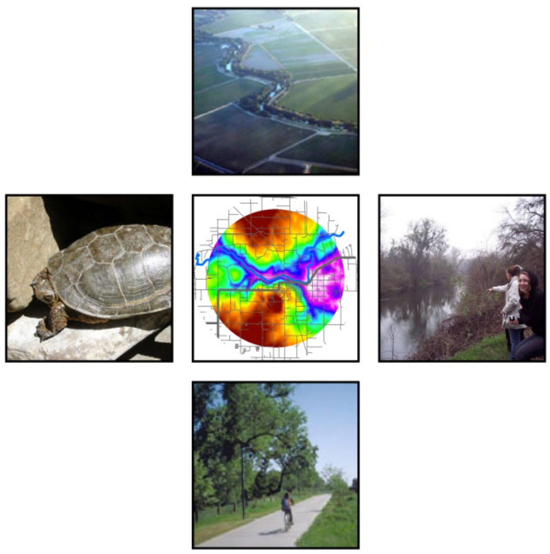
SAFE PASSAGES:
Local and Regional Wildlife Habitat Connectivity Planning



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June 2014

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EXECUTIVE SUMMARY

The ability of wildlife to move through a landscape in order to acquire or complement necessary resources for feeding, cover, and reproduction has been recognized as critical for the survival of animal populations. The Safe Passages project was initiated in 2008 to provide guidance to management agencies on how to incorporate this ecological process into land use planning. This report details a portion of the overall Safe Passages project, a linkage design for a local municipality that collaborated with researchers in order to better understand the ecological needs of their local region and to incorporate them into their local land use planning process.

The city of Riverbank is located adjacent to the Stanislaus River in Stanislaus County in the San Joaquin Valley. Using data derived in earlier portions of the Safe Passages project as well as land cover and species data specific to this analysis, the research team conducted a systematic conservation planning assessment for the area surrounding Riverbank. Marxan optimization software was used to perform conservation priority analyses of land parcels using a number of land cover and species specific data sources as input. These included connectivity assessments for four focal species at several spatial scales, habitat models for 22 sensitive species and ecosystem types, as well as mapped extents of five major land cover types.

Land ownership parcels receiving a high irreplaceability score at any of the scales of analysis in Marxan were identified as part of the linkage. Further, parcels that were not selected by Marxan but nonetheless had high connectivity scores for any of the focal species at any of the scales were included in the final linkage design.

The final linkage design includes: (1) parcels along the Stanislaus River that can either facilitate wildlife movement along the riparian corridor or provide habitat for resident species; (2) extensive, relatively intact grasslands and vernal pool complexes in the eastern portion of the study area; and (3) agricultural lands that can support both food production and ecological needs for native species.

The authors intend for the approach taken in this linkage design to be transferable, especially to other areas in the Central Valley or any regions that include extensive areas of working landscapes. The novel use of connectivity modeling in the Safe Passages project has the potential to provide important benefits to systematic conservation planning in this and other regions of California and beyond.

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Introduction

The Safe Passages project, launched in 2008, is a collaborative effort to advance the concepts, planning, and implementation of local and regional wildlife habitat connectivity within the state of California. The original team included both university research groups and conservation NGOs working closely with state agencies. Funding for the Safe Passages project has been provided by the Wildlife Conservation Society and the California Department of Fish and Wildlife (CDFW) to support the implementation of the State Wildlife Action Plan (SWAP) as well as Caltrans' compliance with requirements of federal transportation legislation. Included among the SWAP recommendations and priorities was the need for wildlife connectivity to be incorporated into state-wide, regional, and local planning processes (Bunn et al. 2007).

One of the major actions associated with the Safe Passages project is the design of a model linkage to serve as a prototype for future community planning efforts. The objective of this portion of the project was to design an implementable wildlife linkage in a location highly impacted by human activity and subject to many constraints imposed by the physical and regulatory setting. We selected as our study area a small incorporated city in the San Joaquin Valley (SJV), an agricultural region in California that is currently undergoing rapid urbanization. We made the decision to select the model linkage location from a group of willing local government entities. This interaction with local governments was deemed important to ultimately achieve the incorporation of connectivity planning results into city and county general plans, the primary policy vehicles guiding land use changes.

Study Area

The study area is located in the southern portion of California's Great Central Valley, in the San Joaquin Valley. The San Joaquin Valley (SJV) includes eight counties and measures approximately 7 million hectares (70,000 km^2) in extent, spanning 450 km from north to south, and 150 km from east to west. The human population of this geographically and biologically diverse region is growing faster than Mexico's (CIA 2002) and has a poverty rate higher than that of the Appalachia region of the United States (Rural Migration News 2006). Prior to European settlement, the wildlife habitats of the valley floor were well connected to the foothills and Sierra Nevada mountains through natural community linkages, comprising a healthy, functioning ecosystem. During the late nineteenth and early twentieth centuries, however, the SJV became one of the most productive agricultural centers in the USA. Today, agriculture remains the predominant land use in the SJV, but burgeoning populations and the need for housing and supportive commercial and industrial development have intensified pressures on the regions natural resources. In the next 35–40 years, the population in the valley is projected to more than double, increasing from 3.3 million today to more than 7 million by 2040 (PPIC 2006). By 2050 there will be close to 8 million SJV residents.

The city of Riverbank is an incorporated municipality with a population of approximately 20,000 residents. It is located in northern Stanislaus County, adjacent to the south bank of the Stanislaus River (Figure 1). The river forms the border between Stanislaus and San Joaquin counties. The city lies on a high bluff (tens of meters in height) overlooking the river. It is primarily an agricultural center, founded as a railroad stop from which to ship locally produced crops. The natural vegetation in the area surrounding the city has been highly fragmented, the result of land conversions accompanying the intensification of post-Gold Rush agricultural production. Currently, about 4% of the area within a 10 km radius of the city can be considered natural vegetation (primarily riparian vegetation and annual grassland), with roughly 70% of the area used for agriculture and 25% converted to urban uses (Huber et al. 2010b). The Stanislaus River is a major ecological feature of the area, and one of the major components of the city of Riverbank's open space and recreational system is Jacob Myers Park, located within the riparian zone. The Stanislaus River's headwaters begin in the Sierra Nevada mountains (east of the San Joaquin Valley), and the river flows roughly east to west for approximately 154 km before its confluence with the San Joaquin River approximately 25 km west of the city.

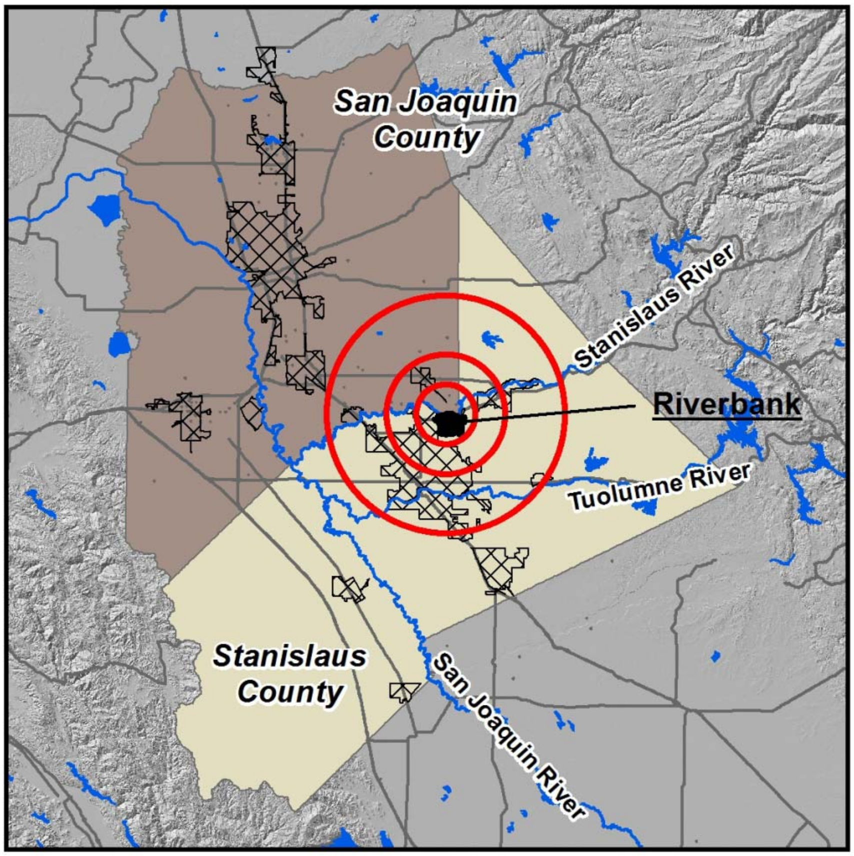

Figure 1. Study area. Red circles depict the three spatial scales assessed in this project: 5, 10, and 20 km radii from a point on the north edge of the city of Riverbank, Stanislaus County, California. Hatched areas are urban centers, except the city of Riverbank which is depicted as solid black fill.

Wildlife Habitat Connectivity

The ability of wildlife to move through a landscape in order to acquire or complement necessary resources for feeding, cover, and reproduction has been recognized as critical for the survival of animal populations (Taylor et al. 1993). One definition of habitat "connectivity" is the ability of an individual or population to move between habitat patches that provide these resources (Hilty et al. 2006). Habitat patches and landscape connectivity are species-specific concepts that are determined by an animal's perception, vagility, and life history requirements, operating within a spatially explicit context of topography, land cover (e.g. vegetation), hydrology, disturbance regimes, and other elements which determine the composition, configuration, and structure of the animal's environment. Connectivity can also be seen as the opportunistic movement of wildlife in response to environmental cues over various time frames. A species can undertake several types of movement events, which generally take place at different spatial and temporal scales at various life history stages. Daily movement can occur in the procurement of food and water, shelter, or other resource requirements. Seasonal movement, or "migration," might generally occur at a much larger spatial scale. Long distance juvenile dispersal or other colonization events might take place once in an individual's life or even less frequently, occurring only after a lapse of several generations. These various types of movement, coupled with inter-specific biological differences, lead to numerous ways in which to measure a landscape's connectivity in terms of habitat needs.

Management for landscape connectivity often focuses on planning and implementation of wildlife "corridors" (Dobson et al. 1999, Bennett 2003). Designed to facilitate animal (and plant propagule) movement between larger "core" habitats, these connective landscape configurations are often linear in form. While these ecological network components often fulfill important conservation management roles, they do not encompass the entirety of animal movement across a landscape. While a designated corridor might promote animal movement within its borders, between discrete termini, important ecological opportunities within the surrounding landscape, or "matrix", may be lost.

A fuller, 360° landscape view of connectivity rather than a constrained corridor-focused approach might be more effective and especially applicable in regions where there are few large core habitat areas (ecological nodes), as is the case in the San Joaquin Valley and the Riverbank study area. Such an approach would seek to "soften" some portion of the agricultural landscape matrix to make wildlife passage through a larger proportion of the landscape possible rather than relying entirely on a designated corridor. When any given landscape is dominated by human land uses, "softening the matrix" signifies an attempt to identify and ameliorate human generated barriers and impediments to ecological processes, thereby encouraging and potentially re-enabling certain ecological functions such as wildlife species movement to occur within those areas characterized by human land uses (e.g., farmland or cities) (Green et al. 2005; Noss and Daly 2006; Wiens 2006; Fischer et al. 2008). Examples of softening the agricultural landscape matrix include augmenting farm edges with hedgerows, constructing tail water ponds in low elevation areas, and vegetating canal edges (Robins et al. 2001; Long and Anderson 2010; Burchett and Burchett 2011). Urban areas and urban edges can also be softened to facilitate animal movement and other ecological functions (Soule 1991; Marzluff and Ewing 2001; Gehrt and Chelsvig 2003; Lundholm and Richardson 2010). Some examples in the city of Riverbank would be creation of multifunctional storm water detention basins that also provide habitat resources near the Stanislaus River and adding tertiary water treatment wetlands adjacent to the existing sewage treatment plant near the river. City parks can also contribute to softening the urban edge and, to some degree, provide wildlife connectivity resources.

This approach to planning for wildlife connectivity views the landscape holistically and strives to create an "ecological network" (Jongman and Pungetti 2004) consisting of traditional natural reserve cores and corridors along with cultural landscape features that function to contribute to animal habitat and movement. Ecological networks can integrate open space, urban areas, agricultural areas, and natural reserves into a single coherent system.

Previous Work

Previous work that the team conducted for this project ("Phase 1") focused on developing new modeling techniques to assess connectivity. These techniques were designed to more fully integrate high circuitry, multi-directional connectivity rather than focusing on movement between a priori endpoints, or termini (Huber et al. 2012). These "least cost surfaces" were developed for four focal species: mule deer (*Odocoileus hemionus*), bobcat (*Lynx rufus*), San Joaquin pocket mouse (*Perognathus inornatus*), and western pond turtle (*Actinemys marmorata*). These species were selected to represent many of the major ecological needs of the region's native species.

Further, it is known that the choice of spatial scale in analyses can affect the outcome of conservation planning efforts (Huber et al. 2010a). To address some of these concerns, connectivity was assessed at multiple spatial scales for each of the focal species, resulting in 12 distinct least cost surfaces (Huber et al. 2012).

Finally, an additional goal of the selection of the study site was to evaluate the future potential for re-establishing landscape connectivity between the relatively intact wildlands of the Sierra Nevada and ecologically important San Joaquin River and its associated riparian ecosystems. A traditional least cost corridor analysis was conducted between Stanislaus National Forest (east) and San Joaquin National Wildlife Refuge (west), based on mule deer habitat and movement patterns.

Linkage Design

While the previous analyses provide potentially useful management information as independent datasets, they were intended as inputs to a larger linkage design. The concept of a linkage design is the creation of a conservation plan that incorporates the important ecological features of the planning area with a particular focus on landscape connectivity for multiple species. The linkage design found in this report includes representative examples of major land cover types in addition to potential habitat for sensitive native plant and animal species. The land cover types included in the analysis were annual grassland (AGS), freshwater emergent wetland (FEW), valley foothill riparian forest (VRI), and wet meadow (WET). There were 22 sensitive species and habitat types also considered here, as well as vernal pool complexes (VP). This analysis also incorporated areas of high potential connectivity for the four focal species that are meant to serve as proxies for a wide array of the region's native species.

Ecological patterns and processes occur at various spatial scales (Turner et al. 1989). The linkage was designed to address multiple scales in order to capture as many of the region's ecological patterns and processes as possible. Land parcels representing land title ownership were chosen as the unit of analysis (as opposed to a normalized unit of land such as a square or hexagonal grid) because they are the most expedient unit for acquiring land or implementing usage regulations for incorporation into a linkage design. Selected parcels include connectivity needs assessed at four spatial scales in order to provide movement potential: (1) in the immediate vicinity of Riverbank; (2) at a larger local scale across the San Joaquin Valley floor; (3) at a larger regional scale that includes the lower end of the Sierra Nevada foothills; and (4) at the largest scale – linking the Sierra Nevada to the San Joaquin River.

The linkage design is meant to serve as a guide for local jurisdictions in making land management decisions. Different portions of the linkage will be included in the design for various ecological reasons and therefore will be associated with management suggestions appropriate for specific parcels. The hypothesis of the linkage design is that if implemented it will provide the basis for sustainable management of existing and potential future ecological resources in the vicinity of Riverbank.

METHODS

Four categories of input data were used for the linkage design:

1. Conservation feature / land cover associations
2. Potential habitat for sensitive species
3. Land cover
4. Connectivity analyses for four focal species

Conservation Feature / Land Cover Associations

Objective: To compile a comprehensive list of land cover types which provide high quality habitat for the feeding, cover, or reproductive needs of the 22 sensitive species considered in the linkage design, or which provide the structural and ecological context for the sensitive habitat types considered. For instance, vernal pools, a sensitive habitat type considered in the linkage design, may be found in areas with land cover types of annual grassland (AGS), perennial grassland (PGS), or pasture (PAS).

Process

1. The California Department of Fish and Wildlife (CDFW) developed and maintains a database/client application called California Wildlife Habitat Relationships (CWHR). This wildlife and habitat information system contains life history, geographic range, habitat relationships, and management information on 694 species of amphibians, reptiles, birds, and mammals known to occur in California (CDFW 2014).
2. For each of the 22 species of special concern and five ecological community types (i.e., conservation targets) considered in the linkage design (Table 1), the ecological literature and CWHR were used to determine the land cover types considered to be of high value for the feeding, cover, reproduction, or ecological context of the conservation target. CWHR uses a scale of 'low,' 'medium,' and 'high' to rate the suitability of land cover types for a species according to its life history requirements (i.e., ecological needs). Any land cover type which ranked 'high' in CWHR for any one of the species' basic needs was considered in our analysis as a 'high' value land cover for that species.

Output

The output of the above process is a text file (hereafter referred to as the 'conservation target/habitat association file.') in which each conservation target is associated with a list of high quality habitat types according to the CWHR classification schema.

Potential Habitat Analysis

Objective: To estimate the total area (in acres) of potential habitat for 22 sensitive native species within each parcel in the scope of analysis (Table 1).

Key Inputs

1. **California Natural Diversity Database (CNDDB) layer**: Point shapefile (CNDDB May 2011) of centroids taken from CNDDB polygons representing species observations.
2. **Land cover layer**: Central Valley land cover shapefile, derived from the National Land Cover Database (2006; Fry et al. 2011) and Fire and Resource Assessment Program (FRAP 2006), then crosswalked to California Wildlife Habitat Relationship (CWHR) classifications.
3. **Vernal pool layer**: US Fish and Wildlife Service (USFWS) Vernal Pool shapefile (USFWS 2005).
4. **Parcel layer** (Figure 2): Riverbank analysis area subdivided by ownership parcel. A 20 km radius was used to circumscribe the scope of analysis around the town of Riverbank. All parcels entirely within or intersected by the demarcation line were included within the scope of analysis. Analysis scopes employing 10 and 5 km radii were also used.

Process

1. For each conservation target, the following process was applied iteratively in ArcGIS 10.0.
    A. CNDDB observation centroids of the conservation target were buffered with a one mile radius to create circular polygons. This radius was selected in order to capture likely usable habitat within a close vicinity of the approximate occurrence points. Usable habitat could potentially be found beyond this distance, but a conservative extent was used to identify only the most likely habitat. The radius distance was also selected to help address the spatial uncertainty of CNDDB data.
    B. The circular polygons of the conservation target were used as a clip shape for the land cover layer.
    C. The resultant clipped land cover was further refined by selecting only high value CWHR habitat types for that conservation target.
    D. These high value land cover polygons for the conservation target were then overlaid with the parcel layer, and their areas summed by each parcel. In this way, land cover was employed as the conservation currency rather than species occurrence counts, making the accuracy of the point locations less critical. For instance, whether a conservation target point was located on one side of a parcel border or the other, a substantial portion of both parcels are likely to have their land cover evaluated for high quality habitat within the buffered polygon area.

Output

The output from the above process is a shapefile of all parcels within the scope of analysis. Each parcel constitutes a single polygon and record in the shapefile attribute table. For each conservation target within the scope of analysis, a field is named and written to the attribute table. The sum of aggregate high value habitat area for each conservation target is then calculated according to each parcel, and recorded in the designated field. For example, if a parcel contained high value habitat for five of the 22 conservation targets, then the parcel record would have the five corresponding conservation target fields written with the summed habitat area for each of those conservation targets, while the fields for other conservation targets not found in that parcel would record zeros.

Notes

1. For conservation targets which are obligate vernal pool species, a USFWS vernal pool shapefile was clipped to the bounds of the CNDDB species shapefile (see 2B above). This vernal pool area was summed and recorded for each parcel record in the field for the conservation target species.

2. For conservation targets which are facultative vernal pool species, both the USFWS vernal pool layer and CWHR cross-walked land cover layer were clipped to the area of the CNDDB species shapefile. A union was performed between the two layers in order to aggregate high value habitat areas of all types pertinent to the species.

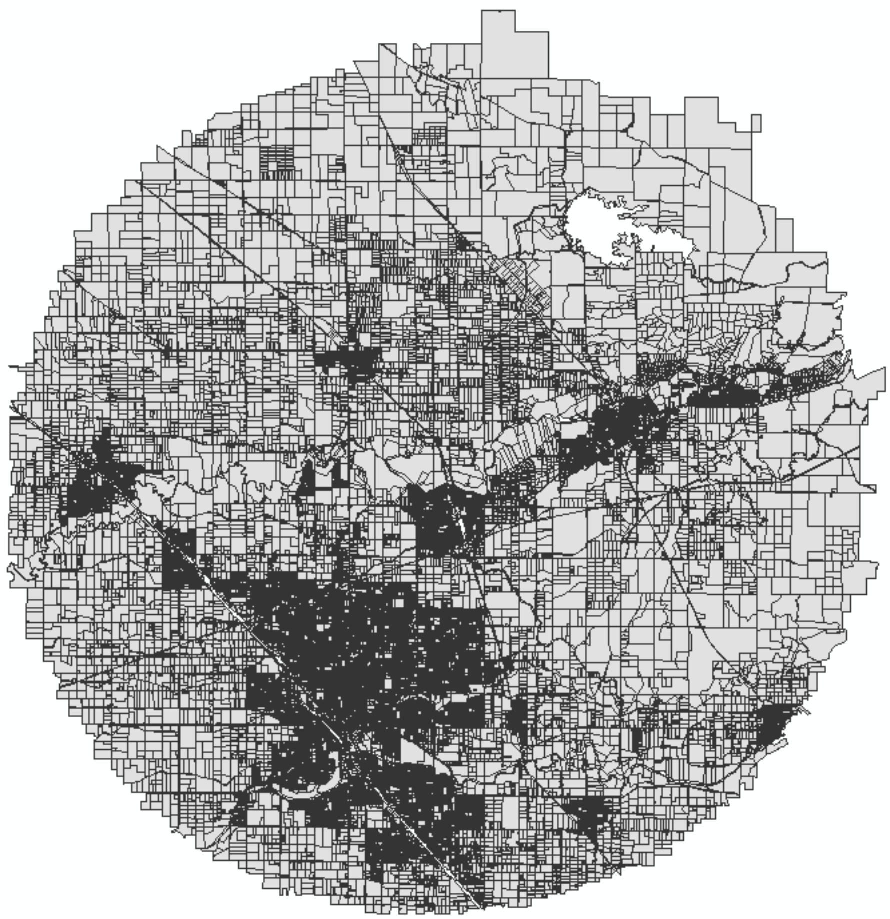

Figure 2. Parcel layer showing land ownerships parcels within the largest (20 km) scope of analysis. A 20 km radius was used to circumscribe the perimeter of the largest study area. All parcels intersected by the demarcation line were included in the scope of analysis. Analysis scopes of 10 and 5 km were also used.

Table 1. Major land cover types and sensitive species. These 27 types were conservation targets in the Marxan analyses. The total area of each in the study region, the overall conservation goal for each (as a percentage of their total area), and the data source for each are included.

Conservation Target	Total (ac)	Target (%)	Source
Annual Grassland	40,365.6	50	CWHR
Freshwater Emergent Wetland	3,151.7	100	CWHR
Valley Foothill Riparian Forest	1,269.8	100	CWHR
Wet Meadow	0.8	100	CWHR
Tricolored Blackbird	3,698.7	75	CNDDB
California Tiger Salamander	2,718.1	75	CNDDB
Burrowing Owl	2,903.2	75	CNDDB
Aleutian Canada Goose	13.6	75	CNDDB
Swainson's Hawk	3,425.7	75	CNDDB
Valley Elderberry Longhorn Beetle	118.0	75	CNDDB
Elderberry Savanna	13.5	75	CNDDB
Western Pond Turtle	183.4	75	CNDDB
Delta Button-Celery	6.8	75	CNDDB
Hoary Bat	120.1	75	CNDDB
Vernal Pool Tadpole Shrimp	11,299.1	75	CNDDB
California Linderiella	6,678.6	75	CNDDB
Hardhead	293.3	75	CNDDB
Yuma Myotis	119.3	75	CNDDB
Colusa Grass	365.8	75	CNDDB
Riparian Woodrat	0.8	75	CNDDB
Nothern Hardpan Vernal Pool	4,741.3	75	CNDDB
San Joaquin Valley Orcutt Grass	322.0	75	CNDDB
Hartweg's Golden Sunburst	390.2	75	CNDDB
Riparian Brush Rabbit	0.8	75	CNDDB
Greene's Tuctoria	322.0	75	CNDDB
Great Valley Mixed Riparian Forest	40.5	75	CNDDB
Vernal Pools	21,526.1	50	USFWS

Land Cover Analysis

Objective: To calculate the total coverage (in acres) of various CWHR land cover types within the parcels in the scope of analysis. The assessed land cover types were annual grassland (AGS), freshwater emergent wetland (FEW), valley foothill riparian forest (VRI), wet meadow (WTM), and vernal pools (VP) (Table 1).

Key Inputs

1. **Land cover layer**: Central Valley land cover shapefile crosswalked to California Wildlife Habitat Relationship (CWHR) classifications.
2. **Vernal pool layer**: USFWS vernal pool shapefile.
3. **Parcel layer**: Riverbank analysis area subdivided by ownership parcel. Parcel data were acquired from each county's Assessor's office: Stanislaus County in 2009, San Joaquin County in 2010. Parcels within or intersected by circles of 20 km , 10 km, and 5 km radii comprised the analysis areas.

Process

1. A clean parcel layer (extraneous attribute fields removed) was created in order to store the summed values of each CWHR land cover type within each parcel (summary parcel layer).
2. A master land cover list was generated of all land cover types which offered high value habitats, by iterating through the conservation target/habitat association text file and extracting one of each high quality land cover type occurrence. Though agricultural crops often constitute high value species habitat, they were not considered to be relevant conservation targets for this analysis. The final master land cover list was comprised of the following land cover types: annual grassland (AGS), freshwater emergent wetland (FEW), valley foothill riparian forest (VRI), wet meadow (WTM), and vernal pools (VP).
3. In the attribute table of the summary parcel layer, a field was created and named for each land cover type in the master land cover list. Each of these fields holds the acreage sum of its respective land cover types for each parcel record in the table.
4. The USFWS VP layer was dissolved into a multi-part polygon and then clipped down to the largest scope of analysis using a dissolved parcel layer as clip shape (a dissolve of the layer in Figure 2, above). The VP polygon was further refined to only those areas which the land cover layer classified as annual grassland (AGS), perennial grassland (PGS), or pasture (PAS). This was achieved by making a selection on the land cover layer for all polygons classified as either AGS, PGS, or PAS, then clipping this target selection with the vernal pool polygon clip shape.
5. The parcel layer was intersected with the land cover layer, hereafter referred to as 'parcel/land cover intersection layer'.
6. For each land cover type in the master land cover list, the following operation was applied iteratively in ArcGIS 10.0.
    A. Each CWHR land cover type was selected from the parcel/land cover intersection layer.
    B. A summary analysis operation was performed on the land cover type selection, which calculated the total acreage of all polygons of the land cover type, for each parcel. The resultant acreage sum of the land cover type for each parcel record was written to the attribute table of the summary parcel layer, in the field named for that land cover type.

7. The parcel layer was then intersected with the refined VP layer. The area of all VP intersect polygons was then totaled by parcel in a summary analysis operation. The resultant acreage sum for VP land cover for each parcel record was written to the attribute table of the summary parcel layer, in the field named for VP.

Output

The output from the above workflow is a summary parcel shapefile in which a field is created for each land cover type in the attribute table. Each parcel within the scope of analysis constitutes a single record in the parcel summary shapefile, in which the total acreage of each land cover type is recorded in the corresponding field.

Notes

1. Total acreage of Vernal Pool habitat for each parcel record was computed from the refined USFWS vernal pool layer, narrowed to those areas which overlapped with a CWHR land cover polygon of type AGS, PGS, or PAS.

Connectivity Analysis

Objective: To calculate a total connectivity value for each parcel for four focal species at three spatial scales and one focal species at a fourth.

Key Inputs

1. **Focal species connectivity rasters**: A set of 10 m connectivity rasters were generated for four focal species: bobcat, pocket mouse, mule deer, and western pond turtle during Phase 1 of this project. The four species were chosen to represent the differential movement and dispersal modes of a range of species through the landscape. For the purposes of this portion of the study, "connectivity" is defined as the ability of a focal species to move through a raster cell. The connectivity rasters for each focal species were generated using a least cost approach, which considered potential animal movement in any direction across the field of analysis, rather than between pre-determined terminal points (with the exception of the Stanislaus – San Joaquin mule deer corridor raster). The final product of a least cost approach is the assignment of a numeric value to each raster cell mapped onto the landscape (see Huber et al. 2010b or Huber et al. 2012 for a description of how connectivity values were calculated for each raster cell). A high cell value indicates high connectivity, while a low value indicates low connectivity. A high connectivity value indicates: (1) ease of movement for the focal species across that cell, which may be a result of favorable vegetation structure or lack of barriers; or (2) presence of vital resources which act as species attractors. Such attractors may be food, water, cover, or special habitat elements such as snags in the case of woodpeckers, or rodent burrows in the case of salamanders or snakes which advantageously make use of them. Low connectivity values within a raster cell indicate greater difficulty for a focal species' movements, due to inhospitable

terrain, unsuitable habitat for movement, or other barriers. Low connectivity values may also imply a paucity of food or other vital resources.

In summary, a high connectivity value for a raster cell mapped to the landscape may be equated with a high suitability rating for that species. The landscape is amenable to the species' needs, and is proximal to other landscape cells which are similarly inviting. In contrast, a low connectivity value for a cell connotes that the landscape is 'hostile' to the species or surrounded by landscape of low suitability for that particular species. Low connectivity values imply that an organism will likely choose an alternate path comprised of higher value cells if presented the choice.

2. **Stanislaus – San Joaquin mule deer corridor raster:** A connectivity raster was generated for a mule deer corridor between the Stanislaus National Forest and San Joaquin National Wildlife Refuge. A high cell value indicates high connectivity, a low value, low connectivity.
3. **Parcel layer:** The Riverbank analysis area was subdivided by ownership parcels, in which each parcel constitutes a record in the attribute table. A field for each of the four focal species at each scope of analysis and the mule deer corridor was created in the attribute table, in order to hold a final 'connectivity score' for each parcel according to each raster.

Process

1. For each of the four focal species connectivity rasters and the Stanislaus – San Joaquin mule deer corridor raster, a Zonal Statistics operation was performed to determine the mean connectivity value of each parcel. This is the sum of all connectivity values from each 10 m cell within a parcel, divided by the number of cells in the parcel.
2. The mean connectivity value was multiplied by the area of the parcel (in acres) in order determine a total 'connectivity score' for the parcel, i.e., the overall attractiveness to species movement and exploration contributed by each parcel.
3. The mean connectivity score for each parcel was written to a field created in the summary parcel layer and named for the focal species and scope of connectivity analysis. This was repeated for each of the four focal species at each of the three scopes of analysis, for a total of 12 connectivity fields written to the summary parcel layer. Each parcel, i.e., each record in the attribute table, received a total 'connectivity score' for each of these 12 fields.
4. To better understand how connectivity scores are analyzed, a brief hypothetical example may help to illustrate:

   Consider three parcels: #1, #2, and #3, where each successive parcel is twice the size of that preceding it. If we consider parcel #1 to have an areal unit of 1, then parcel #2 has an area of 2, and parcel #3 has an area of 4. After finding the average connectivity value for each parcel, the results are as follows:

   Parcel #1. Average connectivity value = 5
   Parcel #2. Average connectivity value = 2
   Parcel #3. Average connectivity value = 3

   The formula for total parcel connectivity is the average parcel connectivity value * parcel area, so results for this example are:

Parcel #1: average value 5 * 1 areal unit = connectivity score of 5
Parcel #2: average value 2 * 2 areal units = connectivity score of 4
Parcel #3: average value 3 * 4 areal units = connectivity score of 12

This example demonstrates the key point that total connectivity contributed by a parcel is a function of both the quality of connectivity and the quantity. Parcel #3 has a mid-range average connectivity score of 3 across all of its cells. However, because parcel #3 is twice the size of parcel #2 and four times the size of parcel #1, its total "connectivity contribution" to a connectivity model is the greatest of the three parcels.

Output

The output from the connectivity assessment operation is a summary parcel layer with a field for each of the 12 connectivity rasters written to the attribute table. To each field is recorded a final connectivity value for each parcel record in the table. The above described zonal statistics operations and total connectivity scores were determined for each parcel for each of the four focal species, at 20 km, 10 km, and 5 km scopes of analysis.

Marxan Analysis: Conservation Feature Summary Table

Marxan input file (puvspr.dat)

The default file name for the conservation feature summary table, one of three principal Marxan input files, is 'puvspr.dat'. 'Puvspr' is an acronym derived from **p**lanning **u**nit **vs sp**ecies, while '.dat' is a file type suffix indicating a 'data' file which in this case is expected by Marxan software to be text.

Objective: Consolidate and reformat GIS analyses of conservation feature quantities within each parcel for input to Marxan software.

Results from CNDDB, land cover, and connectivity analyses have been stored in separate parcel summary layers. The purpose of the conservation feature summary table is to compile the results from these separate analyses, and translate them into the input form required by Marxan optimization software. This puvspr.dat input file consists of a single table with three fields:

1. **'species'**: A field which holds an arbitrary but unique identification number for each conservation feature. The terms 'species' is a logical choice to describe conservation features, as it is typically a suite of true biological species which are the objects of most Marxan based conservation analyses, and 'species' is the naming convention expected by Marxan software to identify conservation features. In our case, however, we have extended our suite of conservation features to include several sensitive habitat types, and in this context we will retain the word 'species' in quotes to designate that it is a table field name which signifies an expanded domain of conservation features.
2. **'pu':** (**p**lanning **u**nit): The unique identification number for a particular parcel.

3. **'amount'**: The amount (in acres) of a conservation feature (‘species’) which occurs in a specific parcel, or planning unit (‘pu’).

Key inputs

1. Summary parcel layers.
   A. **CNDDB results layer**: A parcel layer with CNDDB results fields.
   B. **Land cover results layer**: A parcel layer with land cover results fields.
   C. **Connectivity results layer**: A parcel layer with connectivity results fields.

Process

1. **Write Conservation Feature Summary Table** (puvspr.dat file). Each summary parcel layer is iterated across each field of the attribute table, holding results from the previous CNDDB, land cover, and connectivity analyses. The first field encountered is assigned an arbitrary ‘species’ number (beginning with 1). A new record is created in the conservation feature summary table for each parcel which contains ‘species 1’, and the amount (acreage) of coverage for that ‘species.’ Each subsequent field is assigned the next ‘species’ number in sequence and a new record is created for each parcel, or planning unit (‘pu’) containing the ‘species’, and the acreage of ‘species’ representation is recorded in the ‘amount’ field.

Output

1. The output from the above operation is a table with three fields: ‘species’, ‘pu’, and ‘amount’. The table is written with a new record for each conservation feature (‘species’) occurring in each parcel, along with the acreage sum in which the conservation feature is represented. This table, with a simple name change, becomes the puvspr.dat Marxan input file.

Marxan Analysis: Planning Unit Summary Table

Marxan input file (pu.dat)

The default file name for the planning unit summary table, one of three principal Marxan input files, is ‘pu.dat’. ‘Pu’ is an acronym derived from **p**lanning **u**nit**,** while ‘.dat’ is a file type suffix indicating a ‘data’ file which in this case is expected by Marxan software to be text.

Objective: Consolidate and reformat GIS analyses of planning units (parcels) for input to Marxan.

Each planning unit (parcel) possesses a unique identification number. Each planning unit is also assigned a ‘cost’ for inclusion into a conservation network, as well as a ‘status’ indicating whether the parcel is already conserved (locked into a reserve design), is to be excluded from analysis (e.g. is primarily urban), or is ‘in play’ for potential inclusion in a conservation network design.

Key Inputs

1. **Parcel layer**: The Riverbank analysis area subdivided by ownership parcel. A 20 km radius was used to circumscribe the scope of analysis around the city of Riverbank. All parcels entirely

within or intersected by the demarcation line were included within the scope of analysis. Scopes of 10 and 5 km were also used.

2. **Land cover layer**: This is the Central Valley land cover shapefile cross-walked to CWHR vegetation classifications.
3. **CPAD layer**: The California Protected Areas Database (2011b) shapefile.
4. **NCED layer**: The National Conservation Easement Database (2011) shapefile.

Process

1. **Urban land cover extraction**: Land cover polygons designated as 'urban' were selected from the land cover layer and written to an **urban layer**.
2. **Exclude urban parcels from analysis**: A summary analysis operation was performed on the intersected regions of the urban layer and parcel layer, to produce the sum of urban area per parcel. Parcels > 50% urban were excluded from analysis.
3. **Lock-in conserved areas**: The CPAD and NCED polygons were aggregated into a **protected areas layer**. A summary analysis operation was performed on the intersected regions of this protected areas layer and the parcel layer, to produce the sum of current protected areas per parcel. Parcels > 50% protected were locked into inclusion in our conservation network models.
4. **Create Planning Unit Summary Table (pu)**: The planning unit table is written with three fields: 'id' (unique parcel identification number), 'cost', and 'status'.
    A. **Cost**: Cost is defined here as monetary cost per acre. Cost per acre for each parcel was calculated according to the equation:

    $$\ln(\text{cost/acre}) = 12.55017 - 0.79771(\ln(\text{acres}))$$

    This function was developed for the Elkhorn Slough watershed on California's Central Coast (Thorne et al. 2009). While the actual per acre parcel cost is likely different than in the watershed in which it was assessed, we assume that the general relationship holds: larger parcels have a lower cost per unit area than small parcels, and more recent parcel transactions are more representative than older ones. Unfortunately, specific data for the SJV study area have not been developed to date and is beyond the scope of this study. We use these calculated land parcel values to indicate relativistic costs, not actual costs.

    B. **Status**: There are three potential states for each planning unit (parcel): (1) locked in (> 50% conserved), (2) locked out (> 50% urban), or (3) 'in play,' which describes all parcels not locked-in or out.

Output

The output from the above process is a planning unit summary table (pu) with three fields: 'id', 'cost', and 'status'. Each planning unit (parcel) receives a single record in the table, and is assigned the appropriate cost and status according to the logic described above.

Marxan Analysis: Species Summary Table

Marxan input file (spec.dat)

The default file name for the species summary table, one of three principal Marxan input files, is 'spec.dat'.

Objective: Consolidate and reformat GIS analyses of conservation features ('species') for input to Marxan.

The species summary table (spec.dat file) must have nine fields expected by the Marxan software. Several of these fields may be assigned values of zero and then do not play a role in the Marxan computations. The four pertinent spec.dat fields utilized in this analysis are as follows:

A. **'ID'**: An arbitrary numeric identification code which is assigned to each conservation feature or 'species.'
B. **'Name'**: This field serves to hold the name of the 'species' and associate it with its assigned ID code.
C. **'Target':** The target field defines the acreage goals for each conservation feature which Marxan is attempting to achieve with each of its model runs. These goals are user defined. Total available acreages for each land cover type have been determined in the analyses above, and the user must now select a proportion of what is available to conserve.
D. **'Spf':** This field name is an acronym for '**s**pecies **p**enalty **f**actor.' Varying degrees of penalty factor may be assigned if Marxan fails to meet the user defined goals ('targets') for each conservation feature ('species'). This penalty factor serves to prioritize the magnitude of importance which the user has placed on achieving the goals for each 'species'. Spf was set to 1 for each conservation feature.

The conservation goals that were input into Marxan are as follows:

- Sensitive species habitat: 75% of total extent of each habitat
- Connectivity: 50% of total least cost surface values for each focal species at each spatial scale
- Annual grassland: 50% of total extent of the land cover type
- Vernal pool complexes: 50% of total extent of the land cover type
- Freshwater wetlands, riparian forest, wet meadow: 100% of total extent of each land cover type

Scopes of Analyses

The various GIS-based analyses and consolidation of information for Marxan input files described above were applied at three scopes of analysis around the city of Riverbank. In addition to the 20 km radius which circumscribed the largest scope of analysis, radii of 10 and 5 km were also used to define analysis zones around Riverbank. Any parcels which fell within, or were intersected by the demarcation line, were included in the particular scope of analysis.

Marxan Analysis

Marxan analyses were conducted at the three spatial scales described. Runs totaled 100 for each analysis, and a boundary modifier of 1,500 was used for all analyses at the three scopes. Boundary modifiers are used in Marxan to control the “clumping” of planning units selected during an analysis. We used several test runs to determine a modifier that encouraged some clumping while not forcing a solution that included numerous parcels selected merely for their adjacency to existing conservation areas or parcels selected for their ecological attributes.

Linkage Identification

Parcels were selected in several ways to be included in the final linkage design. First, any parcel that was selected more than 75% of the time in a Marxan analysis at any scale was included. These parcels represent the set of parcels that best met the full suite of ecological goals that were input into Marxan. To ensure that adequate landscape connectivity was represented, parcels were also selected that did not meet the Marxan threshold but did possess high connectivity scores for at least one focal species at one spatial scale. Finally, parcels were selected that did not meet the Marxan threshold but had high values in the analysis conducted for mule deer connectivity between Stanislaus National Forest and San Joaquin National Wildlife Refuge. Together, these three elements constitute the final linkage design.

RESULTS

The Marxan analyses resulted in three sets of output files, one for each scale of analysis. Those used in the linkage design were the “summed solution” files, indicating the number of times out of 100 runs that a particular parcel was selected as part of a low cost set of planning units.

The analysis at the 5 km radius resulted in many of the parcels immediately surrounding Riverbank to be selected at least once by Marxan (Figure 2). Parcels selected all or most of the time were concentrated along the Stanislaus River, the southwestern edge of Riverbank, and several kilometers east of Riverbank.

The 10 km analysis yielded many fewer parcels that had intermediate scores (Figure 3). In fact, almost every parcel was either selected every time or never. Most of the selected parcels were either along the Stanislaus River or scattered to the east of Riverbank.

Results from the analysis at 20 km were similar to those at 10 km; there were very few parcels with intermediate scores (Figure 4). In addition to the patterns found at 10 km, many large parcels at least 15 km east and northeast of Riverbank were selected. These parcels represent the location where farming gives way to ranching, resulting in the presence of relatively intact grassland areas.

To identify the parcels comprising a linkage design, we selected those that were found in more than 75% of the Marxan solutions in at least one of the scales of analysis (Figures 5 and 6). While not implying that those not meeting this threshold are not important to conservation in this region, those that exceed the threshold were found to most likely contribute important features to a regional ecological network. This subset of parcels totaled 853, comprising 69,179 acres of land.

Annual grassland (AGS) had by far the greatest extent of land cover types found in the selected parcels: 26,040 acres (Table 2; Figure 7). Much less freshwater emergent wetland (FEW) was included (1,581 acres), followed by valley foothill riparian (VRI) forest (685 acres) and wet meadow (WTM) (0.9 acres). However, because of the distributed nature of wetlands in the study area, more parcels were needed to meet these totals (296 vs. 275). The combined area of the parcels selected for these land cover types is similar as well: 53,536 acres contained the total AGS compared with 44,624 acres for FEW. The total VRI was also found scattered across many parcels (146, for a total of 23,258 acres). WTM was only found on one parcel.

The greatest extent of habitat within the selected parcels (Table 2) was 8,472 acres (vernal pool tadpole shrimp). Other extents greater than 1,000 acres include: California Linderiella (5,061 acres), northern hardpan vernal pool (3,532 acres), tricolored blackbird (2,778 acres), California tiger salamander (2,003 acres), burrowing owl (1,919 acres), and Swainson's hawk (1,702 acres). The smallest habitat extents were riparian woodrat and riparian brush rabbit (both 0.8 acres). The greatest number of parcels included was for burrowing owl (141 parcels). Other habitats found on numerous parcels were Swainson's hawk (59 parcels) and vernal pool tadpole shrimp (43 parcels).

Parcels will generally be included in the linkage through fee title or easement purchase of the full property rather than portions that may contribute the most towards conservation goals. Therefore, the total area of parcels that would be required to protect the habitat extents (above) were calculated. The total area of parcels in the linkage that included any habitat (Table 2) was greatest for vernal pool tadpole shrimp (16,376 acres). Other large total parcel areas include Swainson’s hawk (10,099 acres), northern hardpan vernal pool (9,546 acres), California tiger salamander (8,932 acres), and California Linderiella (8,274 acres).

The focal species-based connectivity accounted for by the Marxan-selected parcels follows the patterns found in previous analyses (Huber et al. 2010b, Huber et al. 2012). Parcels along the Stanislaus River and comprising the pasture lands just east of Riverbank were selected by Marxan for meeting the 5 and 10 km radius connectivity needs, while those in the more intact grasslands in the eastern portion of the study area were selected to meet the goals for connectivity at the 20 km extent (Figure 8). Parcels meeting the conservation goals for the regional mule deer corridor were concentrated along the Stanislaus River (Figure 9).

Parcels with high levels of modeled connectivity but not selected by Marxan were found for all four focal species at all three scales with the exception of western pond turtle at the 5 km scale (Figure 10). Some important connectivity areas for bobcat and mule deer were found: (1) on the northeast edge of Riverbank linking the Stanislaus River with pasture lands east of the city (5 km); (2) crossing CA Highway 120 just north of Oakdale (10 km); and (3) linking large grassland blocks across CA Highway 120/108 east of Oakdale (20 km). Some important connectivity areas for San Joaquin pocket mouse were found: (1) east of Riverbank linking the Stanislaus River with pasture lands east of the city (5 km); (2) linking pasture lands south of Oakdale (10km); and (3) linking large grassland blocks north of Woodward Reservoir (20 km). Some important connectivity areas for western pond turtle were found: (1) filling gaps along the Stanislaus River west of Riverbank (10 km); and (2) linking large grassland blocks across CA Highway 120/108 east of Oakdale (20 km).

Parcels that provide regional mule deer connectivity but fall outside the Marxan solution (Figure 11) fall into three categories: (1) linking large blocks of eastern grasslands with the Stanislaus River riparian corridor generally north of Oakdale; (2) filling gaps in the Stanislaus River riparian corridor between Oakdale and Ripon; and (3) linking the Marxan-identified parcels along the Stanislaus River with currently protected areas (e.g. Caswell Memorial State Park) along the river in the western portion of the study area.

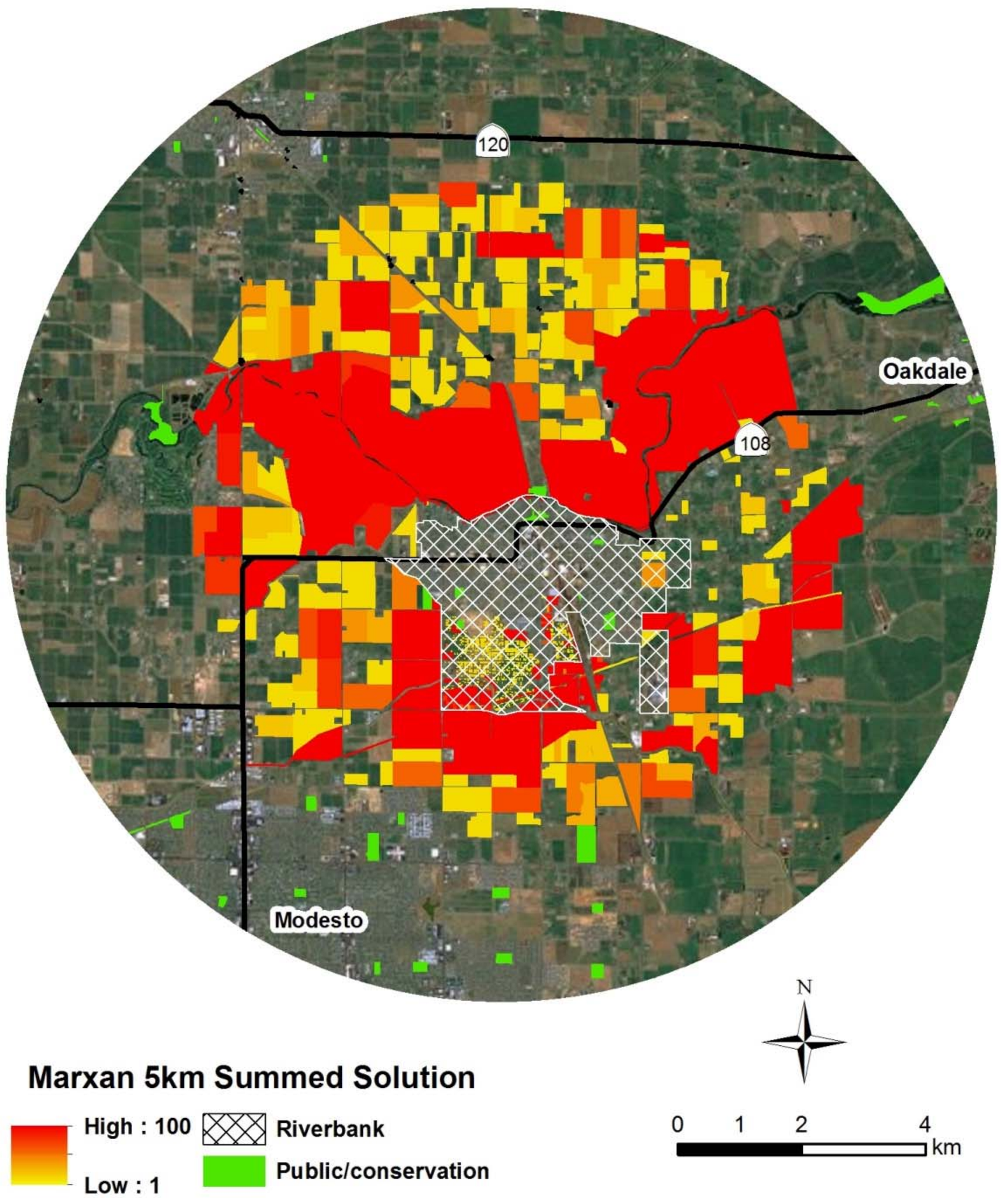

Figure 3. Marxan results at the 5 km scale. Values indicate the number of times (out of 100 runs) that a parcel was selected by Marxan as part of a “low cost” reserve network.

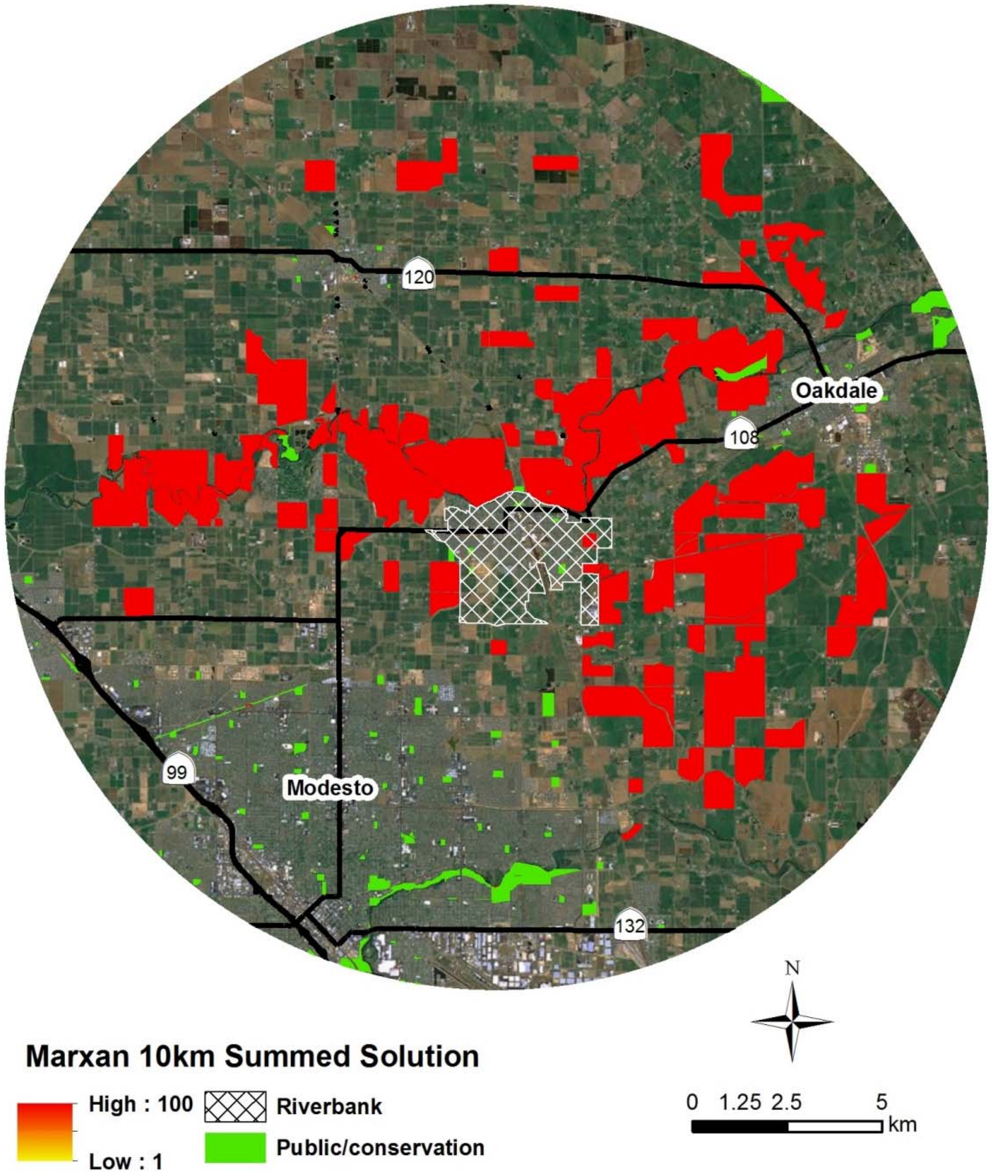

Figure 4. Marxan results at the 10 km scale. Values indicate the number of times (out of 100 runs) that a parcel was selected by Marxan as part of a "low cost" reserve network.

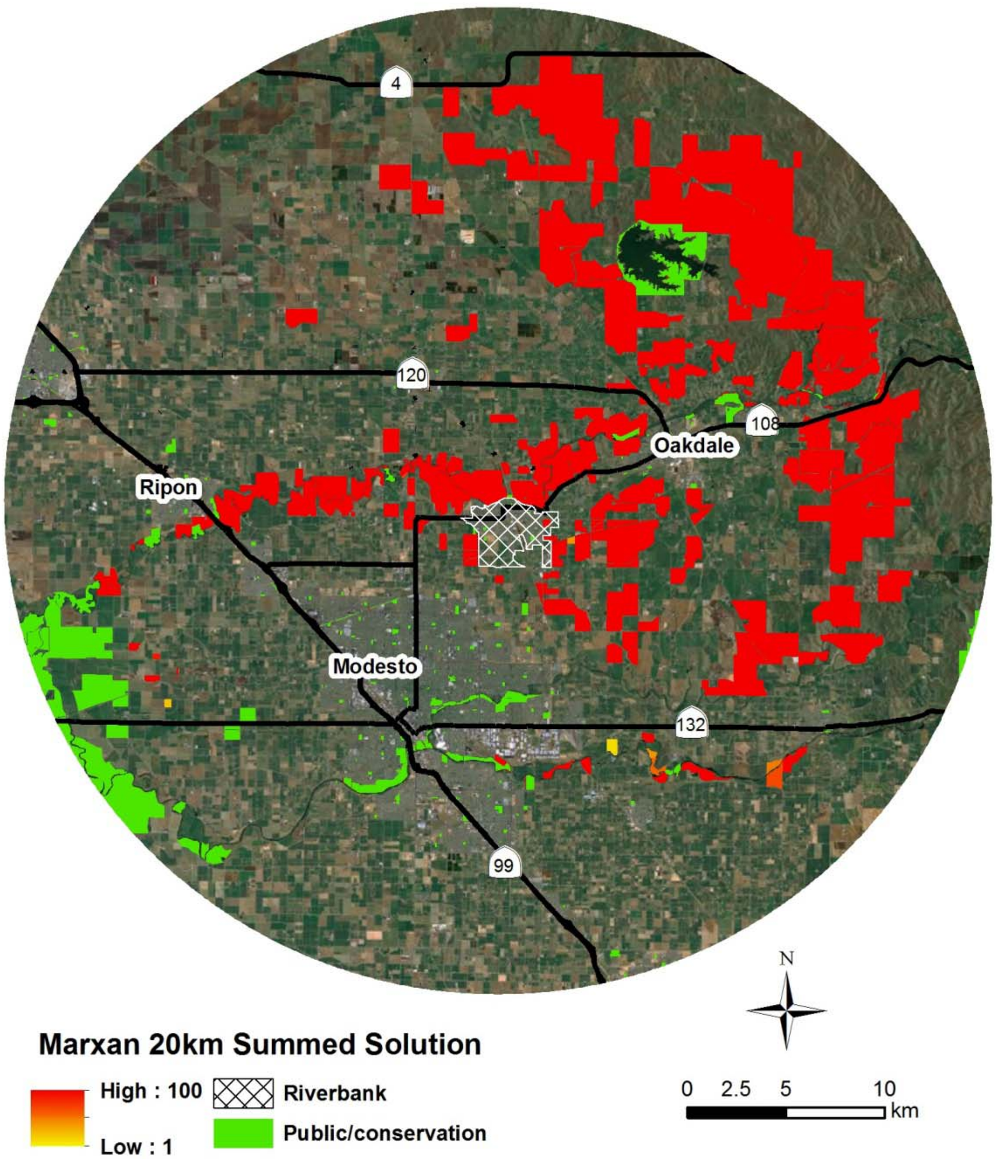

Figure 5. Marxan results at the 20 km scale. Values indicate the number of times (out of 100 runs) that a parcel was selected by Marxan as part of a “low cost” reserve network.

Table 2. Total amount of each conservation target found within the parcels selected by Marxan. "Parcels" refers to the number of parcels on which these conservation targets were located. "Area" is the total area of the parcels (which will usually be larger than the "Total" because there are often multiple land cover types within any given parcel).

Conservation Target	Total (ac)	Parcels	Area (ac)
Annual Grassland	26,039.9	275	53,536.3
Freshwater Emergent Wetland	1,581.1	296	44,624.2
Valley Foothill Riparian Forest	684.6	146	23,257.7
Wet Meadow	0.9	1	28.5
Tricolored Blackbird	2,777.6	20	7,873.0
California Tiger Salamander	2,003.4	24	8,932.0
Burrowing Owl	1,919.1	141	2,915.0
Aleutian Canada Goose	10.8	4	147.8
Swainson's Hawk	1,702.0	59	10,099.0
Valley Elderberry Longhorn Beetle	88.2	23	1,910.7
Elderberry Savanna	13.5	1	179.2
Western Pond Turtle	75.2	12	992.0
Delta Button-Celery	6.8	2	312.7
Hoary Bat	85.1	24	992.7
Vernal Pool Tadpole Shrimp	8,472.1	43	16,375.9
California Linderiella	5,060.9	24	8,273.9
Hardhead	215.5	17	1,549.3
Yuma Myotis	85.1	24	992.7
Colusa Grass	285.9	3	2,390.4
Riparian Woodrat	0.8	1	179.2
Nothern Hardpan Vernal Pool	3,532.1	20	9,546.1
San Joaquin Valley Orcutt Grass	242.1	2	946.4
Hartweg's Golden Sunburst	362.4	6	2,410.0
Riparian Brush Rabbit	0.8	1	179.2
Greene's Tuctoria	242.1	2	946.4
Great Valley Mixed Riparian Forest	40.5	2	312.7
Vernal Pools	15,520.4	77	31,074.2
Total		853	69,179.3

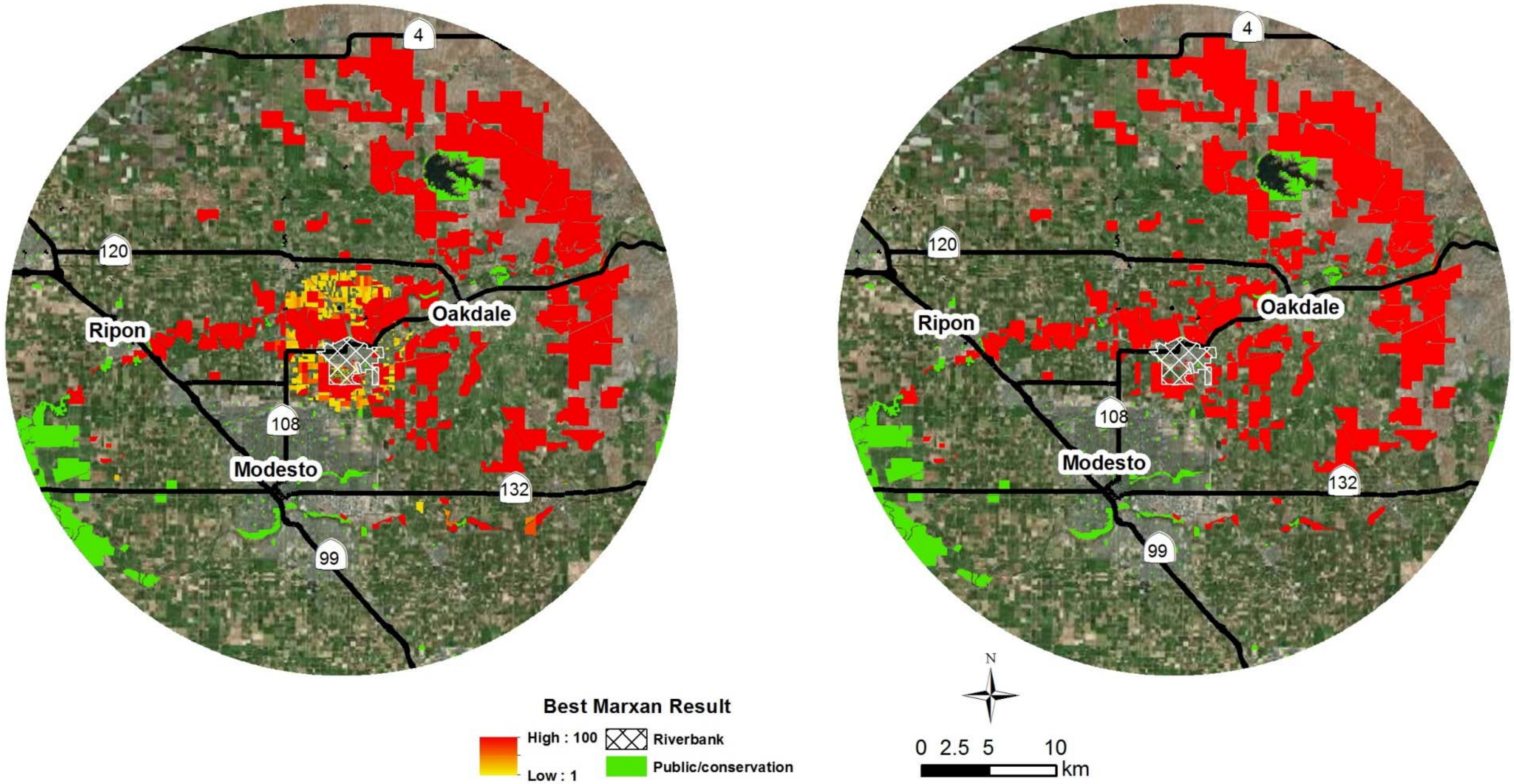

Figure 6. The largest "summed solution" score across the three scales of analysis for each parcel (left) and parcels that had a "summed solution" score of more than 75 in any of the scales of analysis (right). The map on the right represents the final linkage area.

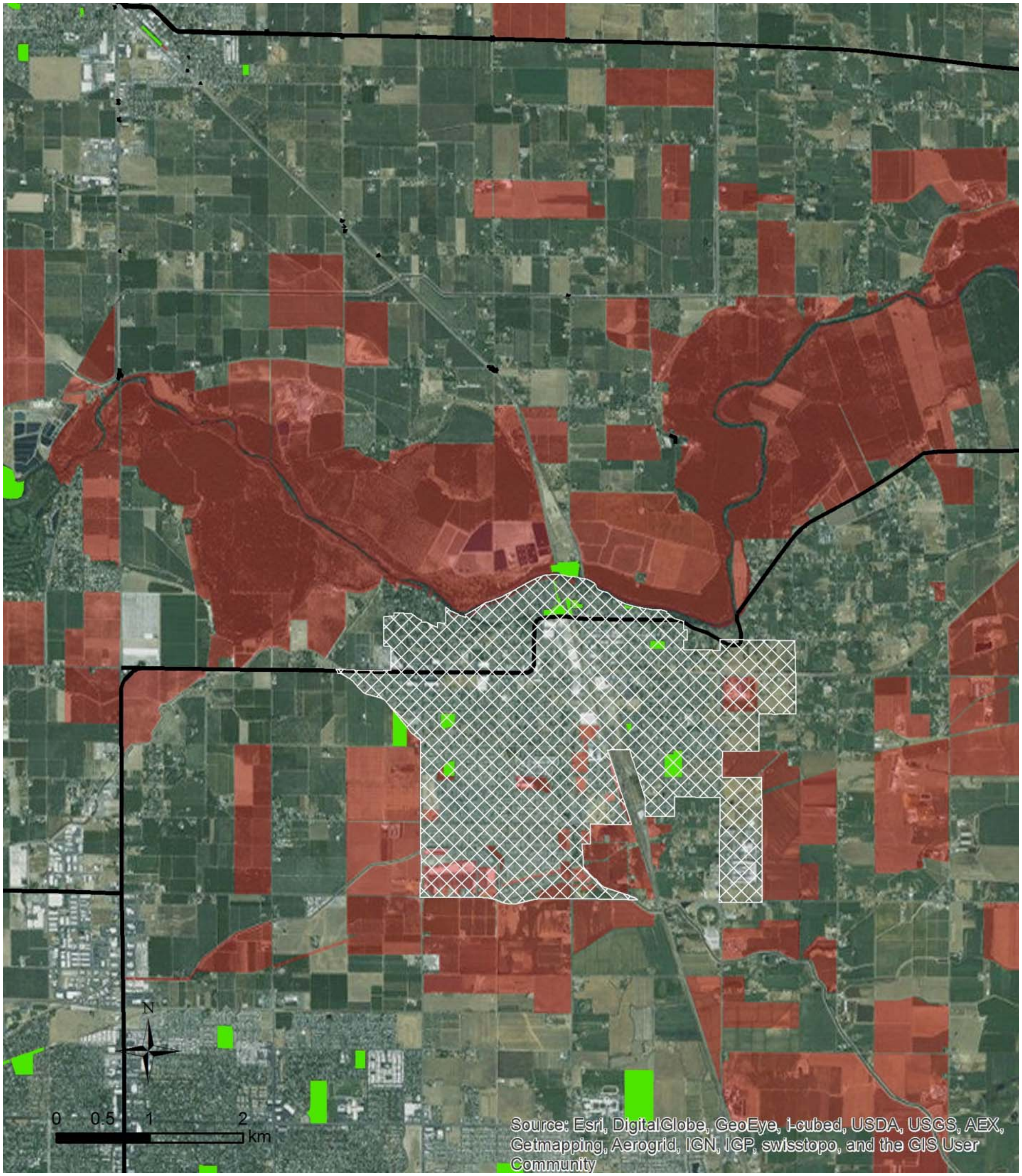

Figure 7. The previous map of selected parcels zoomed to the vicinity of Riverbank.

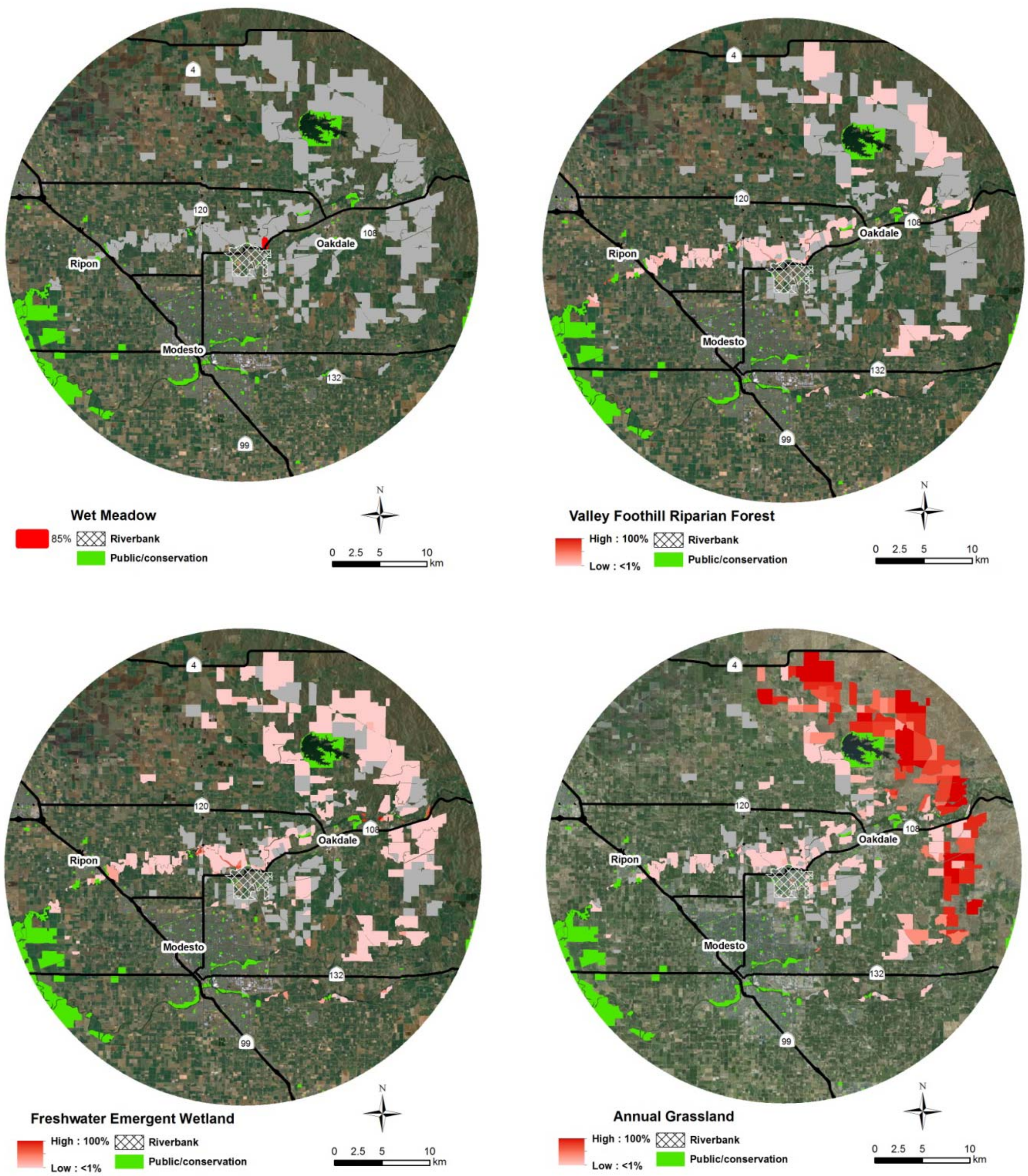

Figure 8. Conservation features in Marxan-selected parcels. The red color ramp indicates either the relative amount of that feature within a parcel (land cover) or the presence of that feature in a parcel (species-specific models). Gray polygons indicate parcels within the network identified by Marxan but lacking the specific conservation feature.

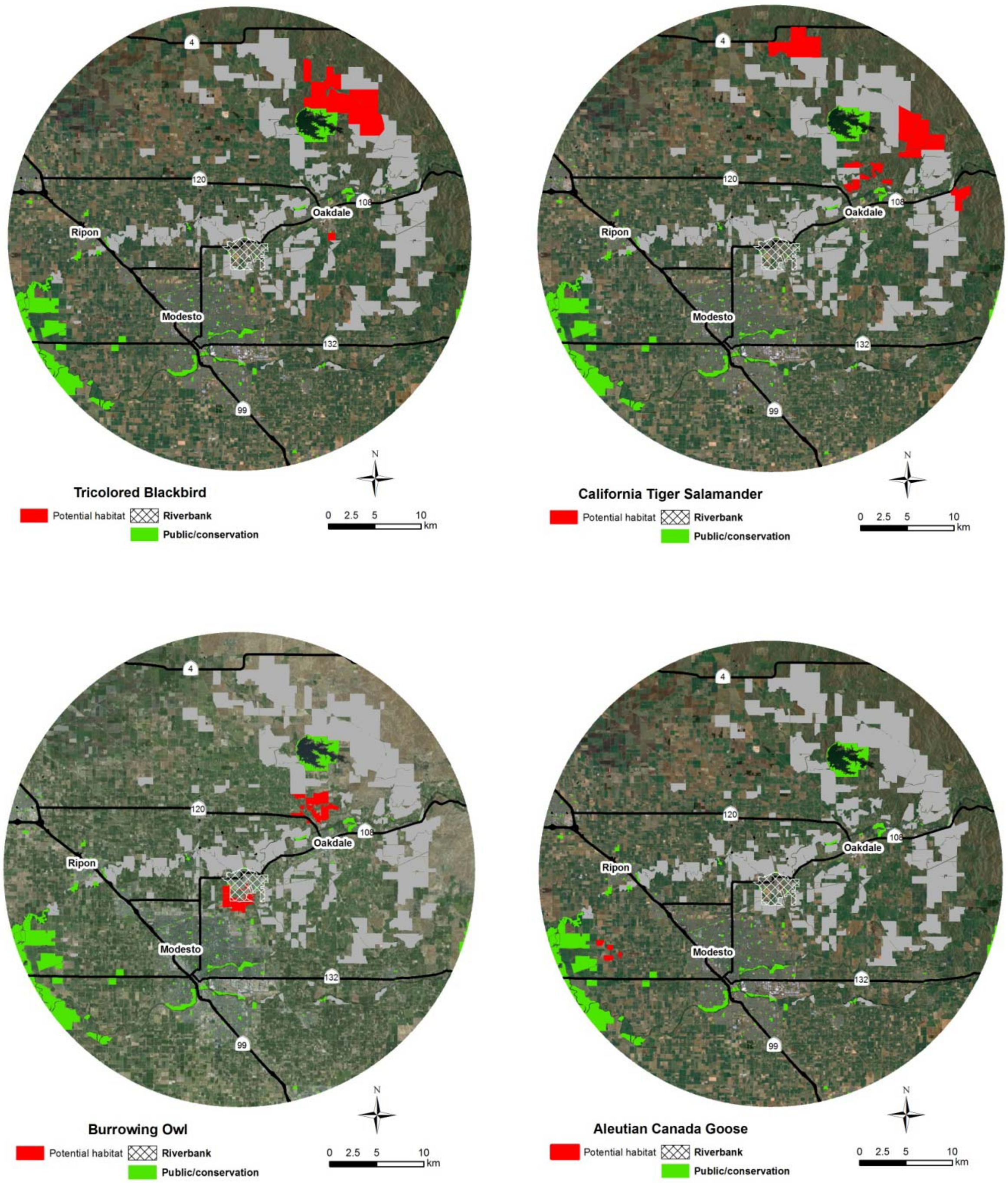

Figure 8. Continued.

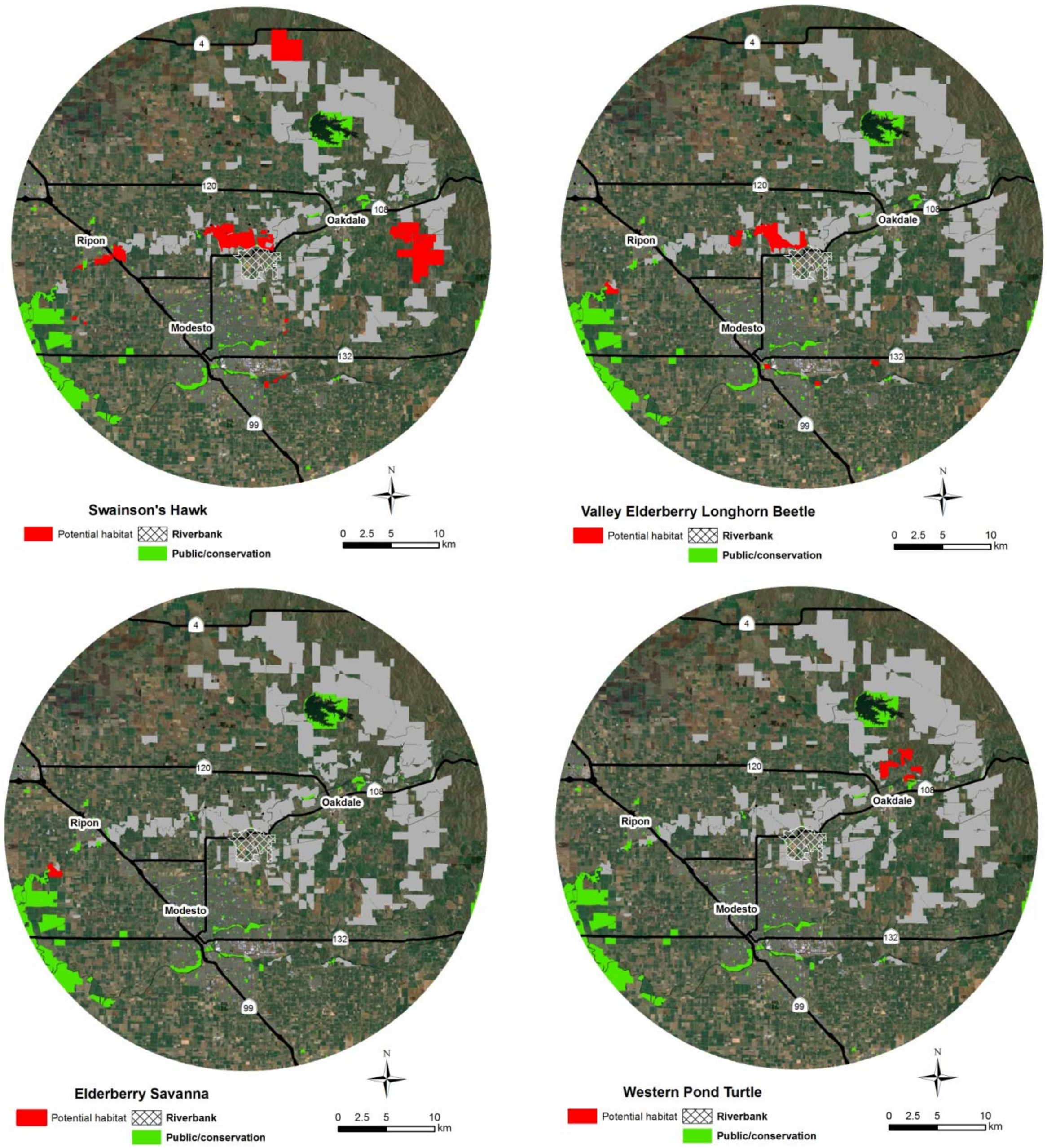

Figure 8. Continued.

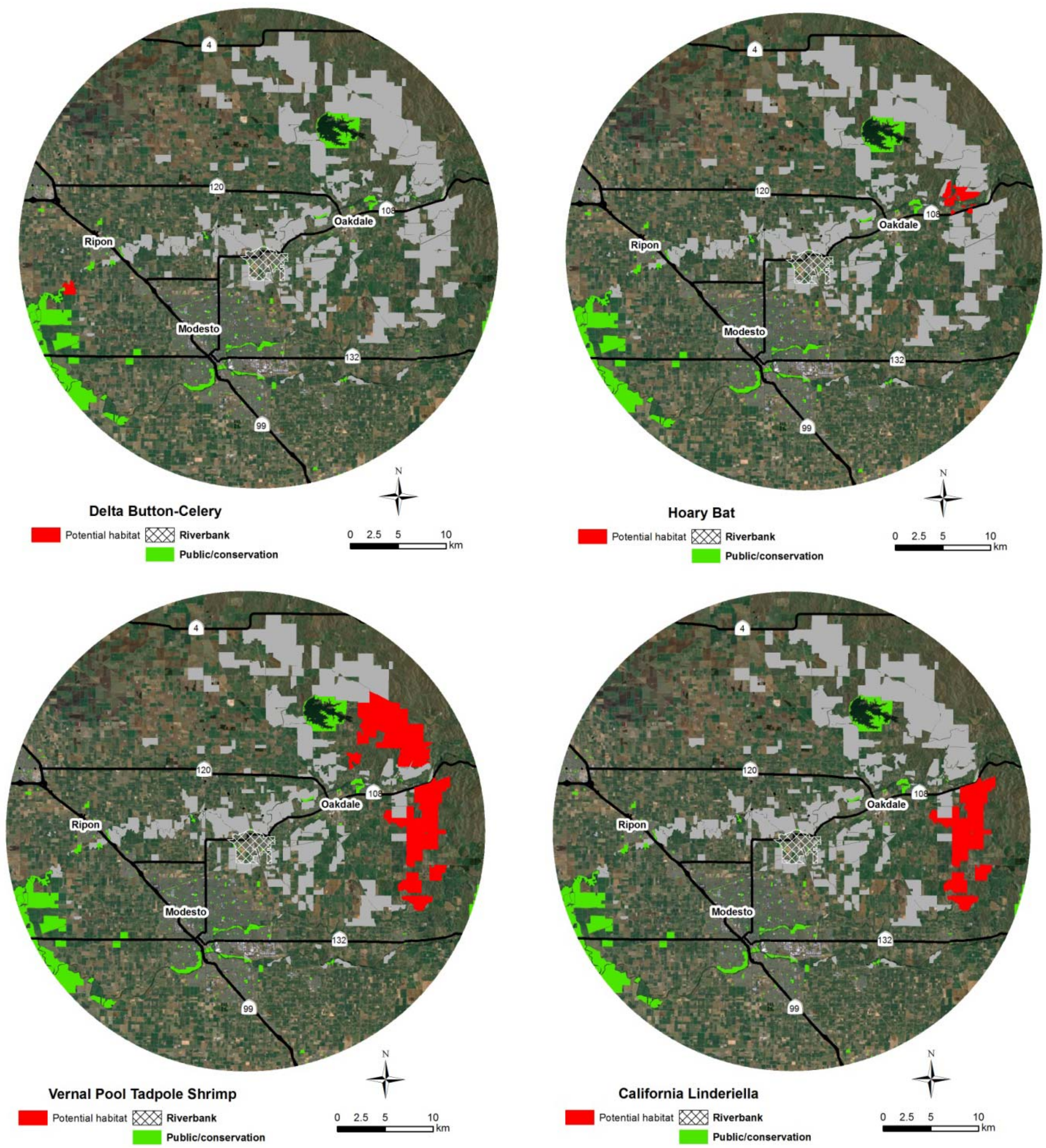

Figure 8. Continued.

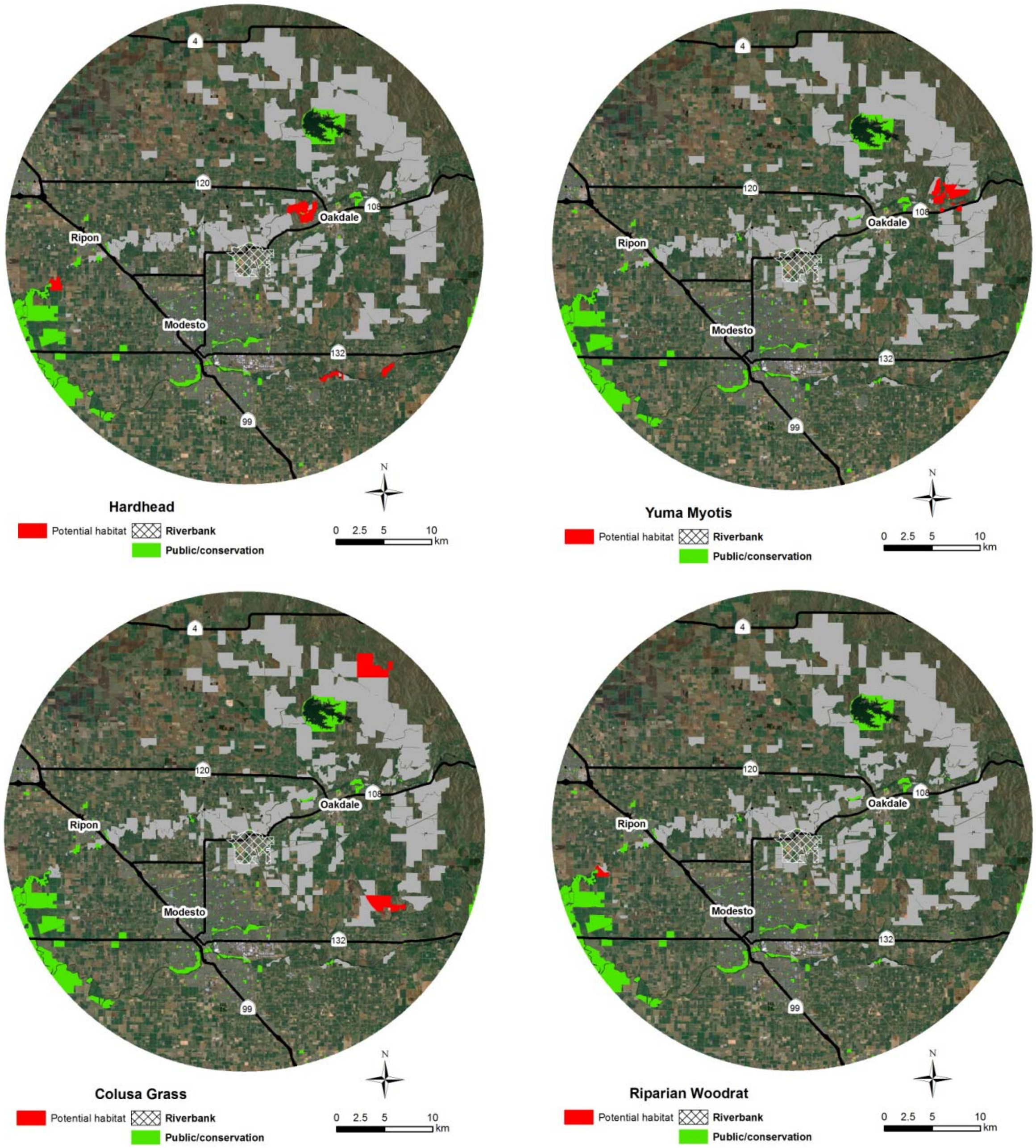

Figure 8. Continued.

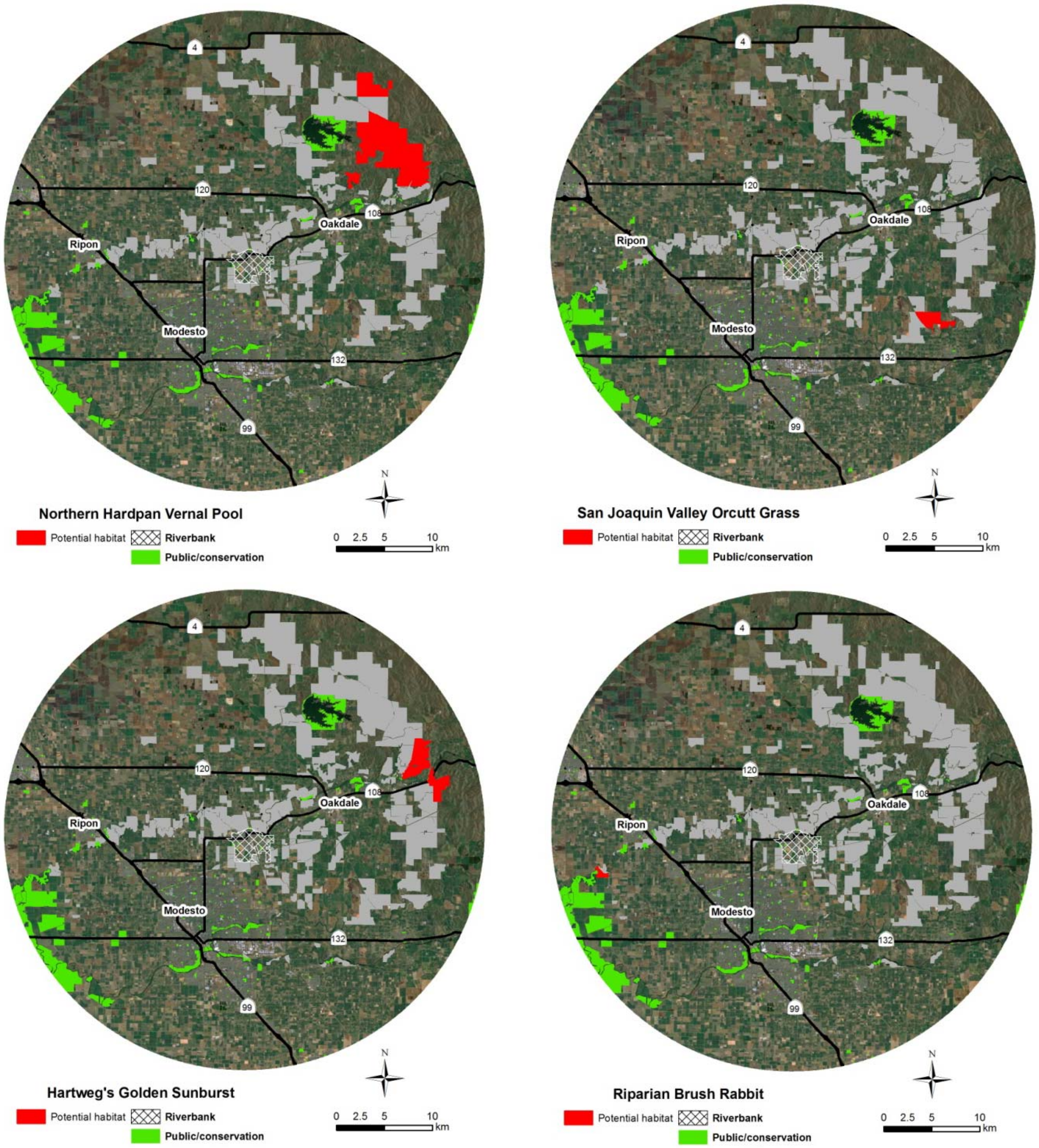

Figure 8. Continued.

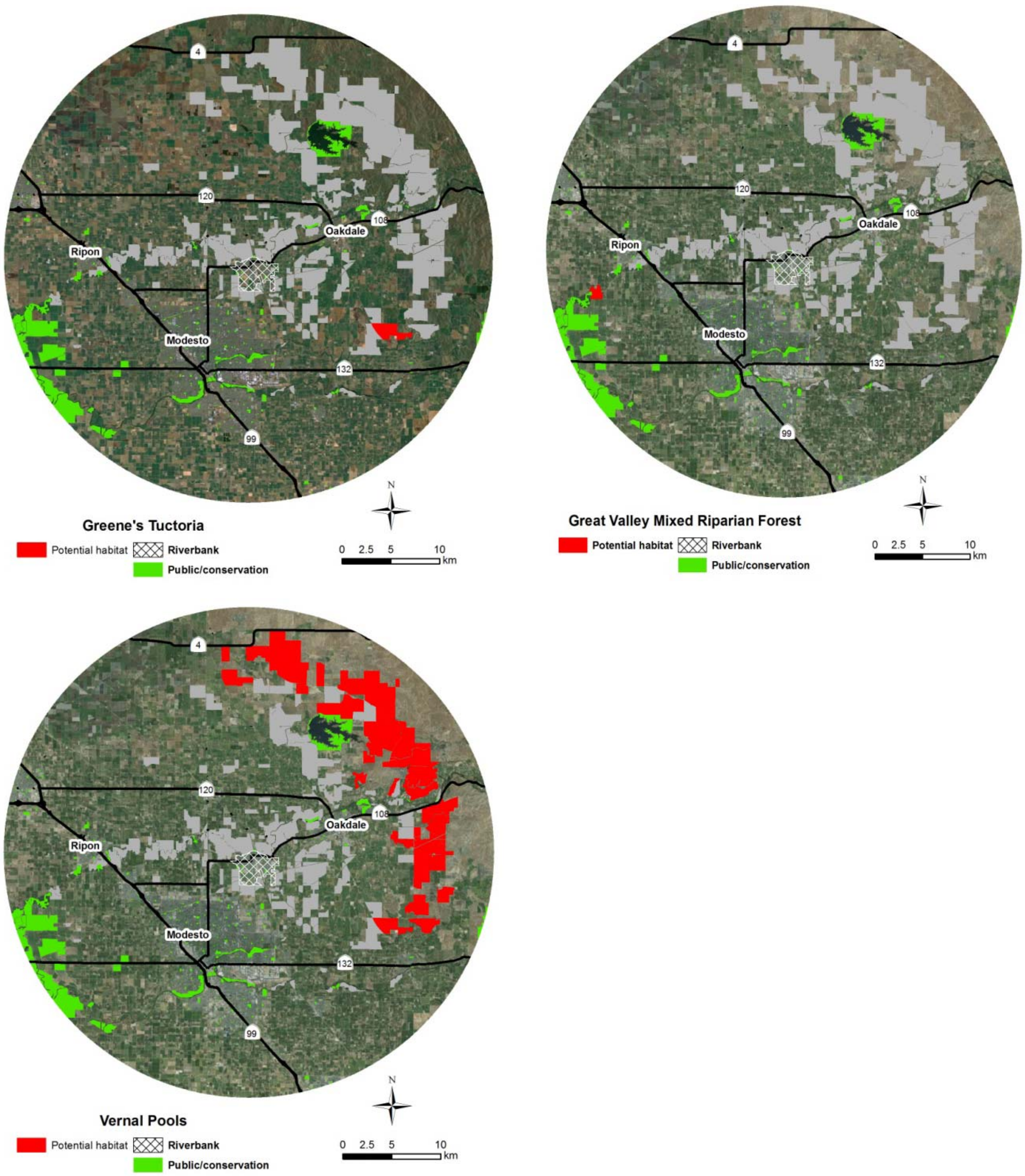

Figure 8. Continued.

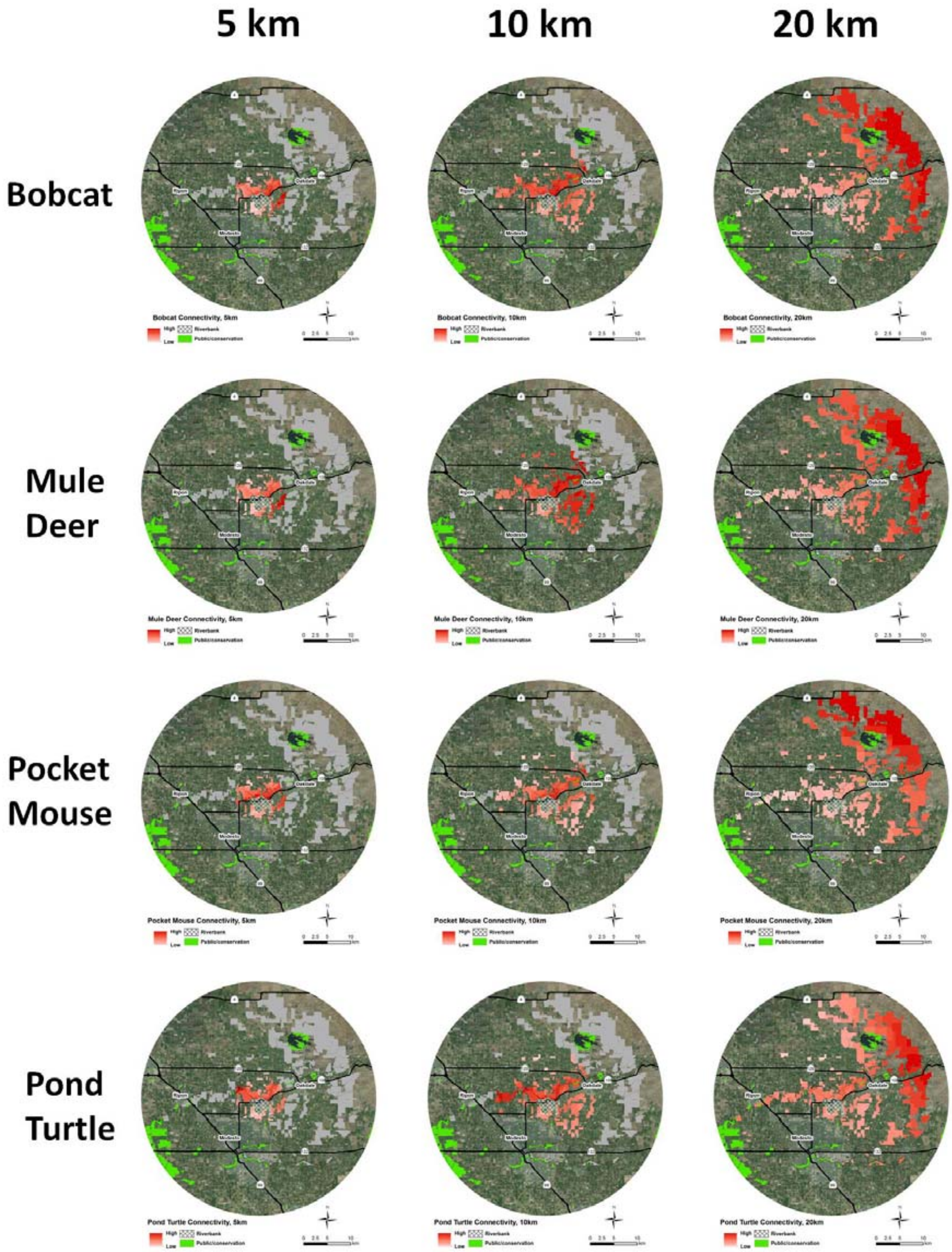

Figure 9. Modeled connectivity for four focal species at multiple spatial scales in Marxan-selected parcels. The red color ramp indicates the relative strength of the modeled connectivity in the parcels. Gray polygons indicate parcels within the network identified by Marxan but lacking the specific conservation feature.

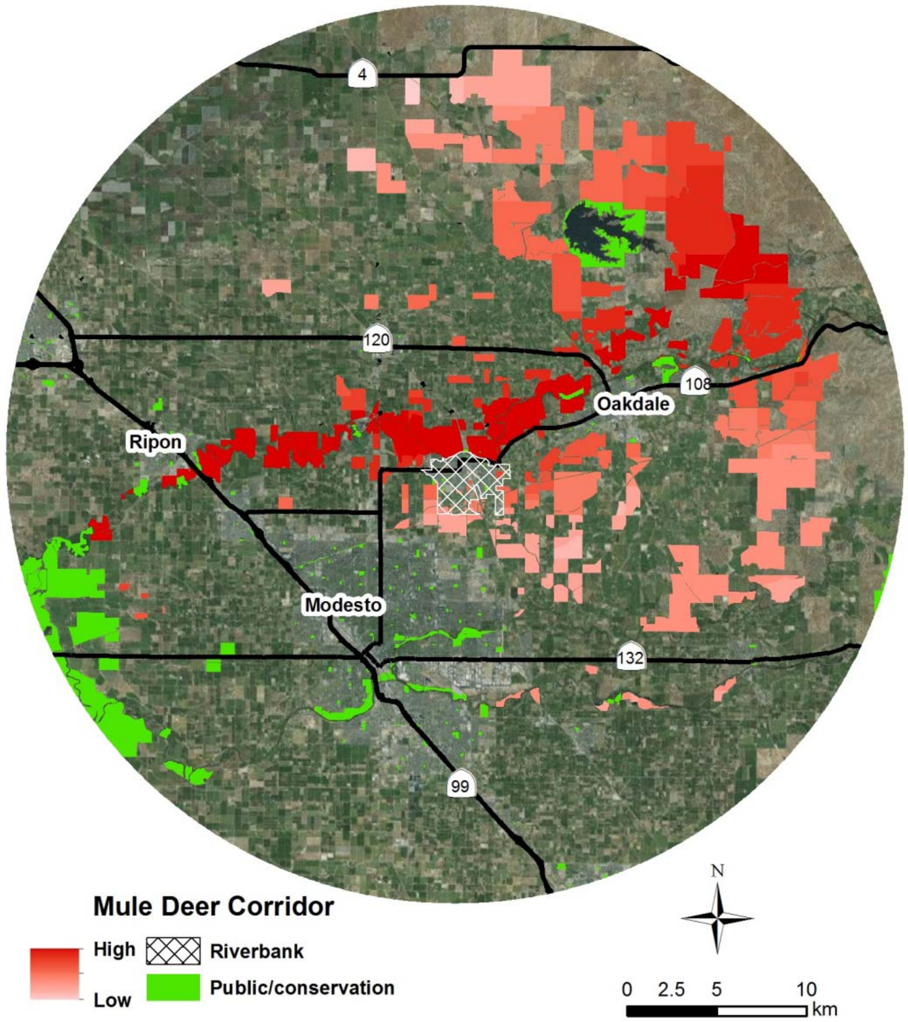

Figure 10. Modeled mule deer corridor results for Marxan-selected parcels. Darker red hues indicate areas of higher landscape connectivity between Stanislaus National Forest (east) and San Joaquin National Wildlife Refuge (west) (note: both of these protected areas are beyond the extent of this map and not depicted).

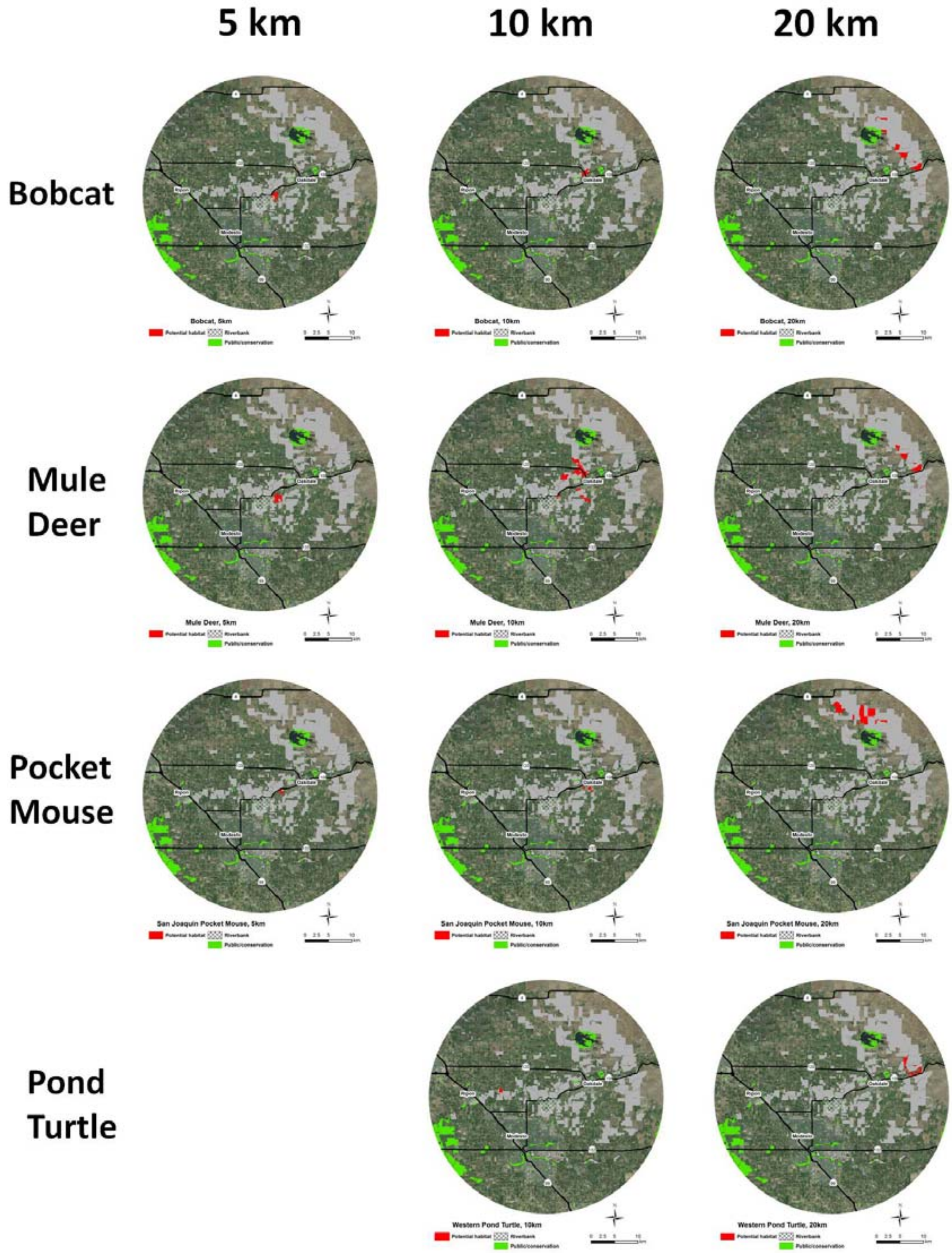

Figure 11. Connectivity areas. Parcels in red were not selected by Marxan to meet regional ecological goals. However, they have high modeled connectivity for the focal species at the indicated spatial scale. They should be considered for management of animal movement across the study region.

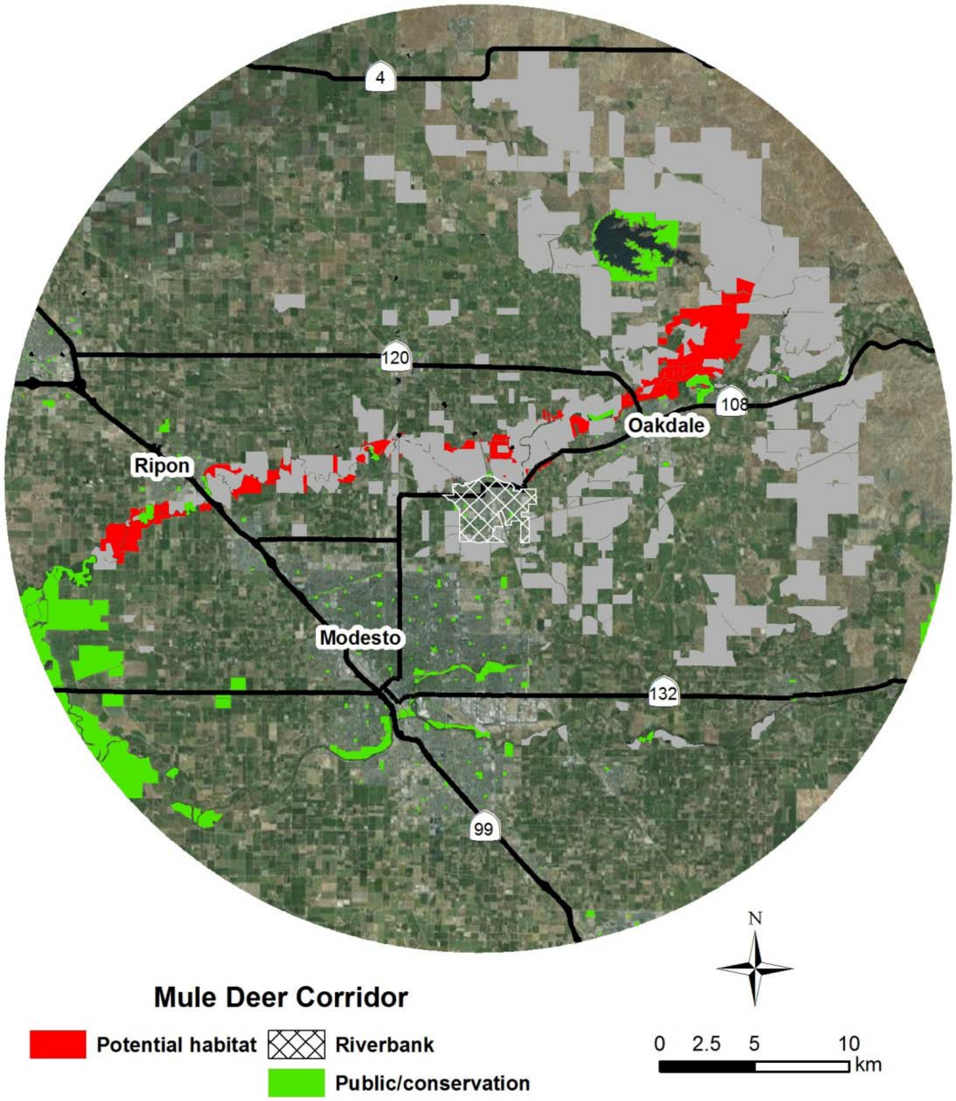

Figure 12. Mule deer corridor areas. Parcels in red were not selected by Marxan to meet regional ecological goals. However, they have high modeled connectivity for regional mule deer movement between the Sierra Nevada and San Joaquin River. They should be considered for management of animal movement across the study region.

LINKAGE DESIGN

The results of the Marxan and other analyses were compiled into a final linkage design (Figure 12). Three kinds of parcels are included: (1) Marxan-identified parcels that should be managed for preservation or restoration of one or more of the conservation targets used in the analysis; (2) those parcels that should be managed for the movement of one or more of the focal species; and (3) those to be managed for long-range movement patterns in order to provide regional connectivity. These are not intended as mutually exclusive management regimes, but rather as high priority considerations within a multi-pronged management strategys.

Some general descriptions of the first type of parcel follow:

Annual Grassland (AGS)

- Total: 26,040 ac
- Parcels: 275
- Total parcel area: 53,537 ac

AGS is the assessed land cover type with the greatest extent in the identified linkage. It is primarily found in the northeastern portion of the study area where the heavily agricultural San Joaquin Valley grades into rangeland at the lower edge of the Sierra Nevada foothills. The large grassland parcels should be considered for easement or fee title purchase to protect these relatively intact working landscapes from future conversion to land uses not compatible with the needs of native species. In addition to the large parcels here, smaller patches of AGS are found scattered across other portions of the linkage. These parcels should be considered for targeted grassland restoration projects in the future.

Freshwater Emergent Wetland (FEW)

- Total: 1,581 ac
- Parcels: 296
- Total parcel area: 44,624 ac

Parcels containing FEW are scattered throughout the linkage, with several near the Stanislaus River with higher densities. The wetlands in the linkage are generally small, comprising about 1/30th the area of the parcels in which they are embedded. Little of the study area was historically comprised of extensive wetlands (GIC 2003), so large-scale restoration is likely not a suitable strategy in the linkage. However, the existing small wetlands should be protected, new wetlands could be constructed (for example, tail water ponds in agricultural fields), and some restoration in the Stanislaus River floodplain should be undertaken to increase the habitat and ecosystem services that wetlands generally provide.

Valley Foothill Riparian (VRI)

- Total: 685 ac
- Parcels: 146
- Total parcel area: 23,258 ac

The riparian areas in the linkage are concentrated along the major rivers in the study area, especially the Stanislaus River. Several parcels along the Tuolumne River and several other smaller waterways in the study area were also identified and selected. The remnant patches comprising the small total riparian land cover should be preserved to maintain ecological health. There are also many restoration opportunities in the much greater area of the parcels which contain the fragmented riparian forest. The primary focus of these efforts should be in the floodplain of the Stanislaus River, where opportunities are greatest for successful remediation and regaining ecosystem processes such as animal movement east/west through the study area.

Wet Meadow (WTM)

- Total: 0.9 ac
- Parcels: 1
- Total parcel area: 28.5 ac

There is one parcel in the linkage that contains this land cover type. It is located just east of Riverbank on the south bank of the Stanislaus River. This parcel should be conserved as part of the river's floodplain ecosystem. Like FEW, there was likely little extensive WTM in this area historically, so restoration/creation of this habitat type should only be a priority in rare cases.

Tricolored Blackbird

- Total: 2,778 ac
- Parcels: 20
- Total parcel area: 7,873 ac

The tricolored blackbird is a sensitive species in California with recent studies showing a rapidly diminishing population (Ortiz 2014). Habitat for the species within the linkage is found primarily in the grasslands on larger parcels northeast of Woodward Reservoir. Smaller parcels are also found just south of Oakdale. This species can be compatible with agricultural operations if the timing of the operations takes into consideration the natural history of the blackbird. Agricultural easements could be pursued for these parcels as well as restoration projects designed to increase the numbers of insects serving as a food source for the birds.

California Tiger Salamander

- Total: 2,003 ac
- Parcels: 24
- Total parcel area: 8,932 ac

Potential salamander habitat is found on several large grassland parcels in the eastern portion of the study area as well as a number of smaller agricultural parcels in the vicinity of Oakdale. Easements or fee title should be acquired on the larger parcels, while grazing could still occur there. Protection and enhancement of salamander habitat on the smaller parcels will be more problematic. The greatest potential for salamander habitat on these parcels probably would occur if they are purchased and restored to a more natural habitat, such as grassland with embedded seasonal wetlands.

Burrowing Owl

- Total: 1,919 ac
- Parcels: 141
- Total parcel area: 2,915 ac

There are two clusters of potential burrowing owl habitat in the linkage: adjacent to Riverbank on the southwest, and just north of Oakdale. The pastureland near Riverbank represents suitable owl habitat most likely to come under threat by near future development, as it lies in the buffer area between Riverbank and Modesto. Easements (or fee title purchases) to secure this area as part of a linkage could also serve as an open space buffer between the two cities, sometimes referred to as "community separators" in planning literature. Many of the parcels containing owl habitat north of Oakdale are also potential California tiger salamander habitat. Grassland restoration projects on these parcels could serve to improve habitat for both species.

Aleutian Canada Goose

- Total: 11 ac
- Parcels: 4
- Total parcel area: 148 ac

This species was delisted in 2001 when its recovery was deemed sufficient, and so it is not a species of great concern in this region. Four agricultural parcels west of Modesto and south of Ripon contain a moderate amount of potential habitat for this species. Easements could be secured here to ensure future agricultural operations benefitting the goose and other species.

Swainson's Hawk

- Total: 1,702 ac
- Parcels: 59
- Total parcel area: 10,099 ac

There are four main clusters of parcels containing potential Swainson's hawk habitat in the linkage: (1) in the northern section adjacent to CA Highway 4; (2) southeast of Oakdale, along the Stanislaus River where it crosses CA Highway 99 near Ripon; (3) along the Stanislaus River immediately adjacent to Riverbank's northern border; and (4) several scattered parcels near the eastern edge of Modesto. Several strategies could be combined to preserve and/or enhance hawk habitat. These include securing easements to keep the identified parcels in agriculture production, specifically row and field crops and alfalfa. Additionally, valley oaks should be planted in these locations to provide future nesting sites in close proximity to the feeding habitat.

Valley Elderberry Longhorn Beetle

- Total: 88 ac
- Parcels: 23
- Total parcel area: 1,911 ac

The major concentration of parcels identified as possessing valley elderberry longhorn beetle (VELB) habitat lies along the Stanislaus River, immediately downstream from Riverbank. While only 88 acres of potential existing habitat were identified, the parcels containing the habitat total almost 2,000 acres. Therefore there may be favorable opportunities for riparian restoration on these sites in order to benefit VELB and other native riparian species. Other locations in the linkage with modeled VELB habitat include a smaller area along the Stanislaus River in the vicinity of Caswell Memorial State Park as well as a few sites along the Tuolumne River.

Elderberry Savanna

- Total: 14 ac
- Parcels: 1
- Total parcel area: 179 ac

There is only one parcel in the linkage identified as elderberry savanna, which is located adjacent to Caswell Memorial State Park. Elderberry savanna is especially critical for VELB, so preservation of this parcel (coupled with restoration activities on the majority of parcel that is in agricultural production) could provide a very beneficial extension to the riparian area currently protected at the state park. Other sites along the Stanislaus River could serve as restoration areas as well.

Western Pond Turtle

- Total: 75 ac
- Parcels: 12
- Total parcel area: 992 ac

While the linkage accounts for longer distance movement events by this species across the study region, known occurrences are limited to an area adjacent to the Stanislaus River just upstream of Oakdale. The parcels identified for the linkage include both riparian and upland areas that could potentially be used by the turtle. The turtle can potentially use water bodies that also serve agricultural purposes (such as tail water ponds); however agricultural activities in the uplands or in riparian areas could negatively affect the species. Therefore, these parcels should be considered for restoration activities.

Delta Button-Celery

- Total: 7 ac
- Parcels: 2
- Total parcel area: 313 ac

Delta button-celery requires wetland habitat associated with riparian systems. Modeled habitat for the species in the study region is only found on two parcels, adjacent to Caswell Memorial State Park. Habitat for the species should be preserved and enhanced through wetland restoration activities. These parcels also include VELB habitat, so restoration should be designed to include a mosaic of multiple kinds of riparian and wetland habitat.

Hoary Bat

- Total: 85 ac
- Parcels: 24
- Total parcel area: 993 ac

Parcels with modeled hoary bat habitat total almost 1,000 acres along the Stanislaus River, just east of Oakdale. Steps that could be taken to preserve this species in the linkage include the creation of patches of large trees, such as riparian forest or valley oak woodland. The bats require larger trees for cover and reproduction. The creation of a patchy or open structure would allow for both cover and foraging opportunities on these parcels. Trees will take a number of years to mature; therefore artificial bat houses could be installed in this area until such time as the trees are usable by the bats.

Vernal Pool Tadpole Shrimp

- Total: 8,472 ac
- Parcels: 43
- Total parcel area: 16,376 ac

Vernal pool tadpole shrimp are found on large parcels in the grasslands on the eastern edge of the study region. Much of this area could be managed for grazing that takes into consideration the needs of this and other vernal pool species (Marty 2005). If there are locations with exceptional quality or density of vernal pools containing tadpole shrimp, they could be purchased to ensure focused management on ecosystem health. Otherwise easements could serve to ensure that vernal pool habitat would not be lost to future development.

California Linderiella

- Total: 5,061 ac
- Parcels: 24
- Total parcel area: 8,274 ac

Parcels selected for potential California Linderiella (or California fairy shrimp) habitat overlaps the southern portion of the vernal pool tadpole shrimp parcels. These are found in the eastern portion of the study region, south of the Stanislaus River. Management suggestions are the same as for vernal pool tadpole shrimp (above).

Hardhead

- Total: 216 ac
- Parcels: 17
- Total parcel area: 1,549 ac

Parcels containing potential hardhead habitat were identified along both the Stanislaus and Tuolumne rivers. For most effective conservation, these parcels should be purchased to allow for restoration or habitat enhancement activities at these sites. Such activities could include riparian vegetation enhancement or augmentation of substrate used by the fish as spawning habitat.

Yuma Myotis

- Total: 85 ac
- Parcels: 24
- Total parcel area: 993 ac

Parcels with modeled Yuma myotis habitat total almost 1,000 acres along the Stanislaus River, just east of Oakdale. Steps that could be taken to preserve this species in the linkage include the creation of patches of large trees, such as riparian forest or valley oak woodland. The bats require larger trees for cover and reproduction. The creation of a patchy or open structure would allow for both cover and foraging opportunities on these parcels. Trees will take a number of years to mature; therefore artificial bat houses could be installed in this area until such time as the trees are usable by the bats.

Colusa Grass

- Total: 286 ac
- Parcels: 3
- Total parcel area: 2,390 ac

Colusa grass is potentially found on three parcels in two locations in the linkage. One is a single parcel northeast of Woodward Reservoir in the eastern grasslands. To ensure preservation of the site, purchase of the parcel is likely the preferred strategy. The other location is just north of the town of Waterford. Only portions of the two parcels remain in a natural condition, so purchase combined with habitat restoration or creation should be considered.

Riparian Woodrat

- Total: 0.8 ac
- Parcels: 1
- Total parcel area: 179 ac

Modeled habitat for the riparian woodrat is found on a single parcel in the linkage. This parcel is adjacent to Caswell Memorial State Park and is also the site of potential habitat for several other target species (such as riparian brush rabbit and VELB). This parcel should be purchased in order to protect and expand the riparian forest serving as habitat for multiple sensitive species.

Northern Hardpan Vernal Pool

- Total: 3,532 ac
- Parcels: 20

- Total parcel area: 9,546 ac

Several thousand acres of northern hardpan vernal pool complex is found in the northeastern grasslands, approximately between Woodward Reservoir and CA Highway 120. Conservation easements can be used to protect these areas from future development while still allowing grazing to occur that can benefit these ecosystems.

San Joaquin Valley Orcutt Grass

- Total: 242 ac
- Parcels: 2
- Total parcel area: 946 ac

San Joaquin Valley orcutt grass is potentially found on two parcels near the town of Waterford. Colusa grass and Greene's tuctoria are also potentially found here. The very limited nature of the habitat for this species in this region suggests purchase of the parcels in question in order to conduct restoration activities and better ensure management practices to protect and enhance the species.

Hartweg's Golden Sunburst

- Total: 362 ac
- Parcels: 6
- Total parcel area: 2,410 ac

Potential habitat for this species is limited to several hundred acres in the eastern grasslands, straddling CA Highway 120. Both the location (adjacent to the highway) and the limited area of the species in the region suggest purchase of the properties as a preferred conservation strategy. Natural habitat could be protected and agricultural land restored to grassland and possibly valley oak woodland.

Riparian Brush Rabbit

- Total: 0.8 ac
- Parcels: 1
- Total parcel area: 179 ac

Modeled habitat for the riparian woodrat is found on a single parcel in the linkage. This parcel is adjacent to Caswell Memorial State Park and is also the site of potential habitat for several other target species (such as riparian woodrat and VELB). This parcel should be purchased in order to protect and expand the riparian forest serving as habitat for multiple sensitive species.

Greene's Tuctoria

- Total: 242 ac
- Parcels: 2
- Total parcel area: 946 ac

Greene's tuctoria is potentially found on two parcels near the town of Waterford. Colusa grass and San Joaquin Valley orcutt grass are also potentially found here. The very limited nature of the habitat for this species in this region suggests purchase of the parcels in question in order to conduct restoration activities and better ensure management practices to protect and enhance the species.

Great Valley Mixed Riparian Forest

- Total: 40.5 ac
- Parcels: 2
- Total parcel area: 312.7 ac

While riparian forest fragments exist in various locations throughout the study area, this particular community is found only in two parcels, adjacent to Caswell Memorial State Park. See the description above for Valley Foothill Riparian for more details on suggested management options.

Vernal Pools

- Total: 15,520.4 ac
- Parcels: 77
- Total parcel area: 31,074.2 ac

This land cover type refers to extensive vernal pool complexes rather than just vernal pools themselves. These are found across the eastern portion of the study area. Conservation easements can be used to protect these areas from future development while still allowing grazing to occur that can benefit these ecosystems.

Connectivity

Linkage parcels not specifically selected for the above ecological features were identified in order to be managed for landscape connectivity within the study area. There are numerous management actions that could support this strategy. Parcels could be purchased and restored to a more natural condition in order to encourage movement between suitable habitats. Alternatively, easements could be obtained and parcels could be managed to reduce wildlife conflicts and/or strategic implementation of small-scale restoration activities could be planned that, while not returning the parcel to a fully natural condition could provide an increased selection of ecological resources. A potential example is the installation of small ponds or other water features to facilitate the movement of western pond turtles. Alternatively, small pockets of valley oak or other native tree species could be planted to provide temporary cover for mule deer or bobcat moving across a parcel.

One crucial need in managing for connectivity lies in designing road crossings that are suited to the particular species in the region. There are several critical locations where crossings should be carefully planned and constructed in order for the linkage to function as successfully as possible. CA Highway 120 just north of Oakdale will need a crossing structure for east-west connectivity through the study area to be maximized. This same highway will need a crossing structure east of Oakdale as well if the two major grassland patches are to be fully connected. CA Highway 108 just east of Riverbank also presents a barrier to movement between the Stanislaus River and the pasture lands east of the city.

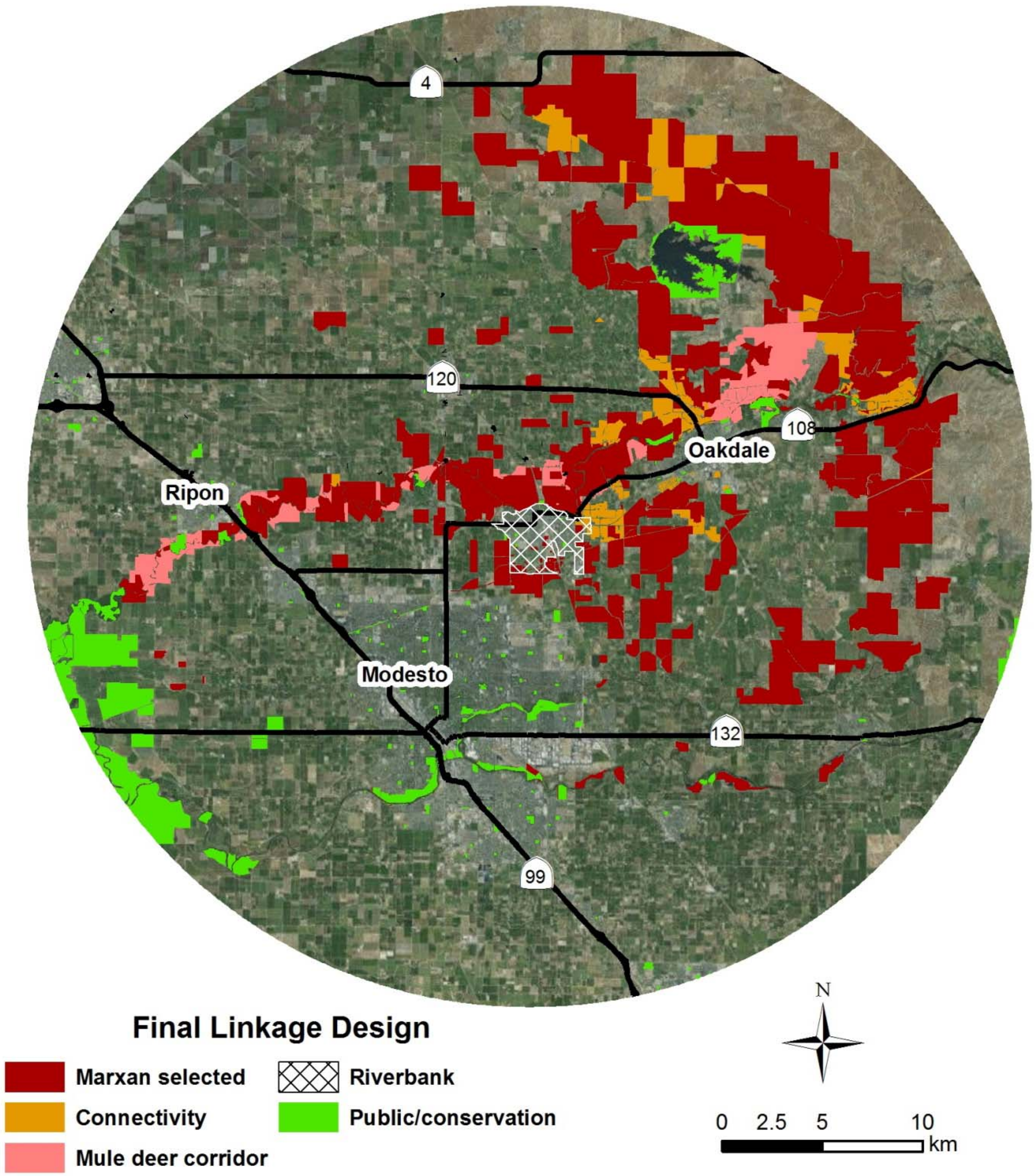

Figure 13. Final linkage design. The four components are: (1) existing public/conservation land; (2) parcels selected by the Marxan analysis; (3) parcels with high connectivity scores not selected by Marxan; and (4) parcels with a high score for the regional mule deer corridor but not selected by Marxan.

Conclusions and Next Steps

The linkage design identified in this study is unique in that landscape connectivity was incorporated in all stages of the ecological assessment process, not in the latter stages as is typically the case. Most designs such as this identify ecological core areas, and then evaluate connectivity between them. However, in working landscapes such as this, there may not be large, relatively intact core areas. Efforts to assess patterns of landscape connectivity may need to occur early in the process in order to identify management strategies that may be most effective in protecting and restoring ecosystem patterns and processes in a region. The linkage design presented in this study represents a hypothesis concerning the most effective strategies for this kind of landscape, which will become increasingly more common as global human resource demands increase over the coming decades.

Another important feature of this design is the effort made to incorporate multiple spatial scales in the plan. Ecosystem patterns and processes occur at many spatial scales and important features may be overlooked and potentially lost if these multiple scales are not taken into consideration. These scales are focused around Riverbank, with the northern edge of the city lying at the center of the 5, 10, and 20 km radii circular zones used in the analysis. If this same kind of analysis were undertaken for the cities of Oakdale or Modesto, we would expect there to be some incongruence in the resulting linkage design due to a change of focus from the vicinity of Riverbank to that of another location. The effects of scale and location should be taken into consideration if similar planning efforts are undertaken in overlapping but non-identical areas.

The regional nature of the linkage design will probably require a coalition of local governments, state and federal agencies, and private non-governmental organizations to move implementation forward. As there were a variety of ecological features considered during planning of the linkage model, so too will there need to be a variety of complementary management strategies. If such a coalition could be formed leading to the implementation of a linkage such as that detailed here, the ecological condition of the region should be preserved and enhanced in the coming decades. One possibility is integrating this information into a regional habitat conservation plan (HCP; under the federal ESA) and Natural Community Conservation (NCCP) planning process. The northern portion of the study area, north of the Stanislaus River, is largely covered by an HCP in San Joaquin County; however, currently there is no HCP or NCCP in Stanislaus County. Recently, a new program has been established to use the state cap-and-trade program's revenue to fund 'community separator' greenbelts for preservation of farmland between cities to limit urban sprawl and encourage compact urban growth and in-fill development (White 2014). The research presented in this study shows that existing agricultural land between the cities of Riverbank and Modesto, and Riverbank and Oakdale, meet these criteria and could contribute to agricultural land preservation and ecological connectivity functions. When these funds become available the CDFW could assist and encourage local municipalities (cities and counties) to utilize these funds for both agricultural and ecological functions.

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