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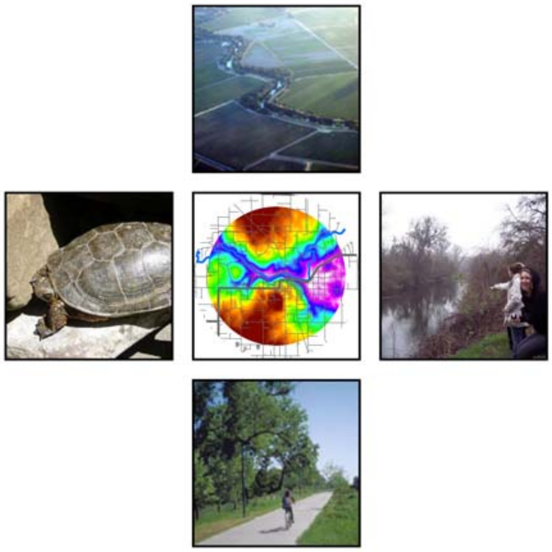

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I. Acknowledgements

We would like to thank the Wildlife Conservation Society and Defenders of Wildlife for their generous financial support of this project. Special thanks to the University of California, Davis, Department of Environmental Science and Policy and the Department of Environmental Design for their administrative support and facilities. This project evolved out of helpful discussions among UC Davis scientists/authors of the present study and South Coast Wildlands; Adina Merenlender (UC Berkeley); Sarah Reed (Colorado State University); Conservation Biology Institute; Defenders of Wildlife; California Department of Transportation; and California Department of Fish and Game.

II. Executive Summary

The Safe Passages project is a collaboration between scientists at UC Davis and non-governmental conservation organizations (Defenders of Wildlife, Conservation Biology Institute, and South Coast Wildlands), in consultation with state agencies (California Departments of Transportation and Fish and Game), and is intended to encourage the inclusion of habitat connectivity planning and protection in local and regional planning in support of the State Wildlife Action Plan. It was designed to be a model effort, with relevance to regions struggling with finding ways to conserve wildlife and natural processes in the face of development. One major ecological process at risk is isolation of wildlife populations and reduction of the permeability of the landscape to wildlife movement. The project draws upon contemporary scientific understanding of wildlife movement, physical connections on landscapes, and land-use and transportation planning in order to better fit development patterns to the needs of natural processes, especially wildlife movement.

As its name implies, the project addresses the need for finding safe passage for wildlife movement through the diverse regions of California. Two philosophical choices were made in designing this project: 1) wildlife movement is not limited to managed reserves and corridors, but may also occur in the non-natural landscape matrix, and 2) that local and regional planners can become aware of and be included in the process of conserving connectivity. In the first case, the computer modeling that was done in this project was based on the idea that wildlife might originate their movement from anywhere and move in the least-costly direction. This results in a surface of possible wildlife movement based on habitat preference and barriers to safe passage. In the second case, planners in the San Joaquin Valley Blueprint process learned of our overall project goals and methods and a number of cities or counties expressed interest in working with us. We chose the city of Riverbank, in part because the community development director showed clear interest in using the products of our work in the General Planning and Specific Planning processes.

This project has evolved to include more ideas and potential partners, including the California Department of Fish and Game (DFG), the Local Government Commission, and other academic researchers. This evolution has extended our project horizon indefinitely with a combination of a DFG contract and collaborative proposal development. However the main project goal of setting the standard for how connectivity can be included in local and regional planning has stayed constant. Our partners will help us develop a sea change in the recognition and protection of safe passages for wildlife movement throughout California's San Joaquin Valley and beyond.

III. Introduction

The Safe Passages project, launched in 2008, is a collaborative effort to advance the concepts, planning, and implementation of wildlife connectivity for the state of California. It is comprised of both university researcher groups and conservation NGOs working closely with state agencies. Initial funding for the Safe Passages project has been provided by the Wildlife Conservation Society (with forthcoming matching funds from the California Department of Fish and Game – "DFG") to support the implementation of the State Wildlife Action Plan (SWAP) as well as Caltrans' compliance with requirements of federal transportation legislation. One of the SWAP recommendations and priorities was for wildlife connectivity to be incorporated into statewide, regional, and local planning processes (Bunn et al. 2007).

Several actions were undertaken to achieve the goals of the project. The first project component was the hosting of a two-day statewide forum on habitat connectivity planning in California. This forum brought together scientists, managers, and policy makers from all of the ecoregions of the state in order to share information and chart some next steps for connectivity planning and implementation in California. A suite of speakers presented on a variety of connectivity-centered topics. This was followed by several breakout sessions focused on both ecoregion-specific and thematic wildlife connectivity issues. The forum speakers were video-taped and compiled into a three DVD box set along with a CD of PDF documents of each slide show.

The second major action associated with Safe Passages 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 due to 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 achieve the incorporation of connectivity planning results into city and county general plans, the primary policy vehicles implementing land use changes.

Policy Framework

The Safe Passages project took place at two spatial scales. We first contacted and presented to the San Joaquin Valley Blueprint Steering Committee. The San Joaquin Valley Blueprint (http://www.valleyblueprint.org/) is a collaborative visioning and planning process comprised of over 60 groups, assembled through the Council of Governments in each of the eight San Joaquin Valley counties. The Blueprint is an on-going effort to address the potential conflicts between rapid human population growth and the region's agriculture, natural resources, and local government services. The University of California, Davis has been providing technical and other support to the Blueprint planning group. Safe Passages team members who are also UC Davis researchers requested time to present to the Blueprint planning group, and two presentations were scheduled.

We presented the concepts of the Safe Passages project on two occasions (one a video conference with the Blueprint Steering Committee on March 17, 2009, and the other in Fresno to the San Joaquin Valley Professional Planners Group on May 9, 2009, attended by about 50 people). We subsequently polled the audience of the second meeting, and requested that local government representatives interested in the ideas identify themselves to us. Eight city and county government groups expressed interest in the initiative. We selected one, the city of Riverbank, to work with for the second phase of this project. This selection was based on our perception of the feasibility for a successful integration of the Safe Passages project's goals with the local land use planning process. tour reasoning was informed by the local regulatory and managerial context (e.g. government personnel, enthusiasm, etc.) along with the presence of high quality ecological resources proximate to the city of Riverbank.

The Safe Passages team initiated a series of meetings and analyses with the city of Riverbank (Figure 1), coordinated by Riverbank's community development director, James Hightower, who participated in the Blueprint planning group meeting. The first meeting between the Safe Passages group and Riverbank's planning department and parks department personnel took place in Riverbank, on October 9, 2009. The planning department personnel expressed interest in the possibility of using wildlife connectivity planning as a way to help promote the sustainable development and attractiveness of the city to tourists on their way to and from Yosemite National Park. Mr. Hightower subsequently invited the group to return and present to the city Planning Commission.

On November 18, 2009, the Safe Passages group returned to Riverbank to present to the evening meeting of the Planning Commission. This group also expressed interest in the ideas presented, and directed Mr. Hightower to continue working with the Safe Passages team. The Commission also agreed to have a city council resolution put forward, stating their interest in the initiative. This resolution was subsequently passed by the city council.

During the meetings with Riverbank representatives, it emerged that they were very interested in using the natural and undeveloped area along the Stanislaus River as a way to improve the quality of life for residents and to attract environmentally-minded tourists traveling to and from Yosemite National Park. In preliminary regional assessments, the Safe Passages team had also identified the Stanislaus River as a major geographic feature which could be benefit wildlife movement if managed appropriately. Several other ideas were presented at the meeting, including the development of a circum-city greenbelt and the development of designated bicycle lanes and green spaces within the city.

To augment our relationship with the city of Riverbank we recruited a representative from the Local Government Commission (LGC) to help us identify funding opportunities to implement some ideas generated from the project. The LGC member, Laura Podolsky, attended the evening Planning Commission meeting. She indicated that her group is also looking for opportunities to collaborate on wildlife connectivity issues. We all discussed the possibility of focusing on the Stanislaus River from its emergence from the Sierra Nevada and Tulloch Reservoir to the east, to its confluence with the San Joaquin River, some 50 miles to the west. Implementation of conservation along this stretch would require the joint planning of multiple municipal jurisdictions, including Ripon, Riverbank, and Oakdale, as well as Stanislaus County and potentially San Joaquin County.

A subsequent presentation in Riverbank took place on the evening of February 8, 2010, when several team members outlined the goals and analyses-to-date of the Safe Passages project to the city council. The Council also expressed interest in collaboration with the team, and directed Mr. Hightower to continue his efforts to integrate wildlife connectivity and open space planning for the city.

The remainder of this report details material presented to the Riverbank Planning Commission and city council in conjunction with associated modeling outputs.

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). Previous to European settlement, the valley floor was well connected to the foothills and Sierra Nevada mountains through natural community linkages, and thus constituted 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. This region now generates half the gross value of California's agricultural production, and ranks fourth in the country with respect to the number of people involved in farming, forestry, and fishing. Historically it has been known strictly as an agricultural center, but as housing and population pressure in California's coastal regions has increased, the human population of the SJV region has increased and pressure on its resources has intensified. In the next 35–40 years, 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.

Riverbank is an incorporated city 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 since post-Gold Rush agricultural production commenced. Currently approximately 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 (Figure 2). The Stanislaus River is a major ecological feature of the area and one of the major components of the Riverbank open space and recreational system – Jacob Myers Park – is located within the riparian zone (Figure 1). The river's headwaters begin in the Sierra Nevada mountains (east of the San Joaquin Valley) and ends at the confluence with the San Joaquin River approximately 25 km west of the city.

What is 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 "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, determined by an animal's perception, vagility, and life history requirements. 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 occur, generally 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 once every several generations. These various types of movement, coupled with inter-species biological differences, result in numerous ways to measure a landscape's connectivity.

Management for landscape connectivity often focuses on planning and implementation of wildlife "corridors" or "linkages" (Dobson et al. 1999, Bennett 2003). These linear features are designed to enable animal (and plant propagule) movement between larger "core" habitats. While these ecological network components often fulfill important conservation management roles, they do not describe the entirety of animal movement across a landscape. While a designated corridor might delineate an area with a greater number of

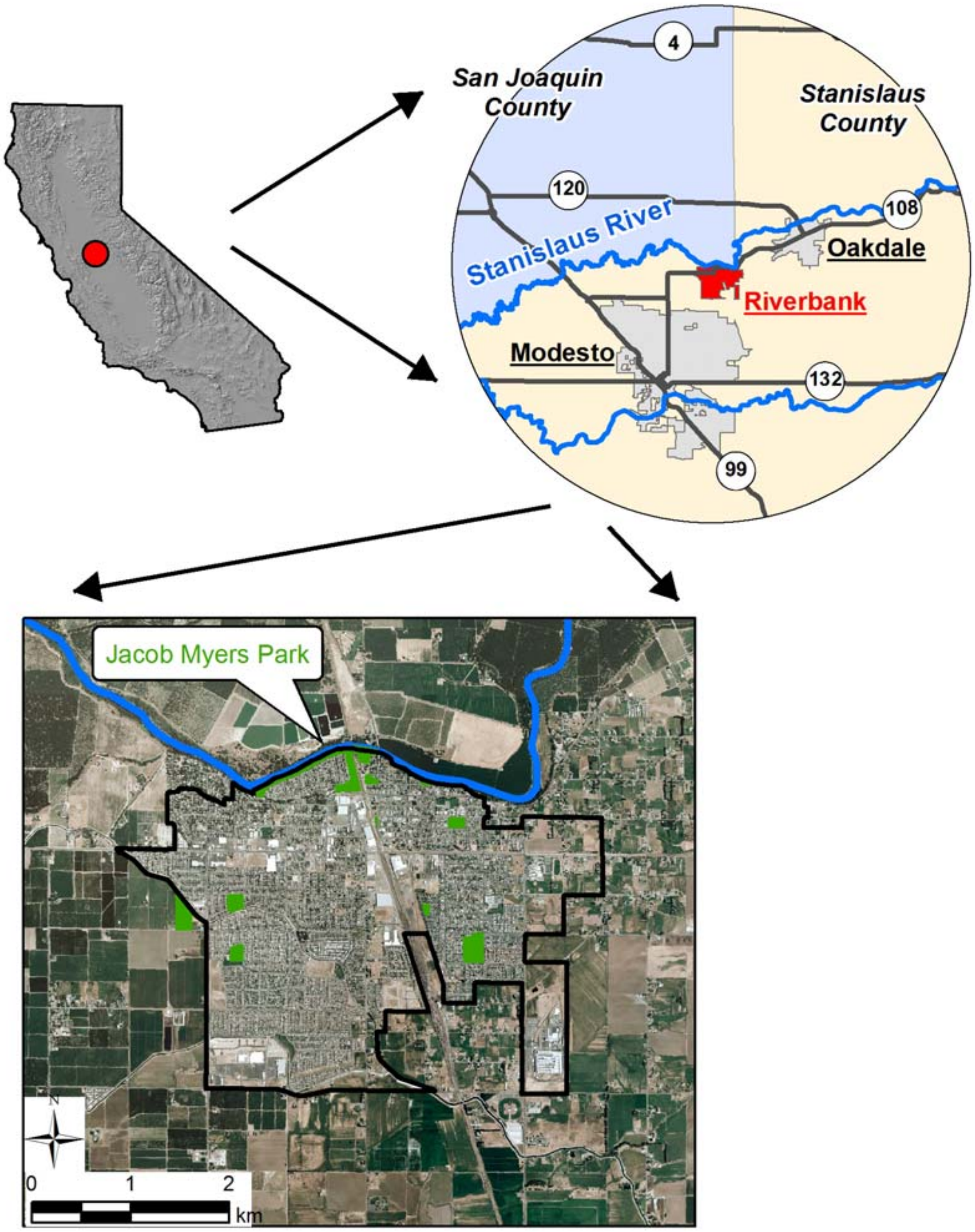


Figure 1. Location of the city of Riverbank study area. Jacob Myers Park is indicated on the lower map.

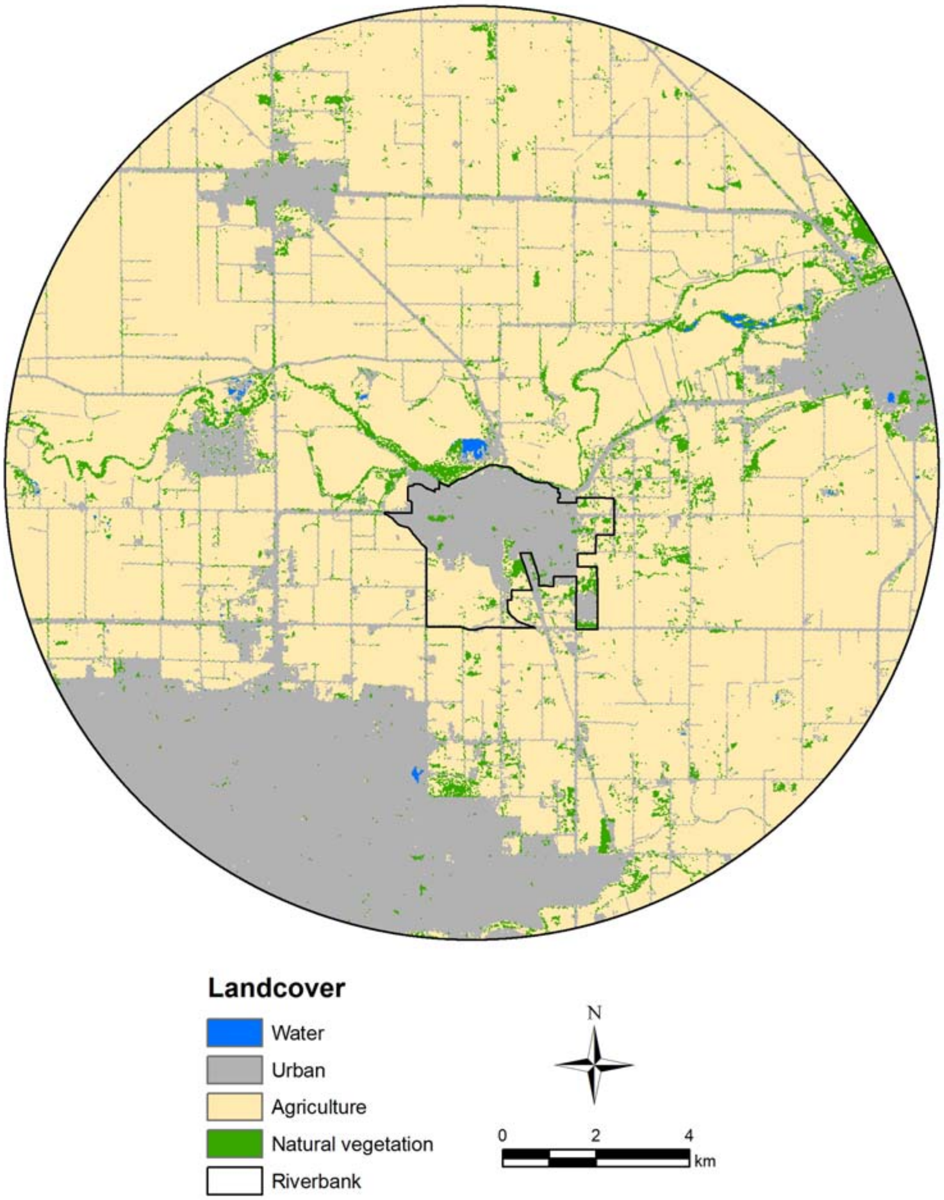


Figure 2. Land cover within a 10 km radius of the city of Riverbank.

movement events, its binary nature will not account for potential movement outside its borders.

A full two-dimensional 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), for example as 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. 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. Urban edges can also be softened to facilitate animal movement. Some examples in the city of Riverbank would be 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 next to 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.

IV. Linkage Modeling

Focal species

Linkages should serve to facilitate the movement of multiple species and ecological processes across the landscape. However, in most ecosystems there are far too many species for which to model movement needs in the planning process. Thus many planners employ a focal species approach to analysis and design of linkages (Beier et al. 2008). This approach assumes that the careful selection of a handful of key (“focal”) species can serve as proxies (or “umbrellas”) for the many other non-focal species in terms of ecological needs (Lambeck 1997). Linkage plans that adequately confer protection on the focal species should then also serve to address the movement needs of the other ecosystem components.

We selected four focal species for connectivity analysis: mule deer (*Odocoileus hemionus*), bobcat (*Lynx rufus*), San Joaquin pocket mouse (*Perognathus inornatus*), and western pond turtle (*Actinemys marmorata*). The mule deer and bobcat were selected because of their long distance terrestrial movement needs as well as for their generalist nature in habitat selection. These characteristics can potentially lead to wide ranging connectivity between the many small remaining fragments of natural vegetation within the study area. The San Joaquin pocket mouse was selected for its grassland dependence and sensitivity to even small gaps in natural cover due to its short dispersal capabilities. Finally, the western pond turtle was selected because of its need for aquatic habitat and adjacent riparian forest. The needs of these species address both of the major natural land cover components of the study area (riparian forest and grassland) and habitat diversity at a larger spatial scale.

Least cost modeling

One popular modeling technique used to analyze landscape connectivity is least cost modeling. This GIS-based approach measures the likelihood of any particular point on the landscape being used by an animal moving between two designated endpoints. This likelihood is determined through a combination of the ecological “cost” to move across that particular point (with a lower cost being equivalent to a greater ease of movement) and the point's spatial relation to both the endpoints and the other intervening points of potential travel on the landscape. This combination is known as "effective distance" (Theobald 2006). The least cost path, as determined through this sort of analysis, is the path of movement traversing a series of low cost points (i.e. high quality habitat for that individual as defined by an inputted "cost surface") while minimizing the overall Euclidean distance travelled. A least cost corridor is similar but generates a connectivity surface between endpoints rather than a single least cost line.

A key to least cost modeling is designation of the endpoints that are to be linked by a path or corridor. Usually in conservation planning these are large reserves areas that could serve as "cores" (Noss et al. 1999), i.e. source populations for dispersing individuals. However, this presupposes a known origin and destination for animals moving across a landscape and establishes a binary corridor/matrix that could potentially relegate land outside the "corridor" as unimportant for conservation management. We instead chose to analyze the full study area for the potential for movement across the landscape regardless of pre-conceived notions of where an individual might disperse from or to as well as to assign a relative connectivity value for all locations in the study area.

To accomplish this, we used a technique (which we are calling "least cost surface" modeling) where we overlaid in an additive fashion a number of connectivity surfaces generated for each focal species. The cost surface used in the analysis was simply the inverse of the habitat value by land cover type (as provided by the California Wildlife Habitat Relationship (CWHR) System's land cover classification system (Mayer and Laudenslayer [1988] developed and maintained by the California Department of Fish and Game) for each focal species. We divided the perimeter of the circular study area into 12 equal length segments and then conducted least cost analyses for each focal species between all pairs of segments (except for adjacent pairs). This led to a total of 54 least cost corridors that were then overlaid and summed. Because the summed connectivity value of any given point is influenced by its location within the circular study area (i.e. centrally-positioned points will be located within more least cost corridors than will peripheral points), we also ran a parallel analysis that used a uniform cost surface to mathematically correct resultant analyses by removing the effects of spatial location from the result.

In order to test the effects of spatial scale (both grain and extent) we conducted nine separate connectivity analyses for each focal species. We used three different radii (5, 10, and 20 kilometers) from a point in central Riverbank to create circular study areas of various sizes. Using each of these extents we conducted analyses using three different data raster cell sizes (10, 30, and 100 meters square) for both inputs and outputs.

We also examined both the potential effects of human impacts on wildlife connectivity and intactness of habitat in areas of high modeled connectivity (see below for those respective methods). While intactness analyses were performed for all focal species, the human impacts analyses were conducted only for the mule deer and bobcat. The San Joaquin pocket mouse and western pond turtle were not analyzed for human impacts because their much smaller home ranges mean that potential human impacts are more localized and not as applicable to the spatial scales that we were investigating. For the mule deer and bobcat we only modeled human impact effects using 30 m raster cells after determining through test analyses that 10 m and 30 m raster cells produced equivalent results while 100 m raster cells missed important remnant patches of natural vegetation.

Human impacts - roads

Human impacts can have direct negative effects on the ability of animals to move across a landscape. Roads are one important source of these impacts (Trombulak and Frissell 2000, Underhill and Angold 2000, Forman et al. 2002). We calculated road effects on potential animal movement by comparing connectivity scores from the least cost surface modeling with road density. Road density was calculated within a moving window equal to the average home range size of each focal species. Both connectivity and road density scores were then normalized on a 0.0 – 1.0 scale and multiplied by each other. The higher resulting road impact scores (closer to 1.0) then showed those areas that had both high connectivity and high road density scores.

Human impacts - urban

Urban areas are another source of direct human impact on landscape connectivity. Not only does the actual development footprint prevent most dispersal for many species, but there are ancillary negative urban edge effects as well (Murcia 1995, Crooks 2002). We calculated urban effects on potential animal movement by comparing connectivity scores with urban area density. We considered "urban" areas to be those raster cells defined as such in the land cover dataset. Urban area density was calculated within a moving window equal to the average home range size of the focal species in question. Both connectivity and urban area density scores were then normalized on a 0.0 – 1.0 scale and multiplied. The higher resulting urban impact scores (closer to 1.0) then showed those areas that had both high connectivity and high urban area density scores.

Human impacts – future urban growth

The previous urban impacts analyses are important to show areas that might currently be affected by human settlement. However, the San Joaquin Valley is expected to see greater than 100% population growth by the year 2050. This future population growth and associated new urban development will potentially have effects on wildlife connectivity across the larger region and within the Riverbank study area.

To assess anticipated future urban impacts on modeled connectivity, we assumed that urban expansion within the study area would adhere to the scenario selected by the SJV Blueprint planning process, the B+ scenario. As part of the SJV Blueprint process (of which the city of Riverbank is a participating member), the spatial footprint of future urban growth was calculated using UPlan, an urban growth model (Johnston et al. 2003). We calculated the density of the UPlan raster output within a moving window equal to the average home range size of the focal species in question and compared this with the connectivity scores. Both connectivity and future urban area density scores were then normalized on a 0.0 – 1.0 scale and multiplied. The higher resulting urban impact scores (closer to 1.0) then showed those areas that had both high connectivity and high future urban area density scores. These areas highlighted places that are more likely to see conflict between competing land use values in the future.

Connectivity intactness

The connectivity analyses conducted here represent *potential* species' movement rather than actual movement. An area with high potential connectivity is merely the "path of least resistance", which may actually be quite high (although still lower than in surrounding areas). Areas of high potential connectivity may include gaps in natural landcover that an animal might not be willing to traverse. These places where usable land cover is constricted to a narrow band or missing altogether can constitute a linkage "chokepoint", or "bottleneck" (Beier et al. 2008). These are areas where land uses not compatible with animal movement reduce (or eliminate altogether) the ability of individuals to traverse that portion of the linkage. Effective linkage design calls for management actions to address chokepoints that could render the linkage degraded or even non-functional.

The inverse of a chokepoint, i.e. an area displaying high potential connectivity as well as large amounts of natural landcover, can be considered a node, or refugium. These locations could serve as resting points for animals in the process of lengthy dispersals or seasonal movements. In some cases, they may even serve as home ranges for several individuals (given the extent of the node is large enough to support them).

In order to assess potential connectivity intactness, we identified those areas that displayed high potential connectivity scores and were embedded in areas with highly suitable land cover scores. To do this, we calculated the mean land cover score for each focal species within several moving windows (mule deer and bobcat: 100 m, 250 m, 500 m; San Joaquin pocket mouse and western pond turtle: 50 m and 100 m). These windows were smaller than mean home range sizes and were chosen to approximate the general width of natural vegetation necessary to provide enough cover for species' movement. Because there is inadequate observational data on what these widths should minimally be for our focal species to allow movement, we chose several to account for a range of potential widths. Both the connectivity and land cover scores were then normalized on a 0.0 – 1.0 scale and multiplied. The higher scores from this calculation then were used to identify areas of more intact connectivity. Lower scores indicate areas either of low connectivity value, undesirable land cover types, or both.

Stanislaus NF – San Joaquin NWR

In order to compare our connectivity surface analysis technique against traditional connectivity techniques (corridor modeling between endpoint "cores"), as well as to situate the project area within a larger regional context, we conducted a corridor analysis between the Stanislaus National Forest (east of the study extents) and San Joaquin National Wildlife Refuge (west of the study extents). This linkage between the Sierra Nevada (with its large amount of public lands) and the San Joaquin River on the floor of the San Joaquin Valley represents a typical approach to modeling connectivity in this region. We used the mule deer as the focal species for this analysis. An intact corridor in this area could allow for potential seasonal movement patterns between the San Joaquin Valley floor and higher elevation natural areas as well as provide a means of adaptation by mule deer to future climate change. The ultimate goal for this portion of the project will be the identification of opportunities for enhancement of animal movement across this large area while incorporating local patterns and processes as well as planning needs into a conservation network, or "greenprint".

Other species of concern

While most of the analysis we conducted focused on the potential for animal movement through the study area, we also wanted to ensure that species of regulatory concern were accounted for in our ongoing planning process. Using the California Natural Diversity Database (CNDDB; California DFG 2009), we identified occurrence records of sensitive species within the study area. We also conducted a landscape-scale habitat analysis for the burrowing owl (*Athene cunicularia*; one of the CNDDB species) where we calculated the mean CWHR land cover scores within an average owl home range (144 ha; Gervais et al. 2003). In addition, we used a dataset provided by the DFG (M. Hoshovsky, pers. comm.) to identify potential Swainson's hawk (*Buteo swainsoni*) habitat within the study area (in addition to locating CNDDB occurrence records).

V. Results

Connectivity

The Stanislaus River is the major natural ecological feature of the study area and much of modeled connectivity followed this east-west conduit (Figures 3-5). Not surprisingly, the focal species whose connectivity surface most adhered to the river corridor was the western pond turtle. The mule deer and bobcat analyses also highlighted this riparian corridor. The San Joaquin pocket mouse connectivity surface paralleled the river to a certain degree, however the areas showing the greatest connectivity for this species were the grassland and pasture areas beyond the outer edge of the riparian zone. One high connectivity area (at least at the smaller spatial extents) for all focal species except pond turtle was the agricultural area east of Riverbank.

We found that the spatial extent and grain used in the connectivity analyses impacted the resulting connectivity surfaces (Figures 3-5). One major impact of spatial extent that we noted was the reduction in modeled connectivity in the vicinity of Riverbank when the analysis was conducted at the 20 km radius (Figure 5). The northeastern portion of the study area contained within this radius is largely rangeland rather than the mix of intensive agriculture and urban areas that comprise most of the remainder of the area. These rangelands then displayed much higher potential for movement of individuals than did the areas of greater human impact on the valley floor. The major exception to this was the modeled western pond turtle connectivity. Even at the larger spatial extent, the Stanislaus River (and to a lesser extent the Tuolumne River) comprised a major potential movement corridor across the study area. These results indicate that habitat enhancements for increased connectivity should be undertaken in the Riverbank area rather than merely preservation of existing habitat. These enhancements could increase the potential for a variety of species to be better able to move within and through the central portions of the study area.

There was also a noticeable effect on connectivity analysis results when different grain sizes (i.e. raster cell sizes) were used (Figures 3-5). The most notable effect occurred when we used 100 m raster cells in our analyses. It was evident that at this spatial scale, much of the remnant valley floor vegetation was of too fine a resolution to be rendered by 100 m raster cells. At the 5 km radius extent (Figure 3), the non-identification of small riparian forest remnants led to a reduced modeled connectivity for the Stanislaus River corridor from just east of Riverbank to the eastern edge of the study area. This was the case for all four focal species.

At the 10 km extent, the same pattern held for the pond turtle (Figure 4). Mule deer connectivity was much reduced along the entire Stanislaus River when modeled with 100 m raster cells. Modeled pocket mouse connectivity around the northern and western edges of Riverbank was similarly reduced because of the small and fragmented nature of grassland remnants in the area (large enough for potential use by the mouse but too small to be acknowledged by the 100 m raster cells). At the 20 km extent, the connectivity potential of the entire Stanislaus (and Tuolumne) River went unnoted for all of the focal species when using 100 m raster cells (Figure 5).

Human impacts

Anticipated human impacts to movement by mule deer and bobcat in the vicinity of Riverbank were relatively constant regardless of spatial extent used for modeling. Urban impacts to connectivity were found throughout the entire perimeter of Riverbank (Figure 6), with a slightly larger impact to bobcat on the eastern edge. The major road impacts to connectivity in the Riverbank vicinity were concentrated in the area between Riverbank and Oakdale along Highway 108 (Figure 7). Although there is not much natural vegetation remaining in this area, it still represents the most feasible route of north-south movement within the study area because this is the only substantial break in urban development along Highway 108 and the Stanislaus River. There were also areas of lower human impact to the west of Riverbank, along the Stanislaus River corridor on the north edge of Riverbank, and to the southeast of Riverbank.

According to the UPlan growth projection model, the major locations where probable future urban development could impact connectivity are the agricultural areas to the immediate east of Riverbank and the area separating the cities of Riverbank and Modesto (Figure 8). Much of the area surrounding

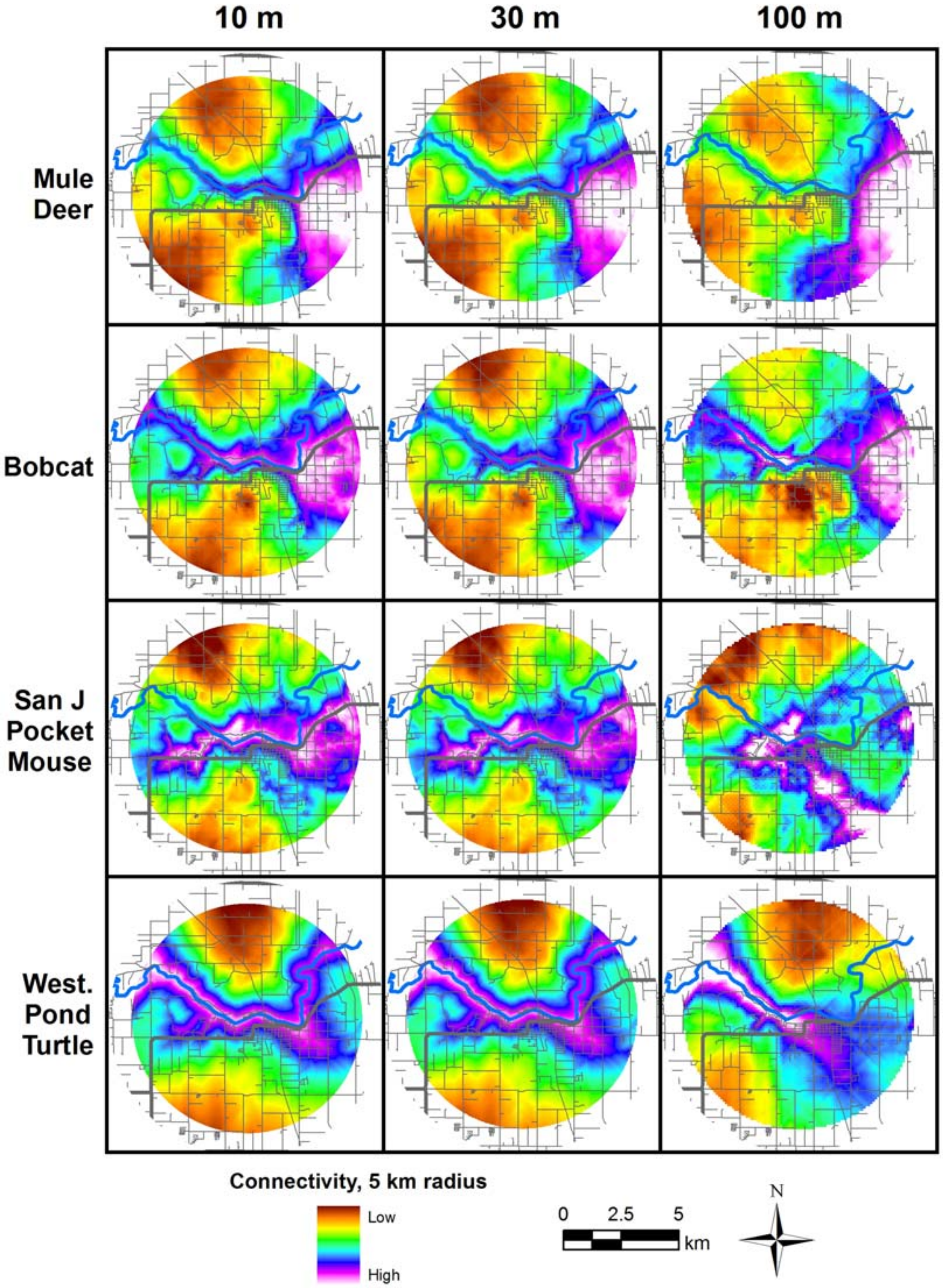


Figure 3. Focal species connectivity as measured at a 5 km radius from the north edge of the City of Riverbank. White represents high potential connectivity while brown represents low connectivity. Analyses were conducted using three raster cell sizes: 10 m, 30 m, and 100 m. The Stanislaus River is the blue line, highways are thick gray lines, and other roads are thin gray lines.

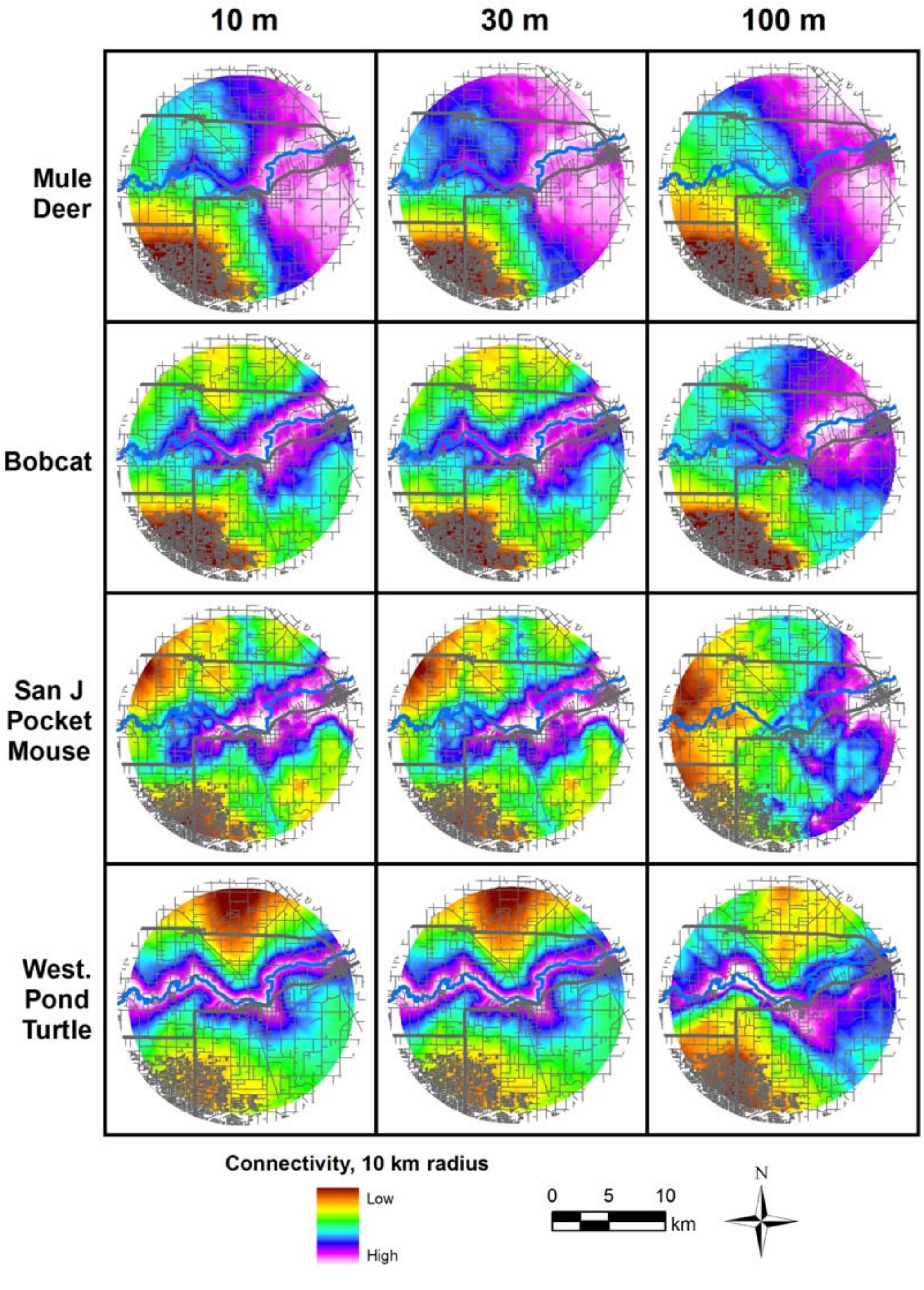


Figure 4. Focal species connectivity as measured at a 10 km radius from the north edge of the City of Riverbank. White represents high potential connectivity while brown represents low connectivity. Analyses were conducted using three raster cell sizes: 10 m, 30 m, and 100 m. The Stanislaus River is the blue line, highways are thick gray lines, and other roads are thin gray lines.

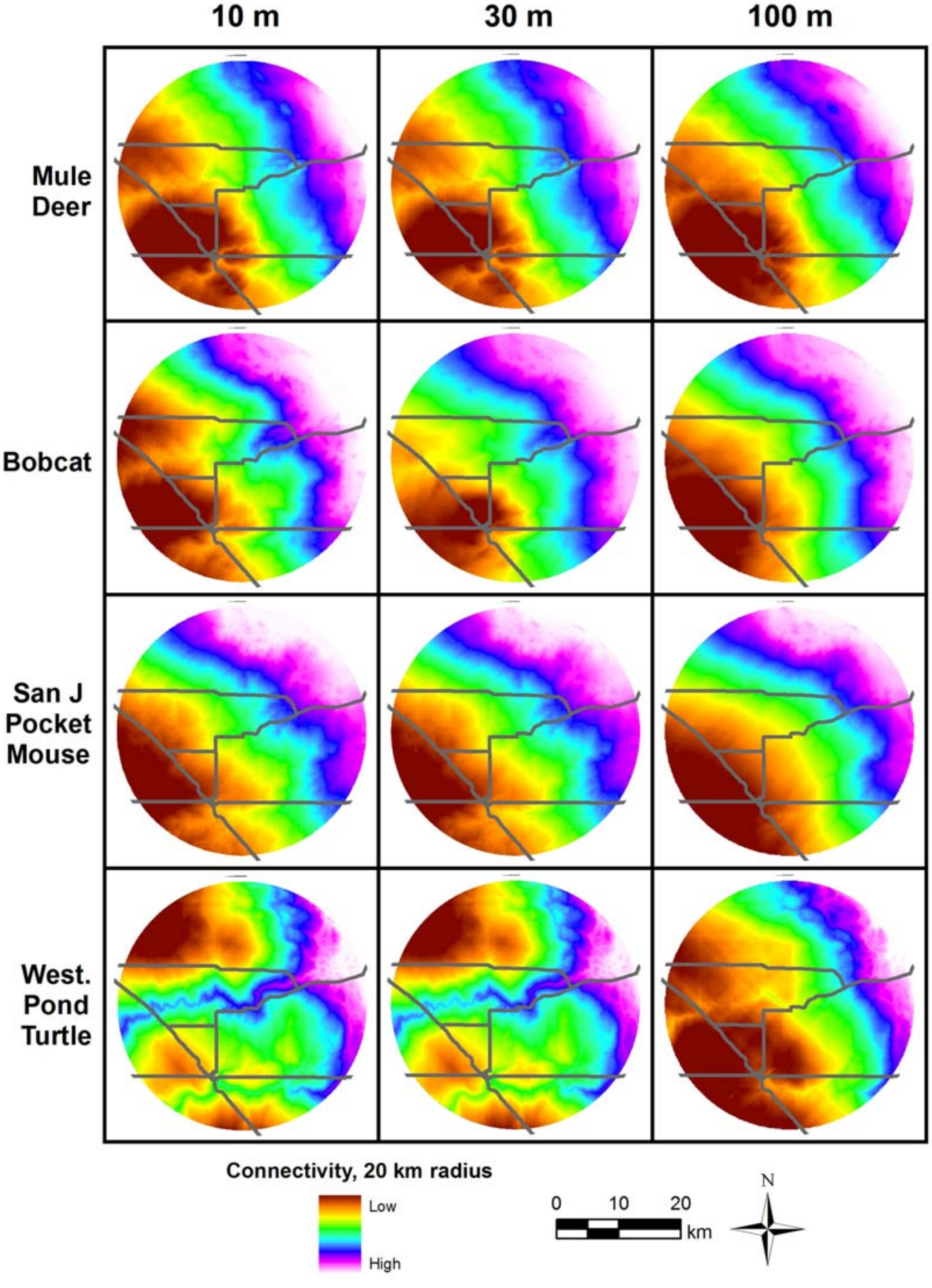


Figure 5. Focal species connectivity as measured at a 20 km radius from the north edge of the City of Riverbank. White represents high potential connectivity while brown represents low connectivity. Analyses were conducted using three raster cell sizes: 10 m, 30 m, and 100 m. Highways are thick gray lines. Other roads have been removed for visual clarity.

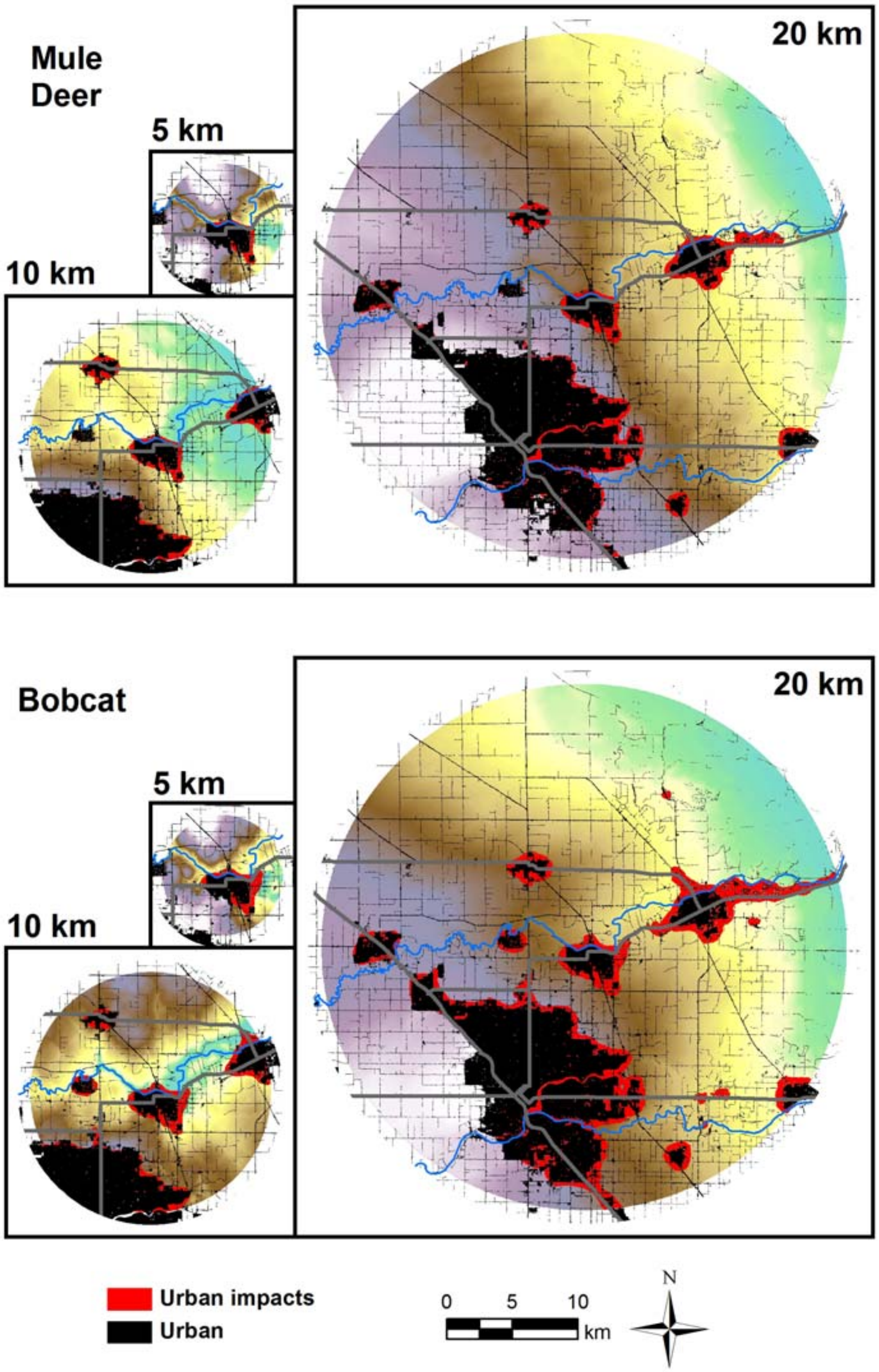


Figure 6. Potential urban impacts on mule deer and bobcat connectivity. Red indicates areas of high urban area density and high potential connectivity. Black is existing urban landcover. Underlying these are the 30 m raster cell connectivity surfaces put on a green (high) to white (low) color scale.

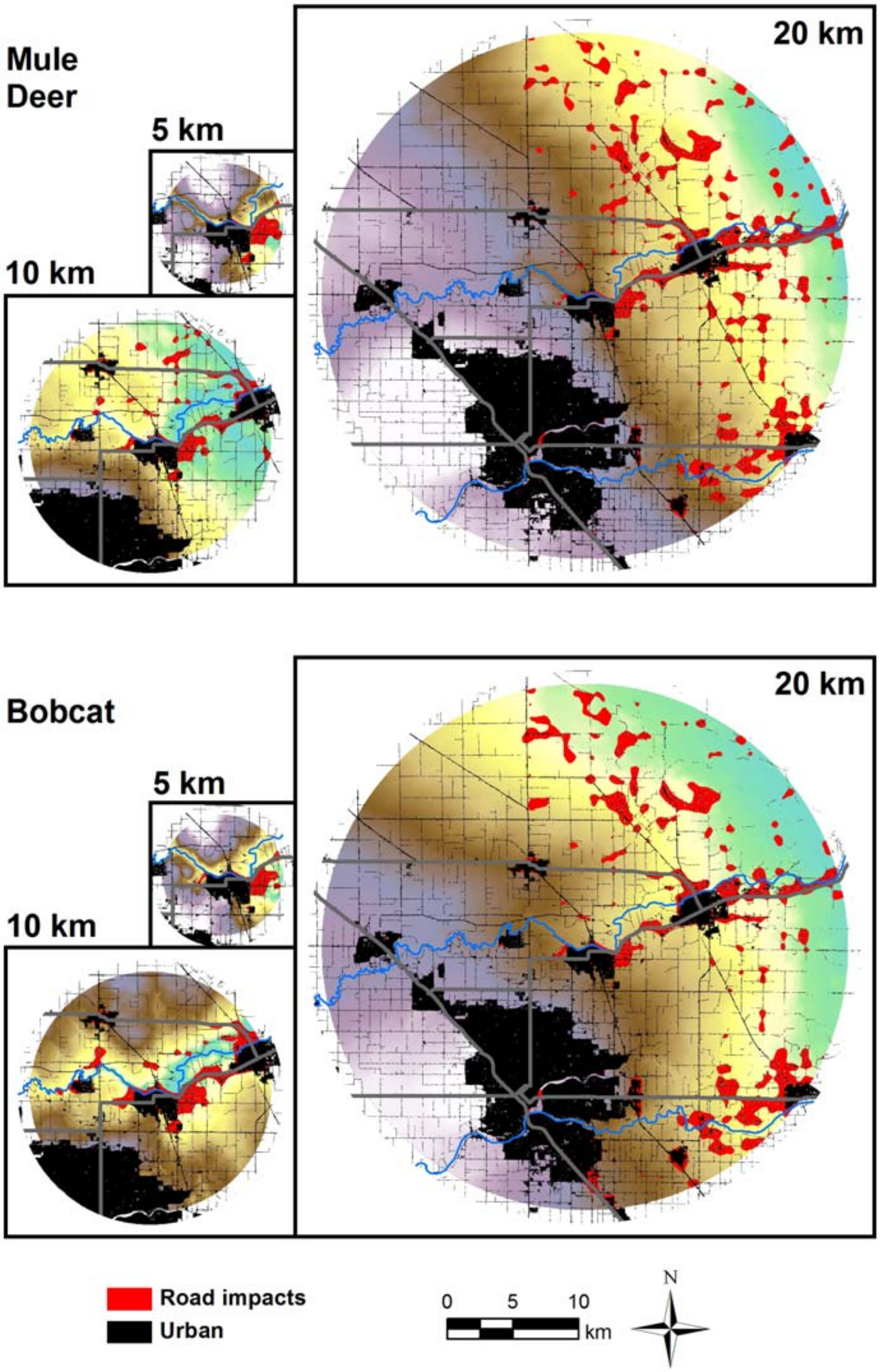


Figure 7. Potential road impacts on mule deer and bobcat connectivity. Red indicates areas of high road density and high potential connectivity. Black is existing urban landcover. Underlying these are the 30 m raster cell connectivity surfaces put on a green (high) to white (low) color scale.

Oakdale is also at risk of losing connectivity potential due to likely new urban development over the next several decades.

Connectivity intactness

The results of connectivity intactness modeling also displayed grain- and extent-related spatial scale effects (Figures 9-11). The relative intactness of the Stanislaus River corridor and other areas in the vicinity of Riverbank were reduced as both grain size (cell size) and spatial extent increased. However, there were some locations, such as the along the river corridor just west of Riverbank that displayed higher levels of intactness than the surrounding landscape regardless of scale change.

Ecological network nodes

Several areas displaying relatively high connectivity intactness could potentially serve as habitat nodes in a Riverbank ecological network. Mule deer, bobcat, and western pond turtle all showed high connectivity in the bend in the Stanislaus River just west of McHenry Ave (Figure 12). Another area of high multi-species connectivity intactness was found in the vicinity of the sewage disposal ponds across the Stanislaus River from western Riverbank. High western pond turtle connectivity intactness was seen along a bend in the Stanislaus River between Riverbank and Oakdale. High San Joaquin pocket mouse connectivity intactness was seen in pastureland between Highway 108 and the Stanislaus River west of Riverbank. Other areas of higher connectivity intactness included the agricultural land east of Riverbank.

Ecological network chokepoints

A number of chokepoints (i.e. areas of high potential connectivity but low probability of actual use for movement due to non-compatible land cover types) were found for all four focal species (Figure 13). One important potential chokepoint – Jacob Myers Park – presents an interesting challenge because it figures to be a critical component of the greenbelt system which is to be integrated in the linkage design. The open turf areas and associated park infrastructure, while desired open space features, do not lend themselves to movement of the focal (and other) species. Of the focal species, only the San Joaquin pocket mouse is not expected to be negatively impacted by this park. Another potential chokepoint for the non-mouse focal species is a segment of the riparian area in between Riverbank and Oakdale in the vicinity of the River Road and Sawyer Avenue intersection. The riparian forest thins considerably at this location, possibly hindering or eliminating movement along the river corridor. Another riparian area just northeast of Riverbank is also narrow, potentially impacting especially the western pond turtle. Finally there are potential chokepoints for the San Joaquin pocket mouse in the areas lying between the Stanislaus River and Highway 108 to the west of Oakdale Road.

Regional corridor

The regional-scale mule deer corridor that we identified shared some overlap with the other connectivity models we developed. Riverbank and the adjacent Stanislaus River are located on the corridor identified, linking the Sierra Nevada and San Joaquin River (Figure 14). The regional corridor skirts the northern edge of New Melones Lake in the Sierra Nevada foothills, crosses annual grassland and pastures in eastern Stanislaus County, meets the Stanislaus River in the vicinity of the City of Oakdale (east of Riverbank), and then follows the river to the confluence with the San Joaquin River (where mule deer are present in the San Joaquin National Wildlife Refuge). While this corridor is coincident with the river-centric high connectivity areas, other areas away from the river (e.g. pastures east of Riverbank) were not identified by the regional mule deer corridor.

Other species

There were 13 sensitive (special status) species identified within the study area (Table 1). The burrowing owl, Swainson's hawk, and

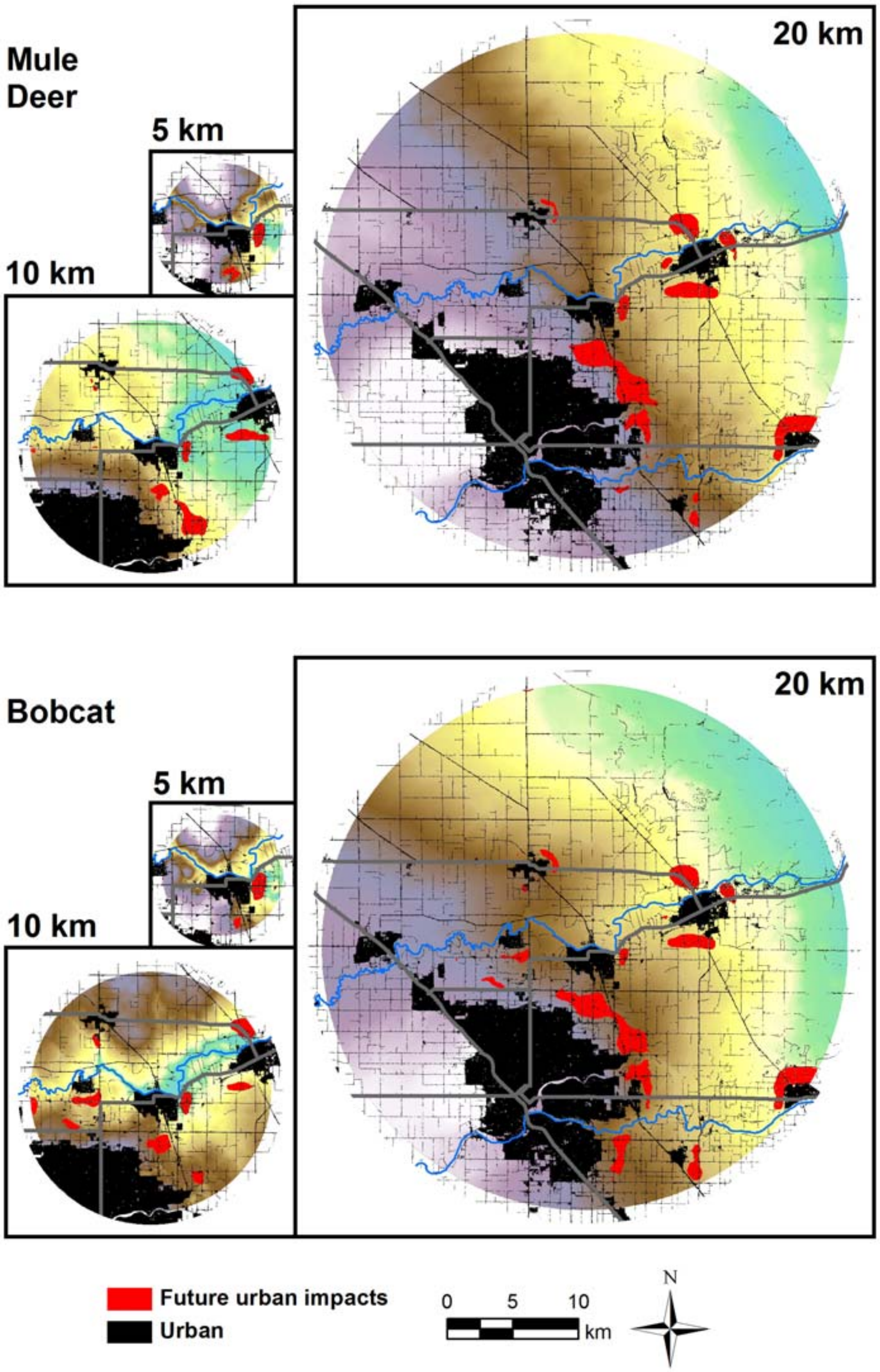


Figure 8. Potential future urban impacts on mule deer and bobcat connectivity. Red indicates areas of high predicted future urban area density and high potential connectivity. Black is existing urban landcover. Underlying these are the 30 m raster cell connectivity surfaces put on a green (high) to white (low) color scale.

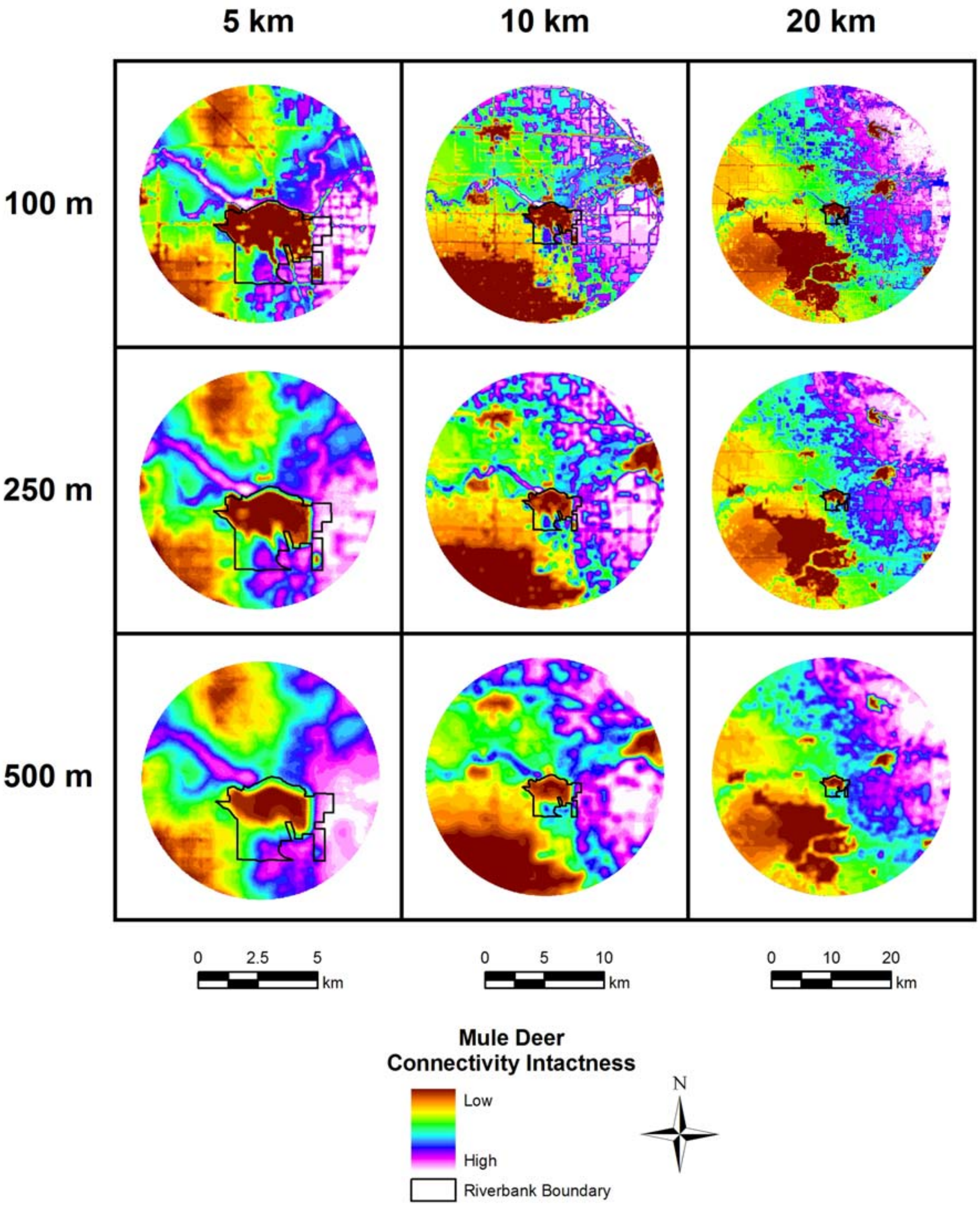


Figure 9. Mule deer connectivity intactness. White indicates areas where there is both high modeled connectivity and high mean habitat ratings for mule deer. Radii used for calculating habitat ratings are: 100 m, 250 m, and 500 m. Analyses were conducted at 5 km, 10 km, and 20 km radii from the City of Riverbank (shown here in black outline).

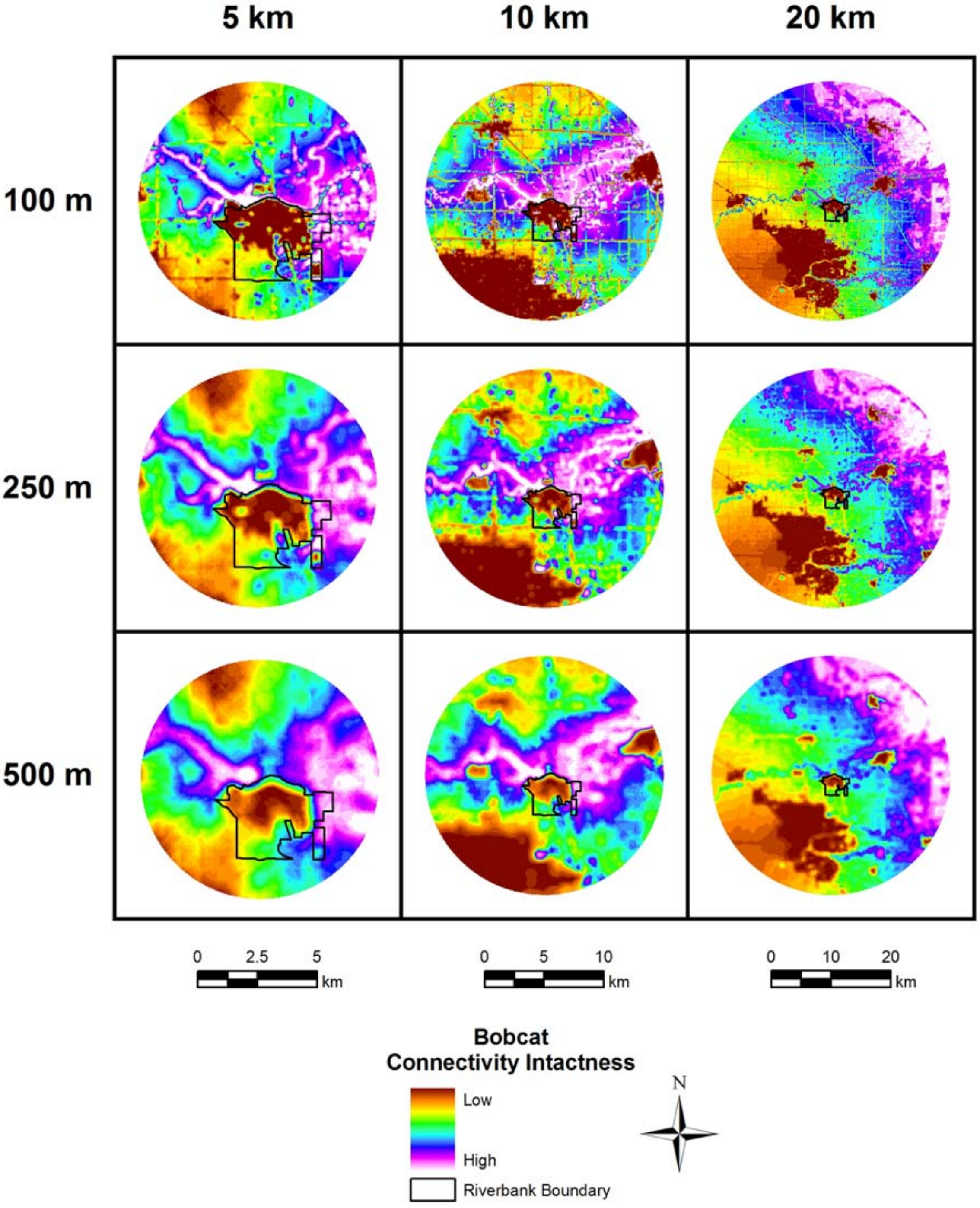


Figure 10. Bobcat connectivity intactness. White indicates areas where there is both high modeled connectivity and high mean habitat ratings for bobcat. Radii used for calculating habitat ratings are: 100 m, 250 m, and 500 m. Analyses were conducted at 5 km, 10 km, and 20 km radii from the City of Riverbank (shown here in black outline).

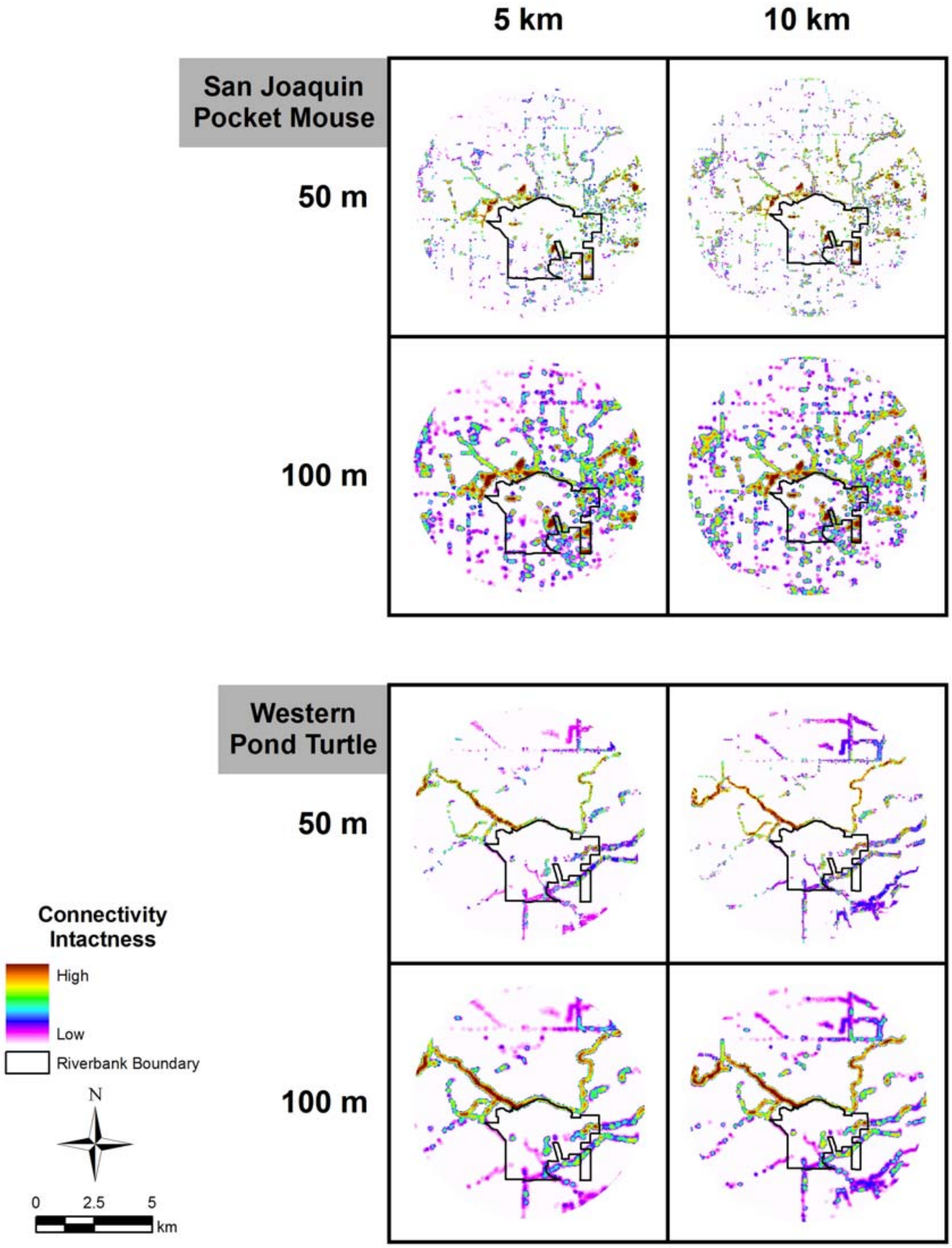


Figure 11. San Joaquin pocket mouse and western pond turtle connectivity intactness. The color scale has been inverted for visual clarity. Brown now indicates areas where there is both high modeled connectivity and high mean habitat ratings for mule deer. Radii used for calculating habitat ratings are: 50 m and 100 m. Analyses were conducted at 5 km and 10 km from the City of Riverbank (shown here in black outline).

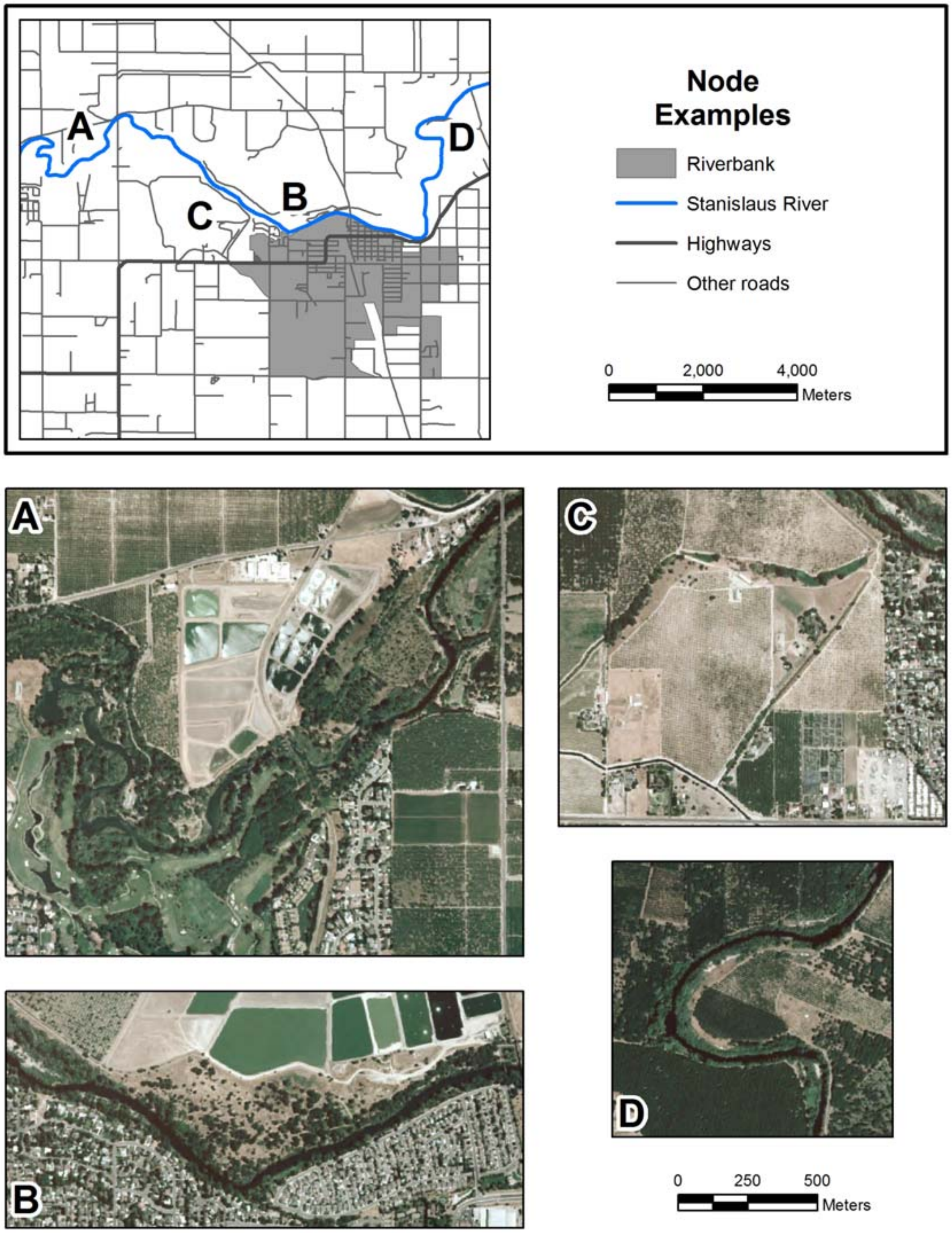


Figure 12. Four examples of potential habitat “nodes” for a Riverbank ecological network. These are areas of both high potential connectivity and habitat value for modeled focal species.

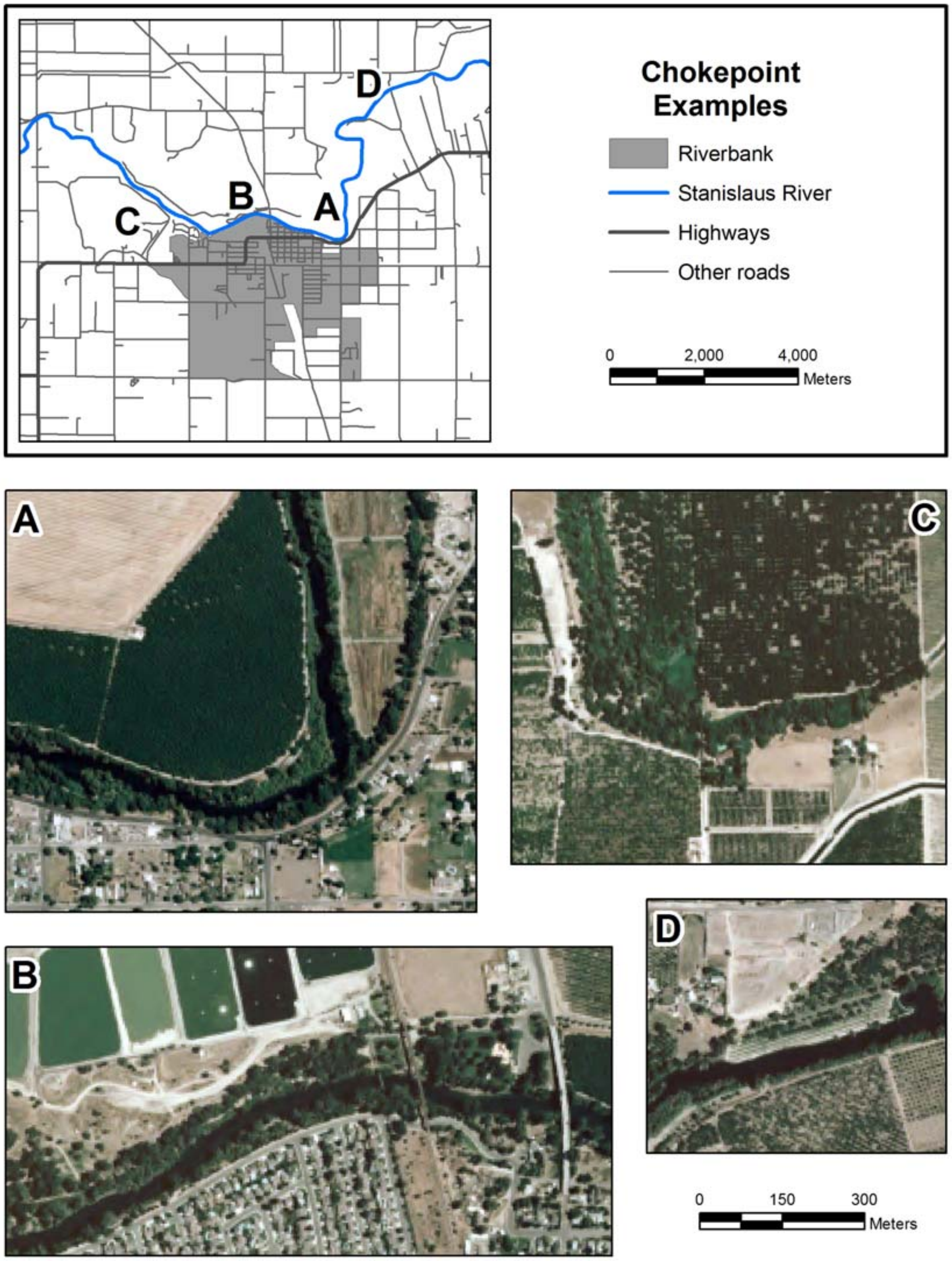


Figure 13. Four examples of potential “chokepoints” (or “bottlenecks”) for a Riverbank ecological network. These are areas of both high potential connectivity and low habitat value for modeled focal species.

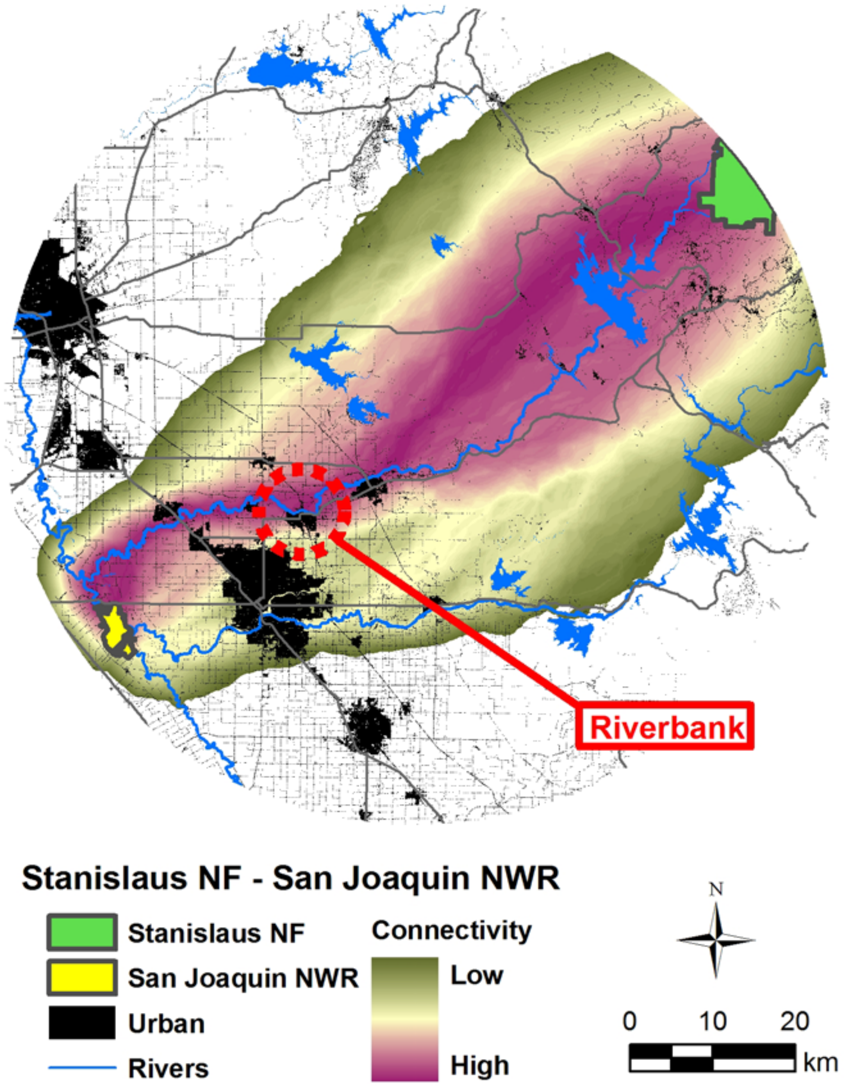


Figure 14. Mule deer corridor between Stanislaus National Forest in the northeast (green) and San Joaquin National Wildlife Refuge in the southwest (yellow). Purple indicates areas of higher connectivity between these core areas. The large blue areas are reservoirs. The City of Riverbank is the black urban area at the center of the red circle.

valley elderberry longhorn beetle (VELB; *Desmocerus californicus dimorphus*) are three species of regulatory concern that occur in the immediate vicinity of Riverbank. Likely habitat and/or occurrence locations for these species are shown in Figure 15. A robust linkage design will include habitat for these species in addition to focal species' connectivity needs.

VI. Future Linkage Design

The analyses described in this report are an interim step in the production of a final design for a wildlife linkage in the city of Riverbank area. The results will need to be assembled and integrated into an overall vision for protection and enhancement of connectivity in the region that also includes human open space, recreational, and quality of life needs. This integration will be the next step, moving beyond the conclusions found in this report.

The next step in the connectivity analysis will be to combine the focal species' results to produce an overall connectivity framework for the study area. This result will represent connectivity needs for a wide variety of species rather than any one individual species. Next, the intactness and chokepoint analyses can be combined to show those locations that could serve as nodes or be seen as bottlenecks for the entire network. This will also be done for the human impact analyses in order to show areas that are likely to impact multiple species both presently and in the future because of urban growth in the area.

Wildlife connectivity

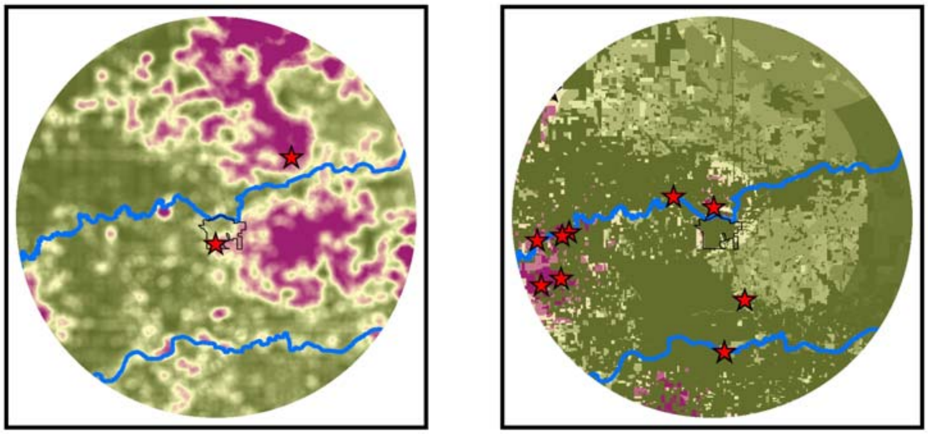
The analyses conducted to-date indicate that the Stanislaus River riparian corridor is an important local natural feature for wildlife connectivity in the greater Riverbank area. It contains the most intact natural land cover in a region dominated by agriculture and urban development. An effective conservation plan should protect as much of the remaining riparian vegetation as possible. This riparian cover will enable the movement both of larger generalist species (e.g. mule deer and bobcat) and smaller, less mobile riparian/aquatic obligate species (e.g. western pond turtle). These focal species can serve as umbrellas for many other species (e.g. migratory songbirds) that could benefit for preservation of this high quality ecological resource.

There are currently several areas of natural land cover located on the river corridor that are large and could potentially serve as habitat nodes for a variety of species. Especially important might be several to the west of Riverbank which not only display high connectivity intactness for several focal species but also include several VELB occurrence records. This indicates that larger mobile species could use these areas as resting habitat while moving along the corridor at the same time smaller sensitive species could establish home ranges there. These nodes are currently not in public ownership (however conservation easement data will need to be obtained to fully answer the question of protection of these areas).

However, the Stanislaus River corridor should not be considered a fully intact ecological feature. There are chokepoint areas that impede or block passage of individuals (especially of larger taxa such as mule deer) attempting to move along the corridor. For instance, mule deer are currently present in the San Joaquin National Wildlife Refuge, yet 3 miles upstream the Stanislaus River in Caswell Memorial State Park no mule deer have been observed moving through the park for at least three years (pers. comm., M. Whelan). There are several locations both upstream and downstream from Riverbank where riparian forest restoration activities should be undertaken to enhance the habitat and connectivity qualities of the corridor. One area of emphasis should be Jacob Myers Park where efforts should be made to integrate an expansion of natural land cover with existing recreational amenities. Currently these amenities may serve to prohibit movement of

CNDDB Species	
Beaked clarkia	*Clarkia rostrata*
Burrowing owl	*Athene cunicularia*
California tiger salamander	*Ambystoma californiense*
Greene’s tuctoria	*Tuctoria greenei*
Hardhead	*Mylopharodon conocephalus*
Legenere	*Legenere limosa*
Moestan blister beetle	*Lytta moesta*
Suisun song sparrow	*Melospiza melodia maxillaris*
Swainson’s hawk	*Buteo swainsoni*
Valley elderberry longhorn beetle	*Desmocerus californicus dimorphus*
Vernal pool fairy shrimp	*Branchinecta lynchi*
Vernal pool tadpole shrimp	*Lepidurus packardi*
Western mastiff bat	*Eumops perotis californicus*

Table 1. Sensitive species in the study area, as found in the California Natural Diversity Database (CNDDB) (California DFG 2006).



Burrowing Owl

Swainson's Hawk

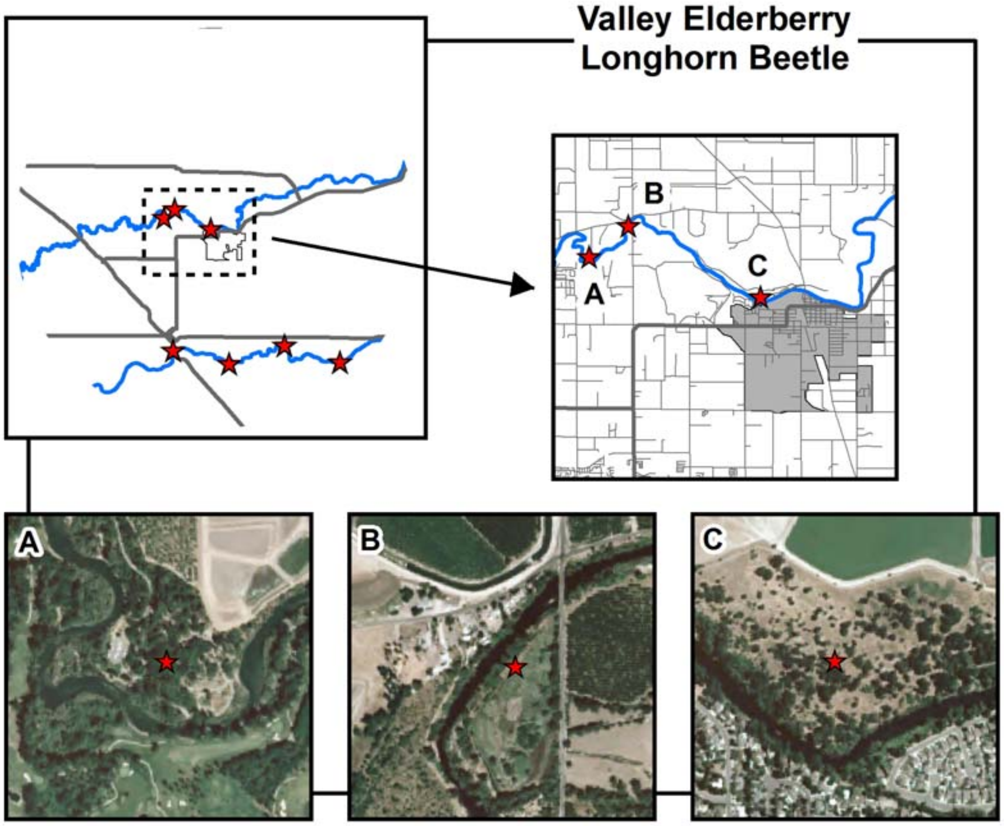


Figure 15. Locations of three sensitive species within the study area. At top left is burrowing owl habitat and occurrence records (red stars). At top right is Swainson's hawk. Purple indicates areas of high habitat density for these species. At bottom are valley elderberry longhorn beetle occurrence records and aerial photos (2005 NAIP imagery) of these locations. The City of Riverbank is represented as the shaded gray area.

many species along the length of the corridor. Structurally-favorable features like this riparian corridor are only important for wildlife movement if animals perceive that there is somewhere to move to, leading to functional connectivity.

When connectivity analysis is extended to greater spatial extents, the importance of the Stanislaus River corridor diminishes somewhat. These analyses tell us that the constricted nature of the existing riparian corridor make it less likely that many species will find their way into and along the corridor from endpoints to the east and west. Both wide-ranging generalist species and grassland-obligate species will be more likely to move through the non-farmed areas above the San Joaquin Valley floor in the eastern portion of the study area where movement is much less constrained. General widening of the riparian corridor combined with grassland components along the length would probably enhance the usability of the corridor from a regional standpoint. However, it could be argued that the Stanislaus River corridor offers the best chance of establishing a conduit for allowing long distance movement between the Stanislaus National Forest to the east and the San Joaquin National Wildlife Refuge at the confluence with the San Joaquin River to the west, especially below the city of Oakdale. This potential movement corridor could benefit both long distance migratory patterns and future required movement to help offset the anticipated effects of climate change.

Connectivity not associated with the Stanislaus River corridor is more problematic. Grasslands in the study area have been greatly reduced in extent and highly fragmented. Large native grassland species (e.g. pronghorn) have been extirpated. Smaller species, such as the San Joaquin pocket mouse may be present but populations most likely are small and isolated. The connectivity analyses for this species shows potential linkage from usable habitat west of Riverbank, through the area north of Riverbank, and across the area east of Riverbank. While there may be some potential pathways in the indicated areas, movement across this area of higher connectivity would necessarily cross the Stanislaus River which is most likely a formidable barrier to small non-riparian species. Movement between the western and eastern sections of higher connectivity could conceivably be achieved via the agricultural land remaining between Riverbank and Modesto (south of Riverbank). However, this area is highly impacted by human disturbance and further is slated to be subject to a new highway alignment as well as future urban growth. It is unclear how connectivity across the full study area for the San Joaquin pocket mouse and other grassland species will be maintained into the future.

One area that is potentially important for focal species connectivity in the study area is the agricultural land between the cities of Riverbank and Oakdale. While the Stanislaus River provides for possible east-west movement by a number of species, relatively few opportunities exist for north-south movement, at least within the 10 km radius of Riverbank. This area is the one place where urbanization has not precluded north-south movement entirely. While there are numerous current risks to individuals moving through this area (primarily roads, but also developed areas and non-natural land cover), it is still likely that some movement is still possible here. However, this area faces urbanization pressures over the coming decades and could be rendered unusable for animal movement as well, effectively creating an impassable barrier between Modesto and Oakdale. Maintaining some non-urban land in this area is necessary to enable north-south movement through the study area. To mitigate for potential losses in connectivity due to new highway construction the placement of under-crossing structures in strategic locations could allow limited movement for some species and be incorporated into an open space system. This open space could also function as a “community separator” to maintain identity between the cities of Riverbank and Oakdale.

Integration of human and wildlife needs

One means by which to integrate both wildlife connectivity needs and the needs of local human residents is through the implementation of a local and regional "greenway" network. This approach couples linear wildlife habitat features with trails and other open space amenities, potentially enabling both people and less-sensitive animals to move relatively freely throughout a city or region (Flink and Searns 1993, Erickson 2004). These linear features can link parks, reserves, and other larger areas within the framework of a larger ecological network. One example of this type of landscape planning is the Florida Ecological Network (Hoctor et al. 2000), a statewide greenway system designed to enable Florida panther (a critically endangered species) and black bear to move between core habitats while at the same time providing recreational amenities for Florida residents. Although this approach has not been shown to provide habitat for wildlife sensitive to human presence, it may provide movement opportunities for less-sensitive species. An important caveat to this theoretical combination is that certain recreational activities, in particular walking dogs, are incompatible with many wildlife needs.

Within the Riverbank area, some components of a potential greenway network are already in place. The Stanislaus River riparian corridor, while impacted and in need of restoration activities in numerous places, is one such component. It is readily identifiable by Riverbank citizens and currently provides habitat for a number of species, including some that are currently imperiled. Jacob Myers Park, within the riparian corridor, is an important recreational feature for the Riverbank community. There are currently a number of potential habitat nodes along the length of the Stanislaus River (Figure 12) that could be linked both by riparian forest and by trails for hiking or biking. These trails could be extended to the cities of Oakdale (upstream) and Ripon (downstream) and beyond. The Highway 99 bridge over the Stanislaus River at Ripon is conducive to both trail under-crossings and wildlife movement.

Other network components could benefit wildlife connectivity while serving non-recreational human needs. For example, the agricultural lands to the south and east of Riverbank that model results point to as currently displaying high connectivity could be the focus of efforts to establish wildlife-friendly agricultural practices (such as hedgerow plantings, tail water ponds, etc.) for the benefit of species moving through the areas between the cities of Riverbank and Oakdale and Riverbank and Modesto. Similarly, wetlands could be created at the sewage treatment plant on the north side of the Stanislaus River for both use by wildlife and to reduce water purification costs. Another opportunity for ecological enhancement of the urban edge is the creation of storm water detention basins with ecological features that provide wildlife habitat. At least two places in the city of Riverbank are suitable for this type of enhancement: the Northwest Specific Plan area on the west edge of the city and the former industrial ponds on the recently transferred Army Corps of Engineers property on the east side of the city.

One important need for successful implementation of a greenway network is the integration of local residents into the planning process. This both provides community "buy-in" to and "ownership" of the process and results and ensures that network components will actually be of use to the residents. Both adults and youth have important perspectives as to community open space needs and should be included in the ongoing planning and implementation process.

VII. Conclusion

A successful wildlife linkage in this or other portions of the San Joaquin Valley will not be implemented through any one action. Numerous local government entities, NGOs, state and federal agencies, and researchers will need to work together to identify regional and local wildlife and community needs acquire funding for implementation piece by piece. This project will hopefully provide a framework for moving forward on planning and implementation of a linkage here that will provide both ecological benefit and recreational and other benefits for people. The approaches taken here can potentially serve as one means of addressing planning and implementation of wildlife connectivity in the San Joaquin Valley (and elsewhere). Of course, every setting is unique and requires a specially-tailored approach, but we present what we believe to be an assortment of useful methods and approaches in this report. Next steps will include moving from the analyses here to development of a “greenprint”, integration with infrastructure blueprints, local implementation, and expansion of planning efforts to other willing neighbors.

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