Ranges, and on the south by the Transverse Ranges, and therefore is geographically isolated. This isolation has resulted in a high level of endemism and relatively limited distributions for a number of endemic animals and plants (USFWS 1998). By 2004, approximately 70% of the over 3.9 million ha of historical habitat in the SJV had been replaced by irrigated agriculture and urban development (Kelly et al. 2005). Remaining natural lands persist primarily at the edge of the Valley along the Diablo and Sierra Nevada ranges, or as isolated and fragmented patches on the Valley floor (Fig. 1). As a result of this profound habitat loss, 6 animal and 6 plant species are federally or California State listed as Endangered or Threatened, and a number of other species are considered at risk (USFWS 1998, Bunn et al. 2007).

In addition to other development types the SJV also is an attractive region for solar energy development. The region is characterized by high insolation rates, flat topography conducive to the placement of solar panel arrays, relatively inexpensive land values, and close proximity to major power transmission corridors. Consequently, a number of solar energy projects already have been proposed for the SJV region, including the nearby Carrizo Plain and Cuyama Valley areas, which share many physiographic features and species with the SJV. Many of these projects are proposed for sites in natural lands, which often are less expensive, compared to lands that have been developed for agricultural and other uses.

The co-occurrence of remaining natural lands in the SJV and landscape characteristics favorable for solar energy development significantly increases the potential for conflict between solar projects and the conservation and recovery of listed animal and plant species. Consequently, limiting adverse impacts to sensitive species will be challenging but necessary to limit additional growth and development *stressors* as characterized in the California's Wildlife Action Plan for the Central Valley (California Department of Fish and Game 2007, Chapter 14, pages 347-351). A better understanding of species distributions and habitat preferences relative to site suitability for solar energy projects will provide necessary information to avoid or at least appropriately mitigate impacts to species.

We conducted a spatially-explicit analysis using a GIS-based model to assess location-specific potential for conflicts between listed species and solar energy development. Overall goals were to identify alternate sites where impacts and conflicts will be reduced to assist parties involved in siting proposed solar energy projects, but also to identify areas where solar projects should not be located based on occurrences or densities of special status species populations or necessary habitat components or linkages important for these populations to persist.



Figure 1. The San Joaquin Valley region in California.

METHODS

To examine conflicts between listed species and energy development, we developed a GIS-based model (Appendix A) to determine how those areas best-suited for solar development compare with habitat for a set of five federally or state listed animal species (Table 1) associated with the arid western and southern San Joaquin Valley described by Germano et al. (2011) as the *San Joaquin Desert*.

Table 1. Five listed animal species associated with the arid western and southern San Joaquin Valley

Species	Status (Federal/California)
Giant kangaroo rat (<i>Dipodomys ingens</i>)	Endangered/Endangered
San Joaquin kangaroo rats (<i>Dipodomys nitratooides</i>) ¹	
Short-nosed kangaroo rat (<i>D.n. brevinasus</i>)	Species of Concern/Species of Concern
Fresno kangaroo rat (<i>D.n.exilis</i>)	Endangered/Endangered
Tipton kangaroo rat (<i>D.n.nitratooides</i>)	Endangered/Endangered
San Joaquin antelope squirrel (<i>Ammospermophilus nelsoni</i>)	Species of Concern/Threatened
Blunt-nosed leopard lizard (<i>Gambelia sila</i>)	Endangered/Endangered
San Joaquin kit fox (<i>Vulpes macrotis mutica</i>)	Endangered/Threatened

1. Includes three subspecies with different levels of federal/state protection.

SUITABILITY FOR SOLAR DEVELOPMENT

We evaluated suitability for solar development using methods similar to Butterfield et al. (2013) to evaluate site-suitability for large-scale photovoltaic (PV) solar facilities (e.g. stations larger than 20 megawatts [MW]). Our criteria included land use, terrain, protected land status, and insolation rates (Table 3, Figure 2). These criteria are not comprehensive and other factors, particularly access to transmission lines, are limiting factors for solar development but we lacked adequate data to include them. We assumed large-scale solar facilities sites would need to be larger than 80 ha (200 acres) in area based on a high estimate (75th percentile) of acres/MW for PV sites larger than 20MW estimated by the National Renewable Energy Laboratory (NREL 2013), and screened out areas smaller than that minimum size. Because we did not include all possible factors, some areas identified as suitable may be impractical to develop because of other limiting factors.

Land use

We developed a GIS layer of current land use classes based on a combination of the National Agricultural Service 2014 cropland data layer (NASS, USDA NASS 2015) and the California Department of Conservation Farmland Mapping and Monitoring Program 2012 important farmland layer (FMMP, CDOC 2015). We combined land use classes from both layers to create a simplified classification (Table 2, Appendix B) that we used to evaluate both solar site potential and habitat availability.

The two source layers (FMMP, NASS) were created using different methods and for different purposes and so differ in thematic accuracy (correct classification) and thematic resolution (number of mapped land use classes). The FMMP layer is created using direct interpretation from aerial photography and field observations (CDOC 2004), whereas NASS

uses semi-automatic classification of satellite imagery. Semi-automatic classification techniques are less reliable for land uses that have similar vegetation and ground cover such as rangeland and idle farmland (two important categories for our analysis). FMMP includes a more accurate depiction of the extent of rangeland, but lacks the thematic resolution (detailed land use categories) of NASS (e.g. orchards, vineyards, wetlands, and forest). Because it takes less time to produce, NASS is updated on a yearly cycle, and is usually more current than what is available from FMMP at any given time. To utilize information from both sources, we used the following classification rules:

1. Where FMMP = *Other* (agricultural land or unknown), use NASS (more detailed categories), otherwise use FMMP (more accuracy for non-agricultural areas, urban areas and water)
2. To these results, update non-agricultural areas (from FMMP, e.g. *Rangeland*) with more-detailed *Forested* or *Wetland* classes available from NASS, but not included with FMMP.

Table 2. Land use classification used to evaluate solar and habitat potential

Land use class	Primary source	Secondary source
Urban/Industrial/Other developed	FMMP	NASS
Permanent crops	NASS ¹	-
Row crops	NASS ¹	-
Fallow or dryland-farmed	NASS ¹	-
Rangeland	FMMP	NASS
Barren	NASS ¹	-
Forests or wetlands	NASS ¹	-
Water	FMMP	NASS

1. No equivalent category in FMMP

Slope

We calculated slope (in degrees) from digital elevation models available from the U.S. Geological Survey National Elevation Program (USGS 2014). We used a *Focal Statistics* to calculate each cell as the mean value of cells within a 640-m-radius circular area (approximately 320 ac or 128 ha). This screened out small patches of flat slope in otherwise steep terrain or small patches of steep slope in otherwise flat terrain.

Other criteria

In addition to land use and slope, we screened out areas identified as protected fee or easement lands (GreenInfo Network 2015) and estimated insolation using solar resource data available from the National Renewable Energy Laboratory (NREL 2012). Solar resource data were derived from NREL estimates for photovoltaic energy (tilt = latitude collector) available as 10-km grids. Using the center of each grid cell, we interpolated a 120-m-resolution surface using *Inverse Distance Weighting* ($Power = 2$, $Search\ Radius = 12$ neighboring) to provide a continuous surface of estimated insolation.

We combined map layers for the four criteria (Figure 2) using a series of *Map Algebra* statements to create a composite map of potential suitability for solar development (Figure 3).

Table 3. Criteria used to evaluate suitability for large-scale solar development.

Criteria	No to low potential (1)	Moderate potential (2)	Highest potential (3)
Land use	Developed (urban areas, industrial, extractive), permanent crops (orchards or vineyards), open water, forests, or wetlands.	Irrigated farmland excluding permanent crops (e.g. row crops)	Rangeland, fallow/idle farmland, or dryland-farmed areas (e.g. winter wheat)
Slope¹	Greater than 15°	Less than 15°	Less than 15°
Protected lands	Protected lands (public lands, private conservation lands, or conservation easements)	Other private land	Other private land
Insolation	N/A	5.68 - 6 kWh/m ² /Day (or row crops with > 6 kWh/m ² /Day)	6 - 6.42 kWh/m ² /Day

1. Slope averaged over a 320 ac (128 ha) neighborhood

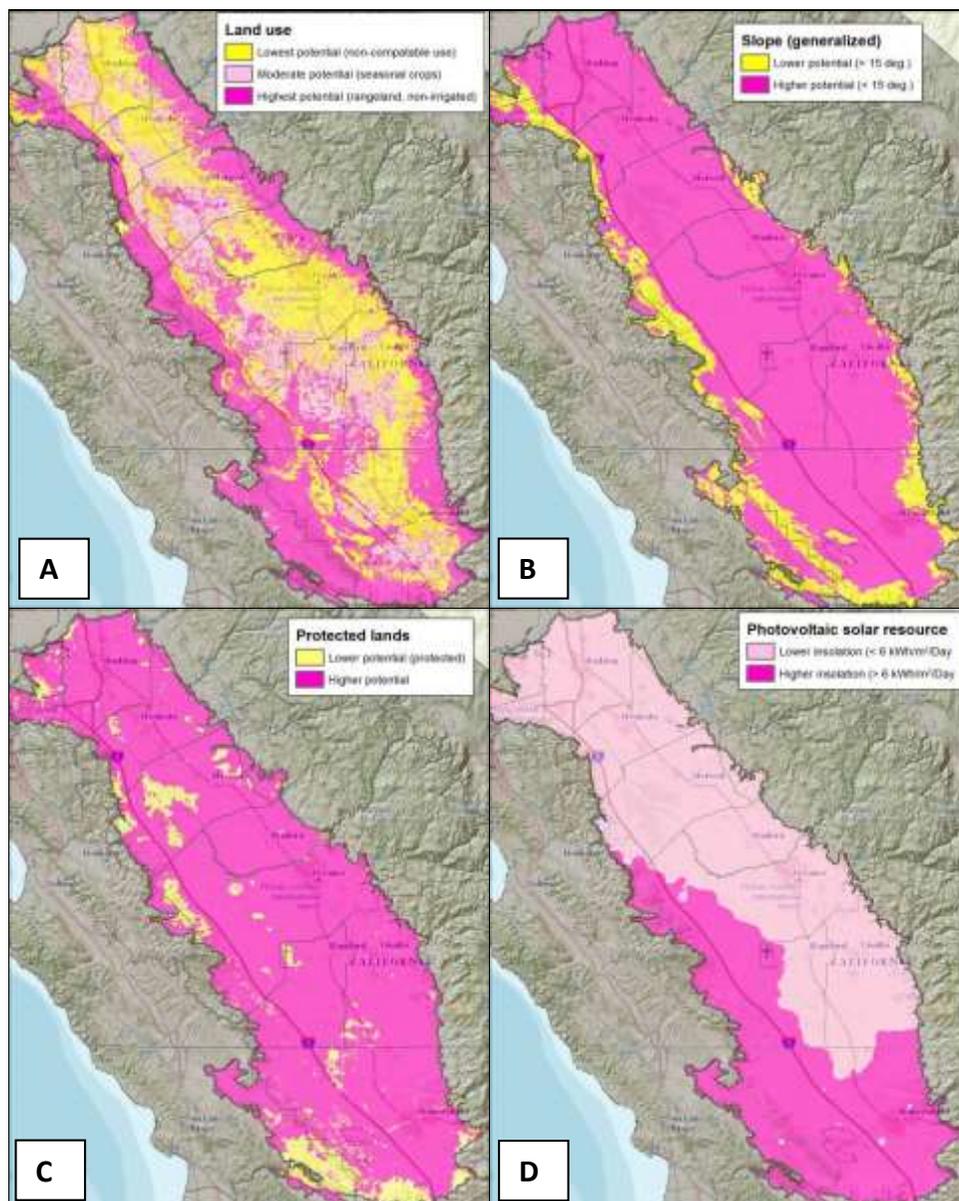


Figure 2. Criteria used to evaluate suitability for large-scale solar development.

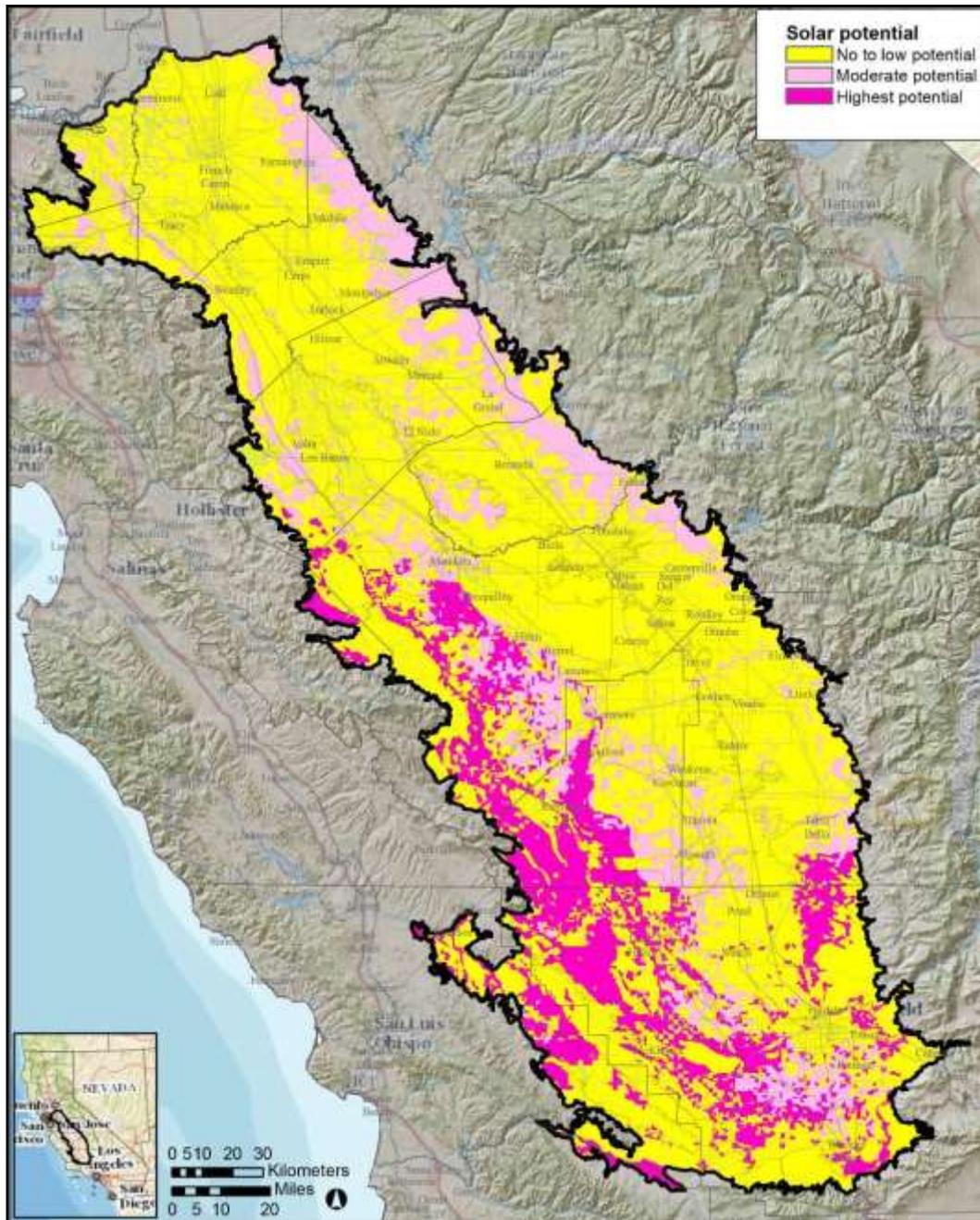


Figure 3. Estimated solar potential based on land use, protected land status, slope, and insolation.

HABITAT QUALITY

We evaluated habitat quality using an approach similar to Germano et al. (2011) who used the distribution of multiple species along with ancillary information to identify a general region (i.e., *San Joaquin Desert*) important to multiple arid-adapted species of the San Joaquin Valley. Our approach was to develop a relatively detailed (c. 1:125,000) GIS layer of historical land cover based on map units digitized from early soil survey maps. We used soil survey descriptions along with ancillary sources to classify map units into general vegetation classes. We used our layer of vegetation classes, along with historical and contemporary species occurrence records, to map historical ranges of target species to specific digitized map units. We used the resulting layer to identify map units that have historically supported higher numbers of co-occurring species (higher-quality habitats) versus those supporting fewer or no species (lower quality).

Estimated historical land cover

To estimate historical land cover (Figure 4), we digitized map units from a set of soil surveys (Nelson et al. 1918, Holmes et al. 1919, Nelson et al. 1921) of the San Joaquin Valley that pre-date most of the conversion of rangelands to irrigated agriculture. To fill some data gaps near the edges of our study area, we also used information from contemporary soil surveys (USDA NRCS 2014, 2015). We assigned vegetation classes to map units primarily using descriptions (and example photographs) of soil series map units. For example, series descriptions may include descriptions of grazing conditions, presence of brush, or information on terrain and drainage. In addition to series descriptions, we used additional map sources (Hall 1890, Piemeisel and Lawson 1937, Kucher 1977, Werschull et al. 1984), historical photographs (MVZ 2015), and climate data (PRISM Group at Oregon State University 2014) to associate vegetation classes to map units.

Estimated historical species ranges

We used a subset of species occurrence records from the Natural Diversity Database (CDFW 2014) and the *Recovery Plan for Upland Species of the San Joaquin Valley of California* (USFWS 1998) along with habitat descriptions from literature sources (Grinnell 1918, 1922, 1932) to assign historical presence of each of our target species to our historical land cover map units (Figure 5). For example, we used historical records of Fresno kangaroo rats to identify map units where they were present, but also included contiguous or nearby map units with similar conditions. For map units with few occurrence records, we reviewed the descriptions and sources of the record to screen out those with high spatial uncertainty (i.e., *non-specific* records) or those where the species identification was questionable (e.g., San Joaquin kit fox records based only on presence of sign but no captures).

Estimated composite historical habitat value

We estimated historical habitat value by adding the number of co-occurring species (Figure 5-H). Using the slope layer (see section *Slope* above), we identified and removed steep and rugged lands (> 30° slope) and grouped the remaining lands into categories of *Low to moderate*; *Moderately high*; and *Highest* habitat value (Figure 6).

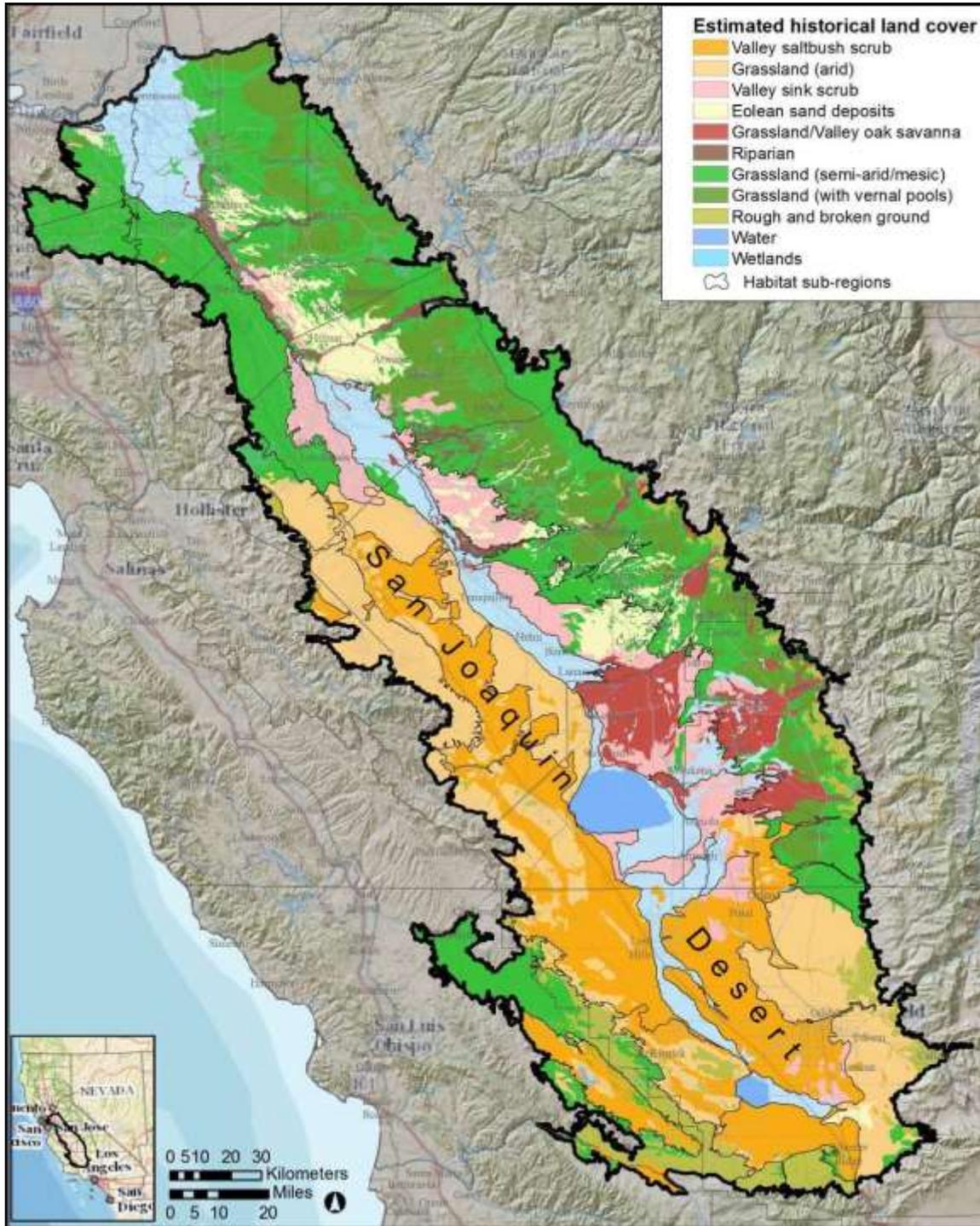


Figure 4. Estimated historical land cover in the San Joaquin Valley.

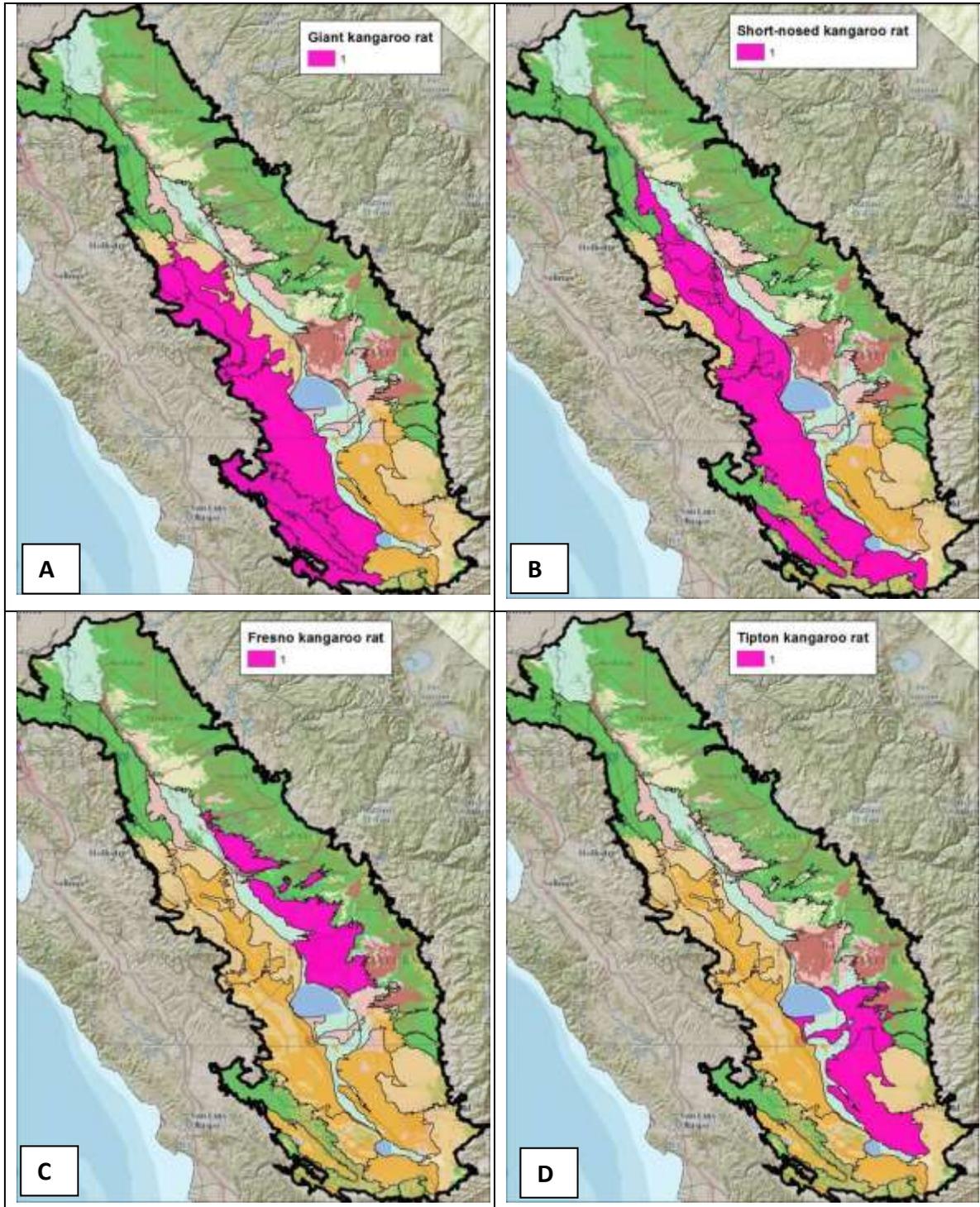


Figure 5. Estimated historical ranges for Giant kangaroo rats (*Dipodomys ingens*), short-nosed kangaroo rats (*D. nitratoides brevinasus*), Fresno kangaroo rats (*D.n. exilis*), Tipton kangaroo rat (*D.n. nitratoides*), San Joaquin antelope squirrel (*Ammospermophilus nelsoni*), blunt-nosed leopard lizard (*Gambelia sila*), San Joaquin kit fox (*Vulpes macrotis mutica*) and total of overlapping ranges.

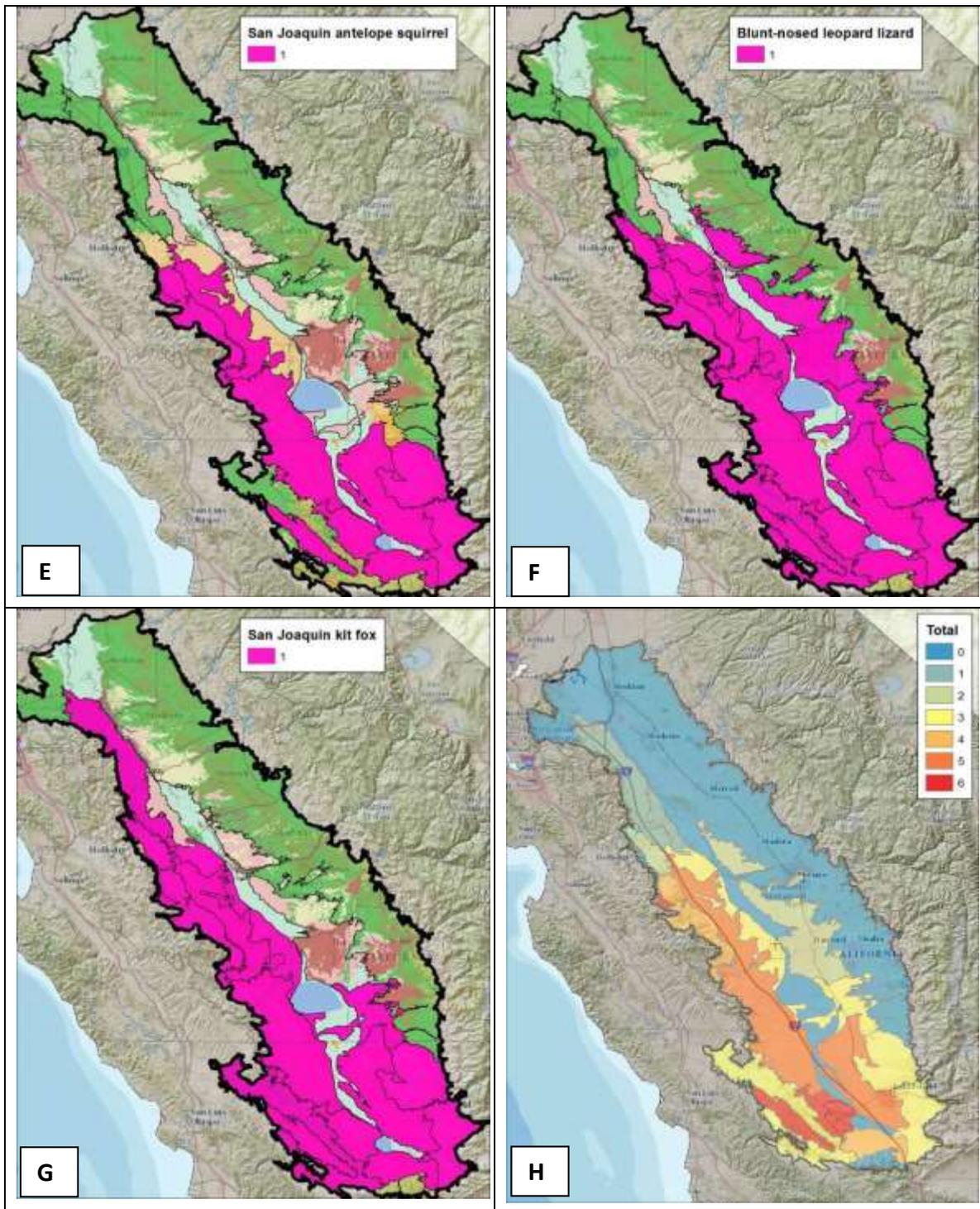


Figure 5 (continued). Estimated historical ranges for Giant kangaroo rats (*Dipodomys ingens*), short-nosed kangaroo rats (*D. nitratoideus brevinasus*), Fresno kangaroo rats (*D.n. exilis*), Tipton kangaroo rat (*D.n. nitratoideus*), San Joaquin antelope squirrel (*Ammospermophilus nelsoni*), blunt-nosed leopard lizard (*Gambelia sila*), San Joaquin kit fox (*Vulpes macrotis mutica*) and total of overlapping ranges (H).

Contemporary habitat conditions

We combined the estimated composite historical habitat layer (Figure 6-A) with a layer of contemporary land use (Figure 6-B, methods described in section *Land use* above).

Contemporary rangelands (e.g., grasslands, saltbush scrub) were assigned their estimated historical value and non-rangelands (e.g., irrigated farmland, developed areas) were assigned a value of No to low habitat value (Table 4, Figure 7).

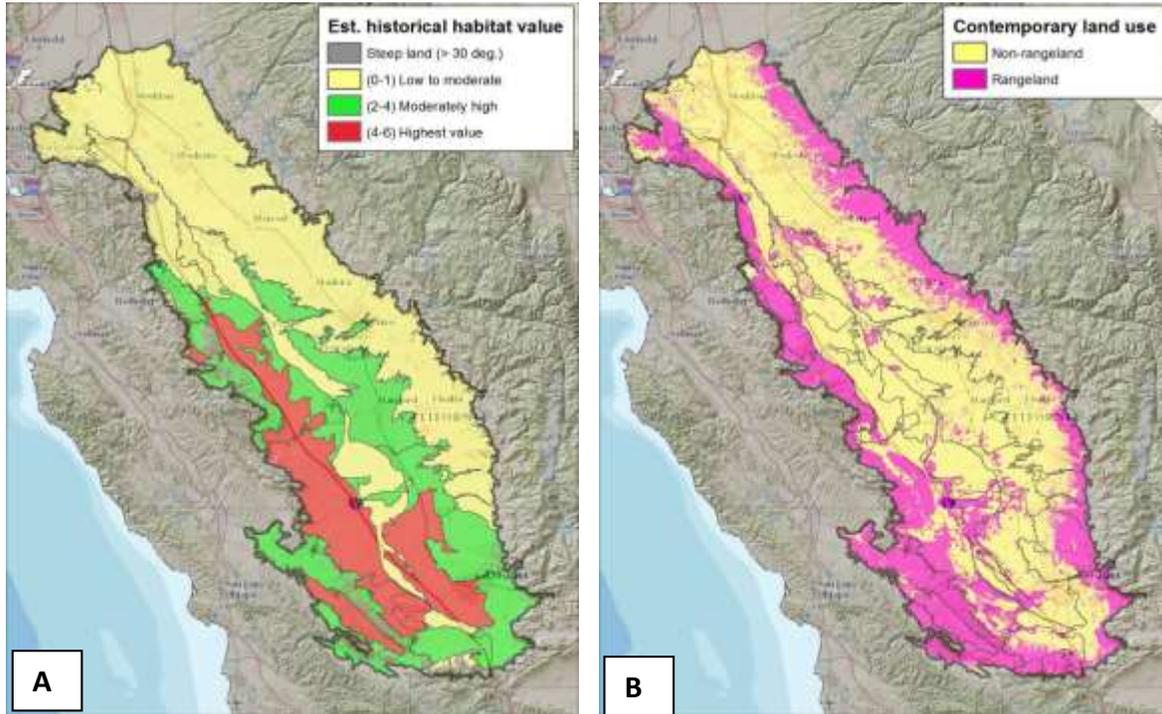


Figure 6. Estimated historical habitat value (A) and contemporary land use showing current rangeland or non-rangeland (B).

Table 4. Criteria used to evaluate habitat quality.

Criteria	No to low habitat value (0)	Low to moderate habitat value (1)	Moderately high habitat value (2)	Highest habitat value (3)
Estimated historical species ranges	-	0 – 1 overlapping ranges	2 – 4 overlapping ranges	Greater than 4 overlapping ranges
Land use	Not rangeland	Rangeland	Rangeland	Rangeland
Slope ¹	Greater than 30°	Less than 30°	Less than 35°	Less than 30°

1. Slope averaged over a 320 ac (128 ha) neighborhood

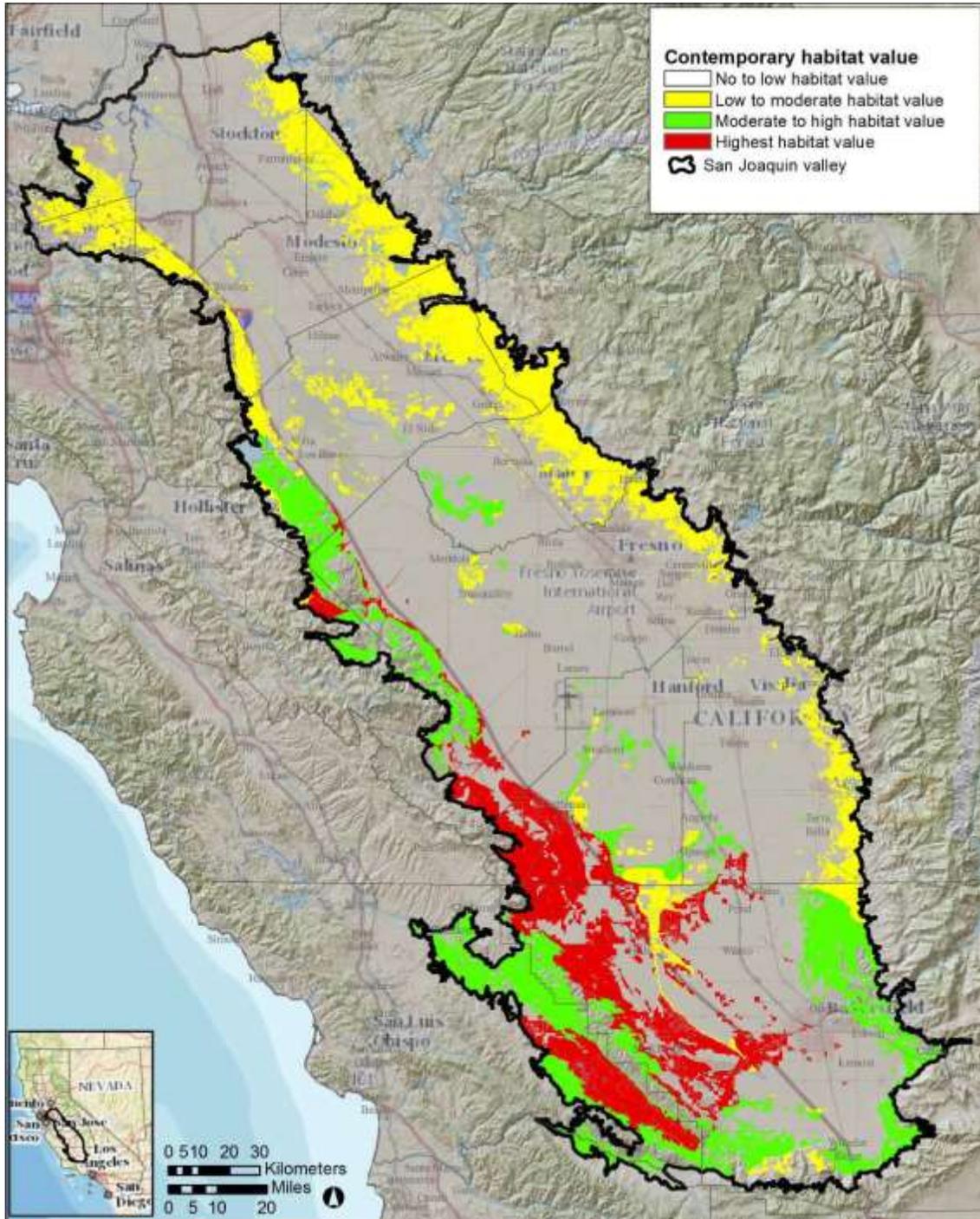


Figure 7. Estimated habitat value based on historical species ranges, land use, and slope.

RESULTS

Nearly 40% of areas with the highest potential for solar development are in what we would label *conflict zones*, or areas with the highest habitat value. If we include areas of both *highest*, or *moderate to high* habitat value, it's nearly two thirds (64%) of high-solar potential areas (Table 5, Figure 8, Figure 9). Nearly a third (31%) of areas with the highest potential for solar development is in areas of less conflict (e.g., marginal or idle farmland). Likewise, two thirds (67%) of the areas of highest habitat value are in the areas with the highest potential for solar development (Table 5, Figure 8, Figure 9).

Table 5. Cross-tabulation of area for zones of suitability for solar development and habitat quality zones.

Habitat Value	Solar Potential			Total
	Low	Moderate	High	
No to low value	9,584 mi ² (24,821 km ²)	1,159 mi ² (3,002 km ²)	691 mi ² (1,789 km ²)	11,433 mi ² (29,612 km ²)
Low to moderate value	746 mi ² (1,931 km ²)	1,288 mi ² (3,337 km ²)	119 mi ² (308 km ²)	2,153 mi ² (5,576 km ²)
Moderate to high value	907 mi ² (2,349 km ²)	170 mi ² (440 km ²)	531 mi ² (1,375 km ²)	1,608 mi ² (4,164 km ²)
Highest value	396 mi ² (1,025 km ²)	33 mi ² (85 km ²)	867 mi ² (2,245 km ²)	1,295 mi ² (3,355 km ²)
Total	11,632 mi ² (30,126 km ²)	2,650 mi ² (6,864 km ²)	2,207 mi ² (5,717 km ²)	16,489 mi ² (42,707 km ²)

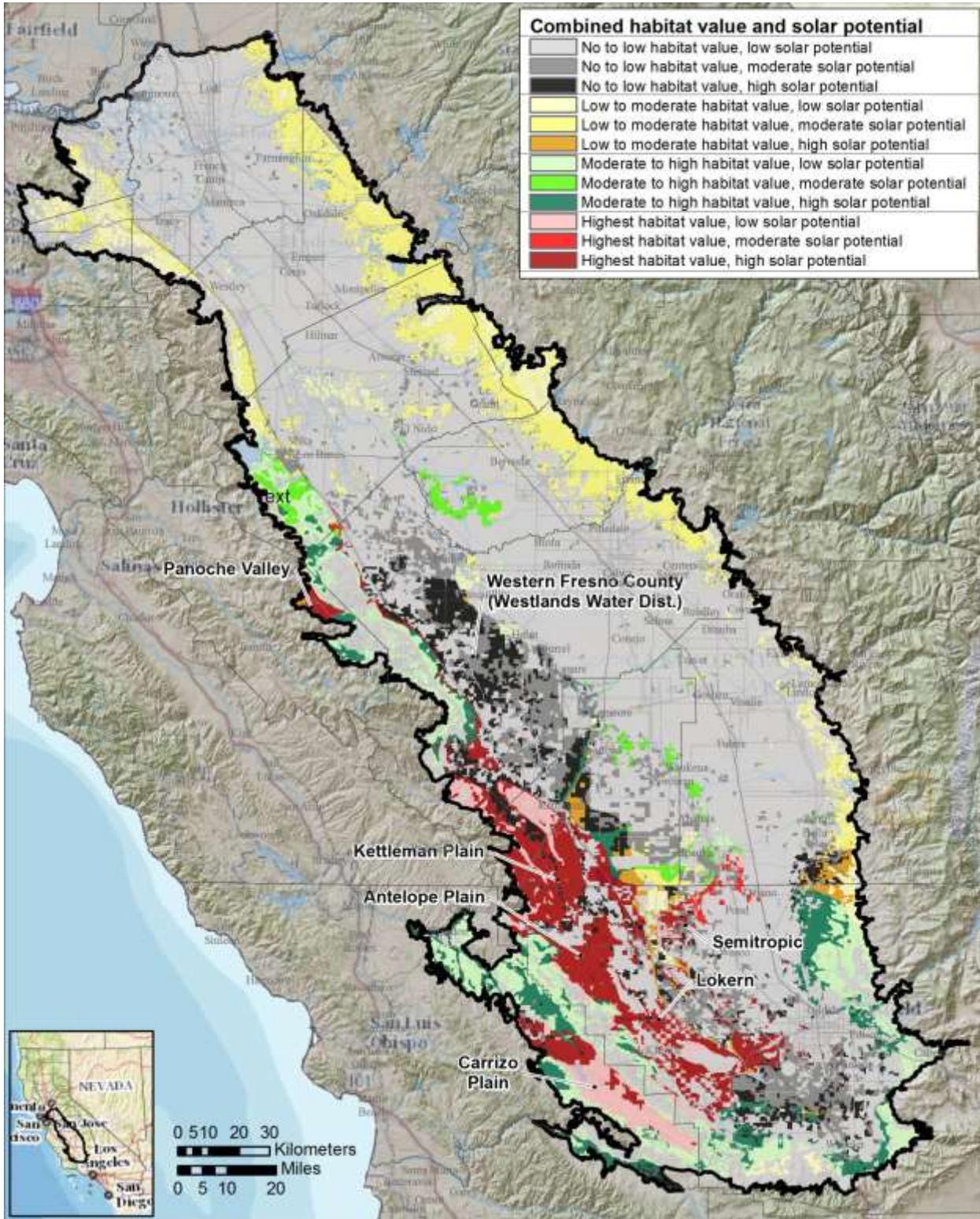


Figure 8. Combined suitability for solar development with contemporary habitat conditions.

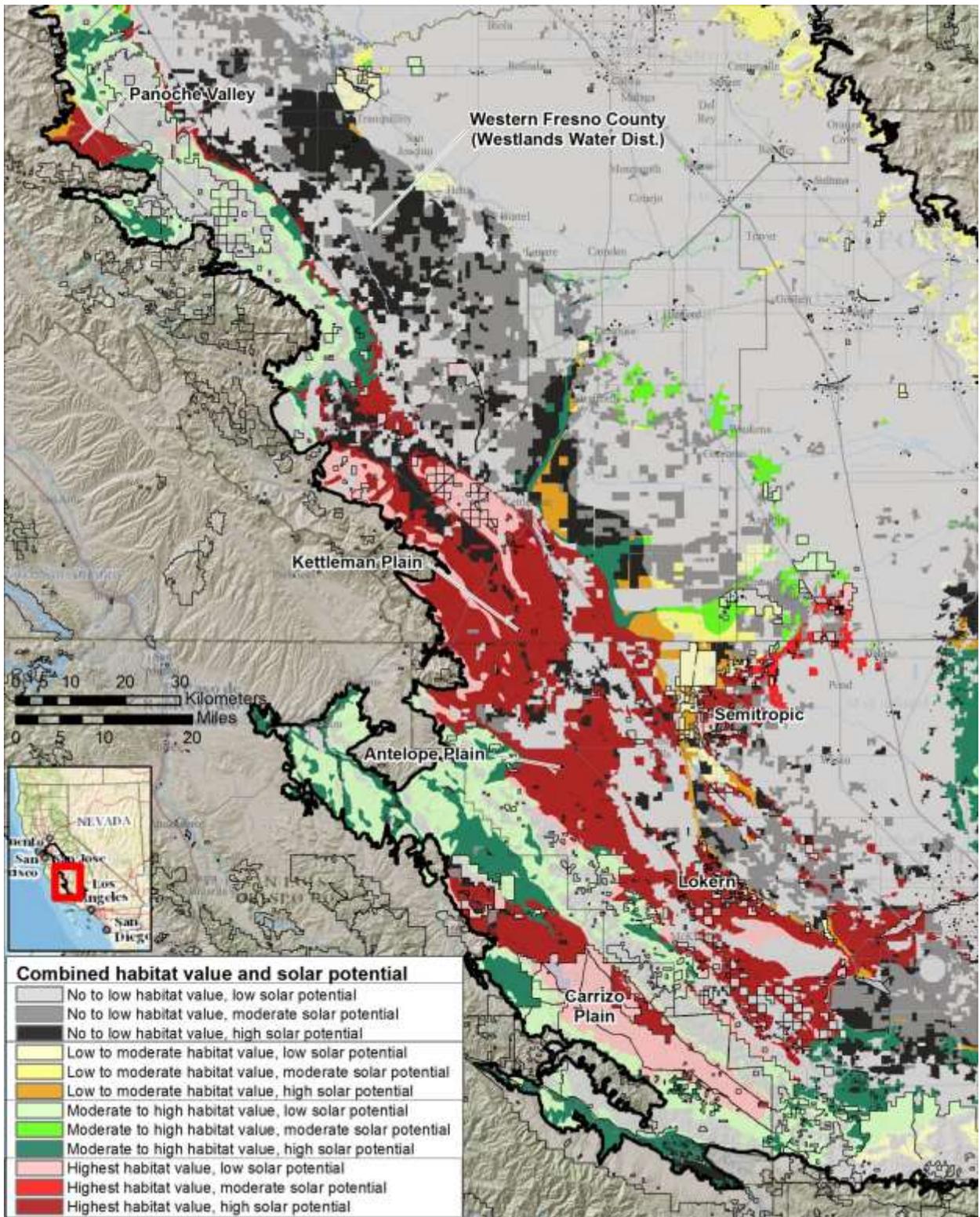


Figure 9. Closer view of combined suitability for solar development with contemporary habitat conditions in the southwestern San Joaquin Valley.

DISCUSSION

Our analysis indicated that there is considerable overlap between site qualities needed for solar energy generation and those areas of remaining habitat for arid-adapted species of the San Joaquin Valley. This overlap results in the potential for real conflict, specifically in areas with a combination of higher potential for solar development and higher habitat quality. Most historical habitat for these species has been converted to other land uses (e.g., agriculture) and habitat loss continues to be the greatest threat to listed arid-adapted species (USFWS 1998). Additional conversion of habitat for any reason, including solar energy development, could further imperil these species. Furthermore, although our analysis was based on select species, a number of other rare species share similar habitat requirements with the featured species (USFWS 1998), and therefore the results of our analyses are applicable to a large suite of arid-adapted species.

Based on our analyses, approximately 4,145 km² (1,601 mi²) have moderate to high potential for solar energy development and constitute moderate to high quality habitat for listed species. These lands comprise the highest potential for conflict. Securing permits to develop these lands, particularly from agencies such as FWS and CDFW that are charged with protecting listed species, is difficult and also costly due to the complex impact analyses and high mitigation requirements typically required. Furthermore, environmental groups commonly have filed lawsuits against project proponents proposing solar energy projects in good quality habitat. This further increases the cost of constructing solar facilities.

Potential conflict areas with moderate to high habitat value and moderate to high potential for solar energy development are particularly concentrated in the southwestern portion of the SJV from Kern County up into southwestern Fresno County (Figure 8). Other areas included private lands in the northern and eastern Carrizo Plain, valley floor lands in northern Kern and southern Tulare counties, and the Panoche Valley region in eastern San Benito County. These areas all are recognized as being important for the conservation and recovery of the listed species considered in this report and other rare species as well (USFWS 1998).

Conversely, approximately 8,436 km² (3,257 mi²) have moderate to high potential for solar energy development but no to moderate value quality habitat for listed species. These lands are the optimal sites for solar energy generation projects. Conflicts with listed species would be minimal or non-existent on these lands. Permit acquisition would be easier and mitigation requirements would be lower. With the ample availability of lands that have high potential for solar development but low habitat value for listed species, there appears to be little justification for siting new solar projects in areas with high quality habitat.

Lands with low habitat value but high potential for solar energy development are scattered throughout the southern SJV with particular concentrations in western Fresno County, southern Kings County, and southern Kern County (Figure 8). This is consistent with the results of an analysis conducted by Butterfield et al. (2013). There also is a small concentration of such lands on the east side of the valley on the Kern-Tulare County boundary. As highlighted in the Butterfield et al (2013) report, many of the lands in western Fresno County are in the Westlands Water District where considerable agricultural lands have been “retired” or otherwise taken out of production due to salt concentrations and drainage issues (Cypher et al. 2007).

Furthermore, siting projects in areas with no or marginal habitat value actually might increase the value of these lands for listed species. Preliminary data from recently

constructed solar generating facilities indicate continued, and in some cases increased, use by listed species. The Topaz Solar Farm in northeastern San Luis Obispo County was largely constructed on active and fallowed dry-land farmed fields. San Joaquin kit foxes were present on the site prior to construction and continue to occupy the site now that construction has been completed and the facility is fully operational (D. Meade, Althouse & Meade, personal communication). The results of surveys involving genetic analyses of fecal samples indicate that kit fox numbers may even have increased on the site (Maldonado and Wilbert. 2015). Similarly, kit foxes continue to use another nearby solar facility, the California Valley Solar Ranch (R. Powers, HT Harvey & Associates, personal communication). This facility was constructed on lands that were previously farmed or intensively grazed. Both sites appear to be used by kit foxes to fulfill all life-history requirements (e.g., foraging, denning, resting). Reproduction by kit foxes also has been documented on both sites (ESRP, unpublished data). Furthermore, giant kangaroo rats were present in low numbers on the California Valley Solar Ranch lands prior to construction and continue to be present and have even increased in some areas now that construction has been completed (Cypher, personal observation). Conservation measures that have facilitated use of these solar facilities by listed species include permeable fencing, movement corridors, vegetation management, enhancements such as artificial dens, and prohibition of rodenticide use.

The examples above indicate that if designed and managed appropriately, solar generating facilities can provide habitat value for listed species. Given the overlap in habitat requirements (USFWS 1998) among the listed species used in our analyses, we predict that San Joaquin kangaroo rats, San Joaquin antelope squirrels, and blunt-nosed leopard lizards also potentially would use solar facilities, similar to that observed for San Joaquin kit foxes and giant kangaroo rats. Thus, solar facilities constructed in low value habitat adjacent to lands occupied by any of these species might actually increase the amount and patch size of useable habitat. Such construction of solar facilities could be particularly valuable if sited in such a manner as to create a corridor across marginal habitat to link areas of higher quality habitat. With the extensive fragmentation of habitat that currently exists in the SJV ecoregion (e.g., USFWS 1998, Kelly et al. 2005, Cypher et al. 2013), the potential for improving conditions for listed species by connecting habitat patches is immense. Cypher et al. (2007) specifically called for establishing corridors and improving connectivity in the region in western Fresno County that includes the Westlands Water District. As described previously, species habitat values are generally low and solar energy development potential is relatively high in this region, and solar projects potentially could contribute to conservation strategies.

To reiterate a previous caution, our analysis did not consider all possible factors that could influence the selection of a proposed site for solar facility. However, our results should be useful for identifying general areas and even specific locations where siting such facilities would result in minimal or no impacts to listed arid-adapted species. Furthermore, the careful selection of sites potentially could even result in a benefit to these species by expanding or linking areas with suitable habitat.

RECOMMENDATIONS

Based on the results of this project, the following recommendations are offered.

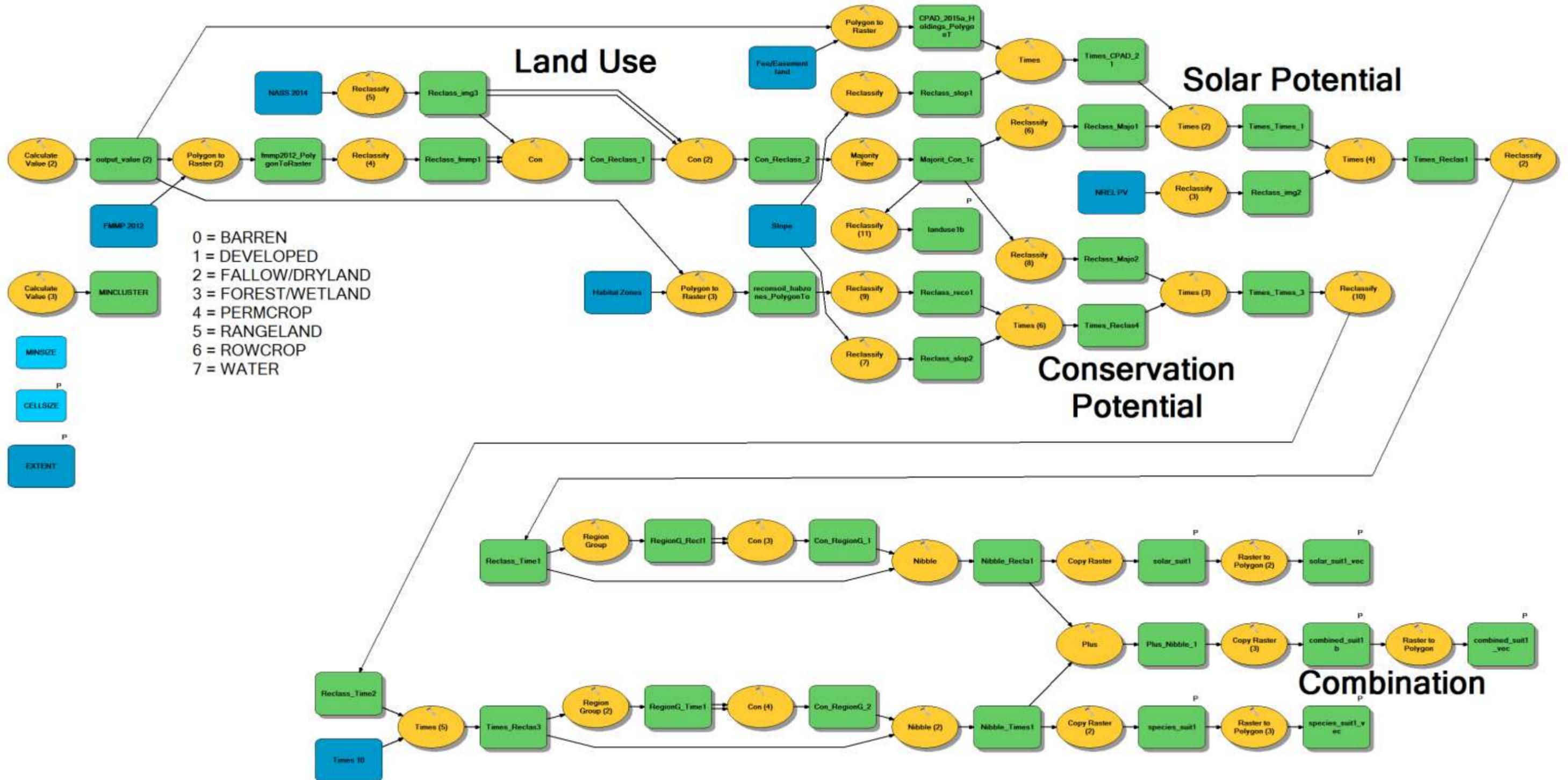
1. Avoid siting of solar facilities in areas with moderate to high habitat value for listed species. While this may seem an obvious recommendation, there a fair amount of overlap between those areas of highest habitat value and high value for solar development (Figure 8).
2. Encourage siting of solar facilities in areas with no or low habitat value for listed species.
3. In particular, encourage siting of solar facilities in marginal habitat adjacent to better quality habitat or in areas where the facilities might actually create a linkage between patches of good quality habitat. Such siting could be encouraged through incentives such as expedited permitting.
4. All solar facilities constructed in or adjacent to habitat for listed species should be designed and managed in a manner to accommodate use by the species. Beneficial measures include permeable fencing, vegetation management to maintain a low structure, movement corridors, enhancements such as artificial burrows, prohibition of rodenticide use, and take avoidance measures to reduce direct impacts to species from facility maintenance and operations activities.

REFERENCES

- Bunn, D., A. Mummert, M. Hoshovsky, K. Gilardi, and S. Shanks. 2007. California Wildlife: Conservation Challenges (California's Wildlife Action Plan). A report prepared by the University of California, Davis, Wildlife Health Center for the California Department of Fish and Game. Pg. 597
- Butterfield, H.S., D. Cameron, E. Brand, M. Webb, E. Forsburg, M. Kramer, E. O'Donoghue, and L. Crane. 2013. Western San Joaquin Valley least conflict solar assessment. Unpublished report. The Nature Conservancy, San Francisco, CA. 26 pages
- California Dept. of Conservation, Division of Land Resource Protection (CDOC). 2004. A Guide to the Farmland Mapping and Monitoring Program. 2004 Edition.
- California Dept. of Conservation, Division of Land Resource Protection, Farmland Mapping and Monitoring (CDOC). 2015. Important Farmland (multiple counties). Geospatial data. URL: <http://conservation.ca.gov/dlrp/FMMP/>
- California Dept. of Fish and Game (CDFG). 2007. California Wildlife: Conservation Challenges (California's Wildlife Action Plan). California Department of Fish and Game, Sacramento. Pp. 359-364; 336-337 Table 14.1
- California Dept. of Fish and Wildlife (CDFW). 2014. California Natural Diversity Database. Geospatial data. URL: <http://www.dfg.ca.gov/biogeodata/cnddb/>
- Constable, J.L. B.L. Cypher, S.E. Phillips, and P.A. Kelly. 2009. Conservation of San Joaquin Kit Foxes in Western Merced County, California. Unpublished report to the U.S. Bureau of Reclamation.
- Cypher, B.L. 2015. Habitat Conservation in the Panoche Valley Region: Contributions to the Conservation and Recovery of Listed Species. CSU Stanislaus Endangered Species Recovery Program. URL: http://esrp.csustan.edu/publications/pdf/Cypher_2015_PanocheValleyConservation.pdf
- Cypher, B.L., S.E. Phillips, and P.A. Kelly. 2007. Habitat Suitability and Potential Corridors for San Joaquin Kit Fox in the San Luis Unit, Fresno, Kings, and Merced Counties, California. Unpublished report to the U.S. Bureau of Reclamation.
- Cypher, B. L., S. E. Phillips, and P. A. Kelly. 2013. Quantity and distribution of suitable habitat for endangered San Joaquin kit foxes: conservation implications. *Canid Biology and Conservation* 16:25-31.
- Germano, D.J., G.B. Rathburn, L.R. Saslaw, B.L. Cypher, E.A. Cypher, and Vredenburg, L.M. 2011. The San Joaquin Desert of California: Ecologically Misunderstood and Overlooked. *Natural Areas Journal* 31:138-147.
- GreenInfo Network. 2015. California Protected Areas Database (CPAD) and the California Conservation Easement Database (CCED). Geospatial data. URL: <http://calands.org/>
- Grinnell, J. 1918. *Natural History of the Ground Squirrels of California*. University of California Press.
- Grinnell, J. 1922. *A Geographical Study of the Kangaroo Rats of California*. University of California Press.
- Grinnell, J. 1932. Habitat Relations of the Giant Kangaroo Rat. *Journal of Mammalogy* 13:305-320.
- Hall, W. H. 1890. Topographic and Irrigation Maps of San Joaquin Valley, Sheets 1-4. 1:126,720. Obtained from the Water Resources Archives, University of California, Berkeley.
- Holmes, L.C., E.C. Eckmann, J.W. Nelson, and J.E. Guernsey. 1919. Reconnaissance soil survey of the middle San Joaquin Valley, California. United States Agriculture Department. Soils Bureau; University of California Agricultural Experiment Station. 115 p.

- Kelly, P.A., S.E. Phillips, and D.F. Williams. 2005. Documenting Ecological Change in Time and Space: The San Joaquin Valley of California. Pp. 57-78 in Lacey, E. A. and P. Myers, eds. Mammalian Diversification: From Chromosomes to Phylogeography. Publications in Zoology Series. University of California Press, Berkeley, CA. 383 pp.
- Kuchler, A.W. 1977. The map of the natural vegetation of California. Pp. 909-938 + supplement, *in* Terrestrial vegetation of California (M.G. Barbour and J. Major, eds.). John Wiley & Sons, NY, 1002 pp.
- Maldonado, J.E., and T.R. Wilbert. 2015. Non-invasive monitoring of the endangered San Joaquin kit fox (*Vulpes macrotis mutica*) on the Topaz Solar Farm: 2013 surveys. Final report, Smithsonian Conservation Biology Institute, Washington, D.C.
- Museum of Vertebrate Zoology at Berkeley (MVZ). 2015. MVZ Field Note, Photograph, and Annotated Map Collections. Online resource (digital photographs). URL: http://mvz.berkeley.edu/FieldnotePhotoMap_Collection.html
- National Renewal Energy Laboratory (NREL). 2012. Lower 48 and Hawaii PV 10km Resolution 1998 to 2009 (us9809_latilt_updated). Geospatial data. URL: http://www.nrel.gov/gis/data_solar.html
- National Renewal Energy Laboratory (NREL). 2013. Land-Use Requirements for Solar Power Plants in the United States. Technical Report NREL/TP-6A20-56290, June 2013.
- Nelson, J.W., J.E. Guernsey, L.C. Holmes, and E.C. Eckmann. 1918. Reconnaissance soil survey of the Lower San Joaquin Valley, California. United States Agriculture Department. Soils Bureau; University of California Agricultural Experiment Station. 157 p.
- Nelson, J.W., W.C. Dean, and E.C. Eckmann. 1921. Reconnaissance soil survey of the Upper San Joaquin Valley, California. United States Agriculture Department. Soils Bureau; University of California Agricultural Experiment Station. 116 p.
- Piemeisel, R.L., and F.R. Lawson. 1937. Types of Vegetation in the San Joaquin Valley of California and Their Relation to Beet Leafhopper. U.S. Department of Agriculture Technical Bulletin No. 557, Washington, D.C. 28 pp.
- PRISM Group at Oregon State University. 2014. United States 30-Year Normals, 1981 – 2010. The PRISM Group at Oregon State University, Corvallis, OR. Geospatial data. URL: <http://prism.oregonstate.edu/normals/>
- U.S. Dept. of Agriculture, National Agricultural Statistics Service (USDA NASS), Research and Development Division, Geospatial Information Branch, Spatial Analysis Research Section. 2015. USDA, National Agricultural Statistics Service, 2014 California Cropland Data Layer. Geospatial Data. URL: <http://www.nass.usda.gov/research/Cropland/Release/>
- U.S. Dept. of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2014. General Soil Map (STATSGO2). Geospatial Data. URL: <https://gdg.sc.egov.usda.gov/>
- U.S. Dept. of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2015. Gridded Soil Survey Geographic (gSSURGO). Geospatial Data. URL: <https://gdg.sc.egov.usda.gov/>
- U.S. Fish and Wildlife Service. 1998. Recovery plan for upland species of the San Joaquin Valley, California. United States Fish and Wildlife Service, Portland, OR.
- U.S. Geological Survey. 2014. National Elevation Dataset (1/3 arc-second). Geospatial data. URL: <http://ned.usgs.gov/>
- Werschkull, G.D., F.T. Griggs, and J.M. Zaninovich. 1984. Tulare Basin protection plan. The California Nature Conservancy, San Francisco, 103 pp.

APPENDIX A. DATA MODEL



APPENDIX B. ANALYSIS CATEGORIES APPLIED TO NASS 2014 CROPLAND LAYER AND FMMP 2012
LAND USE LAYER.

NASS Cropland 2014

Categories for analysis	NASS cropland class	Acres	Hectares
Urban/Industrial/Other developed	Urban/Industrial/Other developed/Open Space	451,731	182,809
	Urban/Industrial/Other developed/Low Intensity	215,041	87,024
	Urban/Industrial/Other developed/Med Intensity	286,291	115,858
	Urban/Industrial/Other developed/High Intensity	64,308	26,024
Total		1,017,371	411,715
Permanent crops	Cherries	26,961	10,911
	Peaches	3,456	1,398
	Apples	3,031	1,227
	Grapes	747,060	302,324
	Other Tree Crops	4,469	1,808
	Citrus	11,065	4,478
	Pecans	1,902	770
	Almonds	942,269	381,323
	Walnuts	190,680	77,165
	Pears	415	168
	Pistachios	209,343	84,718
	Olives	17,799	7,203
	Oranges	200,196	81,016
	Pomegranates	14,151	5,727
	Nectarines	5,011	2,028
	Plums	11,198	4,532
Apricots	1,366	553	
Total		2,390,371	967,349
Row crops	Corn	138,502	56,050
	Cotton	234,884	95,054
	Rice	6,290	2,546
	Sorghum	5,736	2,321
	Sunflower	180	73
	Sweet Corn	393	159
	Barley	53,757	21,755
	Durum Wheat	13,236	5,356
	Spring Wheat	3,843	1,555
	Rye	183	74
	Oats	85,699	34,681
	Canola	2	1
	Safflower	35,025	14,174
	Alfalfa	621,191	251,387
	Other Hay/Non Alfalfa	67,083	27,147
	Sugarbeets	255	103
	Dry Beans	13,845	5,603
	Potatoes	15,654	6,335
	Other Crops	2,685	1,086
	Sweet Potatoes	1,137	460
	Misc Veggies & Fruits	469	190
Watermelons	4,127	1,670	
Onions	21,204	8,581	
Peas	4,001	1,619	

	Tomatoes	246,465	99,741
	Caneberries	0	0
	Herbs	935	378
	Clover/Wildflowers	7,108	2,877
	Sod/Grass Seed	2,971	1,202
	Triticale	19,987	8,088
	Carrots	10,036	4,061
	Asparagus	2,610	1,056
	Garlic	15,279	6,183
	Cantaloupes	3,830	1,550
	Honeydew Melons	1,693	685
	Broccoli	456	185
	Peppers	807	326
	Greens	259	105
	Strawberries	10	4
	Squash	45	18
	Vetch	50	20
	Dbl Crop WinWht/Corn	208,528	84,388
	Dbl Crop Oats/Corn	65,699	26,588
	Lettuce	5,164	2,090
	Pumpkins	1,524	617
	Dbl Crop Durum Wht/Sorghum	30	12
	Dbl Crop Barley/Sorghum	1,927	780
	Dbl Crop WinWht/Sorghum	34,323	13,890
	Dbl Crop Barley/Corn	785	318
	Dbl Crop WinWht/Cotton	288	116
	Blueberries	1,579	639
Total		1,961,772	793,901
Fallow or dryland-farmed	Winter Wheat	265,792	107,562
	Fallow/Idle Cropland	912,582	369,309
Fallow or dryland-farmed Total		1,178,374	476,871
Rangeland	Shrubland	232,330	94,021
	Grass/Pasture	3,363,936	1,361,336
Total		3,596,266	1,455,357
Barren	Barren	229,286	92,789
Forests or wetlands	Deciduous Forest	537	217
	Evergreen Forest	1,700	688
	Mixed Forest	4,941	2,000
	Woody Wetlands	19,598	7,931
	Herbaceous Wetlands	102,257	41,382
Total		129,033	52,218
Water	Open Water	97,320	39,384
Grand Total		10,599,794	4,289,584

FMMP 2012 Important Farmland Categories

Categories for analysis	FMMP category	Acres	Hectares
Urban/Industrial/ Other developed	CI (Confined Animal Agriculture)	90,468	36,611
	D (Urban and Built-up Land)	611,503	247,466
	R (Rural Residential Land)	105,256	42,596
	sAC (Semi-agricultural and Rural Commercial Land)	38,511	15,585
	V (Vacant or Disturbed Land)	270,233	109,359
Total		1,115,970	451,617
Rangeland	G (Grazing Land)	3,193,951	1,292,546
	LP (Local Potential (SLO CO.))	126,020	50,998
	nv (Nonagricultural or Natural Vegetation)	348,569	141,061
Total		3,668,539	1,484,605
Water	W (Water)	66,839	27,049
Other	L (Farmland of Local Importance)	530,593	214,723
	P (Prime Farmland)	2,796,882	1,131,858
	S (Farmland of Statewide Importance)	1,686,336	682,436
	U (Unique Farmland)	670,064	271,165
	X (Other Land)	40,250	16,289
	Z (No data)	19	8
Total		5,724,144	2,316,479
Grand Total		10,575,492	4,279,749