RESEARCH ARTICLE

Landscape-level Connectivity in Coastal Southern California, USA, as Assessed through Carnivore Habitat Suitability

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ABSTRACT: Although the fragmentation of the natural landscape of coastal southern California, USA, is accelerating, large-scale assessments of regional connectivity are lacking. Because of their large area requirements and long dispersal movements, mammalian carnivores can be effective focal species to use when evaluating landscape-level connectivity. Our goal was to make an initial assessment of the extent of landscape-level connectivity in coastal southern California using mountain lions (*Felis concolor* [Linnaeus]) and bobcats (*Felis rufus* [Shreber]) as focal species. We first characterized habitat preferences for mountain lions and bobcats from previously derived habitat relationship models for these species; the resulting maps provided a coarse view of habitat preferences for use at regional scales. We then constructed GIS models to evaluate the disturbance impact of roadways and development, major determinants of carnivore distribution and abundance in the south coast region. Finally, we combined the habitat relationship models with the disturbance impact models to characterize habitat connectivity for mountain lions and bobcats in the ecoregion. Habitat connectivity in the ecoregion appeared higher for bobcats than for mountain lions due in part to higher habitat suitability for bobcats in coastal lowland areas. Our models suggest that much of the key carnivore habitat in the coastal southern California is at risk; over 80% of high suitability habitat and over 90% of medium suitability habitat for carnivores is found in the least protected land management classes. Overall, these models allow for (1) identification of core habitat blocks for carnivores and key landscape connections between core areas, (2) evaluation of the level of protection of these areas, and (3) a regional framework within which to develop and coordinate local management and conservation plans.

Conectividad del Paisaje en la costa Sur de California, USA, Estimada a través del Hábitat Conveniente para Carnívoros

RESUMEN: Aunque la fragmentación del paisaje en la costa sur de California USA, se está acelerando, no existe una estimación a gran escala de la conectividad regional. Porque necesitan grandes áreas y movimientos largos de dispersión, los mamíferos carnívoros pueden ser efectivas especies focales para evaluar el grado de conectividad del paisaje. Nuestro objetivo fue hacer una estimación inicial de que tan conectado está el paisaje en la costa sur de California usando pumas (*Felis concolor* [Linnaeus]) y linces (*Felis rufus* [Shreber]) como especies focales. Primero caracterizamos las preferencias de hábitat para los pumas y los linces a partir de modelos de relación de hábitats previos para estas especies; los mapas resultantes proveyeron una idea gruesa de la preferencias de hábitat para usar a escala regional. Luego realizamos modelos de SIG para evaluar el impacto del disturbio de carreteras e infraestructura, determinantes de la distribución y abundancia de carnívoros en la región de la costa sur. Finalmente, combinamos los modelos de relación de hábitat con los de impacto de disturbios para caracterizar la conectividad de hábitat para los pumas y los linces en la ecoregión. La conectividad en la ecoregión pareció ser mayor para los linces que para los pumas, debido a una mayor conveniencia para los linces en las áreas bajas de la costa. Nuestros modelos sugieren que mucho hábitat clave para los carnívoros en la costa sur de California está en riesgo; más del 80% del hábitat de mayor y más de 90% del de mediana conveniencia para carnívoros se encuentra en áreas con la menor clase de manejo y protección. Más aun, estos modelos son aptos para (1) identificar los hábitats centrales para los carnívoros y las conexiones claves en el paisaje entre ellas, (2) evaluar el nivel de protección de esas áreas, y (3) una red de trabajo regional con la cual desarrollar y coordinar el manejo local y los planes de conservación.

Index terms: connectivity, habitat fragmentation, mammalian carnivores, southern California

INTRODUCTION

Habitat fragmentation is one of the most serious threats to biological diversity worldwide (Wilcove et al. 1998), and in areas with increasing urbanization, fragmentation is virtually inevitable (Soulé 1991). Perhaps nowhere is this threat more evident than in coastal southern California, USA. The six counties of coastal southern California encompass about 25% of California's land area but as of 2000 contained nearly 20 million people, about 60% of the state's population. From 1990 to 2000, the population of Riverside County increased by 32%, San Bernardino County by 20%, Orange County by 18%, San Diego and Ventura Counties by 13%, and Santa Barbara and Los Angeles counties by 7–8% (U.S. Census Bureau 2000). Such massive population growth has severely fragmented native habitat in coastal southern California. Mediterranean scrub habitats are particularly threatened; development over the past century has destroyed all but 10% of native coastal sage scrub habitat (McCaull 1994).

The California south coast ecoregion supports a high diversity of native species. According to the California Department of Fish and Game, native vertebrate species in the ecoregion include 11 fish, 12 amphibians, 61 reptiles, 299 birds, and 104 mammals (California Department of Fish and Game 1996). Almost 2500 vascular plant species occur in the region, accounting for nearly one-third of California's diverse flora on only 8% of its land mass; over 250 of these plant species are endemic to southern California. The widespread loss and fragmentation of habitat in southern California, in conjunction with high levels of local endemism of native species, have helped create a "hot-spot" of endangerment and extinction in the region (Myers 1990, Dobson et al. 1997). About 200 plants and 200 animals in southern California are now considered endangered or sensitive by agencies and conservation groups.

The severe effects of habitat fragmentation on the composition, structure, and function of ecosystems have made a compelling case for preserving existing, and restoring severed, habitat connections within fragmenting landscapes (Noss 1983, Harris 1984, Wilcox and Murphy 1985, Soulé and Terborgh 1999). Landscape-level connectivity is essential to allow for the natural movement of animals among foraging and breeding sites, the dispersal of individuals from natal ranges, genetic exchange between populations, natural range shifts in response to climate change, and the continuity of ecological processes involved in hydrology, succession, and seed dispersal (Noss 1983, Noss and Cooperrider 1994, Soulé and Terborgh 1999). Where connectivity is not retained across developing landscapes, many plant and animal populations will eventually disappear. Although fragmentation of the natural landscape of coastal southern California is accelerating, large-scale assessments of regional connectivity are lacking.

Taken from reserve planning, the focal species concept is a central theme in large-scale conservation planning (Noss 1992, Noss and Cooperrider 1994, Noss and Soulé 1998, Miller et al. 1998, Soulé and Terborgh 1999). Focal species are chosen to symbolize ecological conditions that are critical to healthy, functioning ecosystems (Lambeck 1997). Mammalian carnivores can be effective focal species by which to evaluate degree of landscape-level connectivity. Large carnivores are particularly vulnerable to extinction in fragmented habitat because of their wide ranges and broad resource requirements, low densities, slow population growth rates, and the fact that they are directly persecuted by humans (Noss et al. 1996; Crooks 2000, 2002). Top predators may not be able to persist in landscapes that are not connected by functional movement corridors. Further, their disappearance may generate ecological cascades that alter the structure of ecological communities. In fragmented habitat in San Diego, Crooks and Soulé (1999) found that the extirpation of dominant predators such as coyotes can result in the ecological release of smaller predators and increased extinction rates of their avian prey. Thus, top predators may function as keystone species—animals whose disappearance causes increases in some species and the decline and extinction of others (Mills et al. 1993).

Large carnivores, therefore, are ecologically pivotal organisms whose status can be indicative of the functional connectivity of ecosystems and habitats. The use of mammalian carnivores in conservation planning adds a critical layer of conservation strategy that may provide a robust method for protecting other species with less demanding area needs (Lambeck 1997, Miller et al. 1998, Carroll et al. 1999). In southern California, mountain lions (*Felis concolor* Linnaeus) and bobcats (*Felis rufus* Shreber) are excellent focal species for the evaluation of connectivity across multiple spatial scales (Crooks 2000, 2002). Mountain lions, the largest predator remaining in coastal southern California, occupy ranges that encompass up to 300 km^2, travel on average 6 km per night (Beier et al. 1995), and disperse distances that average 65 km (Beier 1995). Mountain lions, therefore, require large core wildland habitats and functional connections between subpopulations (Beier 1993; Maehr 1997; Sweanor et al. 2000; Crooks 2000, 2002). Bobcats also require connectivity for persistence, but they are less sensitive to fragmentation than mountain lions. Bobcats can persist in smaller habitat fragments, as compared to mountain lions, but only those that have adequate connections to larger natural areas (Crooks 2000, 2002). Bobcats are therefore valuable indicators of connectivity at smaller spatial scales.

Our goal was to use mountain lions and bobcats as focal species to obtain an initial assessment of the extent of landscape-level connectivity in coastal southern California. First, we characterized vegetative habitat preferences for mountain lions and bobcats from previously derived habitat relationship models for these species (Mayer and Laudenslayer 1988, Torres et al 1996, Davis et al. 1998). We then constructed GIS models to evaluate the disturbance impacts of roadways and development, major determinants of carnivore distribution and abundance in the south coast region (Beier 1993, 1995; Swift et al. 1993; Crooks 2000, 2002; Sauvajot et al. 2000). Finally, we combined habitat relationship models with disturbance impact models to provide a characterization of habitat connectivity for mountain lions and bobcats in the ecoregion. These models allowed us to identify core habitat blocks for carnivores, to locate key landscape connections between core areas, and to evaluate the level of protection of core areas and connections by gap analysis (Scott et al. 1993) in the highly fragmented landscape of coastal southern California.

HABITAT RELATIONSHIP MODELS

Habitat preferences for mountain lions and bobcats in the California south coast ecoregion were derived from the California Wildlife Habitat Relationships (CWHR) database (California Department of Fish and Game 1996). The CWHR was compiled and revised by an interagency team of wildlife biologists to represent available information on habitat requirements of terrestrial vertebrates in California (Mayer and Laudenslayer 1988); a version of the CWHR map for mountain lions

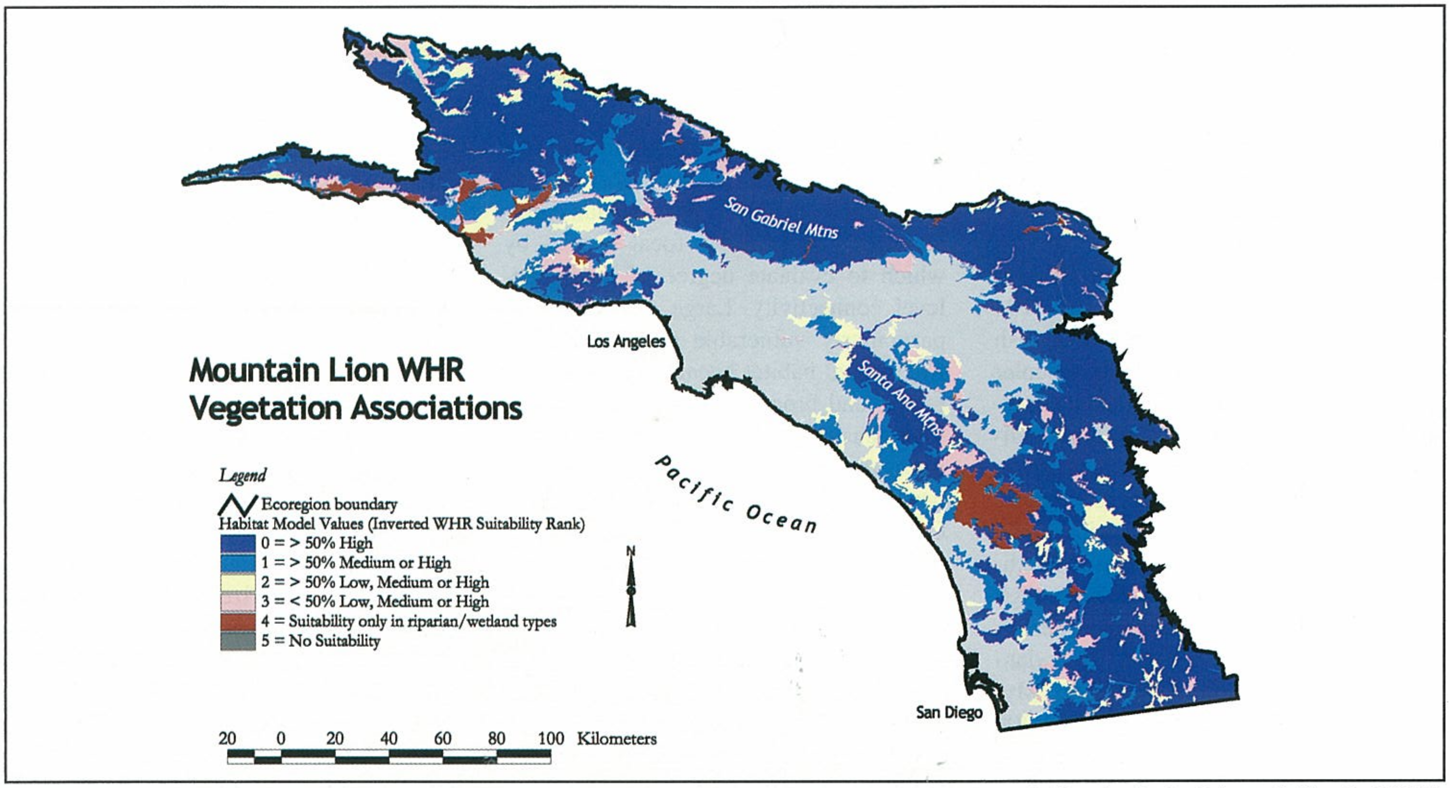

Figure 1. Habitat relationship model for mountain lions, representing potential habitat in coastal southern California. Derived from California Wildlife Habitat Relationships (CWHR) program (Mayer and Laudenslayer 1988) and Davis et al. (1998). The CWHR habitat suitability rankings are shown here as they were inverted for our models to correspond with the relative rankings of our disturbance models (see text).

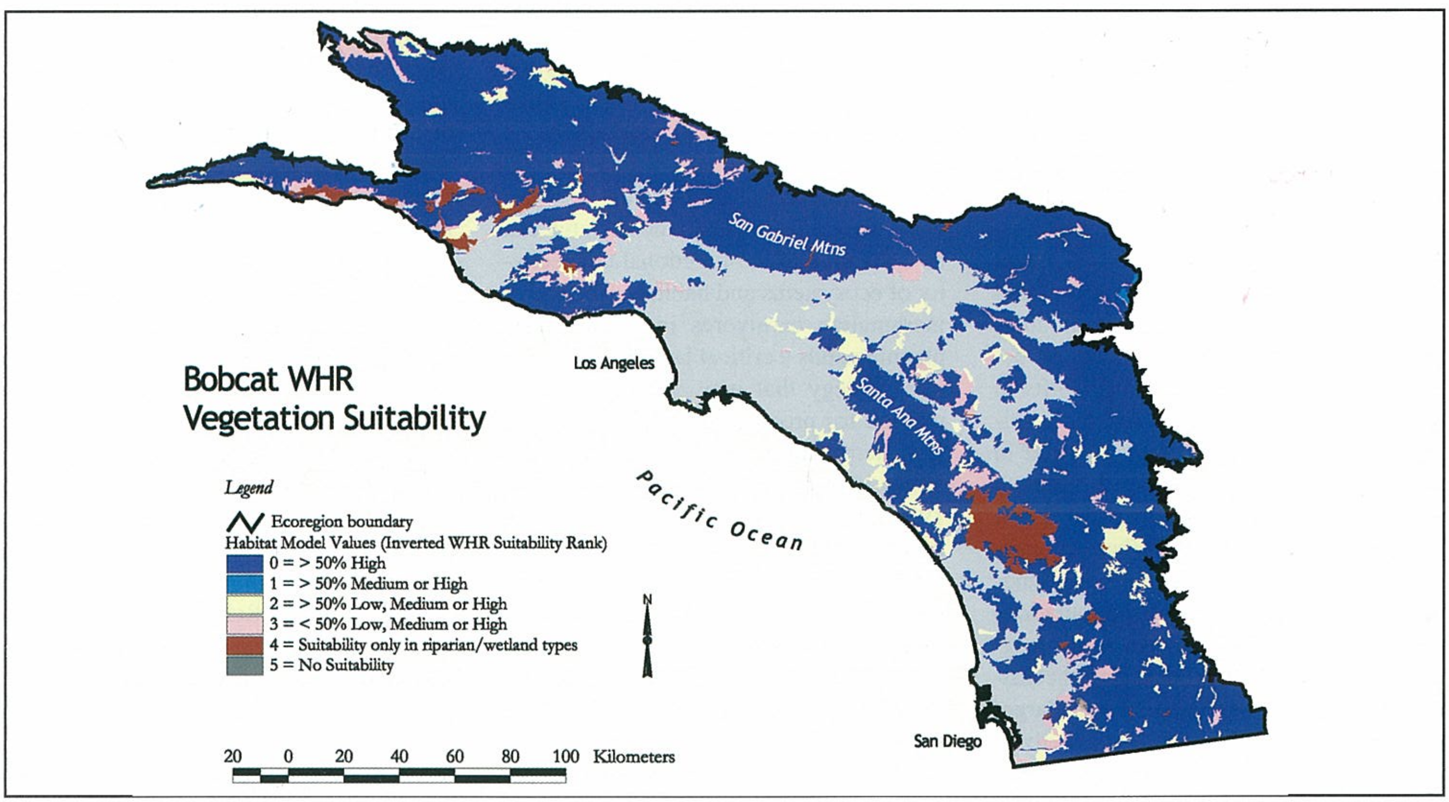

Figure 2. Habitat relationship model for bobcats, representing potential habitat in coastal southern California. Derived from California Wildlife Habitat Relationships (CWHR) program (Mayer and Laudenslayer 1988) and Davis et al. (1998). The CWHR habitat suitability rankings are shown here as they were inverted for our models to correspond with the relative rankings of our disturbance models (see text).

was previously published by Torres et al. (1996). For each focal species, CWHR ranks suitability of each habitat type as high, medium, low, or unsuitable for breeding, feeding, and cover. Davis et al. (1998) linked these CWHR models to GAPVEG, the statewide vegetation coverage created by the gap analysis program (see Davis et al. 1998 for detailed description of methodology). In summary, we assigned each GAPVEG polygon a habitat suitability rank from 0 to 5 based on the proportion of the polygon that was composed of each suitability type: 0 = no suitable habitat, 1 = suitable habitat in wetland/riparian types only (no areal estimate); 2 = <50% low, medium, or high suitability; 3 = >50% low, medium, or high suitability; 4 = >50% medium or high suitability, 5 = >50% high suitability (following Davis et al. 1998). When we later combined these habitat relationship models with our disturbance models (see below), these rankings were inverted, with 5 as no suitable habitat and 0 as >50% high suitability habitat, to correspond with the relative rankings of the disturbance models (5 = high disturbance and 0 = low disturbance). The regional accuracy assessment showed good correlation to other vegetation data mapped at a finer scale (Davis et al. 1998).

The resulting maps (Figures 1 and 2) provide a coarse view of mountain lion and bobcat habitat preferences for use at regional scales (1:100,000 and above) in coastal southern California. We considered these CWHR models as base maps of potential habitat for these carnivore species.

DISTURBANCE MODELS

Road Impact Model

Roadways are a considerable threat to landscape-level connectivity for mammalian carnivores in coastal southern California and elsewhere. During a radio-telemetry study of mountain lions in the Santa Ana Mountains of southern California, 33% of study animals were killed by cars traveling on roads that bisected core habitat (Beier 1995). In Florida, roads contributed to 20% of documented panther deaths in a 10-y period (Schortemeyer 1994). In addition to direct mortality, the presence of roads also correlates with other disturbances, such as residential and industrial development, artificial lighting, noise, logging, grazing, and poaching, all factors that may negatively impact carnivore populations. The impact of roads on carnivores probably depends on the road type. For example, small dirt roads may be used as travel routes for territory defense and hunting, whereas paved roads such as highways can effectively block movement paths.

To reflect these differences, we developed a ranking scheme to evaluate the impact of various road types on carnivore habitat suitability. We selected an existing road GIS compiled and published by Teale Data Center (Sacramento, Calif. <www.teale.ca.gov>) in 1995. Mapped at 1:100,000, the road GIS originated with USGS digital line graph files and has been updated with state road information. Omissions from the road data include minor, small, and unpaved roads, although established and presumably high-traffic routes in these categories are well captured. We converted the vector GIS road coverage to a grid with 100-m cell size. This cell size was arbitrarily selected, but it reflects positional uncertainty due to the scale of the source data. Each cell was assigned a value based on road type: 5 = primary route, 4 = secondary divided, 3 = secondary undivided, 2 = county, 1 = residential, 0 = unpaved. These rankings were intended to reflect the relative impact of roadways on carnivore habitat suitability, with a 5 score representing the greatest road impact and a 0 score representing the least road impact.

A new grid was then created using a neighborhood analysis function (Environmental Systems Research Institute 1998). The road type scores for all cells within a circle of 500-m radius (circle area = 0.785 km^2) were summed for each grid cell. The exact distances within which roads and development disturb mountain lion and bobcat habitat or behavior are not known, but we expect that such impacts would be likely within at least a 500-m radius. We classified the resulting grid cell values using natural breaks (ESRI 1998), a method that groups cells by identifying breakpoints between classes using Jenk's optimization method (Jenk 1977) to minimize the sum of the variance within each of the classes. Six classes were identified for the road impact model: 0 = no road impact (0 < grid cell value < 14), 1 = little impact (14 < value < 33), 2 = low impact (33 < value < 54), 3 = moderate impact (54 < value < 75), 4 = high impact (75 < value < 103), 5 = heavy impact (103 < value ≤ 234). This procedure generated a road impact map across the entire ecoregion (Figure 3).

Development Impact Model

The loss and fragmentation of habitat due to urban and agricultural development represents another severe impact on carnivore populations in coastal southern California (Beier 1993, 1995; Sauvajot et al. 2000; Crooks 2000, 2002). We acquired land use GIS data compiled using air photo interpretation from Southern California Association of Governments (1993 <www.scag.org>) and San Diego Association of Governments (1995 <www.sandag.org>). We used the GIS to map generalized land use categories across the ecoregion; our land use data sources were missing coverage for the San Jacinto mountain range, although this area is generally undeveloped. Each land use category was scored to reflect its relative impact on carnivore habitat: 5 = urban, 4 = agricultural, 3 = open space/parks, 2 = orchard/vineyard, 1 = rural residential, and 0 = vacant undeveloped land (water was also given a 0 score). Thus, a 5 score represents the greatest development impact and a 0 score represents the least development impact. These rankings were derived in part from similar studies based on bobcat tolerance of land uses within the region (Kamradt 1995).

We converted the land use categories to raster format with a 100-m cell size. We then created a new grid using a neighborhood analysis function (ESRI 1998). As with the road impact model, the land use type scores for all cells within a circle of 500-m radius (circle area = 0.785 km^2) were summed for each grid cell. We classified the results into natural breaks (Jenk 1977) to generate a development impact map across the entire ecoregion (Figure 4). Six classes were identified for the de-

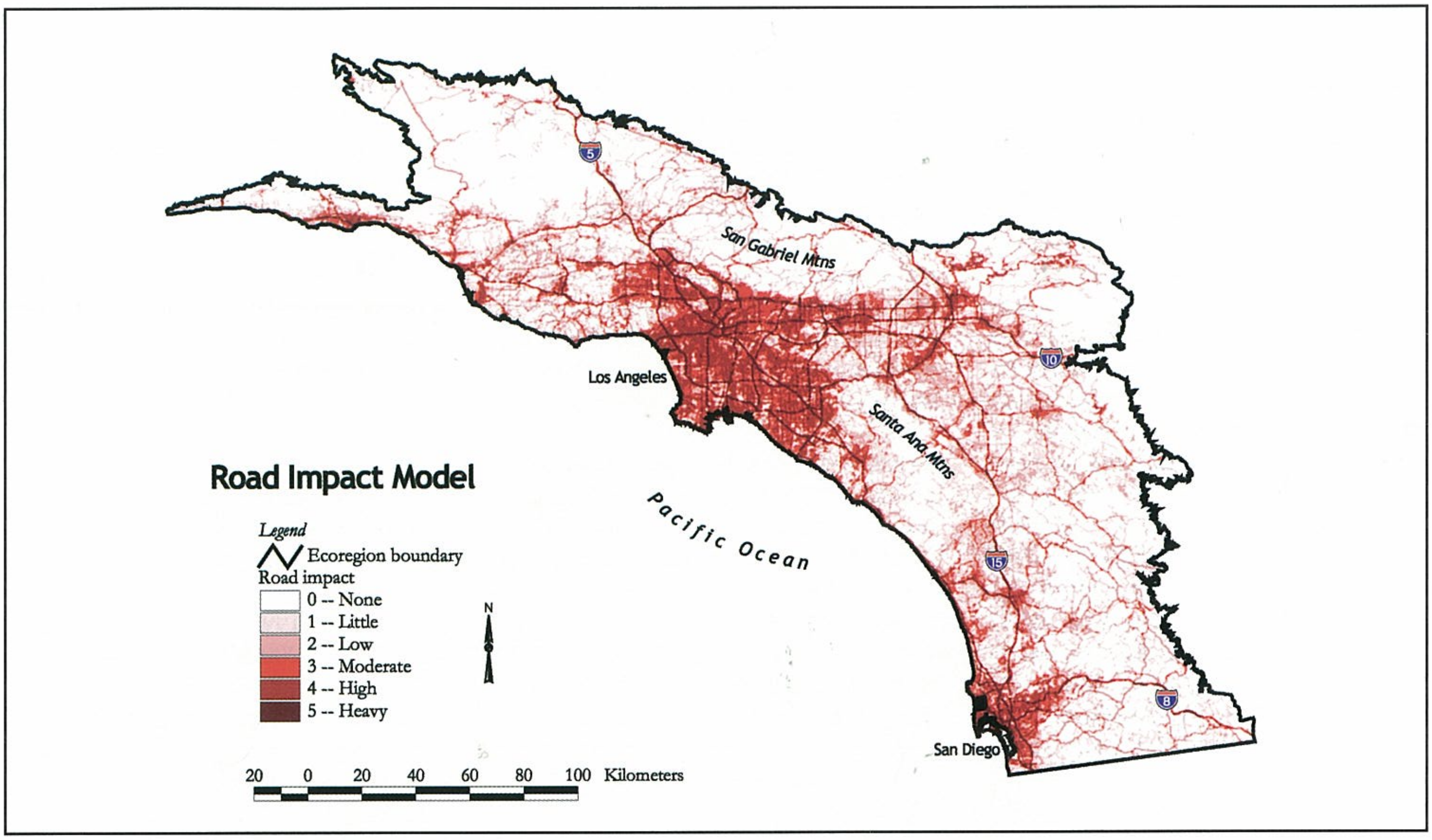

Figure 3. Model of road impact on carnivore habitat in coastal southern California.

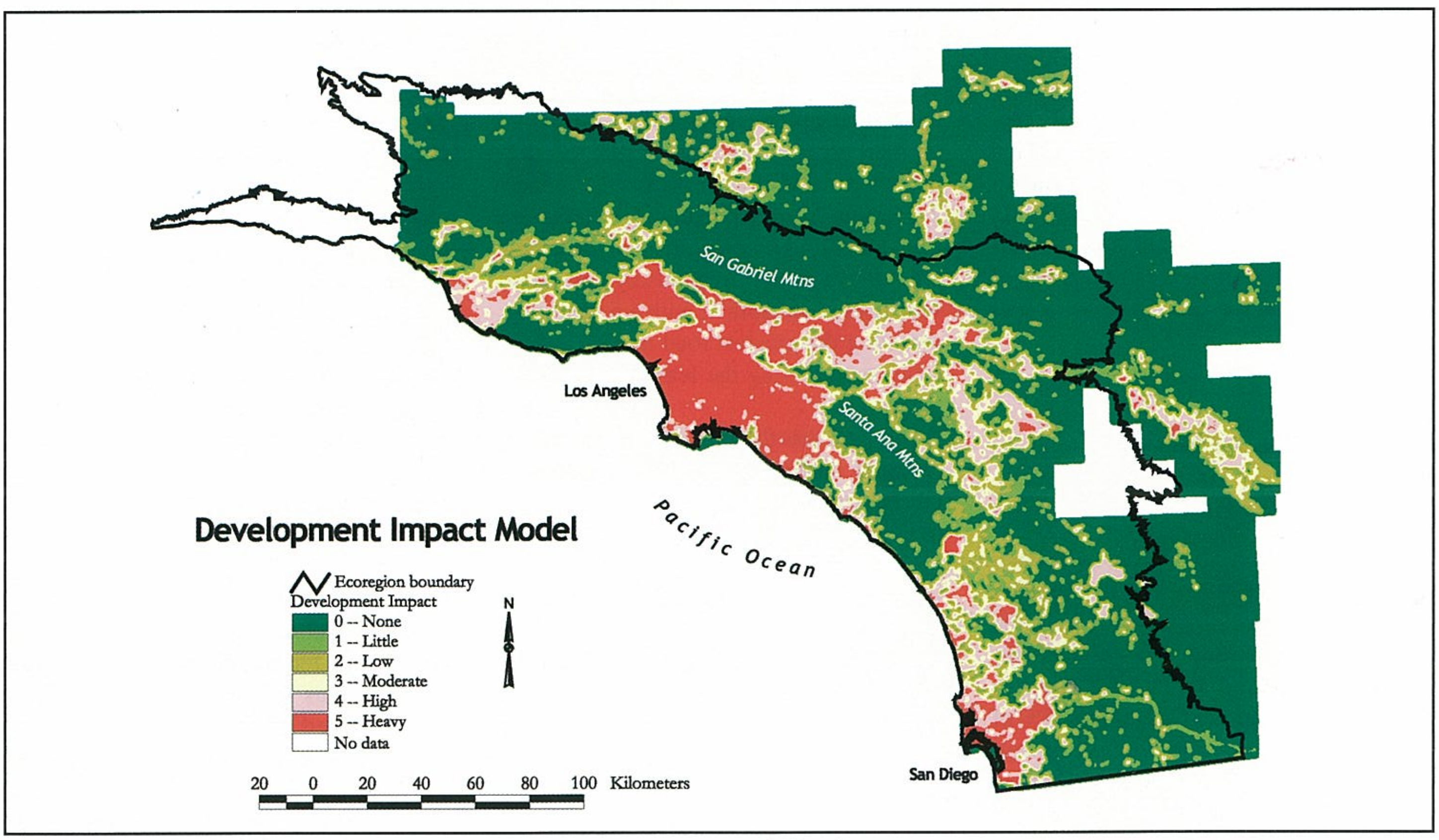

Figure 4. Model of development impact on carnivore habitat in coastal southern California.

velopment impact model: 0 = no development impact (0 < grid cell value < 126), 1 = little impact (126 < value < 386), 2 = low impact (386 < value < 691), 3 = moderate impact (691 < value < 1015), 4 = high impact (1015 < value < 1341), 5 = heavy impact (1341 < value ≤ 1585).

Overall Disturbance Model

We combined the road and development impact models to generate one overall disturbance model. First, we reclassified the road and development impact grids to assign each cell an ordinal rank, from 0 to 5, that corresponded to the categories generated with natural breaks in the road and development models. For each cell in the new grid, road impact and development impact values were summed to create a composite disturbance model with values from 0 to 10. The results were then classified into five categories using natural breaks (Jenk 1977): no impact (0 < grid cell value < 2), low impact (2 < value < 4), medium impact (4 < value < 6), high impact (6 < value < 8), heavy impact (8 < value ≤ 10). The resulting disturbance model (Figure 5) depicts a coarse, but spatially explicit, estimation of major disturbance factors that impact carnivore habitat suitability.

CARNIVORE HABITAT CONNECTIVITY MODELS

The overall disturbance model was combined with the carnivore habitat suitability models to generate habitat connectivity models for mountain lion (Figure 6) and bobcat (Figure 7). For each cell, disturbance values were summed with CWHR values to generate a numeric value of habitat suitability. The results were classified into four categories of habitat suitability using natural breaks (Jenk 1977): high suitability (0 < grid cell value < 3); medium suitability (3 < value < 7); low suitability (7 < value < 12); no suitability (12 < value ≤ 15).

The resulting maps allowed for evaluation of habitat connectivity for mountain lions and bobcats in coastal southern California. The majority of high suitability habitat for mountain lions was in upland areas, including many of the mountain ranges in the ecoregion (Figure 6). Coastal lowland areas with higher road densities (Figure 3) and development pressures (Figure 4) represented less suitable habitat for mountain lions, with the urban clusters of Los Angeles and San Diego yielding little to no suitable habitat. The habitat connectivity model for bobcats (Figure 7) was similar to that for mountain lions, although several differences were evident. Coastal lowland areas retained more high suitability habitat for bobcats than for mountain lions. Further, core areas of high quality habitat in upland areas were less internally fragmented for bobcats than for mountain lions. Overall, the suitability and connectivity of habitat throughout the south coast ecoregion appeared higher for bobcats than for mountain lions.

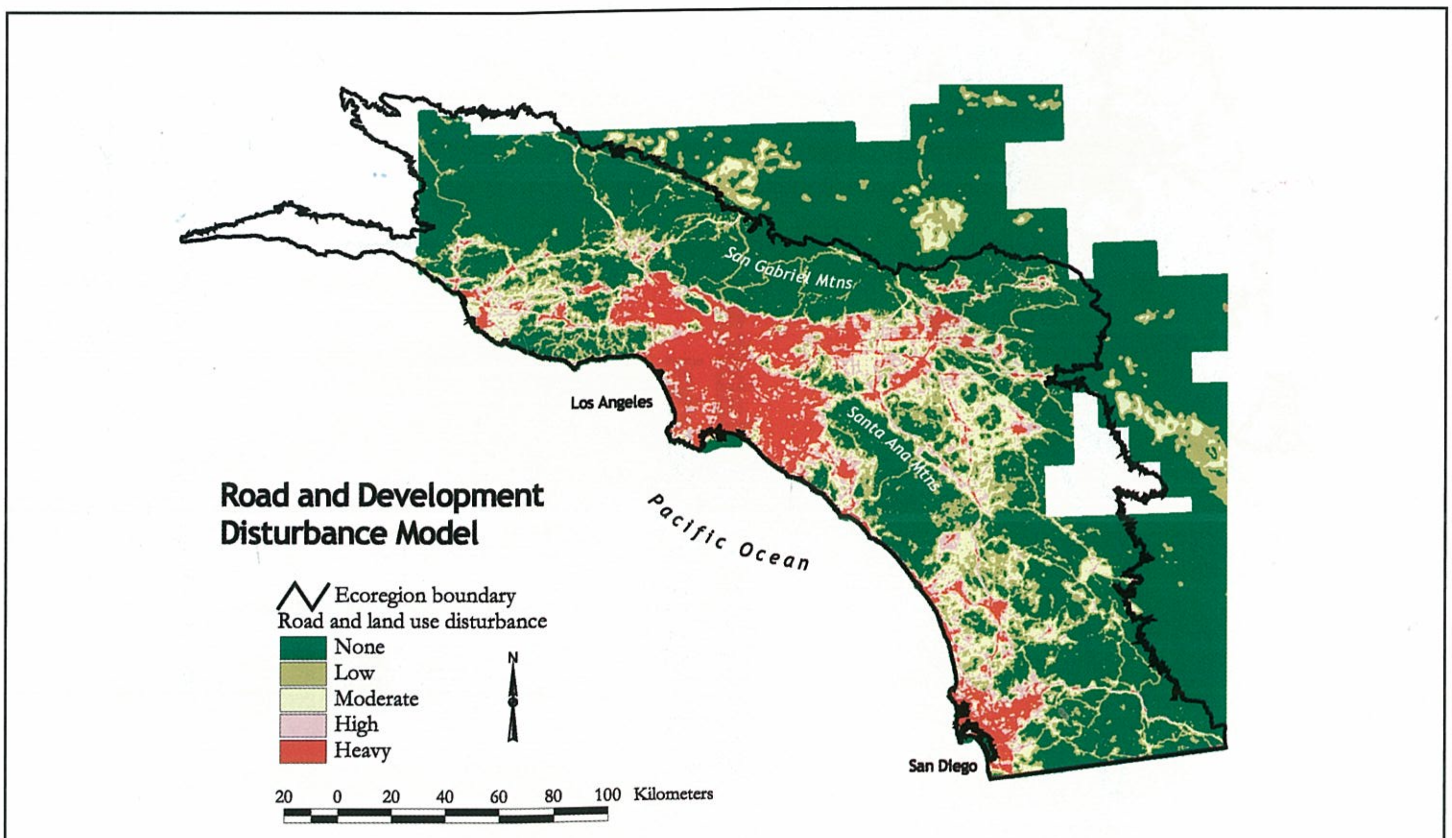

Figure 5. Disturbance model of combined impact of roads and development on carnivore habitat in coastal southern California.

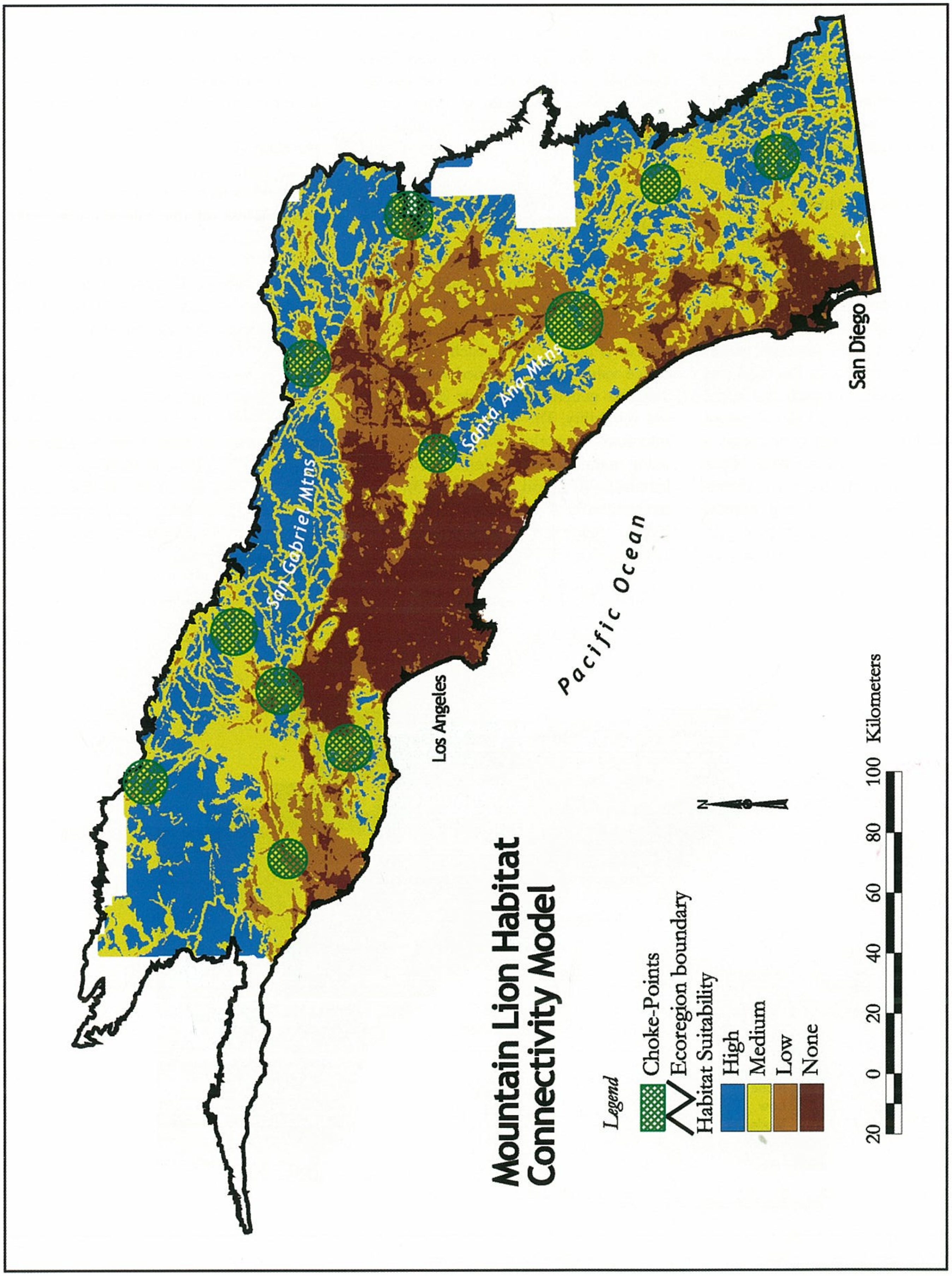

Figure 6. Mountain lion habitat connectivity model for coastal southern California. Key connectivity "choke-points" are identified on the map.

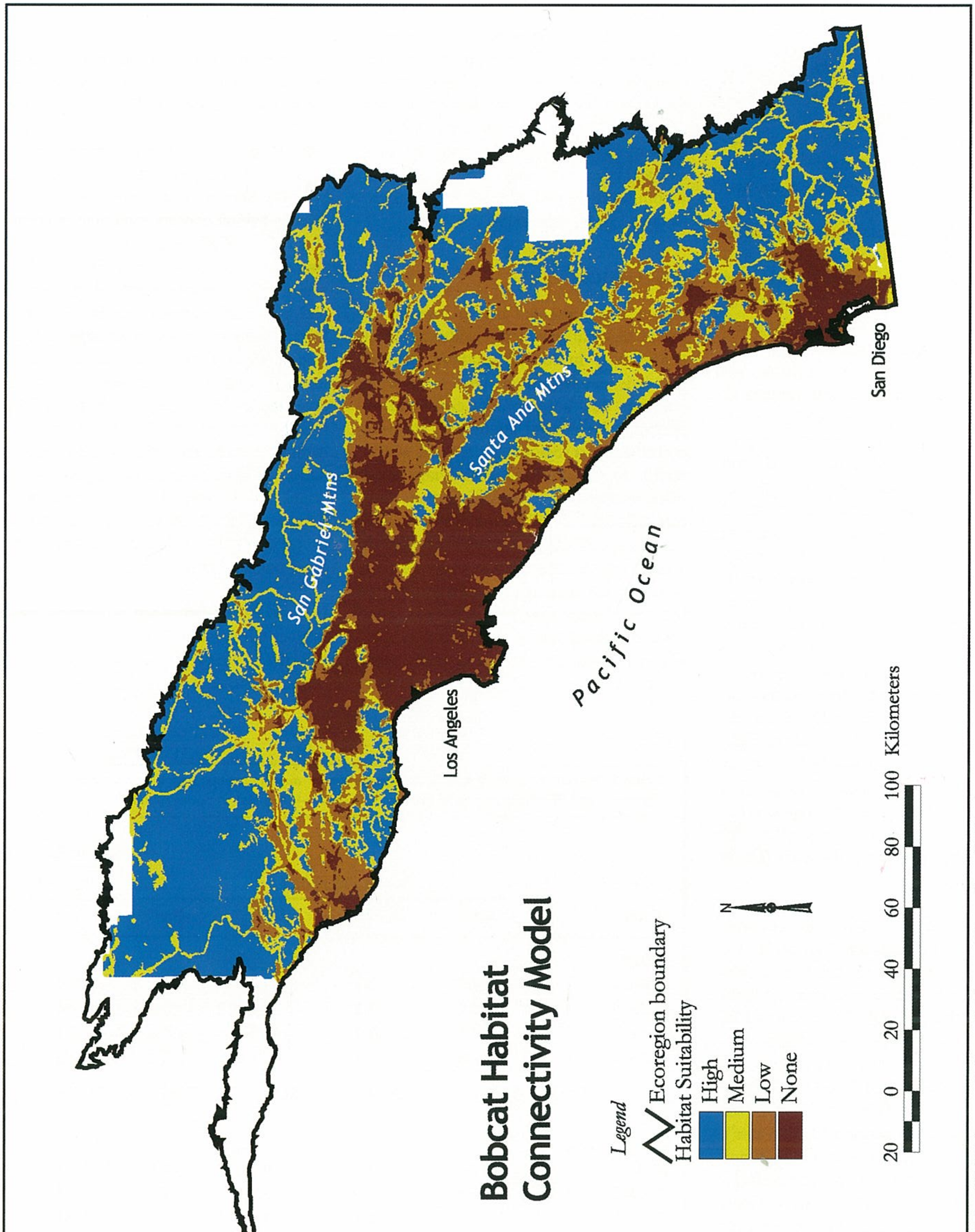

Figure 7. Bobcat habitat connectivity model for coastal southern California.

PROTECTION STATUS OF HABITATS

The gap analysis program (GAP)(Davis et al. 1998), building on previous work by Beardsley and Stoms (1993), ranked the coastal southern California ecoregion landscape into management status categories to evaluate the level of protection for major vegetation types. Four levels of management status were assigned using information about land ownership and management regimes. Status 1 lands have permanent protection from conversion of natural land cover and a mandated management plan to maintain a natural state within which disturbance events are allowed to proceed without interference or are mimicked through management practices. Status 2 lands have permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but may receive use or management practices that degrade the quality of existing natural communities. Status 3 lands have permanent protection from conversion of natural land cover for the majority of the area, but are subject to extractive uses of either a broad, low-intensity, or localized-intense type; these lands also confer protection to federally listed endangered and threatened species throughout the area. Status 4 lands lack irrevocable easements or mandates to prevent conversion of natural habitat types to anthropogenic habitat types and allow for intensive use throughout the tract (Davis et al. 1998).

To evaluate the protection status of carnivore habitat in southern California, we calculated the percent of each habitat suitability category, as derived from the habitat connectivity models (Figures 6 and 7), within the four management classes (Table 1). For bobcats, high and medium suitability habitat occupied 55% (16,921 km^2) and 13% (3934 km^2), respectively, of the total area of the ecoregion (31,026 km^2). However, 39% and 83% of this high and medium suitability habitat, respectively, was located within status 4 lands, the least protected management class. Likewise, for mountain lions, high and medium suitability habitat occupied 43% (13,283 km^2) and 24% (7314 km^2), respectively, of the total area of the ecoregion. Again, however, 30% and 76% of this high and medium suitability mountain lion habitat, respectively, was located in the least protected management class. Overall, only 17% and 20% of high suitability habitats for bobcats and mountain lions, respectively, were within status 1 and 2 management classes, the most protected lands.

DISCUSSION

The results presented herein provide an initial regional vision for landscape-level connectivity in coastal southern California. It is our hope that these large-scale analyses can help inform conservation planning for coastal southern California by providing a regional framework within which to develop and coordinate local management and conservation plans. Future refinements will be required to examine site-specific issues of reserve design at a scale appropriate for site planning. For instance, the disturbance models did not include site-specific disturbance factors such as fencing or vegetation management. These refinements will need to be conducted at a more local mapping scale than we used for our analysis.

We hope to emphasize the need for both large-scale and site-specific approaches to conservation planning. For example, the Natural Communities Conservation Plan (NCCP) of the California Department of Fish and Game and the U.S. Fish and Wildlife Service is an ambitious, multispecies habitat conservation plan in coastal southern California initiated as a response to the Endangered Species Act. The NCCP focuses on coastal sage scrub and grassland communities in high risk, lower elevation areas in Orange, Riverside, and San Diego Counties, emphasizing habitat for the endangered California gnatcatcher (*Polioptila californica*). The NCCP, however, consists of at least 11 local plans with relatively limited coordination for examination of regional-scale issues. We believe that large-scale perspectives such as presented here can prove useful in guiding some components of such local conservation efforts.

Our models are intended as general, preliminary assessments to help focus and prioritize future research and management actions targeting connectivity in the ecore-

Table 1. Percent of habitat suitability categories for mountain lions and bobcats (taken from Figures 6 and 7) within management status classes 1–4. See text for description

	Habitat Suitability				Total Area (km^2)
Status	High	Medium	Low	None	
Bobcat					
Status 1	14.1	2.1	0.2	< 0.0	2481
Status 2	2.9	2.2	0.5	< 0.0	594
Status 3	44.5	13.2	2.0	0.2	8181
Status 4	38.6	82.5	97	99.7	19770
Total Area (km^2)	16,921	3934	5148	5023	31,026
Mountain Lion					
Status 1	17.4	2.1	0.2	< 0.0	2481
Status 2	2.6	3.0	0.7	< 0.0	594
Status 3	50.1	18.7	2.6	0.3	8181
Status 4	29.9	76.2	96.4	99.7	19770
Total Area (km^2)	13,283	7314	5403	5026	31,026

gion. In April 1999, the California Wilderness Coalition organized a two-day workshop inviting academics, field biologists, and resource managers with direct knowledge and local expertise of the region to review our initial connectivity maps. The goal of this workshop was to have local experts, guided by our connectivity models, to identify key core areas and connectivity constrictions for large carnivores and other species in the fragmented landscape of southern California. The team identified the largest intact habitat areas in the connectivity models as core areas for mountain lion; core areas were primarily located in the upland ranges (Figure 6). Based on population estimates and regional habitat suitability, the scientists concluded that almost all the core habitat was critical to mountain lion viability. Indeed, Beier (1993) estimated that 1000–2000 km^2 of habitat would be necessary to maintain a lion population with a 98% probability of persistence for 100 years in the Santa Ana Mountains of southern California. Many of the isolated urban habitat remnants in coastal southern California therefore are probably too small and too isolated to permanently support any resident lion populations (Crooks 2002).

For bobcats, local experts focused on identifying core areas in sensitive, smaller habitat patches because mountain lion core areas covered the largest intact habitat blocks. These smaller patches often occurred in fragmented coastal ecosystems (Figure 7), such as coastal sage scrub, that support endemic, threatened, and endangered species not necessarily found in upland mountain lion habitat (Davis et al. 1998, Laakonen et al. 2001, Fisher et al. 2002). The inclusion of bobcats as a focal species therefore served to accentuate these key coastal habitats in our connectivity models. These coastal fragments are near the threshold for bobcat viability. Bobcats disappear in small habitat patches (e.g., < 1 km^2) that are completely isolated by urban development but that can persist in fragmented landscapes given adequate connectivity (Crooks 2002). Bobcats are intermediate in their sensitivity to fragmentation; this degree of sensitivity is commensurate with the scale of fragmentation across much of coastal southern California (Crooks 2000, 2002). Bobcats are less sensitive to disturbance than mountain lions, which seldom occurred in fragmented coastal areas, yet are more sensitive than coyotes, which are detected in even small urban habitat fragments. The status of bobcat populations therefore is a valuable indicator of the degree of functional, landscape-level connectivity across much of the fragmented coast of southern California.

Connectivity constrictions were also identified by the local experts to call special attention to threatened and narrow habitat linkages connecting larger core areas. Indeed, several core areas for carnivore habitat were identified as isolated or nearly isolated by urban development and roadways. These connectivity "choke-points" were determined to be high conservation priorities to maintain landscape-level connectivity (examples of connectivity choke-points for mountain lions are provided in Figure 6). Several of these choke-points were identified in previous field-based studies of carnivores in southern California (Beier 1993, Kamradt 1995, Sauvajot et al. 2000), thus lending further confidence to the model's predictions. The connectivity choke-points were identified as the largest habitat linkages necessary for carnivore persistence throughout the region. However, there are many other impediments to carnivore movement where habitat restoration, buffer zones, roadway design, wing fencing, and wildlife underpasses need to be addressed to provide better connectivity function.

Our results suggest that much of the key carnivore habitat in the south coast region of California is at risk. The relatively large amount of high and medium suitability carnivore habitat that lies within the least protected management status categories is cause for concern. Over 80% of high suitability habitat and over 90% of medium suitability habitat for carnivores is found in management status classes 3 and 4 (Table 1), lands that are not managed primarily for the protection of biodiversity and that are susceptible to various disturbances. Indeed, status 1 and status 2 lands encompass 2481 and 594 km^2, respectively, only 8% and 2% of the total land area of the south coast ecoregion (Table 1). These results may slightly underestimate the amount of protected land, however, because the GAP map of management status was created with a minimum mapping unit of 100 ha and it does not account for many small reserves and parks (Beardsley and Stoms 1993, Davis et al. 1998). Compiling these areas in a regional database should be a major priority for all conservation planning efforts in the region.

Some broad geographic patterns also emerged from this assessment. For instance, the northern section of the ecoregion (the western Transverse Ranges) has more land in the more protected management categories (status 1 and 2) relative to the southern section (Davis et al. 1998). This is primarily due to the large wilderness areas in the Los Padres National Forest and other public park lands in the northern section. However, the nonwilderness portions of the national forests are classified as status 3 lands, and these lands are open to destructive forms of development. Spitler et al. (1997) documented that, since 1979, the Los Padres National Forest had converted more undeveloped status 3 lands to anthropogenic habitat types than any other national forest in the state (~130,067 acres). Because approximately 45–50% of high suitability mountain lion and bobcat habitat occur on status 3 lands, appropriate management of these areas for wildlife habitat values seems important for regional carnivore populations. Further, some multiple-use public lands (status 3) and private lands (status 4) appear critically important to the maintenance of habitat connectivity. Many of the status 4 areas will require vegetation enhancement and buffering from edge effects to facilitate animal movement, and others will need restoration projects to perforate the roadways for functional connectivity. Because they may be marginal habitats for other species, such status 4 lands may not yet have been identified by habitat conservation planning processes.

To increase their reliability and effectiveness, our connectivity models will certainly require further refinement, validation, and field-testing. Many of the habitat patches, core areas, and connectivity constrictions evident from our models are currently being monitored for carnivore usage through radio-telemetry, track, scat, and remotely triggered camera surveys (Sauvajot et al. 2000, Haas 2000, Lyren 2001, Crooks 2002). Field surveys of habitat patches and core areas have yielded predictive models of the influence of patch size and isolation on probability of occurrence of carnivore species such as mountain lions, bobcats, and coyotes (Crooks 2002). Field surveys on wildlife corridors have quantified the dimensionality of corridors and roadway underpasses necessary to facilitate movement of mammalian carnivores (e.g., Haas 2000). Such field surveys can be used to validate and refine our carnivore habitat connectivity models.

Further, we will use these field surveys, as well as published movement data from previous studies of mammalian carnivores in southern California (Beier 1993, 1995; Beier et al. 1995), to develop "rules" of movements of individual carnivores in response to landscape elements. We will then use these movement rules to construct individual-based computer models that simulate the movement of carnivores through the fragmented landscape of southern California. Landscape elements will be characterized using the connectivity models presented here, incorporating regional data on vegetative characteristics, land use types, road density, development pressures, and carnivore habitat relationships. The predictions from such movement models can be used to assess the degree of connectivity in the south coast ecoregion by ranking alternative landscape configurations with respect to connectivity, by identifying major barriers to animal movement, and by estimating the optimal length, width, habitat composition, and design of movement corridors. The use of individual-based movement models to evaluate reserve design and predict population persistence is a promising new field that has been generating excitement in the scientific community (Ims 1995, Turchin 1998, Soulé and Terborgh1999).

To complement this vision of landscape connectivity for terrestrial habitats, we recommend a parallel, ongoing assessment of watershed integrity in coastal southern California. Examinations of habitat needs and distribution of focal species in aquatic and riparian ecosystems could be used to develop habitat models for similar assessments. This approach could produce a regional assessment of aquatic ecosystems as well as help identify riparian habitats critical to terrestrial connectivity for many species, including mammalian carnivores.

Our connectivity models illustrate the immediate threat of habitat fragmentation to functional connectivity in the southern California ecoregion. We should emphasize that data sources for land use and roadways in our models are 5–10 y old, and urban development and roadway construction are ongoing and widespread in the region. Opportunities to preserve habitat linkages between larger core areas could be lost without immediate action. Coordinated regional attention by local, state, and federal agencies will be required to secure, protect, and restore critical linkages.

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