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South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the USA

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INTRODUCTION

The South Coast Ecoregion encompasses 3.4 million ha or roughly 8% of California. Lying west of the Sonoran and Mohave Deserts and south of the Santa Ynez and Transverse Ranges, the ecoregion extends about 320 km south into Baja California, Mexico (Fig. 22.1). California's most populated ecoregion, it has the dubious distinction of being the most threatened hotspot of biodiversity in the USA, with over 400 species of plants and animals considered at risk by government agencies and conservation groups (Hunter 1999). Despite a human population of over 19 million (2000 census), the South Coast Ecoregion has many large wildland areas, mostly in more rugged and higher-elevation habitats within the Los Padres, Angeles, San Bernardino, and Cleveland National Forests, Santa Monica Mountains National Recreation Area, Marine Corps Base Camp Pendleton, and several State Parks. Although each wildland core area would benefit from expansion, increased protection, and restoration, each enjoys some degree of protection from urban expansion, and few if any major new wildland areas are likely to be designated. Therefore we focus on the previously neglected portion of a wildland network, namely the linkages between core areas.

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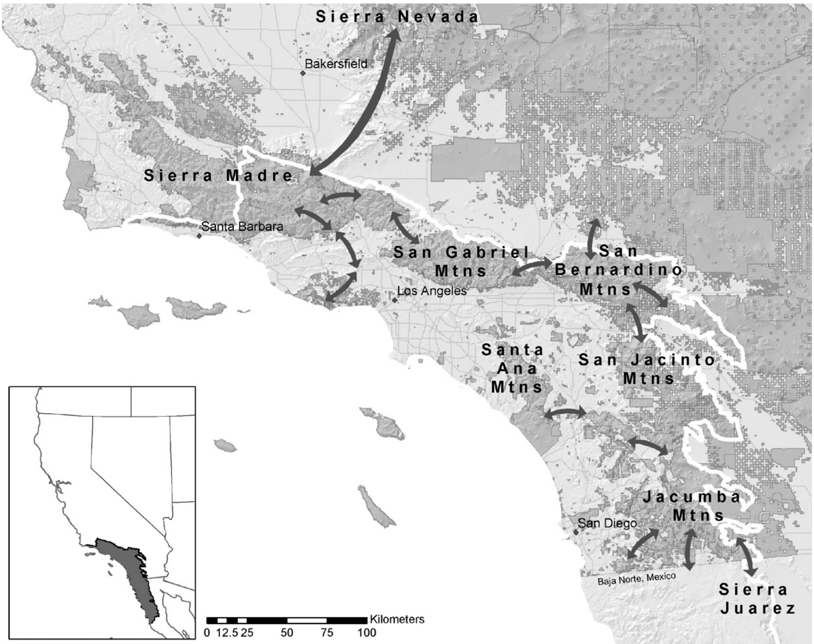

Fig. 22.1. Map of the South Coast Ecoregion (inset) and the 15 priority linkages for South Coast Missing Linkages.

Although numerous conservation efforts are underway, such as California's Natural Communities Conservation Plans (Polak 2001), these efforts do not span the ecoregion, and do not conserve ecosystem processes and functions that operate over grand scales – such as top–down regulation by large predators or gene flow between core areas lying in different planning jurisdictions. To address these gaps, each of us has worked on independent projects to conserve and connect large wildland areas where large-scale processes can operate in a semblance of their natural rhythms. Since 2000, we have worked together on an ecosystem-wide effort – the South Coast Missing Linkages project.

The South Coast Missing Linkages project began with a state-wide workshop in November 2000, sponsored by The Nature Conservancy, US Geological Survey, California State Parks, California Wilderness Coalition, and San Diego Zoo. Over 200 land managers and biologists from throughout California identified 232 actual or potential linkages needed to sustain ecosystem processes in protected wildlands. South Coast Wildlands was formed in early 2001 with an Executive Director, a Board, a team of Science Advisors, and the goal of conserving essential linkages throughout the South Coast Ecoregion. South Coast Wildlands brought together under the umbrella of the South Coast Missing Linkages project a variety of agencies and organizations already engaged in various linkage conservation efforts. We worked with these partners to develop a standardized set of methods for conserving a network of protected wildlands for the region.

Widespread and increasing urbanization in most linkage planning areas constrained conservation options and added urgency to the planning process. We experienced an understandable urge to use expert opinion to quickly map conservation targets – a "seat-of-the-pants" approach (Noss and Daly Chapter 23). However, three ideas compelled us to develop a set of scientific rule-based procedures for delineating what we call our Linkage Design. First, despite our confidence that maps based on expert opinion would lead to sound conservation decisions, when we experimented with more formal methods, we discovered some options that we had overlooked (see also Cowling *et al.* 2003). Second, a model is transparent. Landowners, developers, conservation investors, and decision-makers demand strong support for recommendations to conserve particular areas. If they doubt one or more assumptions, parameter estimates, data layers, or decision rules, they can rerun the model and see if it makes a difference. Finally, rule-based procedures allow formal sensitivity analysis, a valuable tool for conservation planning.

In this chapter, we describe the South Coast Missing Linkages project's science-based, collaborative approach to linkage planning in the largest urban area in the USA. Our goal is to provide one promising recipe for designing plans that conserve and restore connectivity in real landscapes. These methods were developed predominantly by the authors and incorporate a variety of geographic information system (GIS) methods developed by others. Significant elements have been incorporated from conservation efforts by our partners, most notably, the workshop-based approach developed by the San Diego State University Field Station Programs.

This chapter is a broad overview to be supplemented by additional papers on the mechanics and results of prioritization, permeability, and habitat analyses. Because our focus is on a science-based approach, we ignore important considerations of history and organizational theory; future papers will describe false starts, historical lessons, and the interplay among biological foundations, conservation design, and conservation delivery. We have already achieved a number of successes with this approach, but acknowledge that it is a work in progress. We adamantly hope that others will improve on our efforts.

The following sections are numbered and titled as prescriptions, because we hope others will use them as an outline for future efforts. Steps 2 through 7 correspond to the six steps in linkage design suggested by Beier and Loe (1992), which have proven rather discrete and chronological in practice as well as in concept. We add a new Step 1 – coalition building – which is logically first and permeates all other steps.

STEP 1: BUILD A COALITION

Key elements in developing a coalition for South Coast Missing Linkages include serving as a catalyst, engaging partners, holding organizational meetings, forming a steering committee, and developing an inclusive workshop-based approach to conservation planning.

Serving as a catalyst

Conserving a wildland network on a regional scale requires strong collaboration among land management agencies, conservation groups, transportation and resources agencies, sovereign Native American tribes, and others. As the smallest of these entities, South Coast Wildlands serves as a catalyst – an agent that develops synergy among various larger partners. We believe that a small group like South Coast Wildlands can best fill this role because implementing the vision of a connected ecoregional wildland network is our sole focus and *raison d'être*, rather than one of many priorities vying for attention. Furthermore, most other agencies have internal priorities that would favor some linkages (e.g., linkages that serve lands owned or managed by the agency) that could make them an inappropriate lead agency for a regional effort.

Engaging partners

The statewide Missing Linkages workshop had five major sponsors (above). By organizing this successful conference, the nascent South Coast Wildlands earned the respect of these partners. More important, it became obvious at the workshop that all of the management and conservation agencies considered the workshop simply a first step in linkage conservation. The idea had become mainstream and could command enormous energy if an effective plan were in place. The workshop report (Penrod *et al.* 2001) – with the logos of these sponsors on the cover – was distributed to most agencies and consulting firms in California and received front-page coverage in most California daily newspapers during its August 2001 release. Ten days later, capitalizing on this publicity, South Coast Wildlands convened a meeting among the original sponsors, plus other organizations potentially interested in linkage conservation in the South Coast Ecoregion. At that meeting, we outlined the proposal, distributed a brief concept paper, asked for feedback, and solicited and received commitments of time and funding to the effort. From the outset, this was presented as a collaboration, not as a project of South Coast Wildlands with others as junior partners.

Partners now include scientific and educational agencies (Conservation Biology Institute, San Diego State University Field Station Programs, San Diego Zoo, US Geological Survey), federal land management agencies (National Park Service, US Forest Service), state agencies (California State Parks, Department of Fish and Game, Resources Agency, Santa Monica Mountains Conservancy), and conservation non-governmental organizations (NGO) (California State Parks Foundation, California Wilderness Coalition, The Nature Conservancy, The Wildlands Conservancy). Each partner allows use of the organization's name and logo on reports and in publicity events, and provides some form of support (not always funding). In addition, we have excellent working relationships with entities that are not yet partners, including Native American tribes, county planning departments, local land conservancies, Bureau of Land Management, the California Department of Transportation, Pronatura (a Mexican conservation NGO) and Conabio (Mexico's federal Comisión nacional para el conocimiento y uso de la biodiversidad).

Steering committee

In August 2001, we formed a steering committee with representatives from each major partner. The steering committee holds monthly conference calls to ensure that South Coast Missing Linkages is integrated with other efforts, most notably the Natural Communities Conservation Plans being developed by the Resources Agency. The steering committee has averted potentially serious misunderstandings and has kept the project on-track and visible to participating groups and agencies.

Workshops

As described below, we used workshops to engage partners in many aspects of linkage planning. By including developers and their consulting biologists, as well as our natural allies, we demonstrated that our process is transparent, inclusive, and honest. When participants saw that their input is genuinely sought and used, they tended to adopt the effort as their own. We have involved partners in every aspect of the process because the plan will not succeed if South Coast Wildlands simply asks partners to implement its plan. Only by collaborating from start to finish will all players fully engage in implementation.

As with any collaboration, our partnership has faced difficulties. Dwindling resources and staff time have prevented some partners from providing resources necessary to conduct some analyses. Perhaps the most problematic issue has been the rare plea to dispense with time-consuming science and get our products out faster. However, we have managed to keep our focus on the big picture and these distractions have not disrupted our working relationships nor changed our commitment to a scientific approach.

STEP 2: SELECT CORE AREAS AND PRIORITIZE LINKAGES

We initiated Beier and Loe's (1992) first step in science-based connectivity planning – identifying cores in need of linkages – at the November 2000 Missing Linkages workshop. A core area was defined as a large wildland with reasonable prospect for retaining its wild character for the foreseeable future, including large military installations, but excluding sovereign tribal lands. The process was minimally selective; all proposed linkages in California were accepted as long as core areas were identified. For Mexico, where no large protected areas occur within 100 km of the international border but many large wildlands still exist, the nearest areas of natural habitat $>2000\,\text{km}^2$ were used as core areas. In Mexico, Pronatura and Conabio have enthusiastically greeted our initiative, shared their plans and data, and are working to ensure that cross-border linkages will connect to protected areas in Mexico. Conservation Biology Institute (linkage manager for the cross-border linkages) is our primary liaison with Mexico.

Realizing that resources were insufficient to take immediate, effective action on all 60 linkages in the ecoregion and nine additional linkages connecting to wildlands in other ecoregions, we proposed 12 linkages for conservation action. Almost immediately, advocates for particular wildlands not directly served by those 12 linkages lobbied to have the list changed or expanded. Obviously, a defensible prioritization process was needed, and only a transparent process open to all partners would suffice.

Following a process inspired by Pressey *et al.* (1994), Pressey and Taffs (2001), and Noss *et al.* (2002), South Coast Wildlands invited all partners to send representatives to a prioritization workshop, at which each linkage was scored in two dimensions – biological importance and vulnerability. Participants assigned highest priority to linkages that fell in the upper right quadrant (most important, highest threat). Seven criteria were used to assess biological importance: sizes of the two core areas (35% weighting), the degree to which the linkage facilitated connection to other ecoregions, or was essential to the utility of "downstream" linkages (20%), habitat quality in the smaller core area (20%), existing width and habitat quality in the linkage (10%), the degree to which the linkage connects the ocean to salmonid nursery habitat, or would reduce contaminants, sediment, and insolation of riverine habitat (8%), and the degree to which the linkage might allow for seasonal migration or facilitate range shifts in response to climate change (7%). The seventh criterion was a debit of 10 points for each riverine linkage that lacked upland habitat, was over 10 km long, and had an average width narrower than 200 m. This debit distinguished between true landscape-level linkages and those linkages that, while technically "connecting" large core areas, would not facilitate movement of wide-ranging carnivores or other upland vertebrates due to frequent road crossings, severe edge effects (noise and light pollution, garbage-dumping and other disturbance, conflicts with pets), and low diversity and integrity of natural habitats.

The weighting among scores reflects an emphasis on ecosystem processes and top carnivores, and thus area was more important than the particular habitats or habitat quality in core areas. The full 35 points for size of core areas was awarded to linkages that would connect two large ($>2000\,\text{km}^2$ each) wildlands. We assigned lower scores for a linkage between large and medium-sized (60 to $2000\,\text{km}^2$) wildlands, or between large and small ($<60\,\text{km}^2$) wildlands, down to a low of 0 points for a linkage between two small wildlands. The $2000\,\text{km}^2$ and $600\,\text{km}^2$ thresholds correspond to the minimum areas required to support puma (Beier 1993) or bobcats (*Felis rufus*: Crooks 2002), respectively, over the short term. In addition to being among the most area-sensitive species in the ecoregion, these high-level carnivores are important regulators of ecosystem function (Terborgh *et al.* 1999). In addition, one or both of these two species occurred in all core areas, and were thus more appropriate than species such as peninsular bighorn (*Ovis canadensis cremnobates*) that were present only in some core areas.

The relatively low weight given to current habitat conditions reflected our optimism that if we could avoid urbanization of large degraded wildlands, we would conserve at least the opportunity to confront the restoration challenges. The relatively low weight for response to climate change was hotly debated. All participants agreed that global change will have profound impact on biodiversity. However there was considerable scientific uncertainty about the direction, seasonality, and magnitude of changes in temperature and precipitation expected in our ecoregion, with corresponding uncertainty as to which linkages would best facilitate range shifts. To earn the 7 points for this criterion, a linkage had to span an elevation gradient >650 m or two major life zones.

At the November 2000 conference, persons describing each linkage had rated the severity of each of several types of threat to the linkage on a scale of 1 (low) to 5 (high). For our assessment of vulnerability, we used the higher of the threat scores for urbanization or roads. We ignored other threats, such as off-road vehicle use or agricultural conversion, on the grounds that these threats are relatively reversible compared to urbanization and roads.

Determining the criteria and scoring system was an iterative process during which participants gradually reached consensus on the conceptual underpinnings of the gestalt ratings that each person held at the start of the process. Scoring the 69 linkages went quite quickly once these issues were resolved. The biological importance scores were clustered in two groups, with 22 linkages scoring as most important. Twelve of these 22 priority linkages had high vulnerability ratings (≥ 4), and thus emerged as conservation priorities. In addition, we added three linkages with moderate (3) vulnerability scores in areas where our partners had already begun conservation planning. We offer several related justifications for this departure from our prioritization scheme. First, the importance–vulnerability algorithm is not responsive to real-world opportunities, and should be used to inform, but not dictate, conservation decisions (Noss *et al.* 2002). These opportunities related not only to the particular linkages involved, but also to maintaining and strengthening the coalition needed to conserve these linkages. Finally, in one case, acquisition efforts were half complete, and we reasoned that a quick victory would help maintain partner enthusiasm for the full program.

These 15 linkages are the focus of our current efforts (Fig. 22.1). They include nine linkages within the South Coast Ecoregion and six linkages between ecoregions (including Baja California as an ecoregion). The core areas served by these linkages include all the obvious major wildlands in and adjacent to the ecoregion, such as the San Gabriel Mountains, San Bernardino Mountains, San Jacinto Mountains, Anza-Borrego desert lands, and Santa Monica Mountains. The smallest core area is the Otay Mountain area of southern San Diego County ($\sim 150\,\text{km}^2$). The longest linkage spans over 80 km of the privately owned Tehachapi Mountains to connect the large protected wildlands in the Sierra Madre to those in the

Sierra Nevada. The two shortest linkages serve core areas separated only by a freeway and a few small private parcels. For other linkages, the edges of the two protected cores are 6 to 24 km apart.

Each linkage was adopted by a partner organization to serve as its "linkage manager," or the entity most responsible for planning that linkage. South Coast Wildlands, San Diego State University Field Station Programs, National Park Service, The Nature Conservancy, California State Parks, US Forest Service, and Conservation Biology Institute serve as linkage managers or co-managers.

STEP 3: SELECT FOCAL SPECIES FOR EACH LINKAGE

Although our ultimate goal is to conserve ecosystem function, we designed linkages to serve the needs of particular focal species. We used a focal species approach for the practical reason that we do not know how to conduct permeability analysis or design a linkage (Step 4) in a way that directly conserves ecosystem processes in the core areas. We acknowledge that our approach could result in linkages that allow movement of focal species between core areas, but that might fail to conserve natural patterns and mechanisms of gene flow, pollination, seed dispersal, interspecific interactions, energy flow, and nutrient cycling. We do not take this risk lightly. However, given the pace of urbanization, we cannot wait for answers to these questions. We can immediately exploit the focal species approach, which has the further advantage that species-based management is accepted and supported by managers, decision-makers, and public opinion (Lambeck 1997; Miller *et al.* 1999; Carroll *et al.* 2001; Bani *et al.* 2002; Noss and Daly Chapter 23).

To minimize the disconnect between focal species and ecosystem processes, we sought a variety of focal species for each linkage, including species that are closely related to ecosystem function or sensitive to linkage loss, such as indicator species, keystone species, area-sensitive species, and umbrella species (Miller *et al.* 1999; Coppolillo *et al.* 2004). For instance, a linkage that serves focal species such as puma (*Puma concolor*) conserves one necessary condition for top-down trophic regulation. Similarly, we hope that a linkage designed to serve a plant species with limited seed dispersal will conserve that process for less dispersal-limited species.

Our suite of focal species also included a few "orthogonal" species, i.e., a species that occurs within the linkage but not necessarily in the core areas. Planning for such species can help ensure that linkages maintain ecological integrity and are not sterile gauntlets through which other species must pass. Thus, although most of our focal species were "species that need the linkage" (to pass between core areas), the orthogonal taxa represented "species the linkage needs" (to ensure its integrity). For example the little pocket mouse (*Perognathus longimembris*) occurs on fine sandy soils in arid valleys between major mountain ranges, but not in the mountains themselves. Its sensitivity to human barriers, such as roads and concrete ditches, made it a good focal species for ensuring linkage integrity between the mountainous uplands. We did not give rare or threatened species special priority as focal species, although some, such as San Joaquin kit fox (*Vulpes macrotis mutica*), were chosen because they met other criteria. Rarity in itself does not make a species a good keystone, umbrella, or indicator species.

Focal species were selected by participants in five workshops, each organized around one to four linkages in geographic proximity. Participants included land managers, planners, consulting biologists, California Department of Fish and Game staff, and experts on species, habitats, and conservation plans in the linkage area. Selected taxonomic experts gave presentations on what was known about various species habitat connectivity requirements and suggested some initial candidate focal species. Participants then sorted into taxonomic workgroups to select focal species. South Coast Wildlands and the collaborating linkage manager provided detailed instructions on how to select focal species and emphasized how these species would be used to design and justify the linkage, and to serve as indicators of linkage function over time.

Participants were asked to select species that (a) require inter-core dispersal at the scale of *this* landscape for metapopulation persistence, (b) have a localized distribution at the spatial scale of this landscape, (c) have short or habitat-restricted dispersal movements, (d) represent a surrogate for an important ecological process (e.g., predation, pollination, fire regime), (e) need connectivity to avoid genetic divergence of a now-continuous population, (f) might change from being ecologically dominant to ecologically trivial if connectivity were lost, (g) is an important pollinator or seed-disperser, or would suffer reproductive failure if it lost the service of a fragmentation-sensitive pollinator or seed-disperser, or (h) is reluctant to traverse barriers (e.g., culverts under roads) and would be a useful umbrella for other species sharing this trait. Workgroups tried to include focal species that varied with respect to habitat specialization and dispersal distances, but were asked to limit the number of species chosen to fewer than six per taxonomic group. Workgroups reviewed the lists of other workgroups to eliminate redundant species, i.e., species that seemed unlikely to add to the linkage design in light of other included species. In deciding which of two species to consider, we retained the species whose habitat needs and local distribution were better known.

A total of 109 species were identified in all 15 linkages, including 26 plants, 25 invertebrates, 18 amphibians and reptiles, 4 fish, 20 birds, and 16 mammals. Although some species (usually plants or invertebrates) were selected for a single linkage, the average focal species appeared on lists of 2.7 linkages (range 1 to 15 linkages). Puma, mule deer (*Odocoileus hemionus*), and badger (*Taxidea taxus*) each appeared on lists for 14-15 linkages. Steelhead (*Oncorhynchus mykiss*), western pond turtle (*Clemmys marmorata*), and western toad (*Bufo boreas*) each appeared on nine or more lists. On average 19 focal species were identified per linkage (range 14 to 32).

STEP 4: CREATE A DETAILED LINKAGE DESIGN

We developed a multi-stage procedure for identifying priority lands for conservation in each linkage. The first three stages (A—C below) reflect the different types of focal species and the considerable variation in ecological knowledge available for each. For appropriate species (A), we used least-cost corridor analysis (B) to identify lands likely to facilitate movement. Patch size and configuration analysis (C) was then used to evaluate whether each focal species could persist and move through the union of least-cost paths, and to expand that union as needed. The final stage (D) added a buffer to accommodate edge effects, ecological uncertainty, metapopulation dynamics, and processes and species omitted from the analysis.

A: Determine whether least-cost corridor analysis is appropriate to identify lands that best facilitate movement of each focal species, or their genes, between the two core areas

Least-cost corridor analysis (LCCA) is a GIS-based method of estimating the optimal location of a landscape linkage between core protected areas based on estimates or assumptions about how a focal species responds to various landscape features that can be reflected in digital map layers (Singleton *et al.* 2002). Because least-cost *corridor* analysis identifies all pixels with low travel costs, it produces a swath that can include more than one alternative path, and is thus superior to least-cost *path* analysis, which yields a single path one pixel in width for its entire length (Theobald Chapter 17). Other alternative approaches to LCCA are presented by

Bani *et al.* (2002), Tracey (Chapter 14), Carroll (Chapter 15), and Noss and Daly (Chapter 23). We chose LCCA because we lacked detailed data needed for the more sophisticated alternatives (such as movement of radiotagged animals, or parameter estimates for spatially explicit population viability models).

Although the most quantitative and flashy tool in our toolbox, LCCA is the most data-demanding. It is also inappropriate for some focal species. To guard against inappropriate use of this tool, we used it only for species that met all three of the following criteria. First, we must know enough about the movement of the species, or the movement of its obligate pollinators and seed-dispersers, to estimate cost-weighted distance using the data layers available to us. For example, although steelhead and arroyo chub (*Gila orcutti*) are confined to streams, the GIS stream layer is not detailed enough to indicate which stream stretches have aboveground flow (most blue-line streams in the area do not), or what barriers might exist to movements. Second, the species must occur, or have historically occurred, in both core areas to be linked, such that restoration is feasible, and the species or its genes must be capable of moving between the cores (although not necessarily within a single generation). This excluded the orthogonal species from LCCA. Third, the timescale of the species' gene flow between core areas must be shorter than, or not much longer than, the timescale at which currently mapped vegetation layers are likely to be replaced by disturbance events and other environmental variation. This condition excluded focal species such as Engelmann oak (*Quercus engelmannii*), for which gene flow would only occur over many hundreds of years. This criterion would not be needed for a LCCA that included dynamic vegetation maps reflecting vegetation response to disturbance or climate change.

In each linkage, about half of the focal species (including reptiles, amphibians, birds, and mammals, but no fish, invertebrates, or plants) met our criteria for conducting LCCA. We considered the needs of the other species via habitat suitability analysis (Section C, below).

B: For appropriate focal species, conduct least-cost corridor analysis (LCCA)

We conducted LCCA using four GIS data layers that were readily available and likely to influence movement of many animals: vegetation/land use, topographic feature (ridge, canyon bottom, flat, or slope), elevation (classes defined by each species expert), and road density (km of paved road per km^2). Land use (urban, agriculture, disturbed) and paved road density are intended to encompass all the human activities that affect suitability of linkage habitat. Although other measures (densities of humans, livestock, pets, off-road vehicles) seem attractive, most of these are probably highly correlated with urban land uses or paved road density, and none is readily available in GIS format.

For each focal species subject to LCCA, we asked a biologist studying that species or a closely related species to estimate the relative importance of each factor for habitat use by the animal. Recognizing that it is impossible to disentangle the influence of vegetation from that of topography and elevation, we instructed the rater to think of vegetation as the factor that integrates the influence of topography and elevation in a way that is most important to the species. We also stressed the priority of vegetation because there is a much larger literature on selection of vegetation types than on responses to the other factors. Thus the weights for elevation, topography, and roads reflected only their *additional* influence on animal habitat preference; in some cases this resulted in 0% weights for these factors.

The biologist also scored the various vegetation/land-use classes, elevation classes, topographic classes, and road-density classes with respect to animal preference on a scale of 1 (highest preference) to 10 (strongest avoidance). Because Clevenger *et al.* (2002; see also Clevenger and Wierzchowski Chapter 20) found that expert-based models that did not include a literature review performed significantly worse than literature-based expert models, we asked raters to first assemble the literature on habitat selection by the focal species and closely related species, and we offered assistance in gathering those papers.

Although these scores (weights in the equations below) were used to parameterize a LCCA, we asked raters for habitat preference scores rather than *permeability* or *travel cost* scores. We made this decision because experts are much more consistent in rating habitat suitability than in rating ability to move through a habitat (B. McRae and P. Beier, unpublished data on ratings of habitat suitability and permeability provided by six puma experts). Furthermore, there is a large literature on habitat use and preference, but almost no literature on permeability or travel cost in various habitats.

We used California Fire and Resource Assessment Program (FRAP) landcover/land-use data as the source for our vegetation layer, US Geological Survey 30-m digital elevation models (DEM) for our elevation layer, and a topographic feature layer derived from elevation and slope models using Weiss' (2000) topographic position and landform algorithm. Because our fieldwork showed that the only widely available digital road layer (TIGER Line files - Census 2000) failed to differentiate between unimproved roads and paved roads, we used road data from Thomas Brothers, Inc. and 1-m aerial imagery to modify these files to create a paved road density layer. We did not distinguish among types of paved roads (e.g., freeway versus two-lane highway) nor among roads with differing traffic volumes.

Our LCCA was similar to that of Singleton *et al.* (2002) except that we used an additive model rather than a multiplicative one. (We do not claim superiority for our additive model; we are currently assessing whether the two approaches produce different maps.) Pixel size was 0.09 ha (30-m grid) in each linkage except one in which data availability forced us to use 1-ha cells. For each species, each pixel was assigned a travel cost,

$$C = \sum_{i=1}^{4} w_i \cdot s_j, \tag{22.1}$$

where w_i = the weight assigned to factor i (e.g., vegetation type or road density), and s_j = the score assigned to class j (e.g., to the particular vegetation type or road-density class in that pixel). To estimate the cost of movement from the edge of one core area, we assigned each pixel a cost-weighted distance,

$$D = \min \sum_{i=1}^{k} C_i, \tag{22.2}$$

where k = the number of pixels along a path from the focal cell to the largest block of suitable habitat (as defined by California Department of Fish and Game 2002) within one core area. Superimposing (adding) the cost-weighted distances from the two core areas produced a map depicting, for all pixels in the linkage area, the average cost-weighted distances from the two core areas (Fig. 22.2; see also Theobald Chapter 17). We tentatively accepted the lowest percentile of cost-weighted distances that formed a continuous swath of pixels between cores. This was typically 1% or 2% of the linkage area (the smallest rectangle enclosing both cores).

The least-cost corridor for each species was sent to one or more species experts and persons familiar with the landscape, who reviewed the model structure and outputs, and recommended a percentile (e.g., the most permeable 2% of pixels) that would allow movement of the focal species (Quinby *et al.* 1999). Although this recommended percentile sometimes was higher than the lowest percentile that produced a continuous swath,

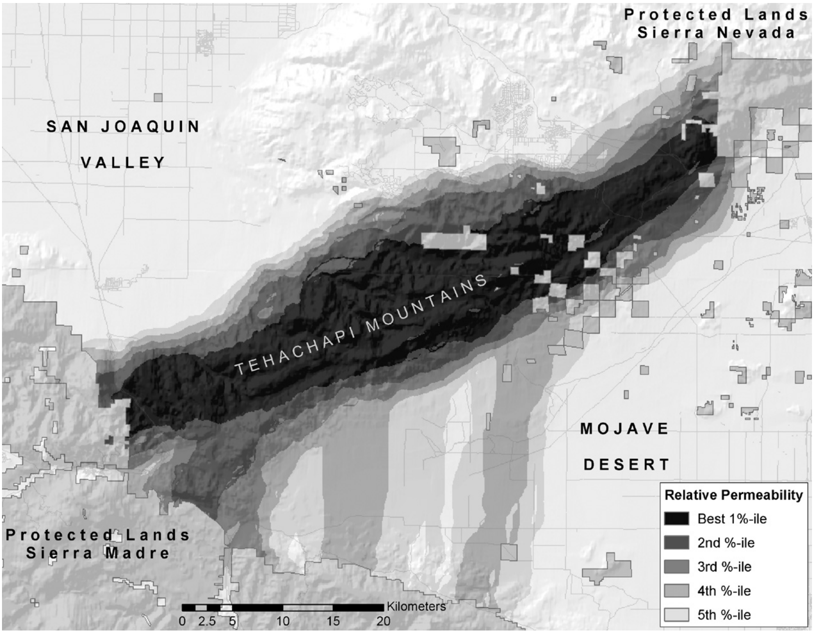

Fig. 22.2. Cost-weighted distance map for puma between protected lands in the southern Sierra Nevada core area and southeastern Sierra Madre core area, highlighting pixels with the lowest total cost, in 1-percentile increments. Percentiles are based on a rectangle encompassing both cores. Because our procedures will always produce a least-cost corridor, even if the ''best'' corridor does not facilitate animal movement, species experts reviewed each map and recommended the smallest fraction of pixels that would ensure animal movement. In this case, the best 0.7% (a subset of the 1% pixels) was considered a sufficient linkage for this species.

the Linkage Design (which reflected needs of additional species and a minimum width) always encompassed the expert-recommended minimum. If needed, we would have expanded the Linkage Design to accommodate an individual focal species, but our multiple-species approach made it unnecessary to engage in this subjective process (Quinby *et al.* 1999).

We combined the maps of all species to produce a union of least-cost corridors (ULCC) that encompassed the entire least-cost corridor of each species. We decided not to map the ULCC using different tones to indicate the number of species served by different parts of the ULCC, on the grounds that this would not promote our policy of ''No species left behind.'' In most cases, the ULCC formed a single band between the core areas.

LCCA will always produce a least-cost corridor, even if the "best" corridor crosses a freeway, aqueduct, or other obvious barrier to movement of focal species. To address this, any competent practitioner will conduct fieldwork to identify such barriers and recommend appropriate restoration or mitigation. However, we caution practitioners about a more subtle pitfall. A transportation agency or developer may be tempted to use LCCA to simulate the impact of adding a road or a golf course to the heart of a linkage area. It is important to understand that LCCA will almost certainly produce the same map – complete with the road or golf course within the best 1% – because this area will still be more permeable than the adjacent housing tract or reservoir. Because someone would inevitably misinterpret such a result as indicating "no impact on connectivity," it is best to avoid such abuse of LCCA altogether. Put another way, LCCA should not be used to evaluate scenarios about landscape features (such as a particular highway) that occur at a finer scale than the inputs into the analysis (such as road density, which is only crudely related to any particular road).

C: Conduct habitat suitability analysis

A least-cost corridor does not necessarily encompass habitat patches large enough to support viable populations, nor are such patches necessarily within the dispersal distance of the focal species. To evaluate the effectiveness of each ULCC to provide connectivity for all focal species (including orthogonal species and other species for which LCCA was not conducted), we mapped the distribution and size of suitable habitat patches for each focal species. We used suitability scores provided by experts, or extracted from literature review or the California Wildlife-Habitat Relationships database (California Department of Fish and Game 2002) to identify suitable habitat in the planning area. We considered a cluster of pixels large enough to support 50 individuals as a *potential population center*; rounding up to the nearest order of magnitude in hectares (e.g., we rounded 2 ha to 10 ha, and 650 ha to 1000 ha). This rounding avoids belabored inferences from published estimates of home range size or density. Similarly we considered a cluster of suitable pixels large enough to support more than two individuals (again rounded to the nearest order of magnitude) as a *potential habitat patch* if it was within twice the species' mean dispersal distance from a potential population center. We chose twice the mean dispersal distance because estimates of dispersal distance are based on small samples (thus missing extreme events) and are biased low (because researchers lose track of individuals that move beyond the researcher's search radius: Barrowclough 1978). The rare dispersals longer than the known mean can be responsible for significant gene flow or demographic rescue (Brown and Kodric-Brown 1977). Thus using the mean would cause potentially important patches to be considered "useless." When data were lacking, we used the home range size and dispersal distances for other species in the same genus or family from studies in the most similar ecoregion.

Typically, most potential population centers and habitat patches fell within a core or the ULCC; the others were considered *candidates* for addition to the ULCC. We added a candidate population center or habitat patch to the ULCC if that addition (a) decreased the total amount of unsuitable habitat that an individual animal would have to traverse in a journey between core areas, or (b) provided a route with greater dominance of potential population centers (instead of potential habitat patches). If the focal species could fly across urban or agricultural areas, the center or patch was added as a disjunct stepping-stone. For other species, we added pixels of native vegetation (or agricultural land if insufficient native vegetation was present) to connect the area to the ULCC.

D: Impose minimum widths on each ULCC

Portions of some linkages were narrow due to the distribution of urbanized or agricultural lands. We expanded any constriction points along the ULCC to a width of 2 km by adding pixels of natural vegetation, or, when there was insufficient natural vegetation, agricultural land (on which natural vegetation should be restored). We did not add pixels of urbanized land, however, and this often precluded expansion to 2 km. When possible we used additions to increase the diversity of topographic elevation and aspect within the linkage, reasoning that this would increase the utility of the linkage during future climate changes.

There are many reasons why linkages should be wide. (1) Many smaller animals, such as salamanders and lizards, will take dozens of generations to cross between core areas, and thus need enough area to support resident metapopulations over time. (2) For species whose needs are not well represented by our focal species, a wide area will help ensure availability of appropriate habitat or habitat elements (e.g., host plants, pollinators, roosting sites). (3) Contaminants, sediments, and nutrients can reach streams from distances >1 km (Maret and MacCoy 2002; Scott 2002; Naicker *et al.* 2003), and fish, amphibians, and aquatic invertebrates often are more sensitive to land use at the watershed scale than at the scale of narrow riparian buffers (Goforth 2000; Fitzpatrick *et al.* 2001; Stewart *et al.* 2001; Wang *et al.* 2001; Scott 2002; Willson and Dorcas 2003; Pringle Chapter 10). (4) A wide linkage buffers against edge effects (pets, lighting, noise, nest predation, nest parasitism). (5) Fire is a natural disturbance factor in the South Coast Ecoregion, and a wide linkage allows for a semblance of a natural fire regime to operate with minimal constraints from adjacent urban areas. (6) A wide linkage enhances the ability of the biota to respond to climate change. (7) Harrison (1992) suggests that a linkage for a species that needs to live in (as opposed to move through) the corridor should be approximately the square root of half an individual home range area.

Harrison's (1992) reasoning provides an attractive argument for a width of 1 to 2.5 km to accommodate badgers, coyotes, or bobcats (home range sizes reported by Goodrich and Buskirk 1998; Riley *et al.* 2003). However, these species probably could use a narrower linkage 6-24 km long (i.e., the lengths of most of our linkages) that provided a combination of live-in and pass-through habitat. None of these arguments provide rigorous support for 2 km (or any other value) as a minimum width. We chose 2 km as a reasonable width that probably achieves 5 of these 7 goals, although it may be too narrow to allow a fire regime that simulates natural conditions (goal 5) or enable biotic response to climate change (goal 6).

The Linkage Design

For each linkage, we use the term *Linkage Design* for the map depicting the buffered ULCC. In most of our linkages, the Linkage Design was a relatively narrow swath 6-24 km long and 2-3 km wide along most of its length, with occasional constrictions to accommodate existing urban development. But several Linkage Designs encompassed broader areas for part of their length, including large patches that can function as stepping stones or even core areas for even the most area-demanding focal species.

A narrative accompanying the Linkage Design map described the extent to which the Linkage Design serves the needs of each focal species. Although the Linkage Design offers the best chance of facilitating movement of each species, we have to admit that our best may not be good enough for some focal species in some linkages. For example, grasslands have been almost entirely lost to development in several linkage areas, making it difficult to create a corridor for badgers. For the remaining focal species, we hypothesize that, even after urbanization of areas outside the Linkage Design, focal species or their genes would move between core areas in a way that ensures species viability. In non-scientific parlance, this hypothesis can be expressed as "If we build it, they will come." For orthogonal species, we hypothesize that the species would persist within the Linkage Design after urban build-out. We discuss testing these hypotheses in Step 7.

STEP 5: SPECIFY RESTORATION OPPORTUNITIES AND MANAGEMENT NEEDS

Linkage managers used high-resolution aerial photos and fieldwork to identify restoration opportunities and management needs (e.g., road and aquatic barriers, land-use patterns) for each Linkage Design. The fieldwork was especially valuable. For instance, high-resolution air photos suggested that an oil refinery was blocking a potential linkage, but fieldwork showed the facility to be abandoned and posted for sale. In another case, lush riparian vegetation on the air photo proved to be thickets dominated by the invasive exotics tamarisk (*Tamarix ramosissima)* and giant reed (*Arundo donax)*. Biologists walked each aquatic linkage and photographed and measured dams, siphons, and encroachments. Highway edges were photographed, and existing crossing structures measured. Sites where improved road crossings could be constructed were identified. In rural areas, biologists noted the local styles in fencing, outdoor recreation, lighting, livestock husbandry, and pet control. Locations of important features were recorded with global positioning systems (GPS). We provided a narrative and accompanying photos to document these existing conditions.

The narrative also included recommendations regarding land use, domestic livestock, pets, off-road vehicles, artificial night lighting, and recreational activities. As appropriate, we proposed restoration of native vegetation, removal of aquatic barriers, rehabilitation of mined areas, and, most especially, improvement of permeability across major roads. High traffic volumes on Southern California freeways for the last 30–50 years have made these roads into especially formidable barriers. For example, California highways 40–60 years old markedly diminish gene flow among bobcat and coyote populations (Riley *et al.* 2006), produce genetic divergence similar to that produced by 15 km of inappropriate habitat between populations of desert bighorn sheep *Ovis canadensis nelsoni* (Epps *et al.* 2005), and are associated with genetic discontinuities similar to that produced by the rock and ice of the Sierra Crest between puma populations (Ernest *et al.* 2003).

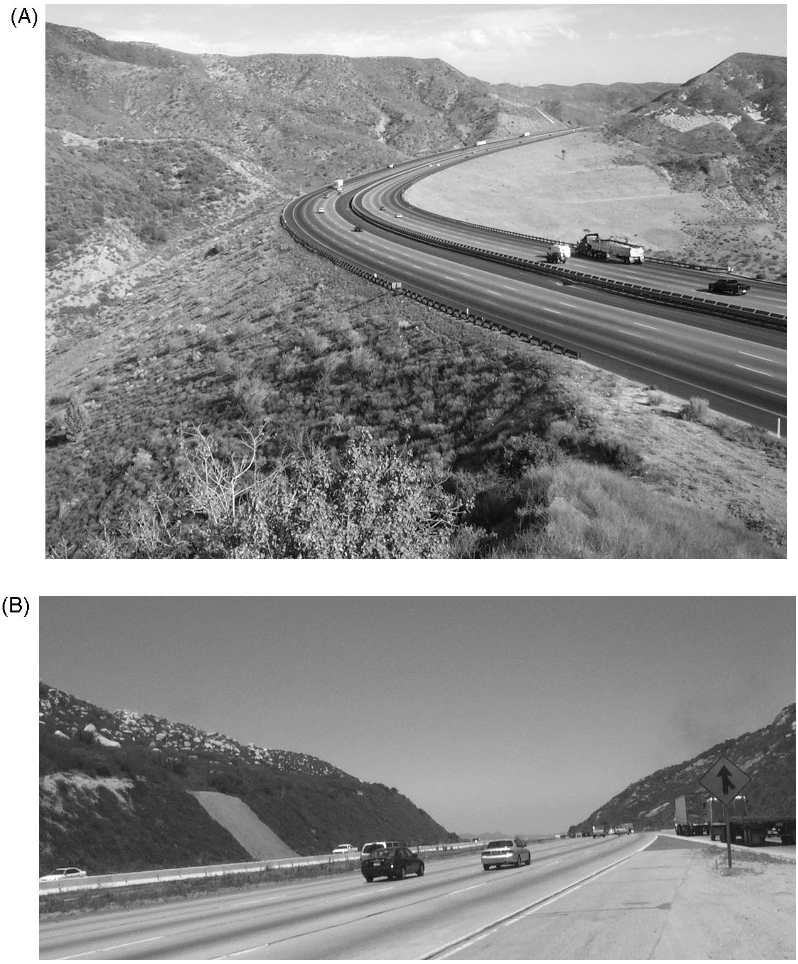

Fig. 22.3. (A) At the bottom of the fill slope, 0.6- m diameter pipes (not visible) accommodate the flow of Cherry Canyon, the largest non-urbanized drainage crossing Interstate 5 along the linkage between the eastern and western Sierra Madre. A bridge here would serve many focal species. (B) Several pumas have been killed in vehicle collisions on this portion of Interstate 15, where the freeway crosses the Santa Ana—Palomar linkage. Because the freeway is already cut into bedrock here, an underpass is not feasible, but a vegetated overpass would facilitate movement of most focal species.

Thirteen of the 15 linkages were crossed by freeways up to ten lanes wide. Only two of these 13 freeway segments had crossing structures that facilitate movement of terrestrial species. Our LCCA and habitat suitability analyses deliberately ignored the location and quality of existing freeway crossing structures, none of which had been located or built to facilitate wildlife movement. Because such structures are easier to create, relocate, and improve than native vegetation, topography, and urban areas, we viewed them as landscape elements that should respond to animal movement patterns, rather than vice versa. We caution conservationists undertaking similar efforts not to let locations of existing road-crossing structures channelize their thought processes and skew their recommendations away from biological optima.

Where more than one biological optimum was apparent, we considered existing culverts and crossing structures within the Linkage Design as places where improved structures could be constructed at lower cost (Fig. 22.3A). Anecdotal information (e.g., road-kills, game trails, animal sign) also helped suggest locations for crossing structures. In some locations, we recommended vegetated overpasses (Fig. 22.3B), or converting vehicle underpasses into wildlife underpasses (Fig. 22.4). Where a highway crosses a linkage for several kilometers, we recommended multiple crossing structures spaced as close as 2 km apart (see Clevenger and Wierzchowski (Chapter 20) for discussion of siting and monitoring crossing structures).

We made bold recommendations for maintenance, enhancement, and construction of wildlife crossing structures, but in discussions with transportation agencies, we did not ask for immediate construction of major improvements. Instead we emphasized the opportunity for the agency to implement meaningful mitigation measures when they next add lanes or otherwise upgrade these freeway segments. Although improvements may not occur for a decade or more, we hope that once connectivity is restored, genomes of all affected species will rapidly recover.

STEP 6: PARCEL-LEVEL MAPS AND IMPLEMENTATION

Throughout our reports and meetings, we have emphasized the importance of connecting two core areas for the sake of biodiversity in all its dimensions. We have to remind even our most sympathetic friends that this is not just an effort "to get the puma across the road." Although roads emerged as the most important potential barrier in every linkage, the best-designed crossing structures only make sense if they are appropriately sited, and if the wildlands between the road and each core area are conserved. Although pumas are an important focal species, whatever linkages we conserve over the next decade will provide all the connectivity any species will enjoy for the next century or more.

Fig. 22.4. An interchange on the Riverside Freeway (SR 91) being converted into a wildlife crossing in February 2003, to facilitate movement along the linkage between the Santa Ana Mountains and the Chino Hills. Although this is not one of our 15 priority linkages, this illustrates the feasibility of the enhancements that we will recommend in some linkage areas. California State Parks is investing $1.5 million to restore natural vegetation and the Coal Canyon stream channel through the underpass.

To promote this broad view, our written reports described the likely biodiversity consequences of losing the linkage and the conservation investments in the core areas that would lose or gain ecological value due to success or failure of this project. The value of state and regional parks, National Forest land, and private reserves in these areas reaches in the billions of dollars, and a relatively modest investment in connective habitats can help ensure their continued value. We also described how linkage protection would advance other conservation efforts in the area.

Although conservation decisions, such as purchases of easements or land, or changes in zoning, will be made at the parcel level, our printed reports offered no recommendations more site-specific than the Linkage Design map and descriptions of improved highway crossing structures. We made a strategic decision to exclude from our published reports any parcel maps and any data on size, value, zoning, or ownership of parcels.

We believe that publishing such data could be counter-productive because media, developers, landowners, and others are likely to focus on the parcel map. Arguments about individual parcels would distract from the scientific and conservation message embodied in the Linkage Design.

Our partners are currently in the process of translating the Linkage Design into priority parcels for conservation action. Partners select priority parcels, and discuss appropriate conservation measures at small workshops at which politically sensitive discussions can take place. For instance, partners can discuss the biological and economic trade-offs of omitting specific parcels from the conservation plan, or of allowing trophy home development on a few key parcels in the Linkage Design, or whether easements, purchase, or zoning would be the most appropriate tool for conserving the linkage value of a particular parcel. These compromises are sometimes disconcerting, but we recognize that decisions to make conservation investments lie with the investors rather than the scientists, and that conservation delivery involves an expanded set of skills compared to conservation design (see Morrison and Reynolds Chapter 21).

The role of science, and of South Coast Wildlands, will not terminate with the release of the 15 Linkage Conservation Plans for the South Coast Ecoregion. We envision a series of implementation meetings at which partners will interactively build scenarios using South Coast Wildlands' biological expertise, photodocumented descriptions of potential barriers, and GIS layers (including 1-m resolution air photos, parcels, zoning, and administrative boundaries). Immediate feedback from scientists on the likely biological consequences of various decisions will help the conservation community make scientifically sound decisions.

Ongoing conservation activities with linkage managers have provided opportunities for enhancing and supporting linkage conservation. For example, the South Coast Conservation Forum, a coalition of county, state, and federal agencies, universities, and NGOs, was recently formed to advise the Department of Defense on reducing urban encroachment and conflicts with military training maneuvers on Marine Corps Base Camp Pendleton. On the basis of information we provided, Department of Defense recognized the linkage as an important mitigator of long-term impacts to sensitive species in this planning area. This effort may effectively protect the western third of the Santa Ana—Palomar Mountains linkage, one of the 15 priority linkages. Similarly, South Coast Wildlands collaborated with other conservation groups to suggest reconfigurations of the proposed reserve system for the Western Riverside County Multiple Species Habitat Conservation Plan. That plan offered better species protection at less cost. Riverside County has incorporated some of our recommendations, which may help secure two of our linkages.

Public outreach is also an important part of implementation. Our interim products are of interest and utility not only to partners, but also to citizens, media, and conservation educators. These materials include maps of conservation designs, biological attributes, and restoration opportunities. We make these available as rapidly and as widely as possible through our website and on CD-ROM. We have also prepared two types of visual journey through each linkage: (1) a flyover animation consisting of color aerial photographs draped over a digital elevation map, and (2) an interactive US Geographical Survey 1:24 000 topographic map of the Linkage Design hyperlinked to digital photographs taken from the ground to simulate a walk through the linkage.

STEP 7: DESIGN AND IMPLEMENT A MONITORING PROGRAM

As described in Step 4, each Linkage Design map, with accompanying recommendations for management and restoration, embodies one or more testable hypotheses regarding focal species. To advance the science of linkage planning, we intend to design monitoring programs that address these hypotheses. Design of a monitoring program must address several related challenges, including formulating testable predictions, securing long-term funding, implementing improvements (e.g., a new crossing structure, restoring vegetation), and collecting data.

Deriving testable predictions from the vague hypothesis that "the Linkage Design benefits focal species" first requires selecting an appropriate dependent variable, such as numbers of linkage passages by individual animals, or demographic or genetic traits of the populations in the core areas (Beier and Loe 1992; Beier and Noss 1998). Movement studies should attempt to confirm whether movements between core areas occur often enough to influence population viability, and that in a landscape without linkages such movements would occur too rarely to benefit the population. Beier and Noss (1998) recommended a Before–After–Control–Impact–Pairs design to maximize strength of inference from these minimally replicated landscape experiments. Two types of control sites are feasible. For example if we are restoring a linkage between two core areas that are apparently isolated from each other, the control site could be either two well-connected core areas or another pair of disjunct cores for which no restoration is planned. We believe the strongest inferences would flow from having both types of controls, but finding suitably matched sites in this rapidly changing landscape will not be easy.

Peculiar funding issues arise because pre- and post-treatment data may need to be collected over the course of many years. Any ecologist who has undertaken studies on vertebrate response to forest treatments can attest to the agony of collecting pre-treatment data and waiting years for well-intentioned management agencies to start and complete treatments. Research on linkage function will be a similar waiting game. Recruiting researchers to conduct independent research on plant and animal populations in linkages with an eye for repeating these studies in 10 to 20 years may be one solution. Finally, interpreting the results of a monitoring program will be complicated by inevitable differences (due to compromise and errors) between planned treatments and treatments as implemented. We do not view any of these problems as insurmountable, and we hope to design a monitoring framework that is rigorous, robust to these difficulties, and relevant to implementing biotic linkages in a real landscape.

Although the long-term (decades to centuries) effectiveness of each linkage is the most important response variable for adaptive management, we also recommend research to document indicators of short-term (months to years) success of each linkage. In most cases, this will involve documenting animal use via camera traps, tracks, scats, trapping, or other surveys. For instance, if adjacent habitat is suitable, a new highway-crossing structure should start to be used by focal species within 1–3 years after construction (N. Dodd, Arizona Game and Fish Department, unpublished data from SR-260 study). Failure to observe such use would indicate that either the design of the structure, or that some other element in the linkage, is defective. Such information should promptly inform improvements in other linkages.

CONCLUSIONS

The remaining large wildlands of the South Coast Ecoregion form an archipelago of natural open space within one of the world's largest metropolitan areas. Until the recent dramatic surge in human domination of this landscape, these wild areas formed one ecological system. We envision a future interconnected system of natural space, and we offer our approach as a biologically defensible and repeatable procedure to design conservation linkages.

Hallmarks of the South Coast Missing Linkages project have been the development of rigorous quantitative methods to prescribe linkage conservation needs and the highly collaborative nature of the planning effort. This approach (1) spans jurisdictional boundaries and promotes the partnerships needed to implement landscape connectivity at this scale, (2) garners greater visibility from agencies and focuses disparate conservation efforts on a coordinated regional plan that appeals to the public and to the agencies, (3) increases the effectiveness of partners working at local scales, (4) increases rigor and objectivity and provides products that are defensible in touchy political and social arenas, and (5) enhances communication by providing beautiful and easily comprehensible graphic outputs for agencies and the public.

We trust that our approach will be copied, tweaked, and improved by others. Arizona has initiated a similar effort with two promising innovations. First, the Federal Highway Administration and Arizona Department of Transportation were involved as lead agencies from the start. Because these agencies are such a critical part of implementing any solution, having them involved in a meaningful way (developing the agenda and providing web-hosting and GIS support for the initial workshop) augurs well for the Arizona effort. Second, at Arizona's initial state-wide workshop, participants were asked to provide the data needed for prioritization, as well as list focal species for each linkage. Obtaining data on biological importance has enabled Arizona to prioritize linkages more rapidly. Although the lists of focal species obtained at the initial workshop are less comprehensive than those developed in California, Arizona may be able to select additional focal species for the priority linkages more quickly, perhaps by an e-mail appeal to knowledgeable persons, followed by dialogs between experts (either one at a time or via conference call) and a highly skilled staff person. Thus Arizona consolidated Steps 2 and 3, and jump-started Step 4.

Arizona's effort is led by a coalition of agencies (chiefly Arizona Game and Fish Department, The Arizona Department Of Transportation, the Federal Highway Administration, and US Forest Service) rather than an NGO. This has advantages (prominent roles for and buy-in from the transportation agencies, more financial stability than a tiny NGO), but we do see a risk in having no analog to South Coast Wildlands. Not one person in Arizona goes to work each day with the sole goal of advancing connectivity in the state. Although the commitment of each transportation agency has been genuine and impressive, will it be sustained as political administrations change, or when key players must pay attention to other priorities? An excellent step toward minimizing this risk was taken in the 2005 reauthorization of the US Transportation Efficiency Act. The law requires the Federal Highway administration and state transportation agencies using federal dollars to consult with state wildlife agencies at the initial stages of project planning. It also permits use of federal dollars to pay the salary of a state liaison. This could ensure that each state would have a staff person in their conservation agency whose primary job is to be engaged in consulting with transportation agencies.

We cannot overemphasize the importance of investing in building and maintaining relationships. Development of technical plans to overcome barriers to animal movement must be matched by efforts to build and maintain linkages among all the players. We advise similar efforts to budget ample time to engage partners, especially including extra time and effort for relationships that span sovereign boundaries. It is not sufficient to e-mail invitations to Mexican and Native American tribal agencies. International travel can be difficult and relatively expensive. Tribal sovereignty and ways of doing business must be respected.

Our effort has received considerable publicity, virtually all of it positive. We believe media exposure has been helpful and urge other efforts to use public-relation specialists in partner agencies to generate and sustain positive publicity. Participants in a workshop get positive reinforcement when they see a news story on the event or on the release of the workshop report several months later. Agencies (such as a transportation agency) gain confidence about moving in a new, "greener" direction when they are publicly praised for their action; it is especially useful if high-ranking officials are featured in press releases. Reporters tend to be sympathetic filters, especially in the early stage of identifying pairs of core areas in need of connectivity (with connective areas only vaguely defined). Developing rapport with reporters, partners, and the public at this time can help set a positive tone for later stories about specific implementation measures.

Although insects, plants, and birds need connectivity, the large four-legged furred creatures will probably be the first to suffer when connectivity is lost, and they are often the best flagships to "sell" a linkage design. We urge practitioners to emphasize the needs of flagships (including reptiles and other non-mammals) to garner public support.

Large mammals also tend to lend themselves to least-cost corridor analysis (LCCA). Because LCCA produces crisp and persuasive GIS outputs, it is tempting to use LCCA for all focal species. However, we advise careful matching of analytical tools to the species' natural history and the data available for each species. For example, although LCCA is appropriate for some highly sedentary birds analyzed on a coarse landscape, for most birds a pixel-to-pixel permeability analysis would not pass the "laugh test" for either scientific or lay audiences, both of which know that most birds can fly over dozens of pixels of inappropriate habitat. We offer patch size and configuration analysis (Step 4C) as a way to meaningfully consider the needs of diverse species, including those for which LCCA is not appropriate.

Finally, in an ecoregion less urbanized than the South Coast of California, we advise that the Linkage Design (Step 4) should rarely be a narrow hard-line corridor. Simberloff *et al.* (1992) suggested that connectivity could best be obtained by managing "the entire landscape . . . as a matrix supporting the entire biotic community." Although massive urbanization in our landscape precluded this option in many of our linkages, we did pursue this option in those portions of those linkages

Fig. 22.5. The confluence of four highways, a railroad line, high-voltage power lines, and microwave communication towers, as seen from the edge of the California Aqueduct, which moves water 440 km from the Sacramento River delta into the Los Angeles Basin. Our project intends to add one more layer of infrastructure to this scene by protecting and restoring the ridge in the background, which provides the only wildland link between the Santa Susana Mountains (off left edge of the photo) and the San Gabriel Mountains (off right edge of photo).

where it was feasible. We envy those who have the luxury of managing broad swaths for permeability throughout their ecoregion.

The USA's largest metropolitan area has a human infrastructure without equal on the planet. People, water, information, electric power, gas, automobiles, and trains move across this landscape with remarkable efficiency (Fig. 22.5). Our goal is to create a "green infrastructure" that is commensurate with these other types of infrastructure. We pray that the quality of our effort befits this global hotspot of biodiversity.

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Data sheets used in workshops and spreadsheets used in prioritizing linkages in California and Arizona are available from the authors on request.

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