Decision-Support Maps
And Recommendations for Conserving Rare Carnivores
In the Interior Mountains of California

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Introduction

This report provides scientifically sound maps and guidance—based on spatially explicit, empirical models—that can be used to support forest management recommendations to sustain populations of four imperiled forest carnivores in the inland mountain ranges of California: Pacific marten (*Martes caurina*), fisher (*Martes pennanti*), wolverine (*Gulo gulo*), and Sierra Nevada red fox (*Vulpes vulpes necator*). The maps depict the distribution of populations and habitat for each species as well as habitat connectivity areas that are important to maintaining species' movements and demographic and genetic processes. These maps and scientific information about each species are used to develop spatially explicit conservation and management recommendations, which should be considered in prioritizing conservation actions (e.g., land acquisitions or easements), revising National Forest Management Plans, planning fuels management or other vegetation treatments, developing road improvements, or other actions that may affect these species or their habitats.

The products and recommendations are intended to be complementary to other planning efforts in the region, such as the following:

- Science synthesis, bioregional assessment and Forest Plan revisions, being developed by the USDA Forest Service
- West Coast Fisher Conservation Strategy, being developed by an Interagency Fisher Biology Team
- Sierra Nevada Conservation Strategy, being developed by Sierra Forest Legacy and other conservation organizations
- Framework for Cooperative Conservation and Climate Adaptation in the Southern Sierra Nevada and Tehachapi Mountains, prepared by the Southern Sierra Partnership and being implemented by multiple stakeholders
- Plans to potentially reintroduce wolverines to National Parks in the southern Sierra Nevada

The maps in this report are small and intended as illustrations of landscape-scale patterns; however, all maps and datasets included in this report can be viewed at finer resolution on a variety of basemaps or aerial imagery in the Sierra Nevada Carnivore Conservation Group at http://databasin.org.

Study Area

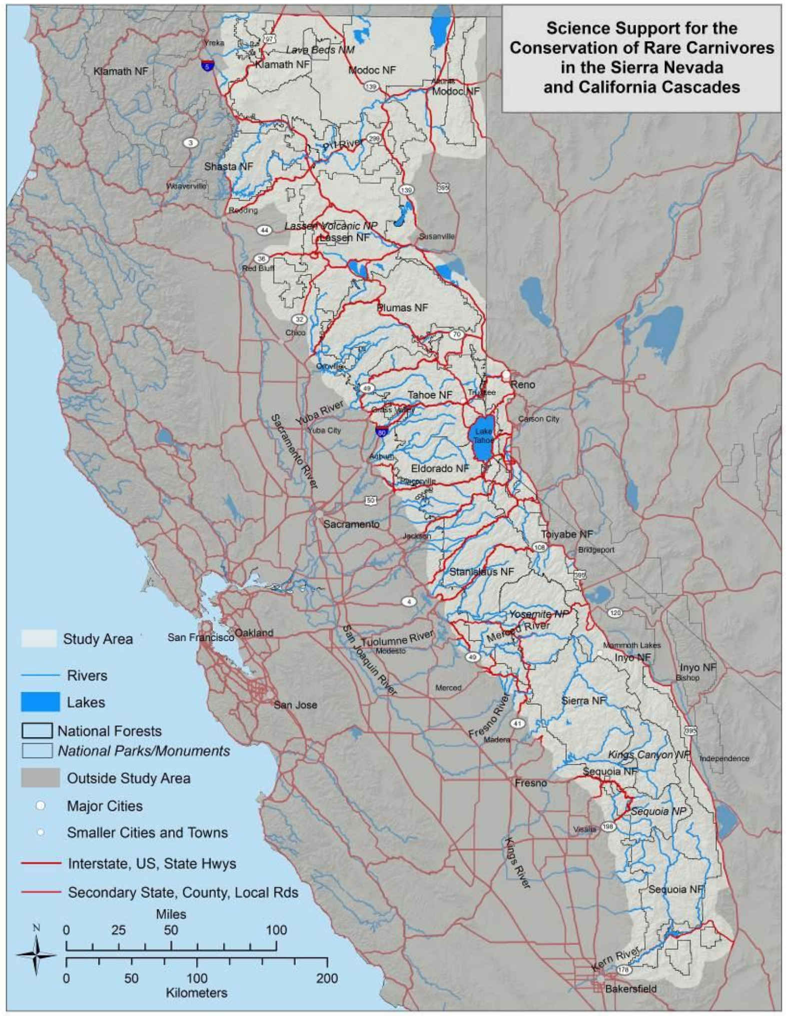


Figure 1. Study area.

The study area (Figure 1) includes the Sierra Nevada and Cascade Ranges in California east of Interstate-5 and west of State Road-395 plus a portion of Nevada on the east side of Lake Tahoe. It includes all or portions of 12 National Forests (Shasta, Klamath, Modoc, Lassen, Plumas, Tahoe, Eldorado, Stanislaus, Sierra, Sequoia, Inyo, and Humboldt-Toiyabe) as well as various parks, private lands, and tribal lands that have potential to contribute to conservation of the four species.

Terrain in the southern two-thirds of the study area (southern and central Sierra Nevada) is very steep, with major river canyons draining west from the dramatic Sierran crest, and steeper, drier slopes dropping eastward from the crest down to desert and Great Basin vegetation. The rain-shadow effect of the Sierran crest creates strong differences in vegetation communities on either side, with generally more mesic forest communities on the somewhat gentler western slopes, and more open, xeric forests on the steeper eastern slopes. The highest elevations (above about 10,000-11,000 ft [3,050-3,350 m) are mostly non-forested alpine communities and rocky, unvegetated peaks.

Terrain in the northern third of the study area (northernmost Sierra Nevada and southern Cascades) is characterized by tall, isolated mountains (e.g., volcanic Mount Shasta and Mount Lassen) rising above somewhat gentler terrain and plateaus supporting relatively open forest and shrub communities. As a result, forest vegetation, and potential habitat for the four carnivore species, tends to be more fragmented in northern compared to southern portions of the study area.

Methods

Although specific methods vary by species (see species-specific methods below), our general approach was to apply the best available data, models, and expertise to identify areas essential to sustaining and recovering habitat and populations of each species. Guided by input from a group of independent science advisors, including species experts, connectivity modelers, and forest, fire, and climate-change ecologists (see Appendix A for list of advisors), we used geographic information system (GIS) models to map habitat quality and/or population distribution for each species and to identify population core and linkage areas and other areas important to population persistence, such as high-quality denning areas for fishers.

We first compiled available species locality datasets, existing species distribution models, and a large array of environmental variables for use in species distribution and habitat suitability models. We reviewed these datasets and existing models with science advisors to determine the best data and methods for mapping population distribution, habitat quality, and habitat connectivity for each species. In some cases we used or extrapolated one or more existing published species distribution models, and in others we created our own empirical distribution models using the Maxent program (Phillips et al. 2006). Maxent predicts and maps the probability of species occurrence across the landscape based on relationships between species detection localities and environmental variables.

Once current species distributions were mapped, we delineated core areas (contiguous areas of suitable habitat large enough to support at least five individuals of the species) and connectivity areas (suitable for species movements if not for year-round survival) between core areas. Connectivity was modeled as normalized least-cost corridors (WHCWG 2010) applied using species-specific movement cost rasters (or resistance surfaces; Beier et al. 2008, 2011). The cost surfaces were developed using objective scoring procedures based on the opinions of species experts about how land cover, topography, roads, and other environmental factors are likely to affect the costs or risks of individuals moving across the landscape (Appendix B).

Core and connectivity maps were then inspected, compared with aerial imagery (in Data Basin, www.databasin.org), and overlaid with various other data sets and model results to identify areas of risk (e.g., major road crossings), bottlenecks in potential movement corridors, important microhabitat areas (e.g., fisher denning habitat), areas of habitat overlap among the species, and so on. These analyses were used to develop spatially explicit recommendations and priorities for conservation and management actions.

The following sections detail the specific methods and issues for each species.

Marten

Marten in Yosemite National Park (Meade Hargis).

Existing information (e.g., Kirk 2007, Rustigian-Romsos and Spencer 2010) suggested that martens are strongly associated with high-elevation, unmanaged forests (especially red fir and during summer) in National Parks and Wilderness Areas, and that maintaining and improving connectivity of late-seral forests between currently occupied sites is a key conservation concern. Monitoring data show higher marten detection rates in winter than in summer, with greater use of lower elevation, mixed-coniferous forests during winter, and more concentrated use of higher elevations during summer (Rustigian-Romsos and Spencer 2010 and unpublished analyses). Marten experts (T. Kirk, W. Zielinski, W. Spencer) therefore recommended basing marten distribution maps on data collected during predominantly snow-free periods (May-November) as representing the most habitat-limited season for martens.

CBI reviewed and discussed available marten distribution models (Kirk 2007, Kirk and Zielinski 2009, Rustigian-Romsos and Spencer 2010, California Wildlife Habitat Relationship [CWHR] program) and connectivity models (Kirk and Zielinski 2010) with advisors and decided that new marten models need to be created for our purposes. Only the CWHR habitat suitability model covered the entire study area, and it clearly over-predicts potential marten distribution. We therefore created empirical marten distribution models for the study area based on extensive marten survey data (compiled with assistance from the USFS Redwood Sciences Laboratory) and using Maxent software. Based on advisor advice that summer habitat is most limiting to martens, we only used marten detection data collected from May to November. To ensure spatial independence of marten detections, we randomly removed (filtered) detections to achieve minimum nearest-neighbor spacing of 7 km before running Maxent. Environmental variables were averaged over a 1-km^2 moving window before input to Maxent.

The resulting modeled occupancy map was further modified by removing urban, open water, cliffs (slopes > 80%), and recent (post-2005) severe burns (VegBurnSeverity10 1, USDA Forest Service, Pacific Southwest Region, Fire and Aviation Management; 2010) as potential habitat. We then delineated marten core areas as contiguous polygons of at least 2,500 ha ($\geq$ 5 marten home range areas) and having predicted probability of marten occupancy (PPO) $\geq$ 0.4. A few isolated potential core polygons in more xeric, northeastern portions of the study area were removed based on lack of evidence of marten occupancy from survey efforts and expert opinion that these polygons were unsuitable for supporting martens (T. Kirk, personal communications).

We created a marten resistance to movement data layer (or cost raster) for least-cost corridor modeling based on the expert judgment of marten experts (W. Zielinski, T. Kirk, W. Spencer) concerning the degree to which landcover (e.g., vegetation type, size class, density), roads, rivers, and other variables may affect marten movements or risks during dispersal. Areas mapped as urban or open water (large lakes) were assigned maximum resistance values (175) and areas $\geq$ 500 ha having PPO $\geq$ 0.4 were assigned the minimum resistance value of 1. All other pixels received values based on the sum of resistance factors occurring there (with a range of 1 to 175; see Appendix B for the resistance values assigned to CWHR vegetation classes, roads, rivers, steep slopes, etc.). Normalized least-cost corridors (5 normalized km wide[1]) were then modeled between the centroids of nearest-neighbor core polygons.

Fisher (E.K. Wellman)

Fisher

Fishers occur in two isolated portions of the study area, separated by an unoccupied gap of >400 km. Habitat (mid-elevation, mixed-coniferous forests having high forest biomass and characteristics of late seral forests) is limiting, and additive mortality due to anthropogenic influences (e.g., roadkill, rodenticide exposure, and diseases transferred to fishers from cats and dogs) may be limiting northward expansion of the southern population in and near Yosemite National Park (Chow 2010, Spencer et al. 2011). In the northern Sierra Nevada, a new population was recently established on the Lassen National Forest, south of previously known occupied habitat in the Shasta National Forest, by translocating fishers from the Klamath-Siskiyou region.

A number of published fisher occupancy models are available for the study area: GAM (generalized additive models) and Maxent models produced by Davis et al. (2007) cover the entire study area either alone ("statewide" model) or as separate subregional models for the Klamath/Shasta, northern-central, and southern Sierra Nevada. CBI developed a finer-resolution GAM model for the southern Sierra Nevada (Spencer et al. 2008, 2011). Zielinski et al. (2010) also prepared a finer-resolution model for the Klamath region. A CWHR index model also covers the entire study area, but tends to overestimate the extent of suitable habitat.

We mosaicked what our science advisors considered the five best available models to create a single probability of fisher occurrence surface that covers the entire study area: the CBI GAM model for the southern Sierra Nevada (Spencer et al. 2011), the Zielinski et al. (2010) model for the Klamath region, and Davis et al. (2007) GAM models for the Klamath/Shasta region (covering the balance of the area north of the Pit River), statewide (covering the north-central Sierra Nevada), and southern Sierra (covering the balance of the southern region). All of these models are based on fisher survey data collected primarily during snow-free seasons; and all averaged environmental variables over 5-km^2 (Spencer et al. 2011, Zielinski et al. 2010) or 10-km^2 (Davis et al. 2007) moving windows.

We further modified this mosaicked distribution map by removing as potential habitat urban areas, open water, slopes > 80%, and post-2005 severe burns (VegBurnSeverity10 1, USDA Forest Service, Pacific Southwest Region, Fire and Aviation Management; 2010). Core areas

[1]The actual width of normalized least-cost corridors depends on the underlying cost factors; where costs are higher, the corridor will be narrower, indicating corridor bottlenecks.

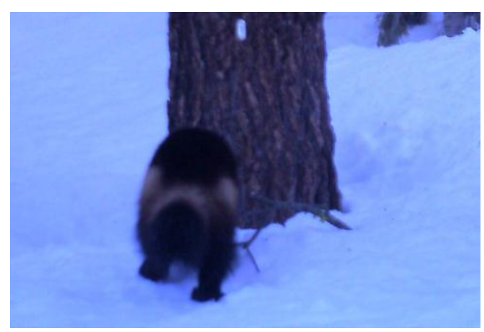
were then delineated as contiguous polygons ≥ 2,500 ha (5 female home ranges) having ≥ 0.4 PPO. A subset of cores having PPO ≥ 0.7 were identified as "high-quality" cores, which correspond very closely with the current distribution of the southern Sierra Nevada fisher population.

We created a resistance-to-movement raster (range of 1 to 175) for fisher using the same methods as for marten, but with different species-specific resistance values assigned to CWHR classes, roads, rivers, etc. (Appendix B). We then calculated normalized least-cost corridors (10 normalized km wide) between the centroids of core areas to define connectivity areas.

We also modeled the distribution of a critical subcategory of fisher habitat—denning habitat used by mother fishers during reproduction. We obtained locality data for natal dens (structures where young are born) and maternal dens (additional structures used as the young grow) from the SNAMP (Sierra Nevada Adaptive Management Program) and KRP (Kings River Project) fisher studies on the Sierra National Forest. Using these den localities we created finer-resolution (2-km^2) Maxent denning habitat models for this portion of the study area, and extrapolated the results of our final best model across the southern Sierra Nevada, using den PPO (PDEN) ≥ 0.4 to delineate potential denning habitat. The den model reinforces what field research has already shown about fisher denning areas: dens are located almost exclusively in the densest forest stands with abundant large trees, and often in areas where black oaks intermix with mixed conifers. The model is highly predictive of denning areas in and near the SNAMP and KRP study areas, but caution should be used in relying on its predictions at increasing distance from these study areas, because fishers may select for different conditions in different regions (e.g., where black oak or Sierran mixed-conifer vegetation are lacking).

Wolverine

Wolverines are considered extirpated from California, although a single male wolverine recently dispersed to the northern Sierra Nevada, probably from the Sawtooth Range in Idaho (Moriarity et al. 2009). Climate change and human influences may affect the potential to establish and sustain a breeding population now or in the future, as wolverines require deep snows that persist well into spring for denning (Aubry et al. 2007, Copeland et al. 2010) and for keeping cached food from competitors during lactation (Inman et al. 2012). Nevertheless, plans to reintroduce wolverines to National Parks in the southern Sierra Nevada are being seriously considered (D. Graber, personal communication).



Wolverine photographed by remote camera near Sagehen Creek, Tahoe National Forest, February 2008 (Moriarity and Zielinski).

Wolverine distribution is not closely tied to particular landcover types or features, but is closely tied to snow cover. Throughout their circumpolar distribution, as well as in particular regions like the western U.S., wolverines are largely restricted to areas where snow cover persists at least into late April or May (Aubry et al. 2007, Schwartz et al. 2009, Copeland et al. 2010). Because there is insufficient wolverine locality data in the study area to derive empirical occupancy models, we therefore delineated wolverine habitat as areas retaining snow cover until May, based on Copeland et al. (2010) and science advisor recommendations. Specifically, core habitat areas were conservatively delineated as contiguous polygons of at least 935 km^2 (based on wolverine expert advice) where snow persisted until May in at least 1 of 7 years (2000-2006; Copeland et al. 2010).

Wolverines are very strong dispersers, capable of moving hundreds of kilometers, and do not seem to use or avoid particular land covers or features when moving (J. Copeland, personal communications). However, their probability of successfully navigating across a landscape is expected to vary with dangers posed by human influences, such as roads, dogs, hunters, etc. Based on input from wolverine experts and science advisors (J. Copeland, B. Hudgens, and D. Garcelon, personal communications), we therefore developed a resistance data layer for wolverine connectivity that represents human modifications to the landscape and other factors likely to decrease the probability of a wolverine surviving as it moves across the landscape. Areas $\geq$ 120 km^2 having PPO $\geq$ 0.4 were assigned the minimum resistance of 1. All other pixels were assigned a resistance value using procedures developed for wolverine by the Washington Wildlife Habitat Connectivity Working Group (WHCWG 2010), accept that we adjusted the elevation range scores to account for latitudinal differences between Washington and California (range of 1 to 1704; Appendix B). We then calculated normalized least-cost corridors (20 normalized km wide) between the centroids of neighboring cores.

Sierra Nevada red fox, "cross" phase, photographed by remote camera near Sonora Pass, September 2010 (USDA Forest Service).

Sierra Nevada Red Fox

The Sierra Nevada red fox is the least understood of the four species. Prior to 2010, there had been only one field study on the species, on a small number of foxes persisting in Lassen National Park and National Forest (Perrine 2005), and there were no recent observations elsewhere in California. In 2010, a population of Sierra Nevada red foxes was detected by remote cameras and scats near Sonora Pass in the southern Sierra Nevada (northeast of Yosemite National Park on Humboldt-Toiyabe National Forest). Surveys performed since then have identified at least 9 individuals (based on genotyping done thus far) and suggest that the total population in that area is probably around 30-60 individuals (based on territory size of the best-documented pair of foxes and the approximate area of documented occupancy; B. Sacks, personal communication). This estimate is highly uncertain and may increase as the survey effort expands over additional potentially suitable habitat area.

In addition, during 2011 a road-killed Sierra Nevada red fox was found near the intersection of State Routes 108 and 395 (Humboldt-Toiyabe National Forest) directly downslope from the Sonora Pass population, from which it was probably dispersing. Finally, another red fox, suspected but not confirmed as a Sierra Nevada red fox (B. Sacks, personal communication), was photographed by a CDFG biologist from a helicopter near the Sierran crest west of Round Valley (Inyo National Forest) more than 100 km south of Sonora Pass.

Based on expert advice (J. Perrine), we used an occupancy model published by Cleve et al. (2011) to delineate potentially suitable habitat. The model used generalized linear regression and fox detection data from the vicinity of Mount Lassen to project suitable habitat over the Sierra Nevada based on variables derived from remote imagery. We further modified this PPO map by removing urban, open water, and slopes > 80% as potential habitat. Cores were delineated as contiguous polygons of at least 150 km^2 (5 fox home ranges) having PPO $\geq$ 0.4. All of the recent locality points in the Sonora Pass area fall within or immediately adjacent to (< 1 km from) predicted core habitat.

We developed a movement cost raster based on input from fox expert J. Perrine concerning how land cover, roads, rivers, elevation, slope, and other factors are expected to influence the costs or risks to red foxes of dispersing across a landscape (range of 1 to 234). Urban areas and open water were assigned the maximum resistance value (234) and areas $\geq$ 30 km^2 having PPO $\geq$ 0.4 were assigned the minimum resistance of 1. All other pixels were assigned a resistance value based on the sum of individual resistance factors occurring there (Appendix B). Normalized least-cost corridors (20 normalized km wide) were then calculated between the centroids of neighboring potential core areas.

Results

This section presents the basic output maps for each species (showing population and/or habitat distributions, core areas, movement cost surfaces, and connectivity areas) with brief descriptions of the primary spatial patterns and issues they reveal. The following section (Application to Conservation Planning) presents more detailed interpretations of these results in support of conservation priorities and recommendations.

Marten

Figure 2 shows the predicted probability of occupancy (PPO, which can also be interpreted as habitat quality) for martens across the study area, and Figure 3 shows marten core areas (PPO $\geq$ 0.4) overlaid on the movement cost raster. Marten detection data verify that martens are well distributed within predicted core areas. In the central and southern Sierra Nevada, core habitat areas are distributed in relatively large, contiguous polygons at higher elevations (above about 2,200 m [7,200 ft]) from the southern portion of Plumas National Forest to near the southern tip of the range (Greenhorn Mountains and Kern Plateau). In the north, however, habitat becomes more fragmented, with martens mostly restricted to isolated or semi-isolated high-elevation areas separated by lower, drier, or more disturbed habitats that don't support martens (at least during snow-free seasons). This suggests that marten conservation should focus on maintaining or improving potential dispersal corridors between suitable habitat areas in the northern forest areas (Plumas, Lassen, Klamath, Shasta, and Modoc National Forests) while minimizing habitat fragmentation in suitable habitats throughout the study area.

Figure 4 shows marten cores and connectivity areas (delineated as 5-km-wide normalized least-cost corridors). Habitat connectivity does not appear to be greatly limiting for martens south from Plumas National Forest (although Interstate 80 may be a significant barrier to movement), but movement corridors are relatively long and constrained from Plumas National Forest north, where relatively xeric, lower elevation, and disturbed habitats separate the higher-elevation red fir and lodgepole pine forests preferred by martens. The Pit River Valley and other lower-elevation and open habitats are likely dispersal filters or barriers for martens. Genetic research should identify to what degree marten populations in this region may be naturally isolated by habitat conditions, and whether working to improve habitat connectivity between isolated habitat areas (e.g., between Mount Lassen and Mount Shasta) should be a conservation priority, especially in light of climate change.

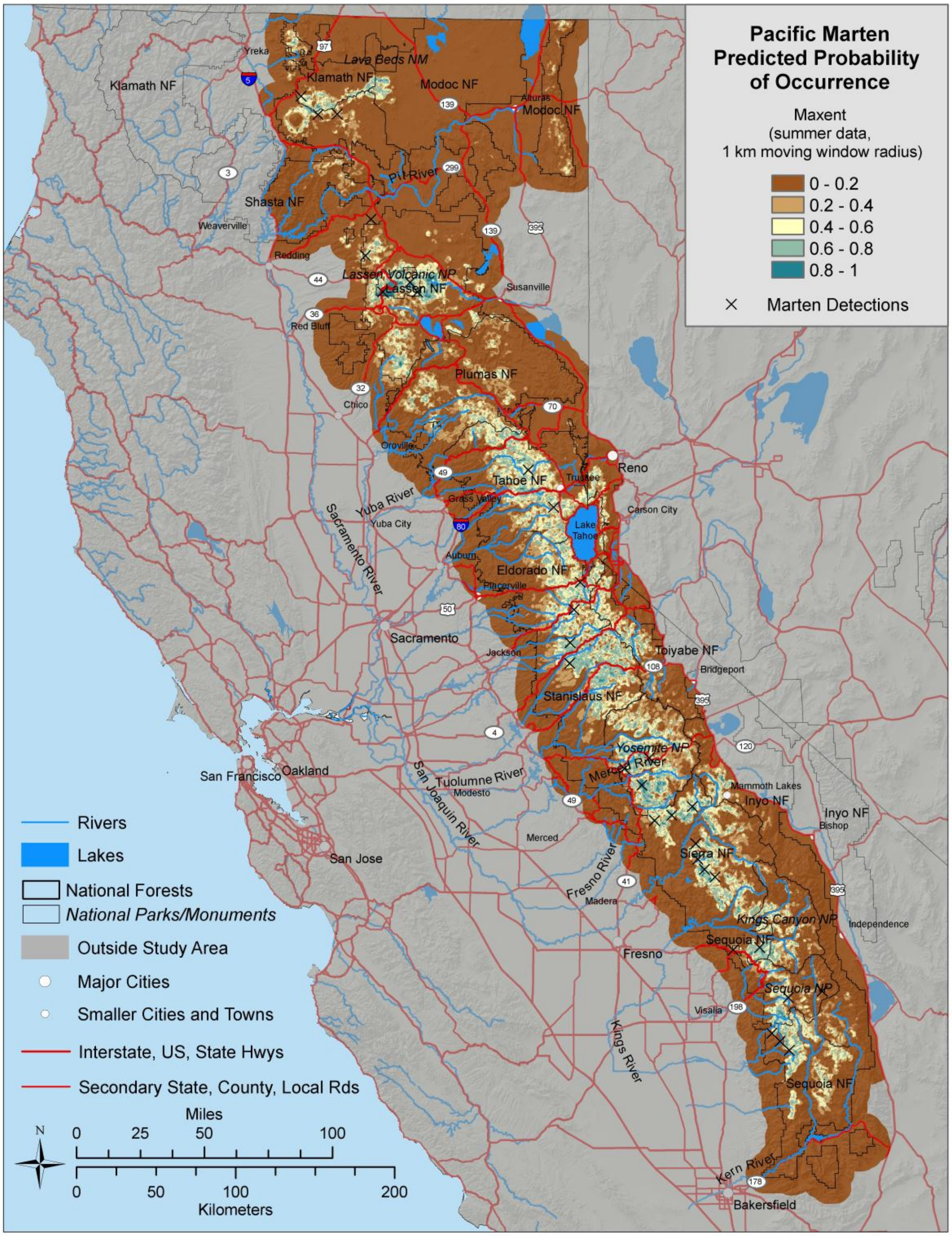


Figure 2. Marten probability of occupancy during summer predicted by a Maxent model at 1 km^2 resolution.

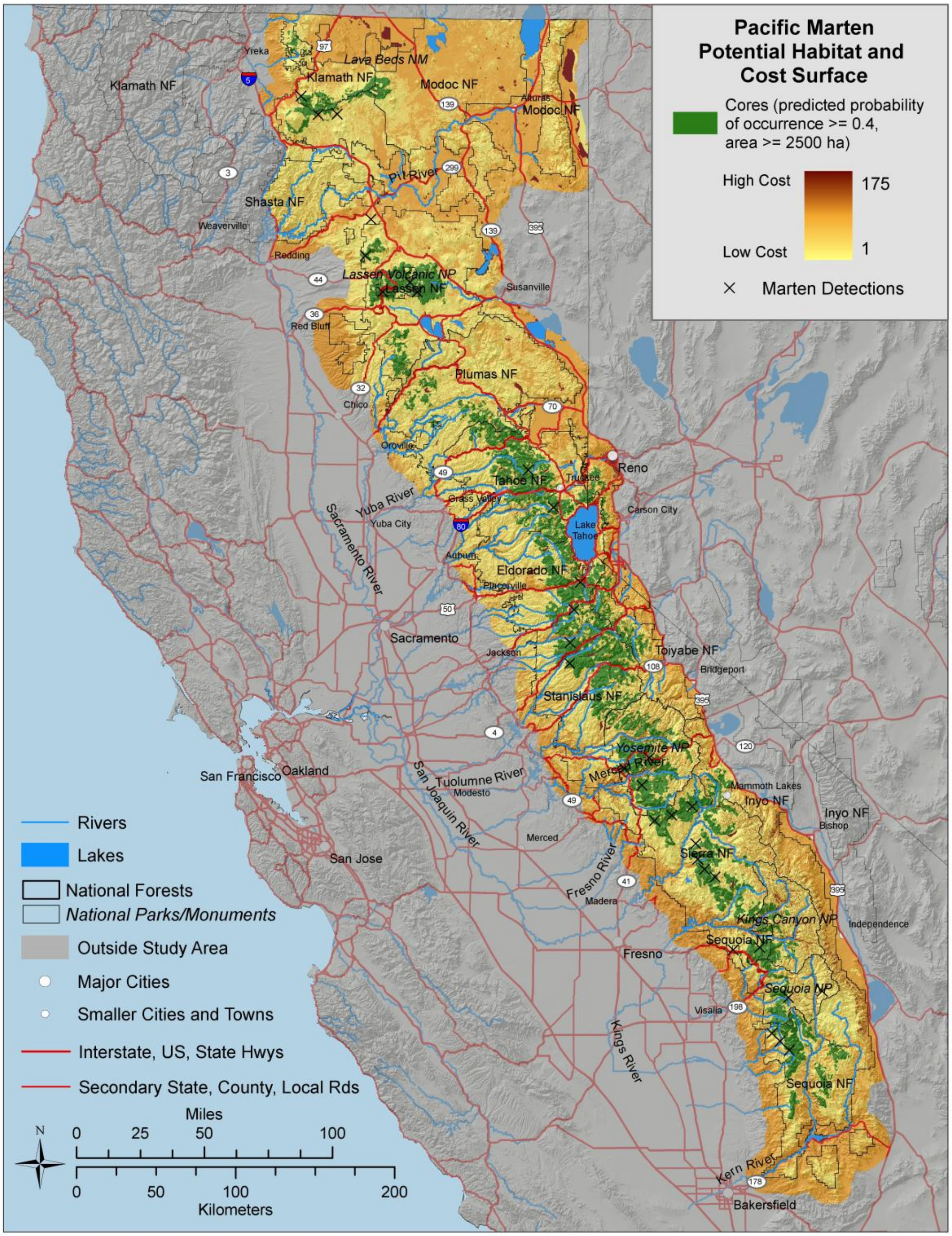


Figure 3. Marten core areas overlaid on the marten cost-of-movement surface. Core areas are more fragmented by topography in the northern portion of the study area than in the south.

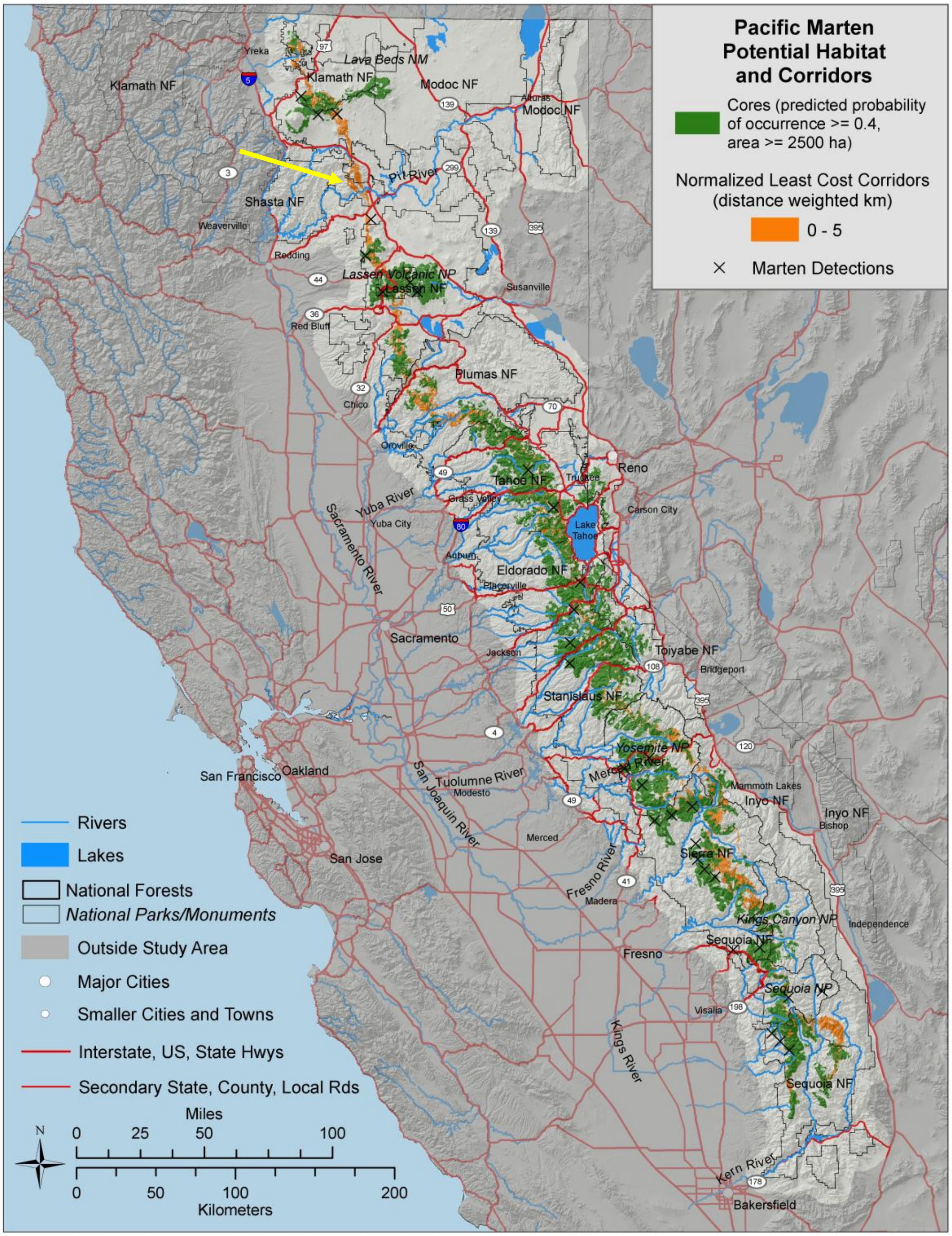


Figure 4. Marten core areas and normalized 5-km least-cost corridors. Note the long and constrained corridor between core areas on the Klamath and Lassen National Forests crossing the Pit River Valley (yellow arrow), which may represent a dispersal barrier or strong filter.

Fisher

Figure 5 shows the predicted probability of occupancy for fishers as a mosaic of 5 regional fisher distribution models. In the south, fishers are well distributed south of the Merced River (Yosemite Valley) in a long, narrow, mid-elevation band of high-quality habitat, segmented into a series of subpopulations by major river canyons. This isolated fisher population is the southernmost in North America, and probably numbers less than 300 adults (Spencer et al. 2011). Habitat quality appears to be under-estimated across Sequoia-Kings Canyon National Park and on the Kern Plateau, where some fisher detections lie in predicted low-probability areas. Some predicted habitat north of the Merced River (in Yosemite National Park and Stanislaus National Forest) is not occupied by fishers. This may be due to the combination of dispersal filters associated with Yosemite Valley (steep slopes, Merced River, heavy traffic) and high mortality in occupied areas south of the Merced River, which probably limits the number of potential dispersers (Spencer et al. 2011, Carroll et al. In Press).

Habitat potential in some northern portions of the study area may be under-estimated by the distribution models, especially the Davis et al. (2007) statewide and Klamath-Shasta models. Note there are some detections in areas with PPO < 0.2 north of the Pit River, adjacent to areas shown as having higher PPO by the Zielinski et al. model, and that habitats currently used by a translocated population of fishers in the southwestern portion of Lassen National Forest have low PPO.

Figure 6 shows fisher core areas (PPO ≥ 0.4) overlaid on the movement cost raster. The cores that are occupied by fishers are shown as a darker green than others and are labeled as "high quality" cores, because the average PPO in the occupied areas is ≥ 0.7. This suggests that moderate habitat quality north of the Tuolumne River ($0.4 \leq$ PPO < 0.7) may play some role in the lack of fisher occupancy there (although the unoccupied habitat between the Merced and Tuolumne Rivers has PPO ≥ 0.7). There are no occupied core areas between the Merced River and the introduced fisher population in southwestern Lassen National Forest, although some small "stepping stones" of potential habitat are scattered on the Plumas and Lassen National Forests. Although some fisher detections fall outside of predicted core areas between Mount Shasta and the Pit River, they are near predicted core areas and in areas of low resistance to fisher movements. As for marten, the Pit River Valley may represent a dispersal filter or barrier that limits potential for genetic exchange between the Klamath-Shasta fisher population and the area where fishers were introduced to the south.

Figure 8 shows the predicted distribution of fisher denning habitat for the southern Sierra Nevada based on den locality data from the Sierra National Forest. Note that confidence in this predicted distribution of denning habitat is lower outside the den model extent (i.e., north and south of Sierra National Forest). Fisher denning habitat is concentrated in lower elevation portions of predicted fisher core areas in the densest available mixed coniferous stands (CWHR density class D) having the largest trees (CWHR size classes ≥ 4), especially where a moderate proportion of the landscape also contains hardwood trees (black oaks).

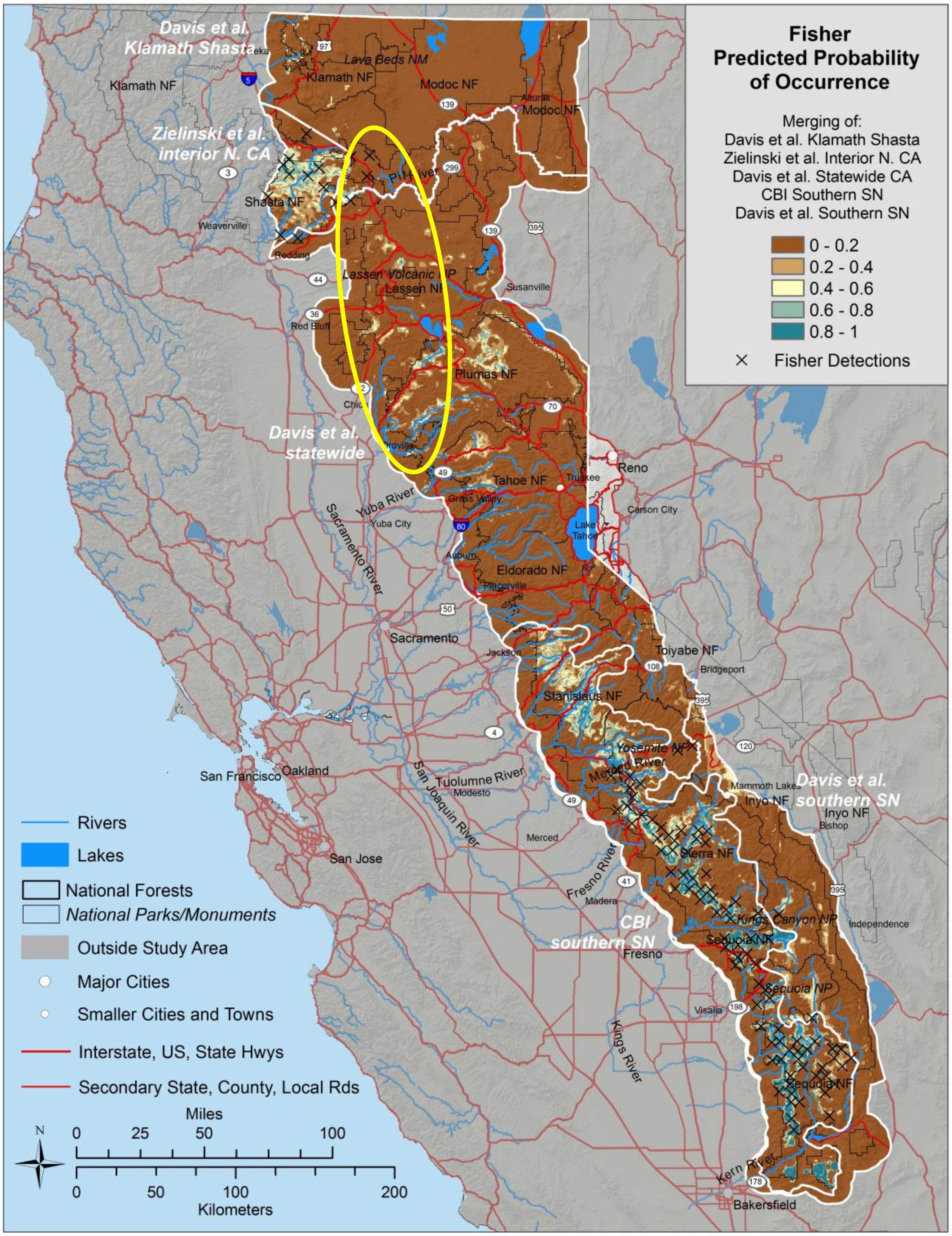


Figure 5. Fisher probability of occupancy created by mosaicking 5 previously published regional models. The Davis et al. (2007) models used for the north-central Sierra Nevada and Klamath-Shasta area may under-represent actual habitat values in some regions (yellow oval).

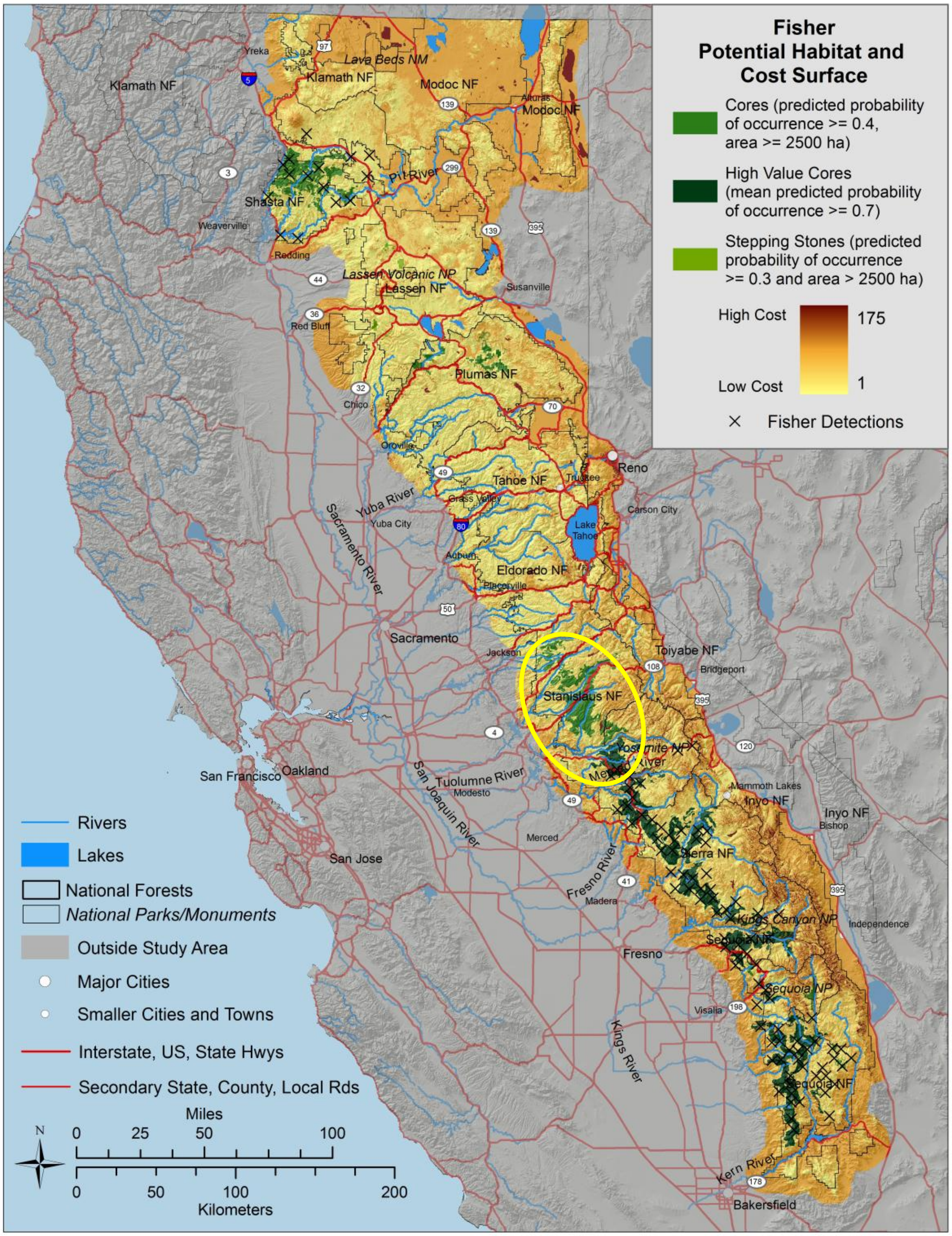


Figure 6. Fisher core areas overlaid on the fisher cost-of-movement surface. Note that the predicted highest-quality core areas (PPO $\geq$ 0.7) are south of the Tuolumne River and that a breeding fisher popultion is absent north of the Merced River (yellow oval).

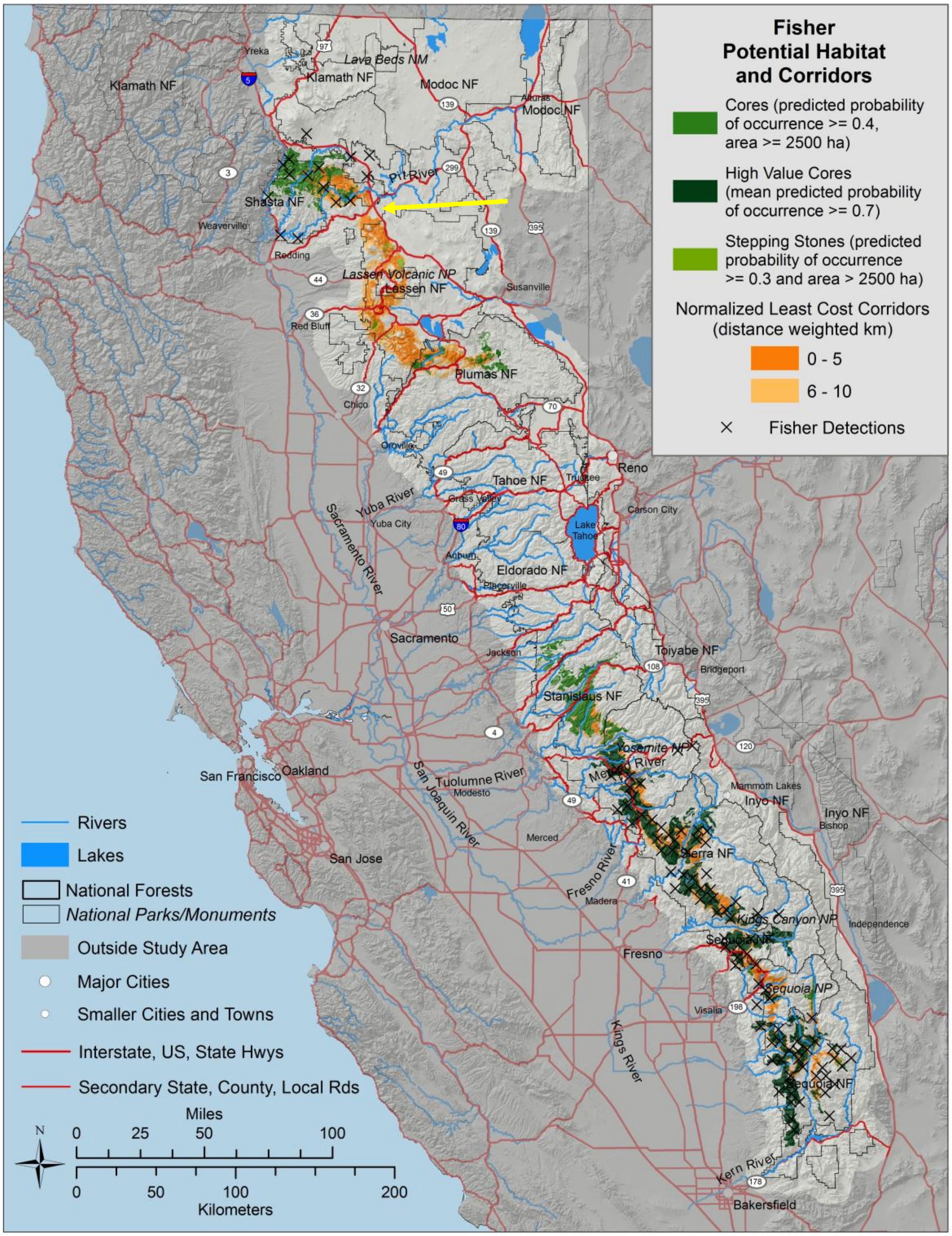


Figure 7. Fisher core areas and normalized 10-km least-cost corridors. Note: no corridor is mapped across the northern-central Sierra Nevada "gap" in fisher distribution, and the Pit River Valley is likely a strong filter to fisher movement (yellow arrow).

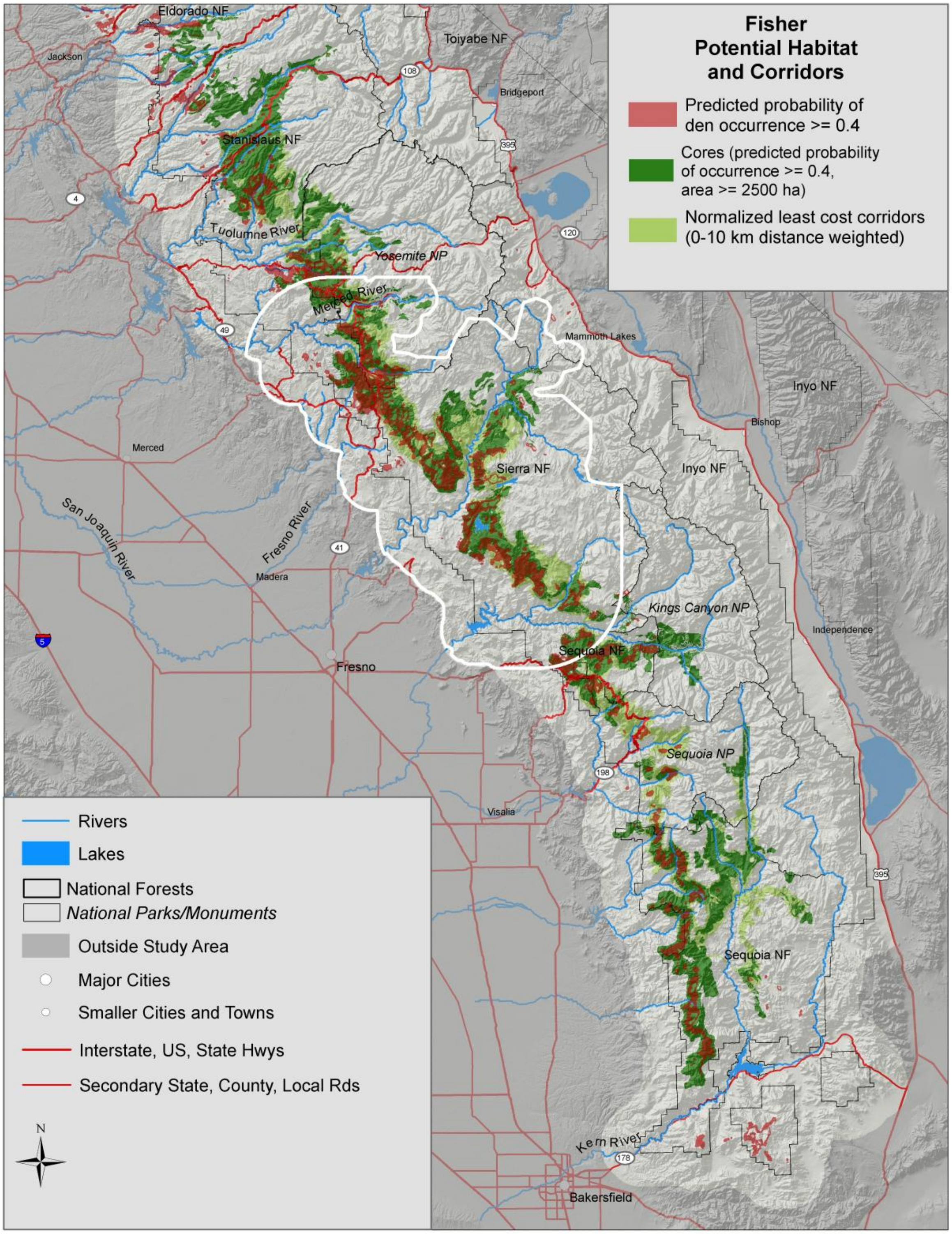


Figure 8. Fisher denning habitat overlayed on core and connectivity habitats in the southern Sierra Nevada. Confidence in the predicted distribution of denning habitat is lower where it is extrapolated outside the den model extent (white boundary).

Wolverine

Figure 9 shows the distribution of potential wolverine habitat (areas having snow cover until May during at least 1 of 7 years; Copeland et al. 2010), and Figure 10 shows predicted core habitat areas overlain on the wolverine movement resistance layer. Potential habitat is extensive and fairly contiguous in the southern half of the study area (from Tahoe National Forest in the north to Sequoia National Park in the south). The one known wolverine in the study area occupies a home range near the northern extent of this large area of contiguous predicted habitat on Tahoe National Forest. North of there (Plumas National Forest to the Oregon border), predicted habitat is much more fragmented, with two potential core areas around Mount Lassen and in the Mount Shasta to Medicine Lake Highlands region. Other isolated patches of potential habitat are too small (< 935 km^2) to qualify as cores, but some could serve as movement stepping stones between cores.

Because wolverines are strong dispersers that can move through most land covers, the risk of movement map shows large areas of relatively low risk; however, numerous highways and areas of human habitation fragment much of the available core habitat and areas of potential movement between them, especially in the northern half of the study area. The larger roadless areas in the high Sierras in the south (including wilderness areas from the Stanislaus National Forest south through Sequoia National Park) offer the largest, most intact and potentially risk-free region to support a wolverine population. Reintroducing wolverines to this region should be seriously considered.

Figure 11 shows normalized least-cost corridors connecting the three potential wolverine core areas, but these are probably not very useful depictions of potential wolverine movement corridors, given the strong dispersal capabilities of wolverines, the great distances between the core areas, and the number of major roads and human disturbances possible in these regions. Establishing a wolverine population in the large roadless areas in the southern portion of the largest core area seems a higher priority than attempting to maintain movement potential to the smaller potential cores in the north. Nevertheless, reducing risk factors in this northern region (e.g., road-crossing improvements) could increase the probability of more wolverines successfully immigrating into the Sierra Nevada from existing populations outside California.

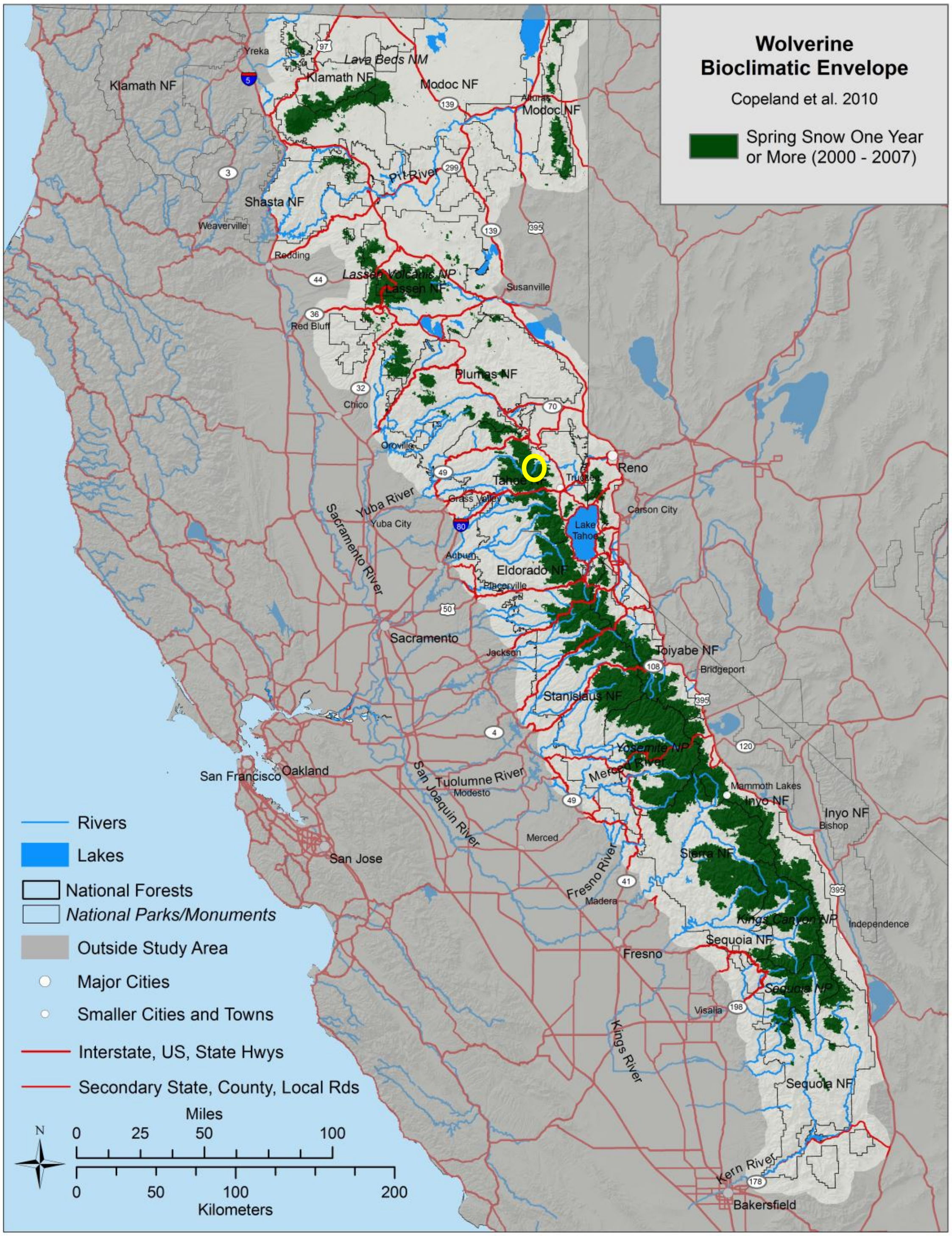


Figure 9. Potential wolverine habitat based on a bioclimatic envelope model (areas having snow persisting until May for at least 1 of 7 years). The approximate home range area of a lone male wolverine is indicated by a yellow oval.

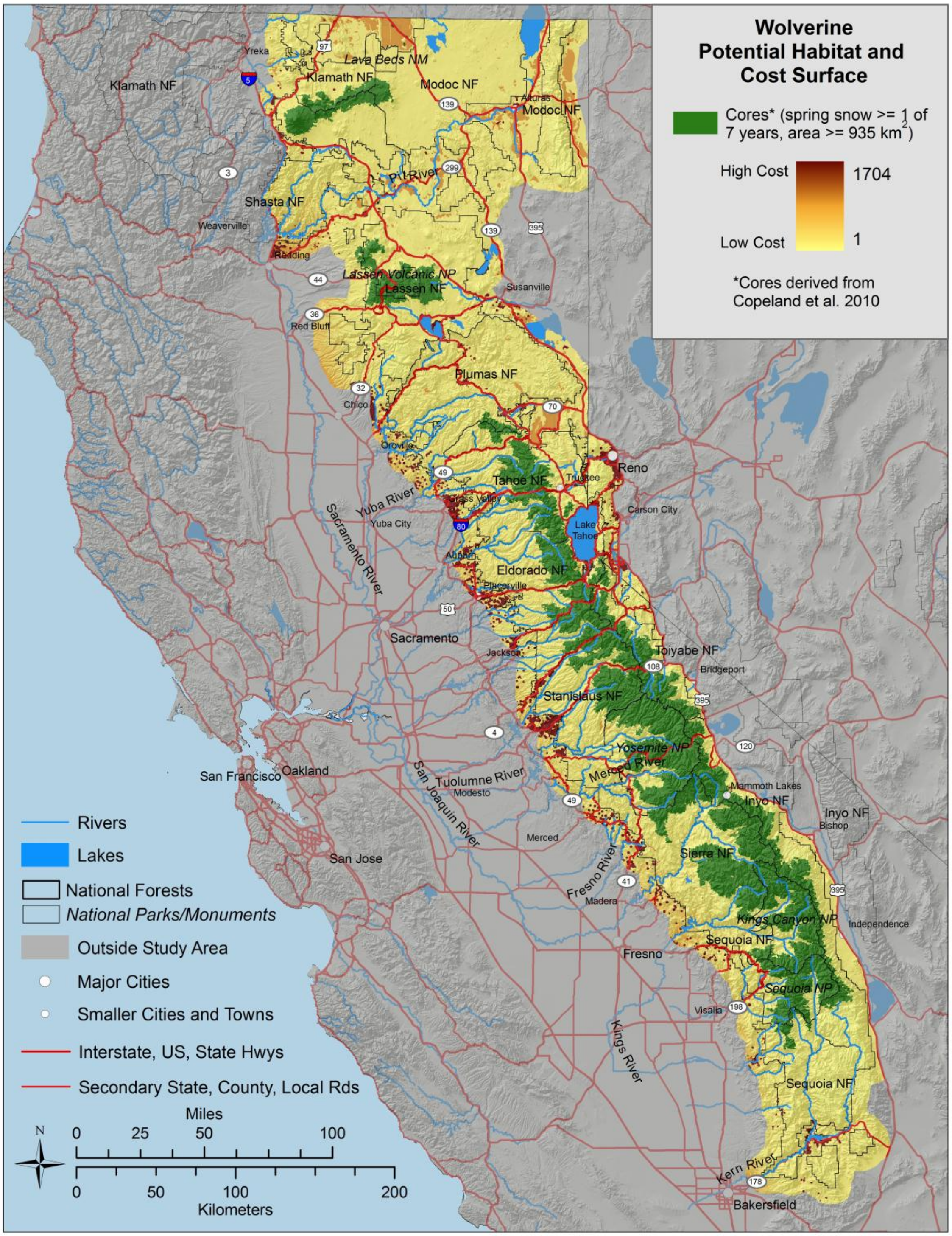


Figure 10. Wolverine potential core areas ($\geq$ 935 km^2) overlaid on wolverine cost-of-movement surface.

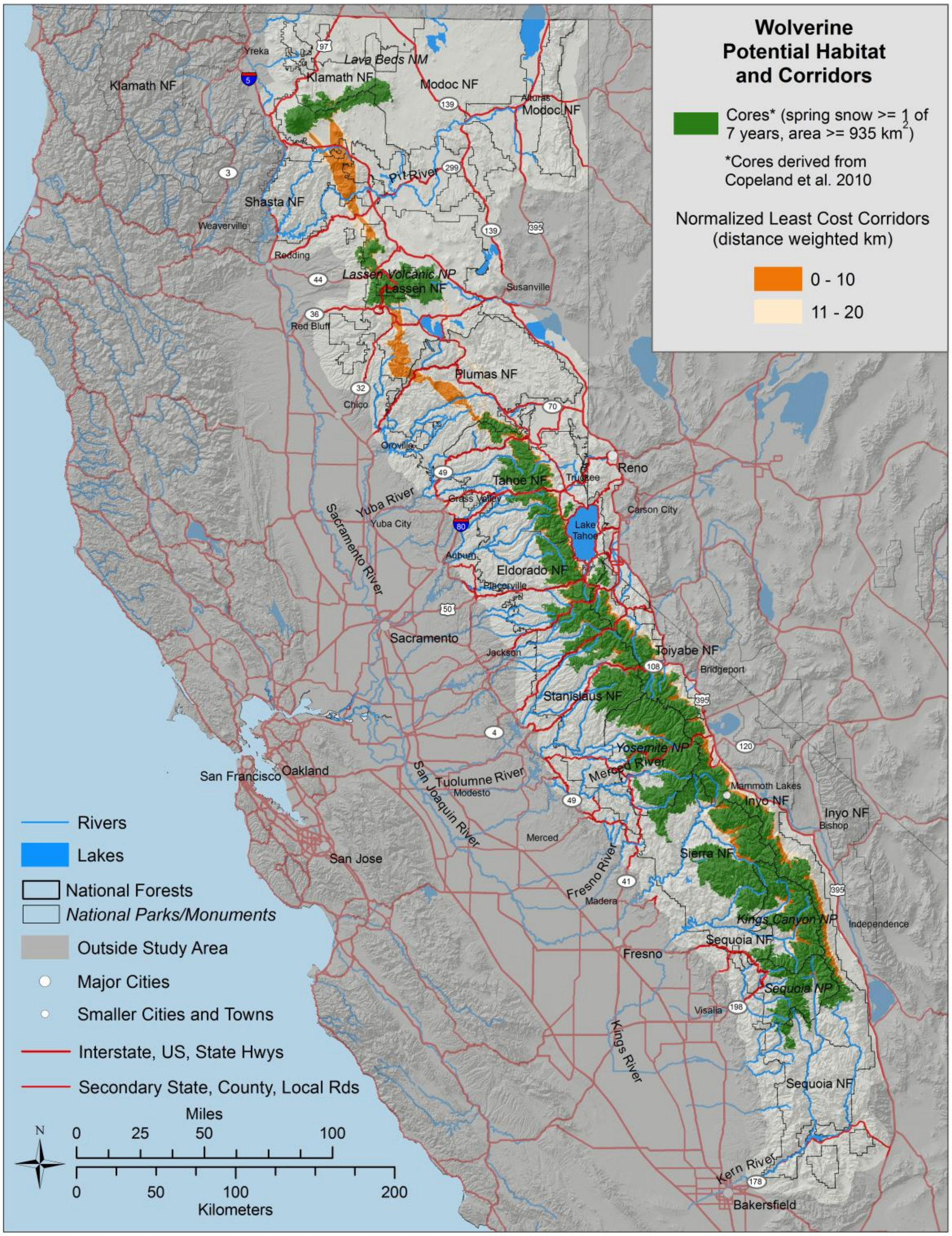


Figure 11. Wolverine potential core areas and normalized 20-km least-cost corridors.

Sierra Nevada Red Fox

Figure 12 shows predicted Sierra Nevada red fox habitat potential based on Cleve et al. (2011), and Figure 13 shows potential core areas overlain on the cost-of-movement surface. Yellow ovals indicate the two areas known to support populations. Figure 14 shows modeled movement corridors between two potential cores from the large southern Sierra Nevada core to the Mount Lassen core), but the functionality of this for fox movements is highly suspect due to the great distance (nearly 100 km between cores), unknown fox dispersal abilities, low-value habitat, and numerous risk factors (e.g., highways and fox predators like coyotes) along the route. The Mount Lassen population has probably been isolated from the southern Sierra Nevada population by low elevations for a long time (Grinnell et al. 1937, B. Sacks personal communication). Minimizing disturbance and mortality factors in the two known occupied areas should be the highest conservation and management priority until more is known about the distribution, abundance, and biology of these populations, while searching for additional local populations (Perrine et al. 2010).

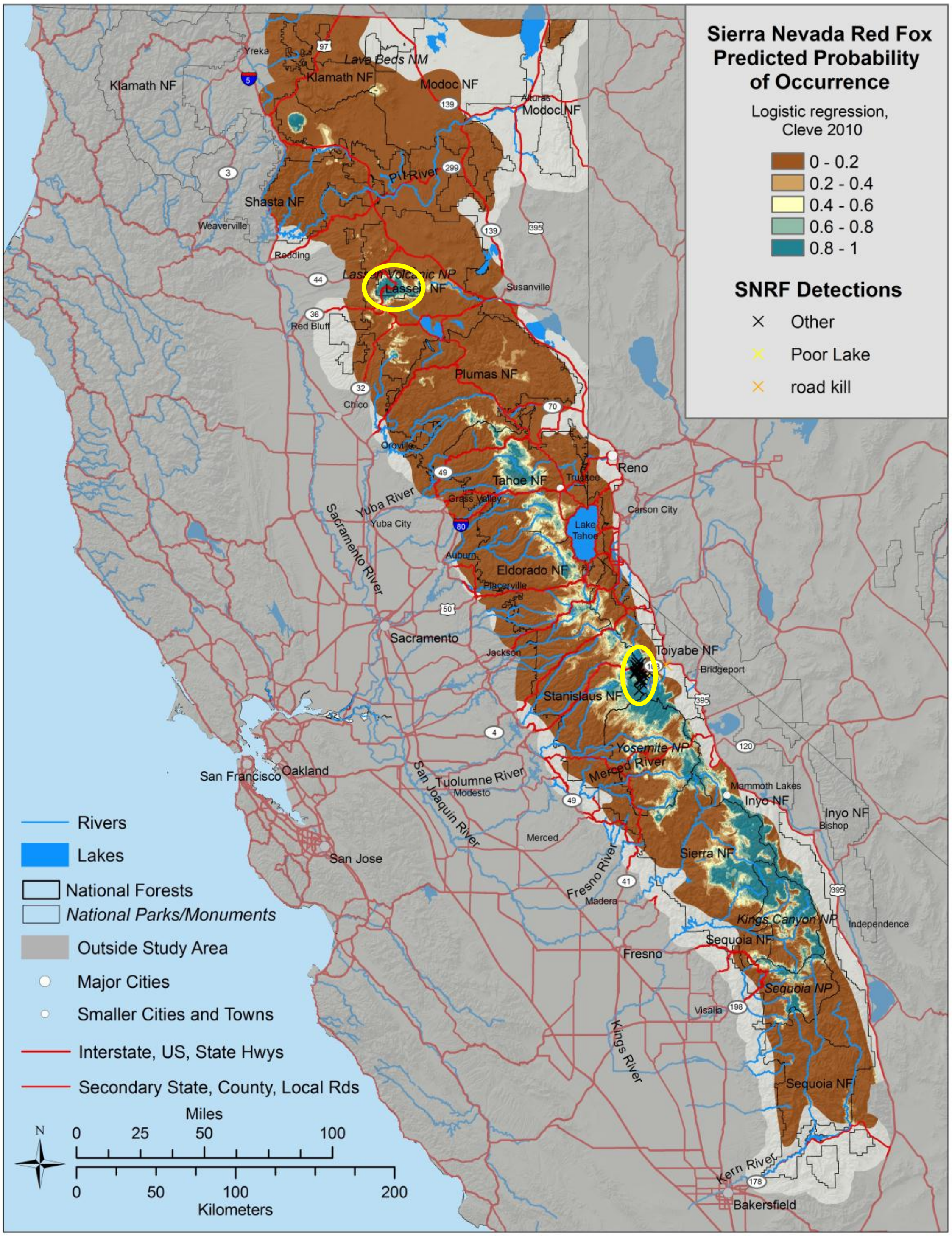


Figure 12. Sierra Nevada red fox predicted probability of occurrence from Cleve et al. (2011) showing approximate area of known, extant populations (yellow ovals).

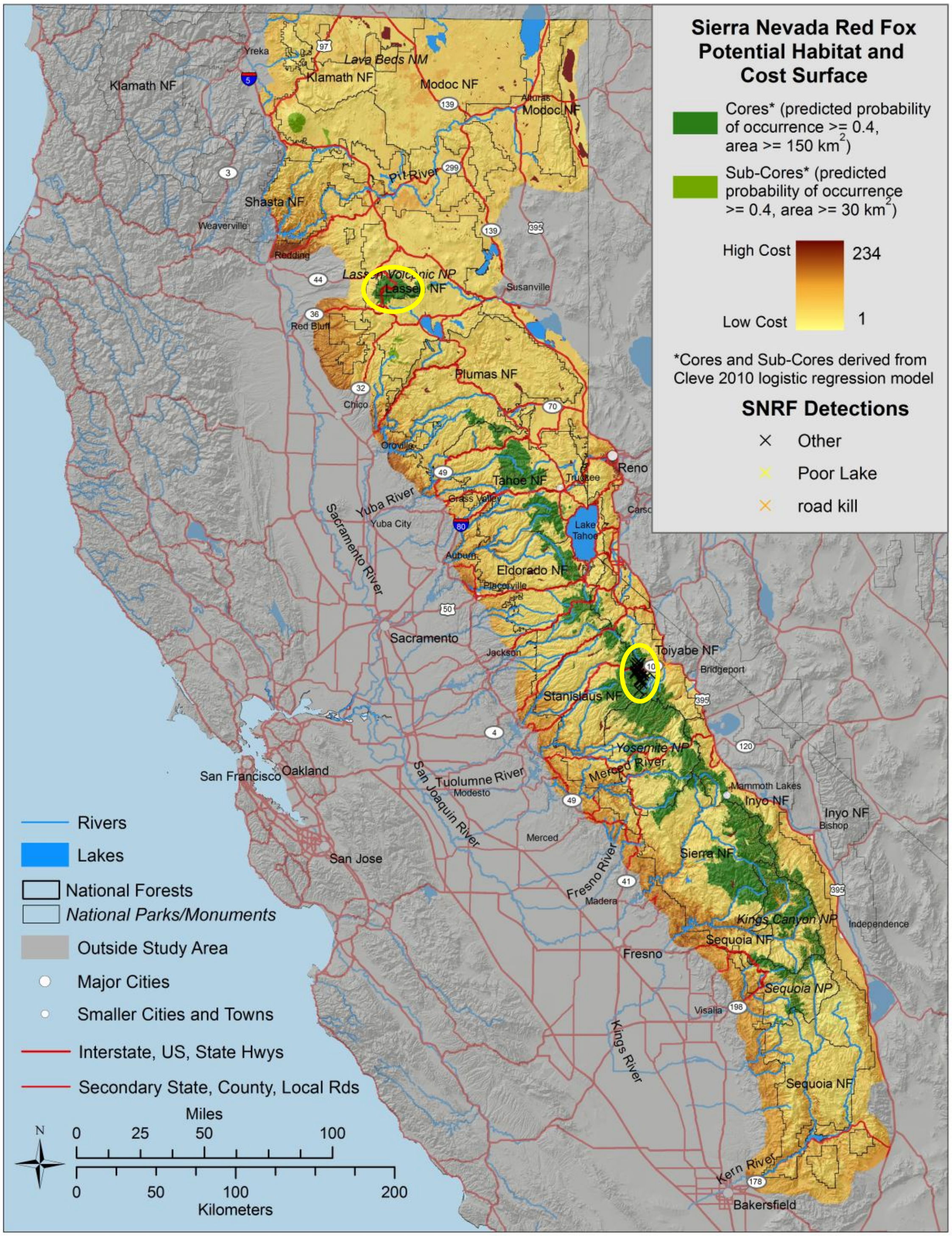


Figure 13. Sierra Nevada red fox potential cores overlaid on fox cost-of-movement surface showing approximate area of known, extant populations (yellow ovals).

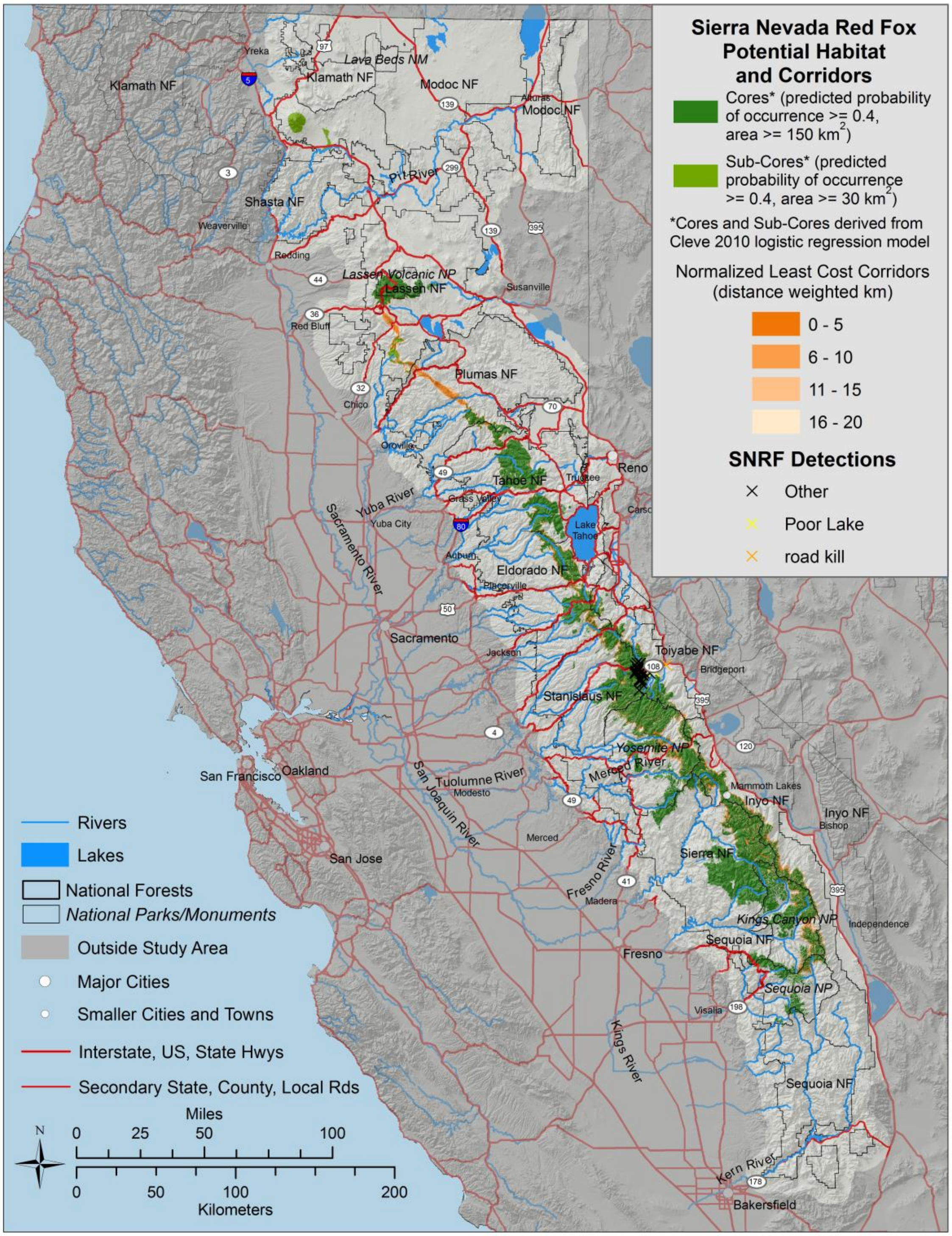


Figure 14. Sierra Nevada red fox potential cores and normalized 20-km least-cost corridors. Functionality of the modeled movement corridor south from Mount Lassen is highly suspect.

Species Overlap

Figure 15 illustrates the pattern of overlap in modeled habitat areas for the four species, to help with prioritizing conservation actions. Note that overlap by the three higher-elevation species (marten, wolverine, and Sierra Nevada red fox) is shown by stacking the number of species predicted to potentially co-occur, but that fisher is shown in a different color for contrast, because it occupies lower elevation areas and generally does not overlap with the other species (except for a narrow elevation band of overlap with martens). Habitat for the three higher-elevation species overlaps considerably in subalpine to alpine areas, much of which is in roadless wilderness areas and National Parks. The habitat for these three species consequently receives less intensive vegetation management than that of the fisher, which occupies mid-elevation, mixed-coniferous forests that have lesser levels of conservation protection and are subject to more intensive forest management (e.g., timber harvest and fuels management).

Note, however, that there is a high degree of overlap in connectivity areas for all four species in the northern portion of the study area. The topographically fragmented nature of habitat for all species in the northern Sierra Nevada and southern Cascades causes least-cost corridors to generally follow the highest-elevation habitats available, linking a series of forested “stepping stones” between the Tahoe National Forest and the Mount Lassen and Mount Shasta regions, such as in the Burney Mountain, Butt Mountain, Mount Hope, Mount Pleasant, and Beartrap Mountain areas. Although these modeled movement corridors may not be functional for all species, their concordance in these regions suggests that maintaining or improving connectivity there for one species (e.g., fisher) has potential to benefit multiple species, at least in the long term.

These potential movement corridors should also be studied for options to mitigate barriers or filters, for example to reduce road-crossing hazards or increase forest cover in places like the Pit River Valley. Predicted road-crossing areas are highly concordant for multiple species across a number of highways. In the northern half of the study area, such multi-species road crossing areas include Highway 299 near Burney, 44 and 89 near Mount Lassen, 36 west of Lake Almanor, 70 near the town of Belden, 49 near Sierra City, and Interstate 80 near Soda Springs. In the southern portion of the study area, crossing areas for the three higher-elevation species include Highway 50 near Twin Bridges, 88 near Kirkwood, 108 near Dardenelle, and 120 near Tuolumne Meadows. Road crossings for fisher tend to occur farther downslope to the west, including 108 west of Pinecrest; 120 near Mariposa; 140, 41, and Big Oak Flat Road in Yosemite National Park (especially near the Wawona Overlook); multiple locations along 140 between Yosemite Valley and Fish Camp; 168 east of Shaver Lake; 180 and 198 in Kings Canyon National Park; and 190 near Camp Nelson. Predicted road-crossing areas should be investigated in the field for the potential benefits of siting road-crossing structures and wildlife fencing to benefit multiple species (including deer and black bear). Such studies are being initiated in some regions by biologists with the National Park Service, US Forest Service, Caltrans, and other agencies and NGOs.

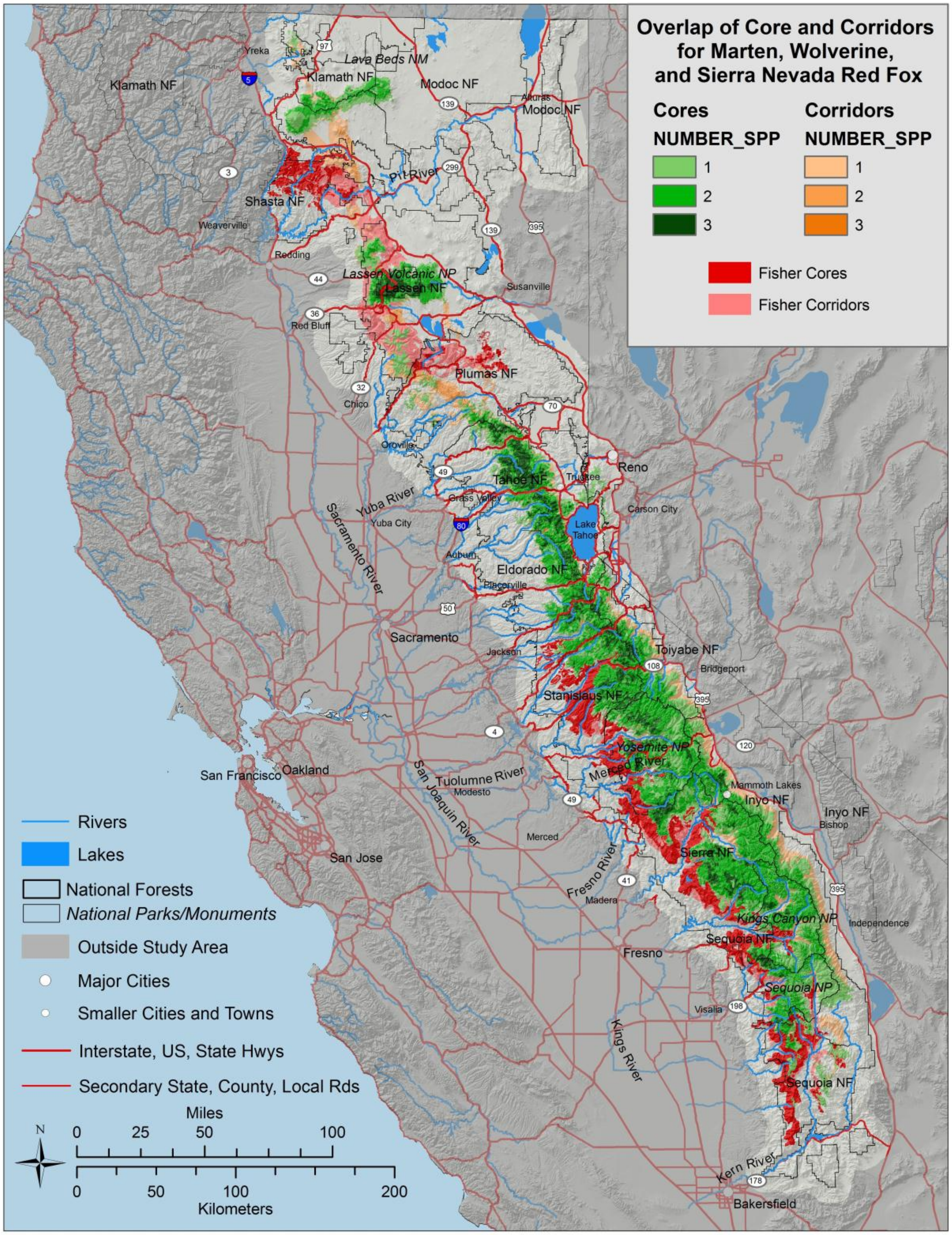


Figure 14. Habitat overlap for four carnivore species. Overlap between the three higher-elevation species (marten, wolverine, Sierra Nevada red fox) is shown by shades of green (cores) and orange (corridors); fisher is shown separately (red for cores, pink for corridors) because it overlaps little with the other species and will require different conservation actions.

Application to Conservation Planning

Conservation and land-management planning need to consider a range of spatial and temporal scales. Relevant spatial scales for forest carnivores range from microsites (e.g., specific structures used for denning, caching, or resting) to forest stands (e.g., the structure and composition of forest stands that provide suitable resting or foraging microhabitats) to home range (the mosaic of habitat conditions that provide all life requisites for an individual animal) to landscape (regional characteristics that support a population or metapopulation of interacting individuals). Relevant temporal scales range from the immediate effects of a management action on an individual animal's behavior or survival, to mid-term effects over the life-span of an individual or changes in stand structure following a management action, to changes in population size or landscape conditions over decades.

The maps provided herein are primarily useful as foundations for conservation planning at the landscape and home-range scales, although some results are also useful at finer, sub-home range scales, such as the fisher denning habitat map or least-cost corridor maps across roads and canyons. Because these maps are static, they are most useful for understanding current, short-term conditions, although they can also inform longer-term processes, such as where dispersal between core habitat areas or population expansion into currently unoccupied areas are most likely to occur on a scale of years or decades. Moreover, these static maps can be coupled with dynamic models, such as climate change, vegetation change, or population models, to aid understanding of longer-term changes (e.g., Sheller et al. 2011, Spencer et al. 2011, Syphard et al. 2011).

This section provides guidance for how to use the maps in this report as foundations for planning conservation and management actions. In general, these maps set the landscape context by focusing attention on where particular management actions are most likely to have positive or negative effects on individual carnivores or their populations. For example, the maps identify habitat areas that are highly fragmented, potential movement corridors that are constrained by roads or other factors, and areas where particular management actions may benefit multiple species. They can therefore help prioritize management interventions, as well as identify areas where certain management actions should be avoided entirely (e.g., road-building or timber harvest in a critical connectivity area) or seasonally (e.g., vegetation treatments in fisher denning habitat during the reproductive season). Although not suitable for all fine-scale site planning tasks, these maps can be useful for site-planning purposes if used carefully in conjunction with field reconnaissance, expert consultation, and other decision-support maps and models.

The versions of the maps within this report are too small and coarse in resolution to be useful as is for site planning, and are only intended to illustrate landscape-scale patterns. However, the maps and datasets included in this report (e.g., habitat cores, connectivity areas, denning habitats) can be viewed at much finer resolution using a variety of base maps or aerial imagery in the Sierra Nevada Carnivore Conservation Group at http://databasin.org. They can also be manipulated, compared with other datasets, and downloaded for use in a GIS. Individuals interested in accessing these datasets or learning to use Data Basin should contact CBI.

The following sections provide more detailed guidance for individual species.

Marten

A significant proportion of marten core habitat is within national parks and wilderness areas, although large areas are also on USFS multiple-use lands that are subject to timber harvest and other vegetation treatments. Such management can fragment habitat and reduce or eliminate use by martens (Slauson and Zielinski 2008, Moriarty et al. 2011). Ski area development also fragments marten habitat, reducing local marten populations due to avoidance of smaller fragments (especially by females) and decreased survival and reproduction within larger fragments (K. Slauson, unpublished data).

Given the large amount and relatively contiguous distribution of suitable habitat in the southern 2/3 of the study area, forest management and development are unlikely to substantially reduce the Sierra Nevada marten population at the landscape scale, although local extirpations are possible. Conservation and management should strive to minimize such effects in key locations, such as narrow constrictions in habitat cores or areas where habitat loss or fragmentation could isolate marten subpopulations from larger, more contiguous habitat areas. For example, increases in housing development, roads, and ski areas north of Lake Tahoe could isolate martens in the Carson Range, east of highway 267, from the more extensive habitat areas to the west. Similarly, there are some narrow constrictions in habitat distribution on the Stanislaus and Sierra National Forests where extensive vegetation treatments, or large, severe wildfires, could potentially fragment the north-south distribution of martens into isolated subpopulations.

In the northern 1/3 of the study area, management should focus on protecting habitat quality within and around the perimeters of the core populations (Mount Shasta-Medicine Lake region; Mount Lassen-Swain Mountain-Thousand Lakes Wilderness region) and especially in and between the smaller cores, stepping stones, and connectivity areas between these regions, and between Mount Lassen and the more contiguous habitat core to the south (i.e., on the west slopes of the Plumas and Lassen National Forests). Genetic studies should be conducted to determine the current degree of marten population fragmentation, especially in these northern areas, to determine whether the landscape currently facilitates dispersal by martens between these habitat "islands." Management should attempt to increase forest canopy and tree size within connectivity areas and increase the size and quality of the smaller core and stepping-stone habitats, such as in the Butt Mountain-Bucks Lake region.

The following information sources should be consulted for additional maps and more detailed recommendations concerning marten conservation and vegetation management actions in the study area:

- Rustigian-Romsos and Spencer (2010) for more detailed maps and recommendations for marten conservation and vegetation management actions on the Lassen National Forest.
- Kirk and Zielinski (2010) for additional maps and recommendations for maintaining and improving linkage areas in the northern portion of the study area.
- Slauson and Zielinski (2008) for a review of how forest thinning and fuels reduction treatments affect martens, with management recommendations.

- Purcell et al. (2012) for detailed guidance for maintaining marten habitat components in vegetation treatments.

Conservation actions or any planned management actions (e.g., timber harvest, road improvements, fuels treatments) in or near any priority regions for marten conservation should be informed by these and other pertinent documents. Also, input and review should be sought from a team of marten experts to evaluate landscape-level and stand-level actions using appropriately scaled maps from this report (and available at for use at finer resolution on Data Basin).

Fisher

Of the four carnivores, the fisher is most likely to be strongly affected by forest management, both positively and negatively. Fisher populations occupy dense forests which are often targeted for vegetation management (e.g., timber harvest and fuels treatments) and are at high risk of severe wildfire. Both management and fires can reduce fisher habitat value, but if management reduces the risk of large, severe wildfires it can also indirectly benefit fishers (Sheller et al. 2011). Thus, balancing the potential negative effects of vegetation treatments and wildfires on fishers requires treating forest management as an integrated risk-management problem that operates on multiple spatial and temporal scales, from the near-term local effects of treatments (e.g., removing potential resting or denning structures or displacing individual fishers) to the cumulative, long-term population effects of both treatments and fires across the landscape. Optimizing management strategies given this complex array of interacting effects requires applying a variety of decision-support tools at multiple spatial and temporal scales. The fisher maps in this report represent one essential set of decision-support tools for this effort. They provide a spatial context for siting, phasing, and scheduling management actions to minimize risks to fisher populations, and can serve as a foundation for developing a spatially explicit fisher conservation strategy for the interior mountain areas of California.

The maps and recommendations in this report should also be integrated with other decision-support tools that address conditions at other spatial and temporal scales. In particular, the following models and information sources should be used in concert with the fisher maps in this report to develop a comprehensive, multi-scalar, adaptive management approach for Sierra Nevada forests that can sustain the fisher population while restoring more sustainable forest conditions:

- A stand-scale fisher resting habitat model based on Forest Inventory and Assessment (FIA) data (Zielinski et al. 2006).
- A Forest Vegetation Simulator (FVS) model to predict stand-scale effects of vegetation treatments and wildfire on fisher habitat at the home range scale (Thompson et al. 2011).
- USDA Forest Service General Technical Report (GTR) 220, which provides guidance for siting and designing silvicultural prescriptions to restore more natural, sustainable forest conditions in Sierran mixed-conifer forests (North et al. 2009).
- GTR 237 (North 2012), which provides additional information on approaches for implementing the concepts in GTR 220 to manage vegetation and wildlife habitat.

- Scenario analyses using a stochastic fisher population model coupled with a landscape-scale vegetation change model, as demonstrated by Sheller et al. (2011).

Research to date suggests that maintaining and improving fisher habitat quality, contiguity, and connectivity, and reducing fisher mortality rates, are high priorities for sustaining fisher populations. The small size and isolation of the two California fisher populations increases the risks of their extirpation, and the relatively narrow distribution of suitable, mid-elevation forests they occupy elevates the potential for populations to be fragmented by fires or management actions. Research has also revealed that the southern Sierra Nevada population suffers high mortality rates from a variety of causes, including predation, poisoning, roadkill, and diseases. Predation by bobcats and mountain lions appears to be a leading cause of mortality, and it is likely that forest roads and forest management actions (e.g., thinning) increase predation risks by facilitating access by these predators into fisher habitat, as well as reducing potential fisher escape and hiding cover (e.g., shrubs, logs, and understory trees).

Vegetation treatments need to be carefully sited, phased, and designed to minimize adverse effects on fishers while maximizing their potential for reducing the risk of large, stand-replacing wildfires. For example, fuels treatments sited near the perimeter of fisher habitat, and outside fisher denning habitat, are preferable to treatments within core habitat or denning areas so long as they are also effective at reducing risks that severe wildfires will spread into fisher core and denning areas. This is especially true where the band of fisher habitat is relatively narrow in the southern Sierra Nevada. For example, fisher core habitat is at most a few kilometers wide east of Bass Lake and on Patterson Mountain on Sierra National Forest, and in the Greenhorn Mountains on Sequoia National Forest. Treatments or fires in such areas could easily segment these narrow swaths of habitat into isolated pieces.

Where fisher core habitats are broader (e.g., in the Dinkey Creek/Shaver Lake area or on Whiskey Ridge on Sierra National Forest) some internal fragmentation by fuels treatments may be necessary to reduce fire risks, but treatments should be carefully sited and phased to ensure that only a small proportion of the occupied habitat is treated per decade. Phasing should allow for some recovery of fisher habitat value following thinning in one area before another nearby area is thinned within the same fisher core polygon. Moreover, treatments should be designed and implemented to minimize adverse effects on fisher habitat components at fine resolution by maintaining sufficient canopy cover, minimizing removal of larger trees, leaving large or deformed trees and snags that provide potential resting and denning structures, retaining black oaks, and so on (see Purcell et al. 2012 and other chapters in GTR 220 and GTR 237 for more detailed guidance). The various decision-support models listed above can also be used to help design an approach to vegetation treatments that minimizes risks to fishers over multiple scales of interest, as presented in Purcell et al. (2012).

Fisher denning habitat and denning structures are critical limiting resources for fishers. Forest management should strive to minimize impacts within potential denning habitat, protect large trees and snags that provide den cavities, maintain high canopy closure around potential den structures, and attempt to maintain adequate escape and hiding cover near the forest floor to reduce predation risks to denning females. Disturbance in and near mapped denning habitat (Figure 8) by vegetation treatments or other actions should be avoided during the reproductive season (i.e., Limited Operating Period from March through June)

Maintaining functional connectivity, or movement habitats, both within and between occupied fisher core areas, is also a high conservation priority. Forest management should strive to maintain or enhance tree and shrub cover in mapped fisher corridors, especially where the models show movement bottlenecks, such as across the Pit and Kings Rivers. Field studies should be used to identify areas where wildlife road crossing improvements, such as wildlife overpasses or underpasses, could be created, along with appropriate wildlife fencing, to keep animals off of roads and increase population connectivity. Such a study has been initiated along highway 41 (Wawona Road) in Yosemite National Park and on Sierra National Forest by a coalition of Park, Forest, and NGO biologists, and another study is in the planning stage for a portion of the northern Sierra Nevada, involving Caltrans, CDFG, USFS, and NGO biologists.

Finally, we re-emphasize that this report does not comprise a comprehensive conservation strategy for fishers in California, and the maps and recommendations herein should be considered just one set of inputs to such a strategy. A coordinated, multi-agency process is needed to integrate all available information, maps, models, and decision-support tools into a conservation strategy that supports the US Forest Services need to manage for sustainable forest conditions while maintaining fishers and other wildlife species. For example, a comprehensive conservation strategy should identify specific actions to reduce threats to fishers (e.g., rodenticide poisoning, roadkill, diseases transmitted from cats and dogs), stabilize or increase populations, and expand populations into suitable but unoccupied habitat areas (e.g., by facilitating natural emigration or via active translocation).

Wolverine

There is currently only one known wolverine in California, although there appears to be a large area of suitable habitat to support a population. Much of the suitable habitat is in large roadless areas, including Designated Wilderness and National Parks. Hudgens and Garcelon (2006) surveyed Sequoia-Kings Canyon National Parks for wolverines, concluded that they were absent, and recommended a reintroduction program, because until the mid-twentieth century the species was an important component of the Sierra Nevada ecosystem. Because their appears to be sufficient core habitat and food availability to support a Sierra Nevada wolverine population (B. Hudgens, personal communication), we suspect that wolverines were probably extirpated due to the cumulative effects of human-influenced mortality factors, including trapping, shooting, and poisoning (e.g., by sheepherders that routinely laced sheep carcasses with poison to kill predators; Grinnell et al. 1937). Because such threats have been reduced in recent decades, the possibility of reintroduction should be seriously considered for the large core areas in the southern Sierra Nevada. Personnel at Sequoia-Kings Canyon National Parks have been discussing the possibility, but no firm decision has yet been made, in part due to budget constraints (D. Graber and K. Nydick, personal communications). If a wolverine population is re-established in the planning area, either by additional, natural immigration or by a translocation program, the primary management focus should be on minimizing mortality risks and disturbance to wolverines. New roads should be prohibited in potential wolverine habitats, and road-crossing improvements should be considered for existing major roads (e.g., Interstate 80) to reduce roadkill risks and habitat fragmentation effects and facilitate dispersal into unoccupied habitat areas. Recreational activities should be controlled in wolverine-occupied areas, especially during the denning season (late winter-spring), because females may abandon dens if approached by humans (Magoun and Copeland 1998). Access by snowmobiles, helicopters, and dogs should be prohibited in large portions of wolverine core habitats, and controls on back-country skiing should be considered.

Sierra Nevada Red Fox

Potential Sierra Nevada red fox habitat is strongly fragmented, with isolated areas of alpine and subalpine habitat separated by lower elevation canyons and plateaus. Potential core habitat areas are found at Mount Lassen (occupied by a small population) and a series of larger potential cores ranging from Tahoe National Forest to Sequoia National Park. The recent rediscovery of a fox population near Sonora Pass, within one of the largest predicted core areas, plus an unconfirmed sighting farther south, provides hope that this species—once feared extirpated from all of its range except for the Mount Lassen population—could be sustained across a broad landscape.

Perrine et al. (2010) compiled a comprehensive Conservation Assessment for Sierra Nevada red fox and summarized major threats to populations, which are briefly repeated here:

- Expansion of non-native red foxes or coyotes into the high elevation habitats used by Sierra Nevada red fox, which could increase competition with or predation on Sierra Nevada red foxes, or transmit diseases or parasites to them. Interbreeding with non-native foxes could also reduce genetic adaptation to local conditions in native Sierra Nevada red foxes.
- Development and recreation can increase fox exposure to humans, vehicles, and pets, and may facilitate the expansion of non-native foxes, coyotes, or other competitors into Sierra Nevada red fox habitat. Foxes exposed to human foods can develop begging behaviors, increasing risks of mortality from roadkill or other human-related causes. Humans, dogs, snowmobiles, or other factors associated with human recreation may disturb or displace foxes. Foxes may also be susceptible to disease from eating fish stocked for recreational fishing.
- Rodenticide exposure can kill or weaken foxes, making them more susceptible to other mortality factors.
- Climate change may reduce suitable habitat area and snowfall, which might help facilitate expansion by non-native foxes and coyotes into occupied habitats.

Perrine et al. (2010) recommended that the most immediate conservation priority for Sierra Nevada red fox is to document the species' current distribution throughout its historical range using a thorough camera-station survey to identify local populations—followed by intensive study of these populations to better document habitat requirements, ecology, and threats to fox populations.

It is highly unlikely that the long potential movement corridor we modeled, from Mount Lassen to larger potential habitat areas to the south, is functional, due to its great length, numerous roads, and the risks of encountering coyotes and other potential predators in the lower elevation habitats along the way. Conservation should instead focus on maintaining and monitoring populations where they exist, reducing potential risk factors in occupied and potential habitat areas, and maximizing potential for dispersal between core habitat areas in the southern and central Sierra Nevada. Although there may also be barriers and filters to fox movement between the series of potential cores in this region, the distances involved are much shorter than the Mount Lassen corridor, and with fewer roads and other potential barriers and threats to dispersers. Modeled movement corridors should be studied at fine resolution to identify movement barriers, movement filters, and potential threats to Sierra Nevada red foxes, and to identify specific actions to mitigate these factors. Such an assessment should first prioritize investigating corridors near known occupied areas.

References

Aubry, K.B., K.S. McKelvey, and J.P. Copeland. 2007. Distribution and broadscale habitat relations of the wolverine in the contiguous United States. J. Wildlife Management 71:2147-2158.

Beier, P., D.R. Majka, and W.D. Spencer. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology 22(4):836-851.

Beier, P., W. Spencer, R. Baldwin, and B. McRae. 2011. Toward best practices for developing regional connectivity maps. Conservation Biology 25:879-892.

Carroll, C., W. Spencer, and J. Lewis. In Press. Use of habitat and viability models in *Martes* conservation and restoration. In: K. Aubry, W. Zielinski, M. Raphael, G. Proulx, and S. Buskirk, eds. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis.

Chow, L. 2010. A survey for fisher in Yosemite National Park 1992-1994. Transactions of the Western Section of The Wildlife Society 45:27-44.

Cleve, C., J. Perrine, B. Holzman, and E. Hines. 2011. Addressing biased occurrence data in predicting potential Sierra Nevada red fox habitat for survey prioritization. Endangered Species Research 14:179-191.

Copeland, J.P., K.S. McKelvey, K.B. Aubry, A. Landa, J. Persson, R.M. Inman, J. Krebs, E. Lofroth, H. Golden, J.R. Squires, A. Magoun, M.K. Schwartz, J. Wilmot, C.L. Copeland, R.E. Yates, I. Kojola, and R. May. 2010. The bioclimatic envelope of the wolverine (*Gulo gulo*): do climatic constraints limit its geographic distribution? Canadian Journal of Zoology 88:233-246.

Davis, F.W., C. Seo, and W.J. Zielinski. 2007. Regional variation in home-range-scale habitat models for fisher (*Martes pennanti*) in California. Ecological Applications 17(8):2195-2213.

Grinnell, J., J.S. Dixon, and J.M. Linsdale. 1937. Furbearing mammals of California, Volume 1. University of California Press, Berkeley, California.

Hudgens, B.R., and D.K. Garcelon. 2006. Winter carnivore survey finds that wolverines (Gulo gulo) are likely extirpated from Sequoia-Kings Canyon National Parks. Unpublished report to Sequoia-Kings Canyon National Parks.

Inman, R.M., A.J. Magoun, J. Persson, and J. Mattisson. 2012. The wolverine's niche: linking reproductive chronology, caching, competition, and climate. Journal of Mammalogy 93:634-644.

Kirk, T.A. 2007. Landscape-scale habitat associations of the American marten (*Martes americana*) in the greater southern Cascades region of California. Master's thesis, Humboldt State University. 115 pp.

Kirk, T.A., and W.J. Zielinski. 2009. Developing and testing a landscape habitat suitability model for the American marten (*Martes americana*) in the Cascades mountains of California. Landscape Ecol. Research Article, published online, DOI 10.1007/s10980-009-9349-5.

Kirk, T.A., and W.J. Zielinski. 2010. Functional habitat connectivity of the American marten (*Martes americana*) in northeastern California using least-cost corridor modeling. Unpublished Report, USDA Forest Service, Lassen National Forest and USDA Forest Service, Pacific Southwest Research Station.

Magoun, A. J., and J. P. Copeland. 1998. Characteristics of wolverine reproductive den sites. Journal of Wildlife Management 62:1313-1320.

Moriarty, K.M., W.J. Zielinski, A.G. Gonzales, T.E. Dawson, K.M. Boatner, C.A. Wilson, F.V. Schlexer, K.L. Pilgrim, J.P. Copeland, and M.K. Schwartz. 2009. Wolverine confirmation in California after nearly a century: native or long-distance immigrant? Northwest Science 83(2):154-162.

Moriarty, K.M., W.J. Zielinski, and E.D. Forsman. 2011. Decline in American marten occupancy rates at Sagehen Experimental Forest, California. J. Wildlife Management 75:1774-1787.

North N, P. Stine. K. O'Hara, W. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed conifer forests. General Technical Report PSW-GTR-220. Albany, CA. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 49 pp.

North, M., editor. 2012. Managing Sierra Nevada forests. General Technical Report PSW-GTR-237. Albany, CA. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 184 pp.

Perrine, J.D. 2005. Ecology of red fox (*Vulpes vulpes*) in the Lassen Peak region of California U.S.A. Ph.D. dissertation, University of California, Berkeley. 251 pp.

Perrine, J.D., L.A. Campbell, and G.A. Green. 2010. Sierra Nevada red fox (*Vulpes vulpes necator*): A Conservation Assessment. US Department of Agriculture, Forest Service R5-FR-010.

Phillips, S.J., R.P. Anderson, and R.E Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231-259.

Purcell, K.L., C.M. Thompson, and W.J. Zielinski. 2012. Chapter 4: Fishers and American martens. Pages 47-60 in North, editor. Managing Sierra Nevada forests. General Technical Report PSW-GTR-237. Albany, CA. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Rustigian-Romsos, H.L, and W.D. Spencer. 2010. Predicting habitat suitability for the American marten on the Lassen National Forest. Report to the Lassen National Forest. Conservation Biology Institute, Corvallis, OR.

Schwartz, M.K., J.P. Copeland, N.J. Anderson, J.R. Squires, R.M. Inman, K.S. McKelvey, K.L. Pilgrim, L.P. Waits, and S.A. Cushman. 2009. Wolverine gene flow across a narrow climatic niche. Ecology 90(11):3222-3232.

Scheller, R.M., W.D. Spencer, H. Rustigian-Romsos, A.D. Syphard, B.C. Ward, and J.R. Strittholt. 2011. Using stochastic simulation to evaluate competing risks of wildfires and fuels management on an isolated forest carnivore. Landscape Ecology 26:1491-1504.

Slauson, K.M., and W.J. Zielinski. 2008. A review of the effects of forest thinning and fuels reduction on American martens (*Martes americana*) pertinent to the Southern Cascades region of California. Final Report. USDA Forest Service, Southwest Research Station, Redwood Sciences Laboratory.

Spencer, W.D., H. Rustigian, R. Scheller, A. Syphard, J. Strittholt, and B. Ward. 2008. Baseline evaluation of fisher habitat and population status and effects of fires and fuels management on fishers in the southern Sierra Nevada. Report to the USDA Forest Service, Pacific Southwest Region. Conservation Biology Institute, Corvallis, OR.

Spencer, W., H. Rustigian-Romsos, J. Strittholt, R. Scheller, W. Zielinski, and R. Truex. 2011. Using occupancy and population models to assess habitat conservation opportunities for an isolated carnivore population. Biological Conservation 144:788-803. DOI 10.1016/j.biocon.2010.10.027.

Syphard, A.D., R.M. Scheller, B.C. Ward, W.D. Spencer, and J.R. Strittholt. 2011. Simulating landscape-scale effects of fuels treatments in the Sierra Nevada, California, USA. International Journal of Wildland Fire 20:364-383.

Thompson, C.M., W.J. Zielinski, and K.L. Purcell. 2011. The use of landscape trajectory analysis to evaluate management risks: a case study with the Pacific fisher in the Sierra National Forest. Journal of Wildlife Management 75:1164–1176.

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Zielinski, W.J., R.L. Truex, J.R. Dunk, and T. Gaman. 2006. Using forest inventory data to assess fisher resting habitat suitability in California. Ecological Applications. 16:1010–1025.

Zielinski, W.J., J.R. Dunk, J.S. Yaeger, and D.W. LaPlante. 2010. Developing and testing a landscape habitat suitability model for fisher (*Martes pennanti*) in forests of interior northern California. Forest Ecology and Management 260(9):1579-1591.

Appendix A: Science Advisors

The following individuals provided guidance, interim review, and advice on the methods used to develop decision-support maps:

- Bill Zielinski (fisher)—Forest Service-Redwood Science Lab
- Paul Beier (connectivity)—Northern Arizona University
- Jeff Copeland (wolverine)—Forest Service-Rocky Mountain Research Station
- David Garcelon and Brian Hudgens (wolverine—Institute for Wildlife Studies
- Healy Hamilton (climate change, wolverine)—California Academy of Sciences
- Dominique Bachelet (climate change)—Conservation Biology Institute
- Tom Kirk (martens)—Forest Service-Redwood Science Lab
- John Perrine (Sierra Nevada red fox)—California Polytechnic State University, San Luis Obispo
- Hugh Safford (fire ecology and climate change)—Forest Service-Pacific Southwest Research Station
- Susan Britting (forest planning)—Sierra Forest Legacy

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Appendix B: Calculation of Movement Cost Rasters

Marten Resistance Values. Total value of each 1-ha pixel = WHR type resistance cost + any additional feature costs

WHR TYPE	WHR_COD	0D	0M	0P	0S	0X	1D	1M	1P	1S	1X	2D	2M	2P	2S	2X	3D	3M	3P	3S	3X	4D	4M	4P	4S	4X	5D	5M	5P	5S	5X	6D	6M	6P	6S
Alpine-Dwarf Shrub	ADS			50	50	50																	50												
Agriculture	AGR					50																													
Annual Grassland	AGS					50	50		50	50	50				50	50		50		50	50			50	50										
Alkali Desert Scrub	ASC					50																													
Aspen	ASP		50	50	50	50	50	50	50	50		50	50	50	50		16	16	50	50		8	8	16	16		8	8	16						
Barren	BAR					8																													
Bitterbrush	BBR		50	50	50	50					50				50	50					50	50	50	50		50									
Blue Oak-Foothill Pin	BOP	50	50	50	50	50	50	50				50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50					
Blue Oak Woodland	BOW	50	50		50	50	50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50	50					
Unknown Shrub Type	CHP					50																													
Unknown Conifer Typ	CON	50	50	50	50	50																													
Coastal Oak Woodlan	COW	50											50				50	50	50			50	50				50		50						
Closed-Cone Pine-Cy	CPC											50	50	50	50		50	50	50	50		50	50	50	50		50	50	50	50					
Chamise-Redshank C	CRC					50					50						50					50													
Cropland	CRP					50																													
Coastal Scrub	CSC					50																													
Douglas-Fir	DFR	50	50	50	50	50	50	50	50		50	50	50	50	50	50	16	16	50	50	50	8	8	16	16		8	8	16	16		8	8		
Deciduous Orchard	DOR					50							50	50	50		50	50	50	50															
Desert Riparian	DRI			50		50						50	50	50	50		50	50	50	50		50	50				50								
Desert Scrub	DSC					50																													
Desert Wash	DSW					50																													
Evergreen Orchard	EOR													50	50		50	50	50	50															
Eastside Pine	EPN	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	50	50	50	16	16	16	16	16	8	8	16	16	16				
Eucalyptus	EUC																50																		
Freshwater Emergent	FEW					25																													
Irrigated Hayfield	IRH					50																													
Jeffrey Pine	JPN		50	50	50	50	50		50	50	50	50	50	50	50	50	16	16	50	50	50	8	8	16	16	16	8	8	16	16					
Joshua Tree	JST			50		50							50	50	50		50	50	50	50															
Juniper	JUN		50	50	50	50				50		50	50	50	50		25	25	50	50		25	25	25	25	25	25	25	25	25					
Klamath Mixed Conif	KMC	50		50			50	50			50	50				50	16	16	50			8	8	16			8					8			
Lacustrine	LAC					100																													
Lodgepole Pine	LPN		50	50	50	50		50	50	50	50	50	50	50	50	50	16	16	50	50	50	1	1	8	8	8	1	1	8	16	16	1	1		
Low Sage	LSG		50	50	50	50					50				50	50					50		50			50									
Mixed Chaparral	MCH					50					50				50	50	50			50	50	50													
Montane Chaparral	MCP		50	50	50	50			50	50	50	50	50	50	50	50	50	50	50	50	50	50		50	50	50			50						
Montane Hardwood-C	MHC	50	50	50	50	50					50	50	50	50	50	50	16	16	50	50	50	8	8	16	16	16	8	8	16	16	16	8	8		

Marten Resistance Values, continued

Montane Hardwood	MHW	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	25	25	50	50	50	25	25	25	25	25	25	25	25	25					
Montane Riparian	MRI	50	50	50	50	50			50	50	50	50	50	50	50	50	16	16	50	50	50	8	8	16	16	16	1	1	16	16					
Pasture	PAS					50																													
Perennial Grassland	PGS					50				50	50				50	50				50	50			50	50					50					
Pinyon-Juniper	PJN	50	50	50	50	50						50	50	50	50		25	25	50	50	50	25	25	25	25	25	25	25	25	25					
Ponderosa Pine	PPN	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	50	50	50	8	8	16	16	16	8	8	16	16		8			
Red Fir	RFR	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	50	50	50	1	1	8	8	8	1	1	8	16		1	1	1	1
Riverine	RIV					25																													
Subalpine Conifer	SCN		50	50	50	50			50		50	50	50	50	50	50	16	16	50	50	50	1	1	8	8	8	1	1	8	16		1			
Saline Emergent Wet	SEW					50																													
Sagebrush	SGB		50	50	50	50				50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50								
Sierran Mixed Conife	SMC	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	50	50	50	8	8	16	16	16	8	8	16	16	16	8	8	8	
Urban	URB					100																													
Vineyard	VIN					50																													
Valley Oak Woodlanc	VOW						50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50		50	50	50	50					
Valley Foothill Ripari	VRI	50		50		50	50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50						
Water	WAT					100																													
White Fir	WFR	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	50	50	50	1	1	16	16	16	1	1	16	16		1	1		
Wet Meadow	WTM					50					50					50		50			50				50										

Marten Additional Feature Costs

Feature	Additional Cost	
Interstate hwys (A15)	50	ESRI data
Primary roads (A21, A25)*	25	ESRI data
Secondary roads (A31, A35)*	15	ESRI data
Large Rivers	5	ESRI data
Steep Slopes (> 80%)	50	NED
Low Elevation	1 to 5	NED
elevation 3000-4000 ft (914.4 - 1219.2 m)	1	
elevation 2000-2999 ft (609.6 - 914.3 m)	2	
elevation 1000-1999 ft (304.8 - 609.5 m)	3	
elevation 500-999 ft (152.4 - 304.7 m)	4	
elevation < 500 ft (152.4 m)	5	

*The following A31/A35 roads were elevated in cost to A21/A25 due to traffic volume:

- 89 between South Tahoe and Truckee
- 257 between Lake Tahoe and Truckee
- 120 from 49 to 140
- 140 from 49 to its terminus in Yosemite Valley
- 41 from 140 to 49).

Fisher Resistance Values. Total value of a 1-ha pixel = CWHR resistance cost + any additional feature costs

WHR TYPE	WHR_COD	0D	0M	0P	0S	0X	1D	1M	1P	1S	1X	2D	2M	2P	2S	2X	3D	3M	3P	3S	3X	4D	4M	4P	4S	4X	5D	5M	5P	5S	5X	6D	6M	6P	6S	6X
Alpine-Dwarf Shrub	ADS			50	50	50																	50													
Agriculture	AGR					50																														
Annual Grassland	AGS					50	50		50	50	50				50	50		50		50	50			50	50											
Alkali Desert Scrub	ASC					50																														
Aspen	ASP		50	50	50	50	50	50	50	50		50	50	50	50		25	25	50	50	50	2	8	25	50		2	8	16							
Barren	BAR					50																														
Bitterbrush	BBR		50	50	50	50					50				50	50					50	50	50	50		50										
Blue Oak-Foothill Pin	BOP	50	50	50	50	50	50	50				50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50						
Blue Oak Woodland	BOW	50	50		50	50	50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50	50						
Unknown Shrub Type	CHP					50																														
Unknown Conifer Typ	CON	50	50	50	50	50																														
Coastal Oak Woodlan	COW	50											50				50	50	50			50	50				50		50							
Closed-Cone Pine-Cy	CPC											50	50	50	50		50	50	50	50		50	50	50	50		50	50	50	50						
Chamise-Redshank C	CRC					50					50						50					50														
Cropland	CRP					50																														
Coastal Scrub	CSC					50																														
Douglas-Fir	DFR	50	50	50	50	50	50	50	50		50	50	50	50	50	50	16	16	25	25	25	1	2	8	16		1	2	8	8		1	1			
Deciduous Orchard	DOR					50							50	50	50		50	50	50	50																
Desert Riparian	DRI			50		50						50	50	50	50		50	50	50	50		50	50				50									
Desert Scrub	DSC					50																														
Desert Wash	DSW					50																														
Evergreen Orchard	EOR													50	50		50	50	50	50																
Eastside Pine	EPN	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	25	25	25	25	25	8	16	16	25	25	16	16	16	25	25					
Eucalyptus	EUC																50																			
Freshwater Emergent	FEW					50																														
Irrigated Hayfield	IRH					50																														
Jeffrey Pine	JPN		50	50	50	50	50		50	50	50	50	50	50	50	50	25	25	25	25	25	8	16	16	25	25	16	16	16	25						
Joshua Tree	JST			50		50							50	50	50		50	50	50	50																
Juniper	JUN		50	50	50	50				50		50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50						
Klamath Mixed Conif	KMC	50		50			50	50			50	50				50	16	16	16			1	2	8			1					2				
Lacustrine	LAC					100																														
Lodgepole Pine	LPN		50	50	50	50		50	50	50	50	50	50	50	50	50	25	25	25	25	25	16	16	16	16	16	8	8	8	8	8	8	8			
Low Sage	LSG		50	50	50	50					50				50	50					50		50			50										
Mixed Chaparral	MCH					50					50				50	50	25			50	50	25														
Montane Chaparral	MCP		50	50	50	50			50	50	50	25	50	50	50	50	25	50	50	50	50	25		25	25	25			50							
Montane Hardwood-C	MHC	50	50	50	50	50					50	50	50	50	50	50	16	16	16	25	25	1	2	8	16	16	1	2	8	8	8	1	1			
Montane Hardwood	MHW	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	25	25	25	2	2	8	16	16	2	2	8	8						

Fisher Resistance Values, continued

Montane Riparian	MRI	50	50	50	50	50			50	50	50	50	50	50	50	50	**16**	16	25	25	25	8	8	16	25	25	8	8	16	16						
Pasture	PAS					50																														
Perennial Grassland	PGS					50				50	50				50	50				50	50			50	50					50						
Pinyon-Juniper	PJN	50	50	50	50	50						50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50	50						
Ponderosa Pine	PPN	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	25	25	25	1	2	8	16	16	1	2	8	8		1				
Red Fir	RFR	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	25	25	25	25	25	16	16	16	16	16	8	8	8	8		8	8	8	8	
Riverine	RIV					25																														
Subalpine Conifer	SCN		50	50	50	50			50		50	50	50	50	50	50	25	25	25	25	25	16	16	16	16	16	8	8	8	8		8				
Saline Emergent Wet	SEW					50																														
Sagebrush	SGB		50	50	50	50				50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50									
Sierran Mixed Conife	SMC	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	16	25	25	1	2	8	16	16	1	2	8	8	8	1	1	2		
Urban	URB					100																														
Vineyard	VIN					50																														
Valley Oak Woodlanc	VOW						50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50		50	50	50	50						
Valley Foothill Ripari	VRI	50		50		50	50	50	50	50		50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50							
Water	WAT					100																														
White Fir	WFR	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	16	16	16	25	25	1	2	8	16	16	1	2	8	8		1	1			
Wet Meadow	WTM					50					50					50		50			50				50											

Fisher Additional Feature Costs

Feature	Additional Cost	
Interstate hwys (A15)	50	ESRI data
Primary roads (A21, A25)*	25	ESRI data
Secondary roads (A31, A35)*	15	ESRI data
Large Rivers	5	ESRI data
Steep Slopes (> 80%)	5	NED
Low Elevation	1 to 4	NED
elevation > 8,000 ft (2438 m)	1	
elevation 2,000-2,999 ft (610-914 m)	1	
elevation 1000-1999 ft (305 - 610 m)	2	
elevation 500-999 ft (152 - 305 m)	3	
elevation < 500 ft (152 m)	4	

*The following A31/A35 roads were elevated in cost to A21/A25 due to traffic volume:

- 89 between South Tahoe and Truckee
- 257 between Lake Tahoe and Truckee
- 120 from 49 to 140
- 140 from 49 to its terminus in Yosemite Valley
- 41 from 140 to 49).

Wolverine Resistance Values. From WHCWG (2010) but adjusting elevation values for California. Each 1-ha pixel scored as the sum of all cost categories. Housing density data from David Theobold (Theobald, David M. 2003. Targeting Conservation Action through Assessment of Protection and Exurban Threats. Conservation Biology, Vol. 17, No. 6, pp.1624-1627, December 2003).

Landscape category\Landscape class	**Resistance**
Landcover	
agriculture	100
urban/developed	1000
water	100
sparselyvegetated	0
alpine	0
riparian	1
wetland	1
grass-dominated	1
shrub-dominated	1
dryforest	0
wetforest	0
Elevation	
0–250 meters	100
>250–500 meters	50
>500–750 meters	25
>750–1000 meters	10
>1000–1500 meters	10
>1500–2000 meters	10
>2000–2500 meters	1
>2500–3300 meters	0
> 3300 m	0
Slope	
0–20 degrees	0
>20–40 degrees	1
> 40 degrees	5
Acres/DwellingUnit	

> 80 ac/du	1
> 40 to≤80 acres/du	5
> 20 to ≤40 acres/du	10
> 10 to ≤ 20 acres/du	200
≤ 10 acres/du	200
TransFreeway	
>500–1000 m buffer	100
>0-500 m buffer	200
Centerline	400
TransHighUse	
>500–1000 m buffer	5
> 0–500 m buffer	10
Centerline	70
TransMedUse	
>500–1000 m buffer	2
>0–500 m buffer	4
Centerline	8
TransLowUse	
>500–1000 m buffer	1
> 0–500 m buffer	1
Centerline	1
ForestStructure	
Nonforest	0
0–40%; ≤ 25 m	0
0–40%; > 25 m	0
>40–70%; ≤ 25 m	0
>40–70%; > 25 m	0
>70–100%; ≤ 25 m	0
>70–100%; > 25 m	0

Sierra Nevada Red Fox Resistance Values. From John Perrine. Total value of a 1-ha pixel = CWHR resistance cost + any additional feature costs

WHR TYPE	cost
Alpine-Dwarf Shrub	2
Agriculture (IGR/IRF)	16
Annual Grassland	25
Alkali Desert Scrub	25
Aspen	8
Barren	8
Bitterbrush	50
Blue Oak-Foothill Pine	50
Blue Oak Woodland	50
Unknown Shrub Type	16
Unknown Conifer Type	16
Coastal Oak Woodland	50
Closed-Cone Pine-Cypress	50
Chamise-Redshank Chaparral	25
Cropland	16
Coastal Scrub	50
Douglas-Fir	16
Deciduous Orchard	16
Desert Riparian	25
Desert Scrub	50
Desert Wash	50
Evergreen Orchard	25
Eastside Pine	16
Eucalyptus	25
Freshwater Emergent Wetland	16
Irrigated Hayfield	16
Jeffrey Pine	16

Sierra Nevada Red Fox Resistance Values, continued.

Joshua Tree	50	
Juniper	25	
Klamath Mixed Conifer	25	
Lacustrine	100	
Lodgepole Pine	16	
Low Sage	25	
Mixed Chaparral	50	
Montane Chaparral	16	
Montane Hardwood-Conifer	25	
Montane Hardwood	50	
Montane Riparian	16	
Pasture	16	
Perennial Grassland	16	
Pinyon-Juniper	25	
Ponderosa Pine	16	
Red Fir	16	
Riverine	16	
Subalpine Conifer	8	
Saline Emergent Wetland	50	
Sagebrush	25	
Sierran Mixed Conifer	16	
Urban	100	
Vineyard	16	
Valley Oak Woodland	50	
Valley Foothill Riparian	50	
Water	100	
White Fir	16	
Wet Meadow	8	

Sierra Nevada Red Fox, Additional Feature Costs. From John Perrine.

Feature	Additional Cost	
Major Highways (Primary and Secondary Hwys)	15	ESRI data
Large Rivers	30	ESRI data
Recent Wildfires (since 2005)	5	USFS data
Low Elevation		NED
elevation 3000-4000 ft	5	
elevation 2000-2999 ft	10	
elevation 1000-1999 ft	25	
elevation 500-999 ft	50	
elevation < 500 ft	50	
OTHER		
Steep slope (>80%)	50	NED
Wilderness	-5	USFS data
Human infrastructure (campgrounds, parking lots, houses, etc.)	5	USFS R5 data, used only polygons with Status = 'existing operational'