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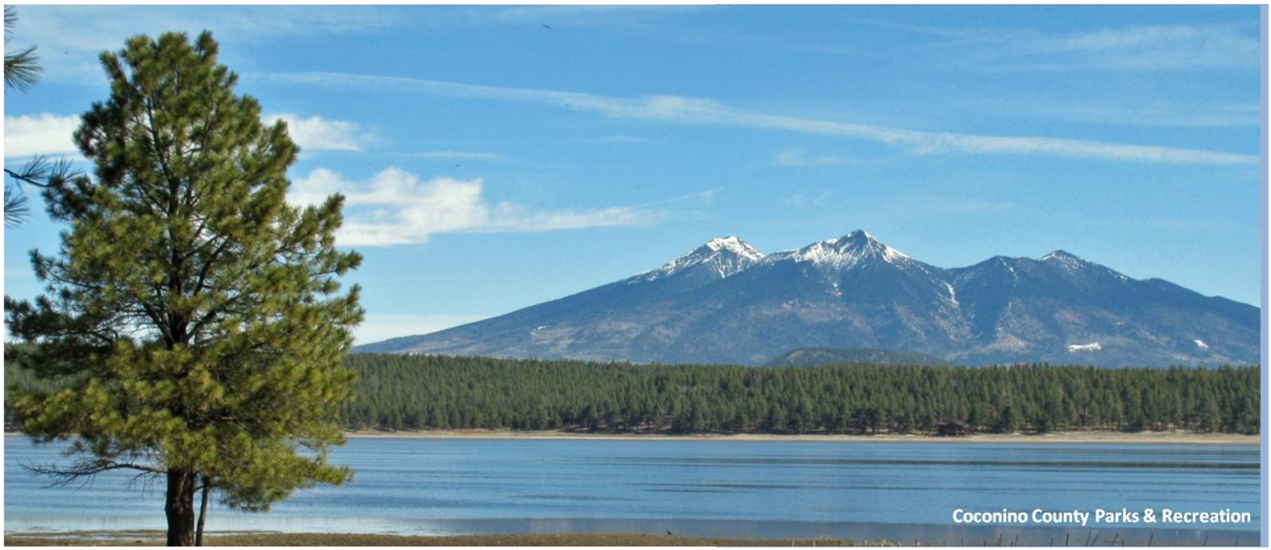
Coconino County Wildlife Connectivity Assessment: Detailed Linkages

San Francisco Peaks to Mogollon Rim Linkage Design

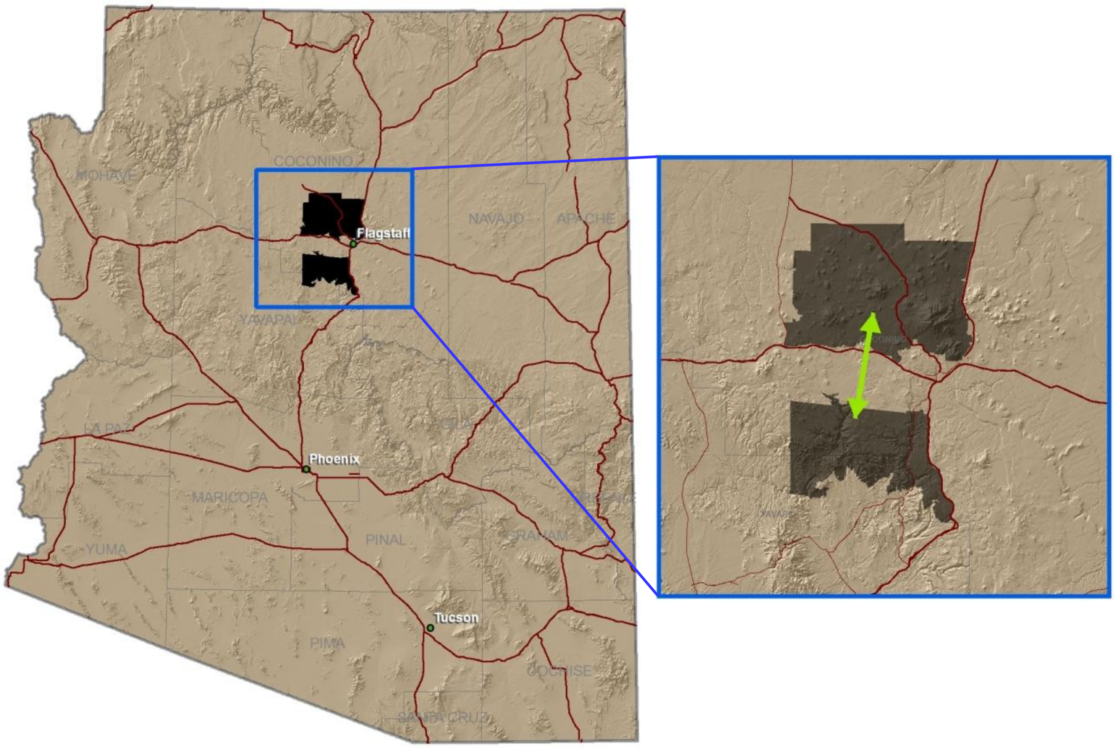


Arizona Game and Fish Department

Coconino County

SAN FRANCISCO PEAKS – MOGOLLON RIM LINKAGE DESIGN

Prepared by
Jessica Gist and Mark Ogonowski
22 August 2013



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RECOMMENDED CITATION

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GIS DATA

Accompanying GIS data for this linkage design are available from the Arizona Game and Fish Department's Habitat Branch by request.

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TERMINOLOGY

Biologically Best Corridor: Continuous swath of land expected to be the best route by which a focal species can travel from a potential population core in one wildland block to a potential population core in the other wildland block, and which may consist of 1 or more strands.

Focal Species: Species chosen to represent the needs of all wildlife in the linkage planning area including a) species dependent on a single habitat type, b) area-sensitive species, and c) species most sensitive to barriers. Focal species include "passage species" able to travel between wildland blocks in days or weeks and "corridor dwellers" requiring multiple generations to move between blocks. For some species GIS analysis may not produce a corridor model.

Habitat Connectivity: Extent to which an area of landscape facilitates ecological processes such as wildlife movement, seed dispersal, and gene flow. Reduced by habitat fragmentation.

Habitat Fragmentation: Process through which previously intact areas of wildlife habitat are divided into smaller disconnected areas by roads, urbanization, or other barriers.

Linkage Design: Land that if conserved will maintain or restore the ability of wildlife to move between wildland blocks. A linkage design is produced by joining biologically best corridors for focal species then modifying this area to delete redundant strands, avoid urban areas, include parcels of conservation interest, and minimize edges.

Linkage Planning Area: The wildland blocks plus Potential Linkage Area. Implementing this linkage design will enhance the biological diversity of the entire Linkage Planning Area.

Permeability: Opposite of travel cost; a perfectly permeable landscape would have a travel cost of zero. Permeability refers to the degree to which landscapes are conducive to wildlife movement and can sustain ecological processes.

Pixel: Smallest unit of area in a GIS map (30 meters by 30 meters in our analyses). Each pixel is associated with a vegetation class, topographic position, elevation, and distance from paved road.

Potential Linkage Area: Land between wildland blocks where urbanization, roads, and other activities threaten to prevent wildlife movement. Linkage designs conserve a portion of this area.

Travel Cost: Effect of habitat on a species' ability to move through an area, reflecting quality of food resources, suitable cover, and other resources. Our model assumes that habitat suitability is the best indicator of the cost of movement through the pixel.

Wildland Blocks: Areas the linkage design connects. Wildland blocks can include varied land ownership, but must be biologically important to focal species and likely to remain in relatively natural condition for at least 50 years. Blocks may contain non-natural elements but have a long-term prospect of serving as wildlife habitat, and their value is eroded if habitat connectivity between them is lost. Tribal sovereignty includes the right to develop tribal lands within blocks.

EXECUTIVE SUMMARY

As western communities expand to accommodate growing populations, roads, urban and rural developments, railways, energy facilities, and utility corridors create physical barriers that can fragment habitat, isolate wildlife populations, and disrupt critical ecological processes. Habitat fragmentation can be mitigated by conserving networks of large wildland blocks connected by habitat corridors or linkages that promote the safe movement of wildlife while maintaining gene flow, seed dispersal, and other processes. Such connected landscapes may also prove crucial in helping wildlife populations adapt to shifts in vegetation and environmental conditions associated with climate change. GIS-based linkage models provide a powerful tool for identifying wildlife linkages, and can guide the siting of crossing structures and other actions.

In an effort to maintain habitat connectivity in northern Arizona the Arizona Game and Fish Department collaborated with Coconino County to develop this GIS-based linkage design for an area of conservation priority. At workshops held in 2009 and 2010 we convened stakeholders with expertise in planning, wildlife conservation, land management, transportation, and other areas to identify and map important wildlife movement areas across Coconino County. Attendees identified the San Francisco Peaks to Mogollon Rim movement area as a priority, a selection supported by County planners with knowledge of future growth patterns and potential conservation opportunities.

We used least-cost corridor modeling (www.corridordesign.org) to identify lands to maintain wildlife movement between two large areas of USFS-administered lands near the cities of Flagstaff and Williams, Arizona. These “wildland blocks” encompass significant portions of the Coconino and Kaibab National Forests, four federal wilderness areas, span a broad elevational range, and provide habitat for diverse wildlife. Running east-west through the landscape between the blocks are Interstate Route 40, the Burlington Northern Santa Fe railroad, and areas of urban and rural development presenting obstacles to animal movement. Our linkage design identifies areas which if conserved and enhanced will maintain animal movement patterns and the overall biological integrity of this important area.

The linkage design is based on a focal species approach. We selected 11 species known to inhabit both wildland blocks based on recommendations of workshop participants and other agency and academic scientists including 9 mammals, 1 reptile, and 1 amphibian. The species are sensitive to habitat loss and fragmentation and represent the range of habitat and movement requirements of the region’s wildlife. Species such as pronghorn and mule deer are averse to crossing roads, while black bear requires large areas to ensure population viability and successful dispersal. Others such as Gunnison’s prairie dog and northern leopard frog require specialized habitats and are threatened or rare. Thus the species used to create this linkage design should provide for the connectivity needs of many others not modeled.

For each focal species we created habitat suitability models in ArcGIS using www.corridordesign.org tools based upon habitat use information provided by species experts. We selected patches of suitable habitat large enough to support breeding populations of each species in the wildland blocks and used least-cost corridor techniques to model biologically-optimal corridors between the blocks. We refined individual species’ corridor models with empirical data as available then combined these models to produce the multi-species linkage design. For species requiring multiple generations to move between blocks ("corridor dwellers") we did not model corridors, but examined the distribution of suitable habitat to ensure they were also accommodated by the linkage design.

Our linkage design includes three strands linking core habitats in the San Francisco Peaks and Mogollon Rim wildland blocks. The strands encompass lands under diverse ownership including public lands administered by the U.S. Forest Service and other agencies. Comparison of our modeled focal species corridors with available location datasets provided a high degree of validation for our design. Through field investigation and collaboration with the Arizona Game and Fish Department Contracts Branch we also identified potential locations for mitigation measures such as highway crossing structures at critical points in the modeled linkage.

We believe that integrating empirical data with GIS-based linkage designs provides a powerful way to mutually validate each approach, and can extend connectivity planning beyond those species for which field data are available. We recommend this synergistic approach to conserving connectivity for wildlife for other important wildlife movement areas in which the Arizona Game and Fish Department and partners are working in other areas of the state.

This linkage design identifies areas that will maintain animal movements and ecological processes if conserved and enhanced via land acquisition, conservation easements, zoning, habitat restoration, fence removal and improvement, roadway crossing structures, and other tools. We hope this report and GIS dataset will help guide regional landscape-scale planning efforts and be integrated with future linkage designs to promote large-scale habitat connectivity. Successful implementation will require the support of many partners. Fortunately, diverse organizations and agencies including the Arizona Department of Transportation, Arizona Game and Fish Department, Arizona State Land Department, Camp Navajo, City of Flagstaff, Coconino County, Northern Arizona University Centennial Forest, U.S. Department of Defense, U.S. Forest Service, U.S. Naval Observatory, U.S. Fish and Wildlife Service and others are engaged in a range of conservation partnerships in the linkage planning on which to build.

INTRODUCTION

Habitat connectivity matters

All animals move across the landscape in order to acquire the resources necessary for survival such as food, water, protective cover, and mates, and the distance and timing of animal movements can vary considerably. Species such as mountain lion, black bear and mule deer roam over vast expanses that can encompass thousands of acres, while smaller animals such as Abert's squirrel and northern leopard frog engage in essential movements on a much smaller scale. Some animal movements occur on a daily basis, seasonal migrations occur annually, while the dispersal of young from their natal sites to new breeding territories happens once in an individual's lifetime. These diverse movement patterns ensure individual survival, help protect local populations from extinction (Laurance 1991, Beier and Loe 1992), enable gene flow and reduce the risk of inbreeding (Beier and Loe 1992, Bennett 1999), and facilitate critical ecological processes such as pollination and seed dispersal.

Roads, urban development, agriculture, energy production, and other land uses present barriers to animal movement that can threaten the long-term persistence of wildlife populations and the long-term stability of ecosystems (Noss 1983, Wilcox and Murphy 1985, Noss 1987, Bennett 1999, Henle et al. 2004, Noss and Daly 2006). The process through which previously intact areas of habitat are divided into smaller disconnected areas by human activities is known as habitat fragmentation. Habitat fragmentation can cause problems ranging from roadway mortality to genetic isolation, and negatively impact human welfare by increasing the risk of wildlife-vehicle collisions and the frequency of unwanted "close encounters" with wildlife.

The negative effects of habitat fragmentation can be mitigated by identifying and protecting areas that wildlife use for movement, known as wildlife linkages or corridors (Beier and Noss 1998, Haddad et al. 2003, Eggers et al. 2009, Gilbert-Norton et al. 2010). Ridgelines, canyons, riparian areas, cliffs, intact swaths of forest or grassland, and other features may function as linkages and some species may spend their entire life cycle within a linkage rather than moving through it (Perault and Lomolino 2000, Beier et al. 2007b). Wildlife linkages are most effective when they connect relatively large and unfragmented areas of habitat known as wildland blocks. Wildland blocks are areas large enough to sustain healthy wildlife populations and essential ecological processes for the foreseeable future (Noss 1983, Noss and Harris 1986, Noss 1987, Noss et al. 1996) and for which a relatively high measure of natural resource protection exists.

Conserving wildlife linkages and the habitat blocks they connect may also help wildlife adapt to climate change, by allowing populations to shift their range with latitude or elevation as the distribution of vegetation communities and suitable environmental conditions changes (Hannah et al. 2002, TWS 2004, Glick et al. 2009, Wildlands Network 2009). Climatologists agree that global average temperatures will rise significantly over pre-industrial levels in coming decades with attendant changes in regional climate (Millennium Ecosystem Assessment 2005, IPCC 2007, USGCRP 2009). Most climate models predict a hotter and drier Southwest (Seager et al. 2007, Mearns 2010, Overpeck and Udall 2010) and a likely increase in the frequency and severity of wildland fires (Westerling et al. 2006, Marlon et al. 2012, Moritz et al. 2012). Despite uncertainty about the direction and magnitude of local climatic changes, there can be no doubt that the regional distribution of vegetation types will be significantly different in coming decades. The ponderosa pine forest which covers much of the linkage planning area addressed in this report may be particularly vulnerable: some studies suggest these forests may be threatened by climate change independent of increases in fire, insect outbreaks, and other disturbances (Allen et al. 2010, Ironside et al. 2010). Including a diversity of aspects, slopes, and elevation in a linkage design provides a better chance that the linkage will have most vegetation types well-distributed along its length during coming decades of climate change. The diversity of focal species we used ensures that our linkage design includes considerable topographic and elevational diversity and thus should be resilient to future changes in vegetation communities.

Maintaining wildlife linkages also benefits human communities, perhaps most obviously by improving public safety. One study estimated that over 200 motorists are killed and approximately 29,000 injured annually in the United States as a result of deer-vehicle collisions alone (Conover 1995). Wildlife collisions are a significant problem in the area addressed by this linkage design: from 2007 to 2009 over 190 wildlife-vehicle collisions occurred on Interstate Highway 40 between Williams and Twin Arrows, the majority involving elk (Arizona Game and Fish Department 2011a). Identifying wildlife movement areas that intersect transportation corridors permits informed siting of wildlife over- and underpasses that can greatly reduce the likelihood of collisions (Clevenger et al. 2001, Forman et al. 2003). This approach has proven successful in Arizona along State Route 260 where a combination of underpasses and ungulate-proof fencing reduced elk-vehicle collisions by 97% (Gagnon et al. 2010).

Identifying and conserving wildlife linkages can provide a number of other societal benefits to Arizonans. These include helping municipal and county governments prioritize lands for acquisition as open space and avoid land use decisions which could lead to conflicts with wildlife. By helping to maintain healthy wildlife populations, linkage conservation provides economic benefits given the significant contribution of wildlife-based recreation to the economies of Coconino County and the state of Arizona (Southwick Associates 2003, American Sportfishing Association 2007). In 2001 alone non-consumptive wildlife recreation such as wildlife viewing generated an estimated $87 million in Coconino County (Southwick Associates 2003) while fishing and hunting generated over $124 million, supported 1,860 jobs, provided residents with $22 million in salary and wages, and generated $6 million in state tax revenue (Silberman 2003).

A statewide-to-local approach for conserving habitat connectivity in Arizona

Habitat connectivity can be represented at various spatial scales. In Arizona, we have found it valuable to identify habitat blocks and wildlife linkages at state, county, and local scales to serve different conservation and planning objectives. The linkage planning tools created at each scale have led to a progressive refinement of our knowledge of wildlife movement areas and threats to habitat connectivity across the state, and the fine-scale linkage design presented in this report owes much to the broader-scale efforts that preceded it.

Arizona’s wildlife linkage planning efforts began in 2004 when federal, state, municipal, academic, and non-governmental biologists and land managers participated in a workshop to map important habitat blocks, linkages, and potential threats to connectivity across the state.

The Arizona Wildlife Linkages Workgroup represented a collaboration of the Arizona Game and Fish Department, Arizona Department of Transportation, Federal Highways Administration, Northern Arizona University, Sky Islands Alliance, US Bureau of Land Management, US Fish and Wildlife Service, US Forest Service, and the Wildlands Network and resulted in *Arizona's Wildlife Linkages Assessment* (*AWLA;* Arizona Wildlife Linkages Workgroup, 2006). The AWLA provides a vision for maintaining habitat connectivity in a rapidly growing state and has served as the foundation for subsequent regional and local efforts, including the creation of fine-scale GIS linkage designs by scientists at Northern Arizona University (available at www.corridordesign.org) that provided the template for this report.

The statewide assessment was followed in 2008 by an effort to map wildlife linkages and potential barriers within individual Arizona counties. The Arizona Game and Fish Department partnered with counties to organize stakeholder workshops to create county-wide maps of wildlife linkages (Arizona Game & Fish Department 2011b) and a list of priority linkages for future fine-scale GIS modeling[1]. In Coconino County stakeholders highlighted the San Francisco Peaks to Mogollon Rim linkage area as a high priority, a selection supported by County planners with knowledge of future growth patterns and conservation opportunities. This linkage design is the result.

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[1] A report describing the Coconino County workshops and resulting linkage data is available online at http://www.azgfd.gov/w_c/conn_Coconino.shtml. This report, *The Coconino County Wildlife Connectivity Assessment*, has informed local and regional planning efforts & led to creation of this linkage design.

STUDY AREA AND METHODS

Study area

The linkage planning area spans three ecoregions of central Arizona: Arizona-New Mexico Mountains, Apache Highlands North, and Colorado Plateau (descriptions taken from Arizona Game and Fish Department 2006a). The majority of the planning area lies within the Arizona-New Mexico Mountains Ecoregion which overall covers over 6 million acres in Arizona and ranges from approximately 1,220 to over 3,700 meters (4,000 to 12,000 feet) in elevation. This ecoregion includes extensive ponderosa pine forest, pinyon-juniper woodland and high elevation grassland and features some of the most dramatic landforms in the state including the Mogollon Rim at its southern boundary and the volcanic San Francisco Peaks, the highest point in Arizona. The northwest and southwest corners of the linkage planning area transition into the Apache Highlands North Ecoregion, spanning 9.4 million acres in Arizona ranging from approximately 640 to 2,700 meters (2,100 to 8,800 feet). Landforms vary from rolling hills, flat valleys, and broad plateaus to steep mountains and the rugged canyons of the Mogollon Rim. The northeastern corner of the linkage planning area overlaps a small portion of the Colorado Plateau Ecoregion, an area of extensive plains interspersed with canyons and buttes. The latter two ecoregions span grassland, chaparral, pinyon-juniper, desertscrub and small areas of ponderosa pine, mixed conifer, and oak woodlands.

The linkage planning area provides habitat for diverse wildlife including the federally-protected Mexican spotted owl, roundtail chub, bald eagle, and San Francisco Peaks groundsel (USFWS 2013), and supports important game species and state species of concern. Our linkage design does not directly address connectivity for native riparian species but perennial portions of the Sycamore and Oak Creek drainages in the Mogollon Rim block support speckled dace, desert sucker, Sonora sucker, narrow-headed garter snake, and lowland leopard frog.

Existing and potential barriers to wildlife movement in the potential linkage area include Interstate Highway 40, the Burlington Northern Santa Fe Railroad, urban and rural development around Flagstaff (U.S. Census Bureau 2011) and along the I-40 and I-17 corridors, expanded military activities and infrastructure on Camp Navajo, fencing, OHV recreation, grassland shrub encroachment, wildland fire, invasive species, and drought. The linkage planning area is less-densely populated than Maricopa County to the south but is affected by Maricopa’s recent explosive growth through purchases of first and second homes, greater highway traffic, increased year-round recreation on national forest lands and wilderness areas, and other impacts.

Delineation of wildland blocks

We defined two wildland blocks we named the San Francisco Peaks and Mogollon Rim blocks after prominent landscape features (Figure 1). Each is primarily administered by the US Forest Service—Kaibab National Forest to the west and Coconino National Forest to the east[2]. The blocks do not have a formal designation but encompass lands providing habitat for diverse wildlife expected to remain in good ecological condition into the future and are contiguous with hundreds of thousands of additional acres of National Forest. We used major highways and

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[2] A very small part of the southwest corner of the Mogollon Rim block is administered by Prescott National Forest.

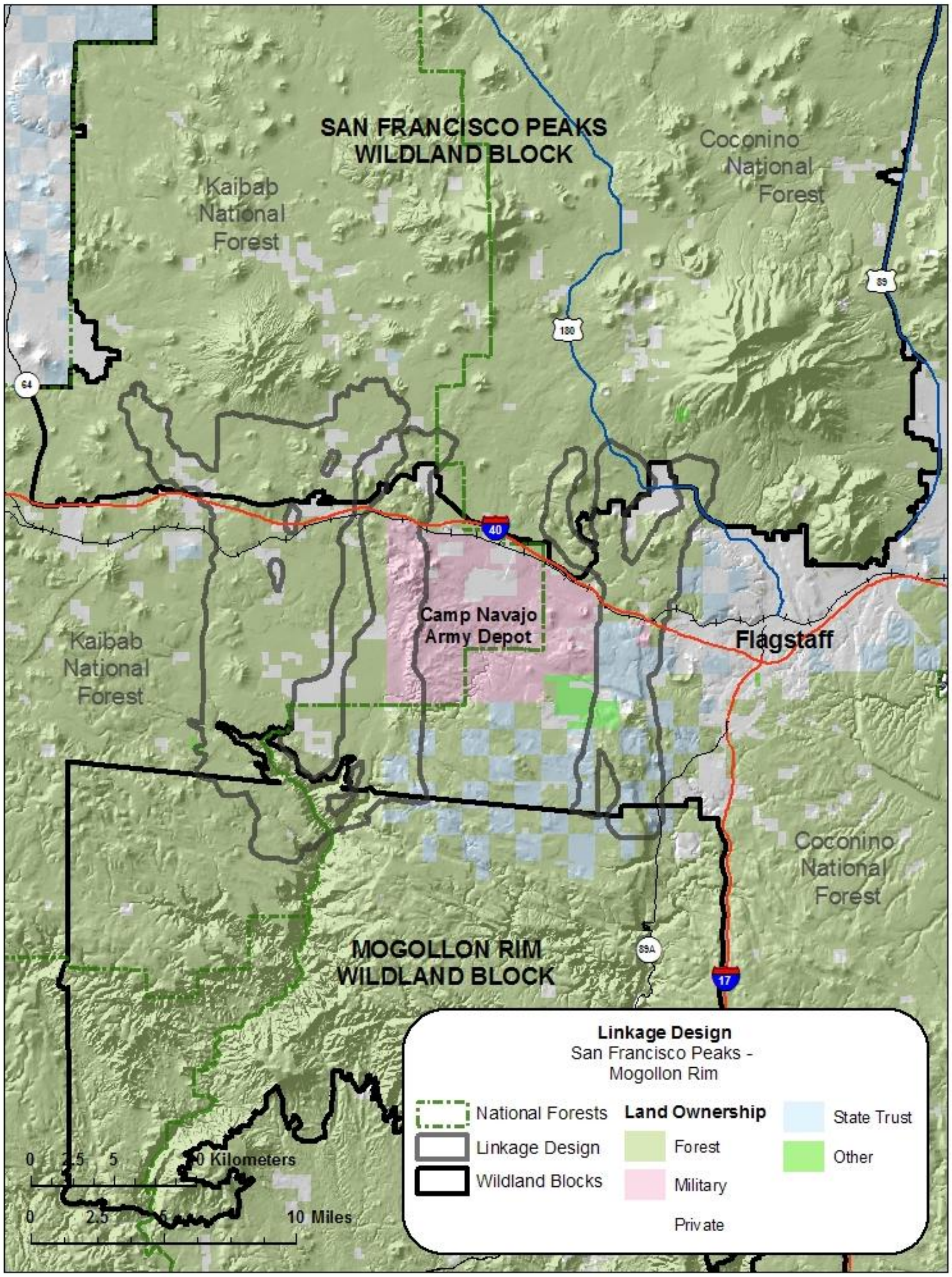

Figure 1: Land ownership within the linkage planning area

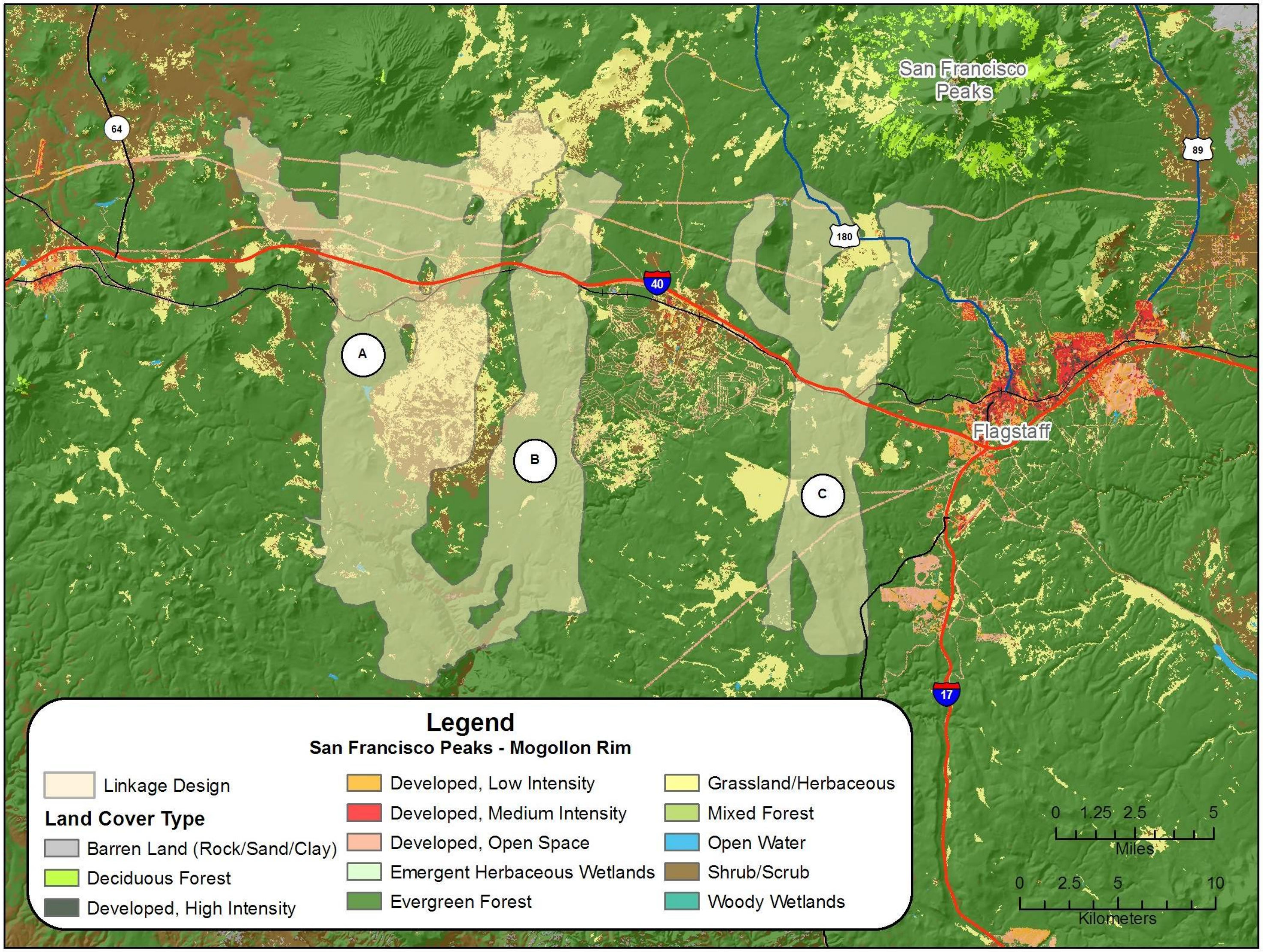

Figure 2: Land cover within the linkage planning area

National Forest and Wilderness boundaries to delimit the blocks, and retained private inholdings where development is low-density and valuable wildlife habitat remains. We included state-owned parcels managed by Northern Arizona University's Centennial Forest in the Mogollon Rim block. The blocks are separated by Interstate Highway 40, the Burlington Northern Santa Fe railroad, and private, state, and federal lands developed to varying degrees.

The San Francisco Peaks wildland block encompasses 430,500 acres and includes prominent volcanic mountains such as the San Francisco Peaks and Kendrick Peak. Elevation ranges from approximately 1,750 to 3,850 meters (5,760 to over 12,630 feet) supporting high-elevation grassland, pinyon-juniper woodland, ponderosa pine, aspen, mixed conifer, and alpine tundra vegetation (Figure 2). This block includes the U.S. Forest Service-administered Kachina Peaks (18,616 acres) and Kendrick Mountain (6,510 acres) Wilderness Areas. The Mogollon Rim wildland block encompasses 241,200 acres and includes a significant portion of the Mogollon Rim, a 320-kilometer long escarpment defining the southern edge of the Colorado Plateau. Several major drainages including Sycamore Creek and Oak Creek leave the Mogollon Rim via deep canyons in this block. Elevation ranges from 1,090 to 2,325 meters (3,575 to 7,630 feet) supporting chaparral, grassland, pinyon-juniper woodland and ponderosa pine, and riparian communities at lower elevations. This block includes the Sycamore Canyon (55,937 acres) and Red Rock-Secret Mountain (47,194 acres) Wilderness Areas and is adjacent to the Munds Mountain Wilderness Area (24,411 acres), all administered by the U.S. Forest Service.

The linkage planning area also includes several smaller conservation investments. The Centennial Forest encompasses 22,269 acres of "checkerboard" State Trust and Forest Service lands jointly administered by the Arizona State Land Department and Northern Arizona University School of Forestry to serve research and teaching goals. The Coconino County Parks and Recreation Department's Pumphouse (128 acres) and Rogers Lake (2,490 acres) County Natural Areas are managed for natural resource values including wildlife habitat. The Camp Navajo Army National Guard training facility (28,255 acres) includes intact forest and grasslands actively managed for wildlife.

Focal species selection

We selected 11 focal species known to inhabit both wildland blocks based on recommendations of workshop participants and agency and academic scientists, including 9 mammals, 1 reptile, and 1 amphibian (Table 1). Species selected are sensitive to habitat loss and fragmentation and represent the range of habitat and movement needs of wildlife in the region. For example, pronghorn and mule deer are averse to crossing roads, while black bear requires large areas to ensure population viability and successful dispersal. Others such as Gunnison's prairie dog and northern leopard frog require specialized habitats and are threatened or rare. We included four species (marked in Table 1 by a "*") that we classified as "corridor dwellers" requiring multiple generations to move between blocks. Other species were considered but not included due to a lack of understanding of their habitat use, unavailability of GIS data to quantify habitat use, or because they can likely travel (e.g. fly) across unsuitable habitat. Together the focal species provide for the connectivity needs of many others not modeled but found locally.

Table 1: Focal species selected for San Francisco Peaks – Mogollon Rim linkage design

Mammals		Amphibians & Reptiles
Abert's squirrel*	Gunnison's prairie dog*	Arizona black rattlesnake*
badger	mule deer	northern leopard frog*
black bear	porcupine	
bobcat	pronghorn	
elk		

*Species modeled as "corridor dwellers" requiring multiple generations to move between wildland blocks. For these we modeled habitat suitability (not corridors) and verified that the linkage design included high quality habitat and patches of adequate size.

Modeling methods and field investigations

For each focal species we created a habitat suitability model based on expert rankings of habitat use of classes within up to 5 factors: land cover, elevation, topography, distance to roads, and perennial water. Habitat suitability was modeled in ArcGIS using www.corridordesign.org tools to create a weighted overlay of data layers corresponding to each factor, resulting in an overall suitability score for each pixel in the analysis extent. We selected patches of suitable habitat large enough to support breeding populations of each species in the wildland blocks. We then used least-cost corridor modeling techniques to identify biologically-optimal corridors linking breeding patches in the two blocks based on the modeled suitability scores. We only created corridor models for species capable of moving between wildland blocks in a single generation. We refined individual species' corridor models with empirical data when available, then combined all the species-specific corridors to produce the linkage design. For "corridor dwellers" requiring multiple generations to traverse wildland blocks we did not model corridors. Instead we examined the distribution of suitable habitat to verify that the linkage design included high quality habitat and patches of adequate size for these species. (See Appendix A for full details of our modeling methodology).

Through a combination of field investigations and recommendations provided by Arizona Game and Fish Department colleagues (Gagnon et al. 2012), we also identified potential locations for highway crossing structures and other mitigation at critical points in the final linkage design which we detail below.

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RESULTS: LINKAGE DESIGN AND MODEL VALIDATION

Linkage design

Our final linkage design (Figure 3) is composed of three strands linking core habitats for focal species in the San Francisco Peaks and Mogollon Rim blocks across the Interstate 40 corridor. The strands encompass 9,530 acres of ponderosa pine forest, mixed conifer forest, pinyon-juniper woodland, grassland, canyon, and wetland habitats ranging in elevation from 1,570 to 2,590 meters (5,148 to 8,497 feet). We label these strands A, B, and C from west to east and describe them in that order; strands A and B overlap at their southern end near the point where each enters the Mogollon Rim block.

Strand A ("Garland Prairie Strand") includes ponderosa pine forest, pinyon-juniper woodland, high-elevation grassland, and ephemeral wetland and provides live-in and pass-through habitat for species utilizing these habitat types. It is approximately 30 km long at its greatest extent and is largely protected within the Kaibab National Forest. This strand is composed of biologically-best corridors for badger, black bear, bobcat, elk, mule deer, porcupine, and pronghorn, and provides breeding and dispersal habitat for corridor dwellers including Abert's squirrel, Arizona black rattlesnake, and Gunnison's prairie dog and potential habitat for northern leopard frog. Strand A includes relatively flat meadows including Government and Garland Prairies, gentle forested slopes in its western half, and it overlaps the Sycamore Canyon Wilderness at its southern terminus.

LINKAGE DESIGN GOALS

- Provide move-through habitat for diverse species
- Provide live-in habitat for species with dispersal distances too short to traverse linkage in one lifetime
- Provide adequate area for a metapopulation of corridor-dwelling species to move through the landscape over multiple generations
- Buffer against edge effects such as pets, lighting, noise, nest predation & parasitism, and invasive species
- Allow animals and plants to move in response to climate change

Strand B ("Volunteer Mountain Strand") follows the wooded highlands on the western edge of the U.S. Army's Camp Navajo installation and is dominated by ponderosa pine forest, with small areas of pinyon-juniper and grassland at its southern and western edges, respectively. It is approximately 23 km long and much of it is protected by the Kaibab and Coconino National Forests and NAU Centennial Forest, and includes undeveloped portions of Camp Navajo not generally utilized for military operations. Strand B includes biologically best corridors for black bear, bobcat, and mule deer and provides breeding and dispersal habitat for corridor dwellers including Abert's squirrel and Arizona black rattlesnake and potential habitat for northern leopard frog. Strand B includes considerable areas of steep slopes on its eastern flank including Volunteer Mountain and gentler terrain along its western portion at Garland Prairie. This strand includes more rugged terrain at its southern terminus, including the head of the Sycamore Canyon Wilderness and the portion of Volunteer Canyon where this joins Sycamore Canyon.

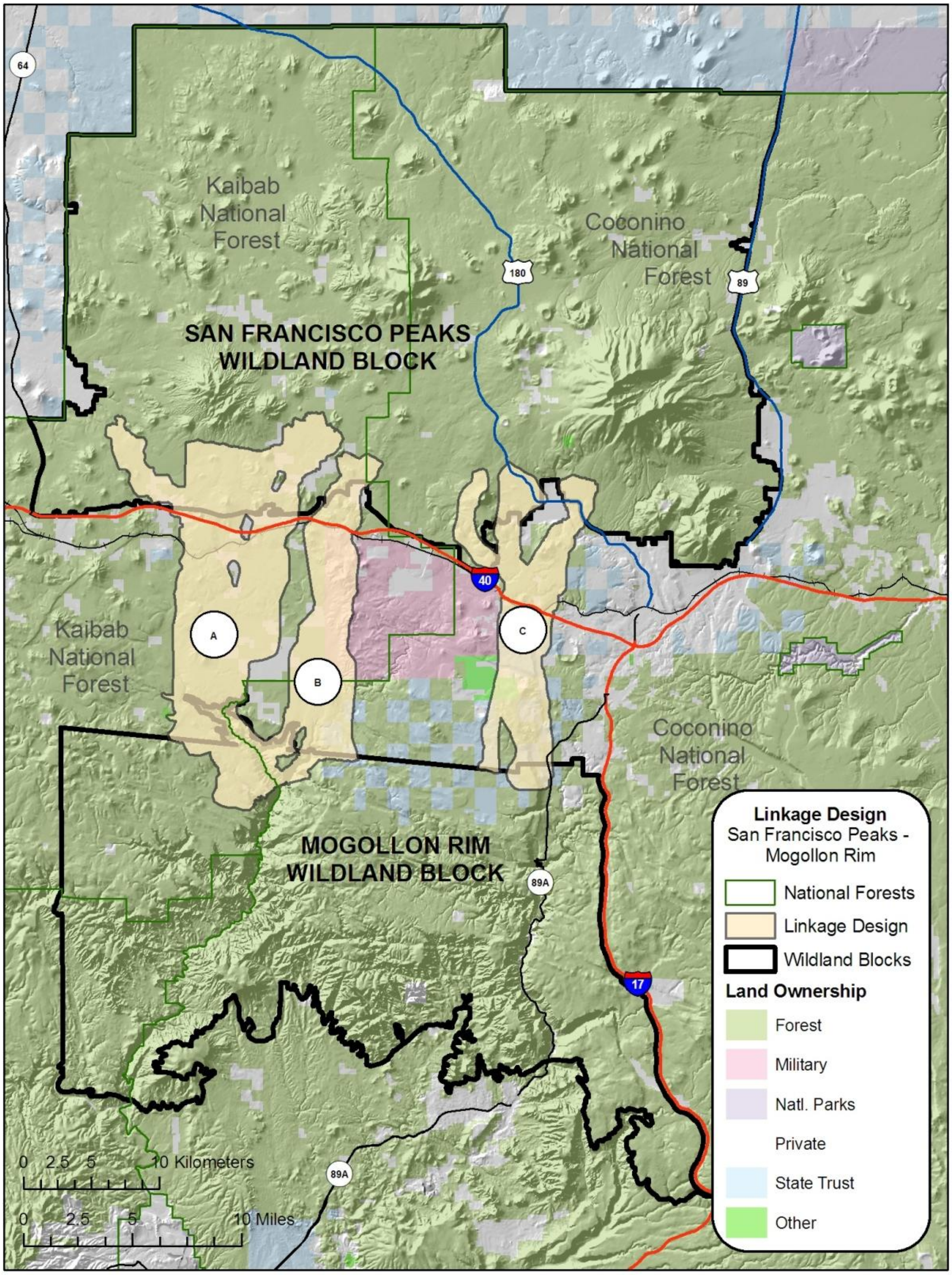

Figure 3: The linkage design between the San Francisco Peaks and Mogollon Rim wildland blocks includes three strands each serving different species. A: Garland Prairie Strand; B: Volunteer Mountain Strand; C: Woody Ridge Strand.

Strand C (“Woody Ridge Strand”) encompasses most of north-south trending Woody Ridge east of Camp Navajo. This area is predominantly ponderosa pine forest and of rugged topography. Strand C is approximately 24 km long and largely protected by the Coconino National Forest and NAU Centennial Forest, though the area just south of I-40 and east of Camp Navajo is predominantly Arizona State Trust Land potentially vulnerable to development. Strand C includes biologically best corridors for black bear, bobcat, mule deer, and porcupine, and provides breeding and dispersal habitat for corridor dwellers including Abert’s squirrel and Arizona black rattlesnake and potential habitat for northern leopard frog. Strand C includes the most developed area of the linkage design on the western edge of Flagstaff, and includes an important bottleneck where the BNSF Railroad crosses under I-40 near the U.S. Naval Observatory. Strand C overlaps the ephemeral wetland of Rogers Lake and a west-east wildlife movement area from this feature to the Dry Lake caldera.

The strands in this linkage design are wider on average than those described in many previously published least-cost corridor linkage designs (e.g. Beier et al. 2008). Strand A for example measures approximately 8 km at its widest point. This is a reflection of the number of modeled species underlying our linkage design, our best judgment of the species-specific minimum corridor widths needed to ensure their long-term functional integrity, and our desire to provide maximum flexibility in facilitating collaboration among the range of land owners and management agencies with jurisdiction in the potential linkage area.

Model validation

We used available data to inform and validate our linkage design. Camp Navajo biologists shared camera trap data for black bear locations. Several of these locations overlapped Strand B while others aligned with Volunteer Canyon, an area of more localized wildlife movement (see Appendix B). Mule deer locations obtained from the Arizona Game and Fish Department’s Contracts Branch strongly overlapped the easternmost strand of our modeled corridor for this species, and guided a small extension of this strand where it crosses US Highway 180 just inside the San Francisco Peaks block (Figure 4).

We also compared wildlife-vehicle collision data obtained data from the Arizona Department of Transportation for Interstate Highway 40 with our modeled corridor for elk (Figure 5). These data too support our modeling results. While significant numbers of elk collisions were reported at several areas along I-40 for the study period, a peak is evident in the vicinity of milepost 175. This milepost is included within our modeled biologically-best corridor for elk.

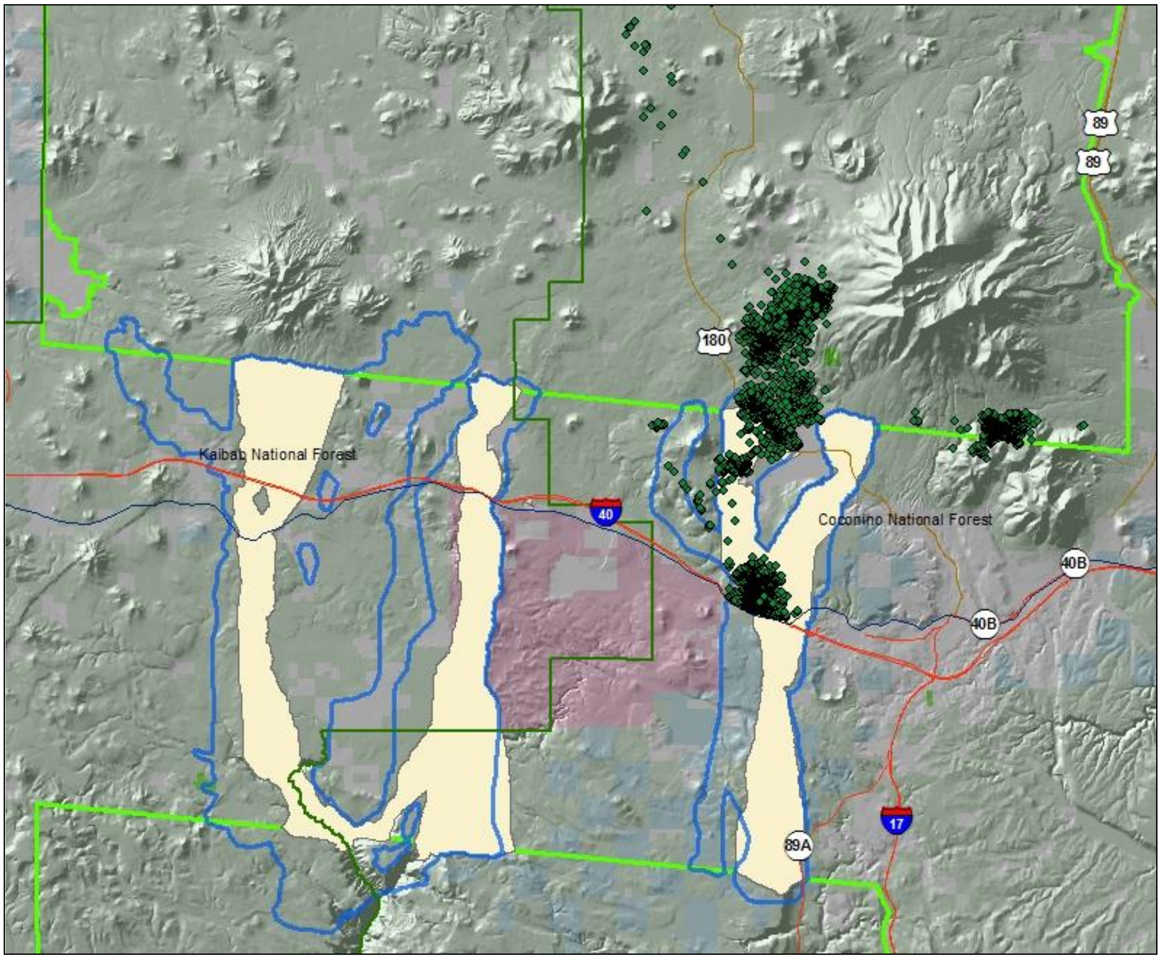

Figure 4: Mule deer telemetry data (green dots) validate modeled mule deer corridor (white).

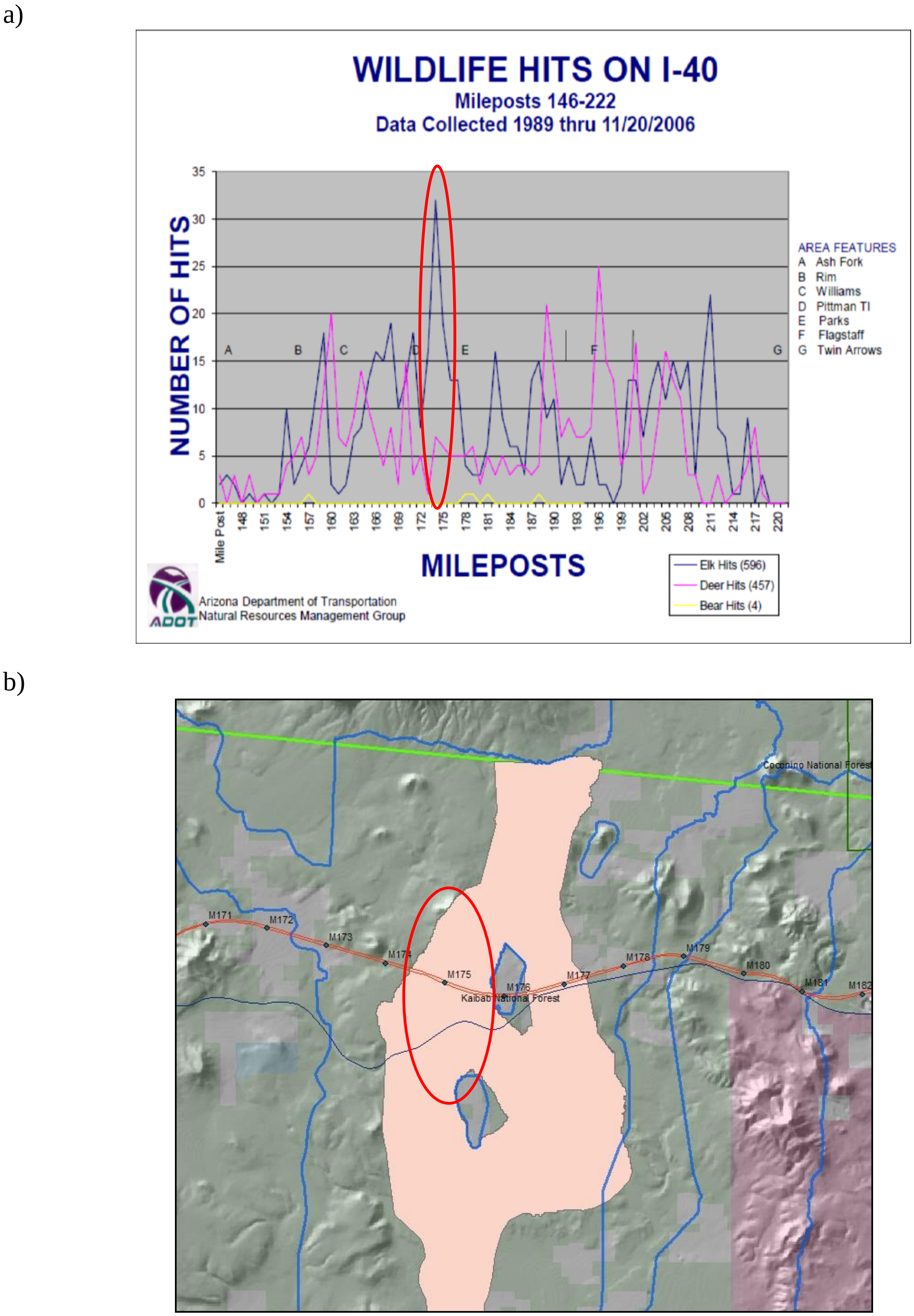

Figure 5: Relation of elk-vehicle collisions on Interstate Route 40 to elk corridor model. a) Wildlife-vehicle collisions between Ash Fork and Twin Arrows, AZ 1989-2006 (elk data in blue; note circled peak at milepost 175). b) Modeled elk corridor includes milepost 175.

Non-modeled areas important to wildlife movement

The linkage planning area includes several additional areas important for maintaining habitat connectivity that are not part of the modeled linkage design which we identify here for future conservation efforts (Figure 6). Government Prairie overlaps the northeastern lobe of Strand A, and constitutes important grassland habitat. This area is used by a range of species and connects to other areas of grassland and ponderosa pine forest further north within the San Francisco Peaks Wildland Block. Future collaborative efforts should focus on removing and improving fencing for wildlife and restoring grassland habitat in this area. Volunteer Canyon, which originates on Camp Navajo and connects to Strand B at its southern end, provides an important linkage between Rogers Lake, habitats on the Camp, and the head of Sycamore Canyon in the Mogollon Rim block. It is used for seasonal movements by turkey and provides breeding habitat for Mexican spotted owl. The area between Rogers Lake and Dry Lake in Strand C allows east-west movement for ungulates including pronghorn, elk and mule deer and provides further connectivity to habitats on Camp Navajo including Volunteer Canyon. Rogers Lake is a significant ephemeral wetland and surrounding grasslands and forested uplands support a diversity of birds including migrant passerines, raptors, and Mexican spotted owl. Coconino County acquired State Trust parcels around Rogers Lake in 2010 and future collaborative efforts with Camp Navajo may augment the amount of protected land.

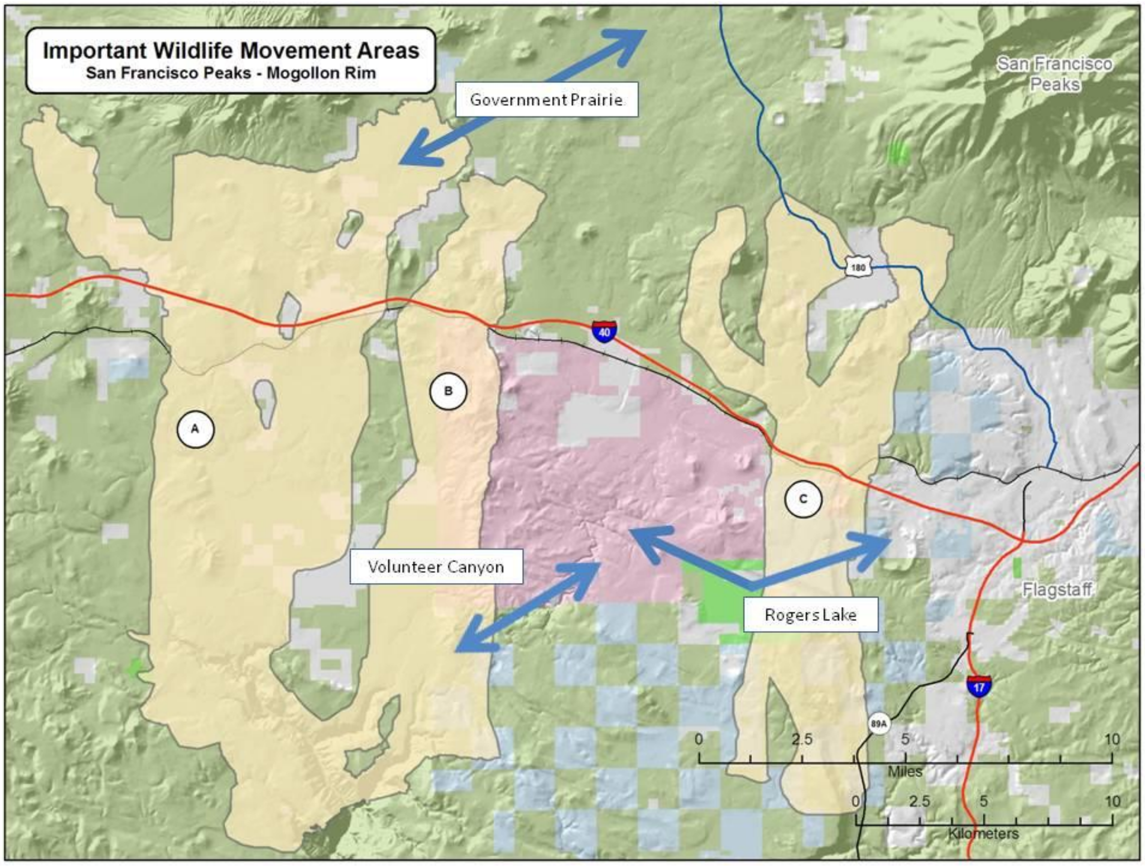

Figure 6: Non-modeled areas important to wildlife movement in the linkage planning area

MANAGEMENT RECOMMENDATIONS

Roads, rail lines and developed lands occupy a fraction of the area within the linkage design yet present significant obstacles to animal movement between the wildland blocks. Here we review existing literature on impacts of such features on ecological processes, identify specific barriers within the linkage design, and suggest mitigation options. It is important to realize that crossing structures, while critical, are one of several measures needed to successfully implement this linkage design. Investment in a crossing structure is futile if habitat between the structure and either wildland block is lost, or if the wildland blocks themselves become developed. Ongoing stewardship is also needed to maintain and improve permeability for wildlife, e.g. by removing or redesigning fences and addressing impacts from irresponsible recreation, noise, lighting, invasive species, unrestrained domestic pets, and other sources.

Impacts of roads and railways on wildlife

While the physical footprint of the over 4 million miles of roads in the United States is relatively small their ecological influence extends much farther. Direct effects of roads include mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on species' ecological characteristics (Table 2). Most species are vulnerable to direct roadkill, with severe impacts documented for wide-ranging predators such as the cougar in southern California, Florida panther, ocelot, wolf, and Iberian lynx (Forman et al. 2003). In a 4-year study of 15,000 km of road observations in Organ Pipe Cactus National Monument, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km killed annually due to vehicle collisions. We may not think of roads as causing habitat loss, but a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mi^2 section of land results in the loss of 4.4% of habitat area for species that cannot live in the right-of-way. Roads fragment habitat by breaking large areas into small isolated patches supporting fewer individuals, and these small populations can lose genetic diversity and are at risk of local extinction (Dodd et al. 2011, Theimer et al. 2012). Traffic volume likely contributes to fragmentation by reducing the frequency with which wildlife cross busy highways (Gagnon et al. 2007). While the effects of railways on wildlife are not well understood, it is likely that heavily-utilized rail lines have many similar impacts as have been observed for roads.

In addition to these obvious effects roads create noise and vibration that interfere with ability of reptiles, birds, and mammals to communicate, detect prey, or avoid predators. Roads also increase the spread of exotic plants, promote erosion, create barriers to aquatic species, and pollute water sources with roadway chemicals (Forman et al. 2003). Highway lighting also has important impacts on animals (Rich and Longcore 2006).

Table 2: Characteristics which make species vulnerable to the three major direct effects of roads (Source: Forman et al. 2003)

Species Characteristic	Effects of Roads		
	Road mortality	Habitat loss	Reduced connectivity
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		

Multiple-resource needs	★		★
Large area requirements/low density	★	★	★
Low reproductive rate	★	★	★
Behavioral avoidance of roads			★

Types of roadway mitigation structures

A range of wildlife crossing structures including overpasses, “green bridges,” bridges, culverts, and pipes have been used in North America and Europe to facilitate movement over or under roads and railways (Figure 7). While many of these structures were not originally constructed with ecological connectivity in mind they benefit many species (Clevenger et al. 2001; Forman et al. 2003). No single structure will mitigate road barriers for all species. For example, rodents prefer to use pipes and small culverts (McDonald & St Clair 2004) while bighorn have been shown to use unvegetated overpasses in Arizona (Figure 8). A concrete box culvert may be readily used by a mountain lion or bear, but not by a deer or bighorn sheep. A number of crossing structures have been implemented successfully in Arizona (see below). Other strategies have been employed where topography does not lend itself to under- or overpasses. Flashing, motion-sensor warning signs coupled with fencing have proven effective at alerting motorists to large animals approaching the roadway (Gagnon et al. 2010). These can be utilized on highways with low traffic volumes, and provide low-cost interim solutions where major highway improvements are not yet planned or financed.

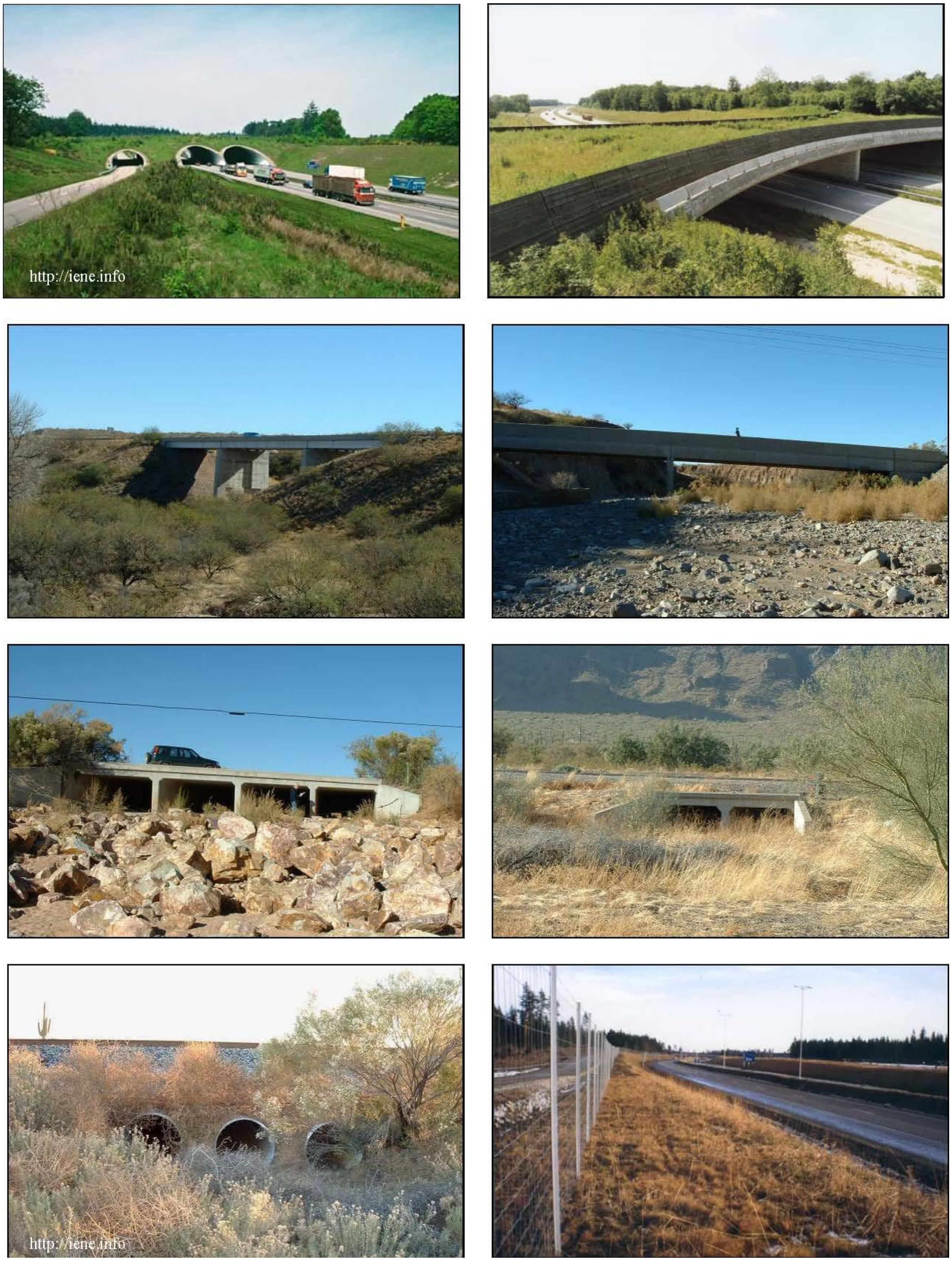

Figure 7: Road mitigation structures (top to bottom) include overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) is used to guide animals to structures. (Photographs from Beier et al. 2007a).

Wildlife overpasses are most often designed to help large mammals cross busy highways. Overpasses are typically 30-50 meters wide but can be as wide as 200 meters. In Banff National Park, Alberta grizzly bears, wolves, and ungulates (bighorn sheep, deer, elk, and moose) prefer overpasses while species such as mountain lion prefer underpasses (Clevenger & Waltho 2005). In northwestern Arizona studies of desert bighorn sheep movements around State Route 93 near the Hoover Dam informed design and construction of a series of overpasses and associated directive fencing. Camera data have validated the efficacy of these structures in facilitating bighorn movements (Figure 8; J.Gagnon, Arizona Game & Fish Department, pers. com.).

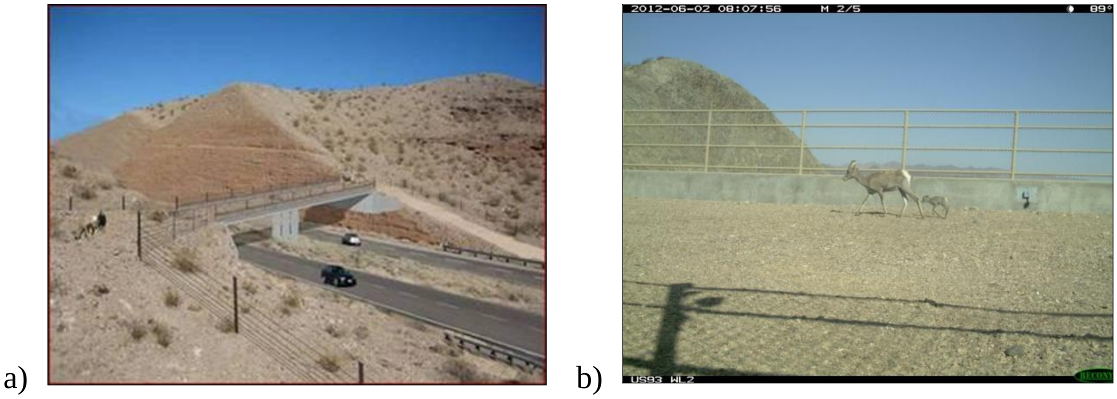

Figure 8: Desert bighorn sheep overpasses in northwestern Arizona. Telemetry studies informed design and siting of three overpasses and directive fencing along State Route 93. These structures have been readily adopted by bighorn. a) Artist rendering of overpass. b) Bighorn ewe and lamb using overpass, June 2012. (Source: Arizona Game and Fish Department Contracts Branch).

Wildlife underpasses include viaducts, bridges, culverts, and pipes typically designed to ensure drainage beneath highways. For ungulates such as deer that prefer open crossing structures tall, wide bridges are best. Mule deer in southern California only used underpasses below large spanning bridges (Ng et al. 2004), and the average size of underpasses used by white-tailed deer in Pennsylvania was 15 feet wide by 8 feet high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should ideally extend to uplands beyond the scour zone of the stream and be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures have increased connectivity for smaller species crossing bridges on floodplains (Forman et al. 2003). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). “Funnel fencing” can help guide animals to underpasses and greatly improve their utilization. Along State Route 260 in Arizona, a series of underpasses linked by ungulate-proof fencing has proven very successful in facilitating movements of large mammals while conveying significant safety benefits to motorists, having reduced the frequency of elk-vehicle collisions in the area by over 95% (Figure 9; Gagnon et al. 2010).

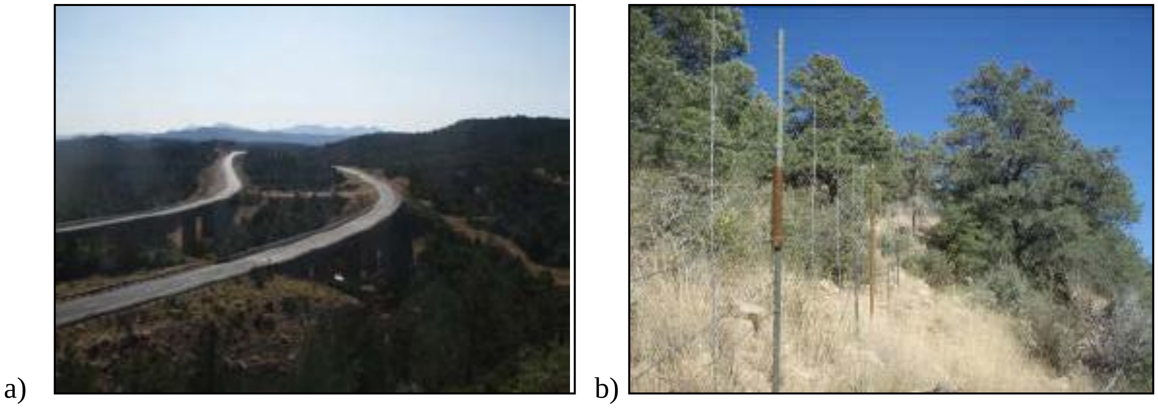

Figure 9: Highway underpasses linked by ungulate-proof fencing near Payson, Arizona along State Route 260 have reduced elk-vehicle collisions by over 95%. a) Bridge over Preacher Canyon on SR 260. b) Fencing used to direct wildlife to underpasses. (Source: Arizona Game and Fish Department).

Bridges are a roads supported on piers or abutments, while a *culvert* is one or more round or rectangular tubes under a road. The most important difference is that the streambed under a bridge is mostly native rock and soil rather than the concrete or corrugated metal of culverts. Even when rip-rap or other scour protection is installed to protect bridge piers or abutments, stream morphology and hydrology usually return to near-natural conditions in bridged streams and vegetation often grows beneath. In contrast vegetation does not grow inside culverts and hydrology and stream morphology are permanently altered, not only within the culvert but for some distance upstream and downstream from it.

Despite their disadvantages well-designed and sited culverts can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species including mice, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards and snakes (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). In south Texas, bobcats most often used 1.85 meters high by 1.85 meters wide box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom and establishing a ledge in locations where the culvert floor is persistently covered with water (Cain et al. 2003). It is important for the lower end of a culvert to be flush with surrounding terrain as scouring can undercut the culvert lip; many small mammals, snakes, and amphibians are less likely to find or use suspended culverts.

Guidelines for implementing wildlife crossing structures

We offer the following research-based guidelines to assist with design and implementation of wildlife crossing structures. The Arizona Game and Fish Department has also created guidelines including detailed design specifications for design of bridges (AGFD 2008) and culverts (AGFD 2006b) to ensure their permeability for wildlife that are available through our website.

1. Multiple crossing structures should be constructed to provide connectivity for all species likely to use a given area (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald & St Clair 2004; Clevenger & Waltho 2005; Mata et al. 2005). Open structure such as bridges best accommodate ungulates. For medium-sized mammals, black bear, and mountain lions, large box culverts with natural substrate flooring are optimal (Evink 2002). Small mammals tend to prefer pipe culverts from 0.3 meters to 1 meter in diameter (Clevenger et al. 2001; McDonald & St Clair 2004).
2. At least one crossing structure should be located within an individual's home range**.** Because most reptiles, small mammals and amphibians have small home ranges, metal or cement box culverts should be installed at intervals of 150-300 meters (Clevenger et al. 2001). Larger crossing structures such as bridges, viaducts, or overpasses that accommodate ungulates and predators should be located no more than 1.5 km apart (Mata et al. 2005; Clevenger and Wierzchowski 2006). Inadequate size and insufficient number of crossings are two primary causes of poor use by wildlife (Ruediger 2001).
3. Suitable habitat should occur on both sides of a crossing structure (Ruediger 2001; Barnum 2003; Cain et al. 2003; Ng et al. 2004). This applies at both local and landscape scales. On a local scale, vegetative cover appropriate to the target species should be present near entrances to give animals security and reduce road-associated deterrents such as lighting and noise (Clevenger et al. 2001; Cain et al. 2003; McDonald & St Clair 2004). On the landscape scale, crossing structures are only as effective as the land and resource management strategies around them (Clevenger et al. 2005). Suitable habitat must be present throughout the linkage for animals to use a crossing structure.
4. Whenever possible, suitable habitat should occur within a crossing structure. This can best be achieved by designing bridges high enough to allow light for vegetation to grow beneath and to span upland habitat not regularly scoured by floods. If this is not possible rows of stumps or branches under large span bridges can provide cover for smaller animals such as reptiles, amphibians, rodents, and invertebrates; regular visits are needed to replace artificial cover removed by flood. The type and amount of vegetation on wildlife overpasses should be appropriate to the species for which the structure is intended. Within culverts, earthen floors are preferred by mammals and reptiles.
5. Structures should be monitored for and cleared of obstructions such as detritus or silt blockages that impede movement. Small mammals, carnivores, and reptiles avoid crossing structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004). Bridged undercrossings rarely have similar problems.
6. Fencing should never block entrances to, but should direct animals toward, crossing structures (Yanes et al. 1995). In Florida, construction of a barrier wall to guide animals to a culvert system resulted in 93.5% reduction in roadkill and increased the number of species using culverts from 28 to 42 (Dodd et al. 2004). In Arizona, use of ungulate-proof fencing to guide animals to a below-grade underpass reduced elk-vehicle collisions by 97% (Gagnon et al. 2010). Fences, guard rails, and embankments at least 2 meters high discourage animals from crossing roads (Barnum 2003; Cain et al. 2003; Malo et al. 2004). One-way ramps on roadside fencing allow animals to escape if trapped on a road (Forman et al. 2003).
7. Raised sections of road discourage animals from crossing roads and can encourage animals to use crossing structures. Clevenger et al. (2003) found that vertebrates were 93% less susceptible to road-kills on sections of road raised on embankments compared to road segments at the natural grade of the surrounding terrain.

8. Manage human activity near crossing structures. Clevenger & Waltho (2000) suggest that human use of crossing structures be restricted and foot trails relocated away from structures intended for wildlife, though large crossing structures (viaduct or long, high bridge) can accommodate both recreational and wildlife use. Educating recreational users to maintain utility of the structure for wildlife can create conservation allies. At a minimum, nighttime human use of structures should be restricted.
9. Design culverts to provide for animal movement. Most culverts are designed to carry water under roads and minimize erosion. Culvert designs adequate for transporting water often have pour-offs at downstream ends that prevent wildlife usage. At least 1 culvert every 150-300 meters of road should have openings flush with the surrounding terrain and native land cover up to both culvert openings as noted above.

Existing roads affecting the linkage design

The principal roadway in the potential linkage area is Interstate 40 which crosses all three strands of the linkage design for a total length of approximately 10.5 miles. The Burlington Northern Santa Fe railroad, also a major barrier, roughly parallels I-40 for a total distance of approximately 17 miles across the three linkage strands. Other roadways impacting the linkage design are over 7 miles of U.S. Highway 180 in the northern portion of Strand C and approximately 2.3 miles of U.S. Highway 89A in the extreme southeastern portion of this strand. Local paved roads also intersect one or more of the linkage strands (e.g. State Route 66) as well as a large number of tertiary roads maintained by the Coconino and Kaibab National Forests. The recent implementation of Travel Management Rules (e.g. USDA 2012) has resulted in the closure of many of these USFS routes which may have a positive effect on wildlife connectivity within the strands of the linkage design.

Recommendations for crossing structures in the linkage design

Interstate Highway 40: Arizona Game and Fish Department biologists with support from the Arizona Department of Transportation have studied large mammal movements along many of Arizona’s major highways to define optimal locations for wildlife crossing structures (AGFD 2011a, AGFD 2012a, Gagnon et al. 2012). Their findings for Interstate Route 40 reinforce our modeling results. Gagnon et al. (2012) evaluated our modeled biologically-best corridor for elk by comparing several indices of elk use for 0.1 mile segments of I-40 within vs. outside both our elk-specific corridor model and our multi-species linkage design (Figure 10). For our elk biologically-best corridor, per-segment mean elk-vehicle collisions, mean elk approaches to the highway, and mean rating scores (a composite of several parameters reflecting overall suitability of the segment for a crossing structure) were all higher than for segments of I-40 outside the elk corridor, validating our elk model and lending added support for Gagnon et al.’s crossing recommendations (see below). No significant differences were observed in these elk parameters for segments within vs. outside the multi-species linkage design.

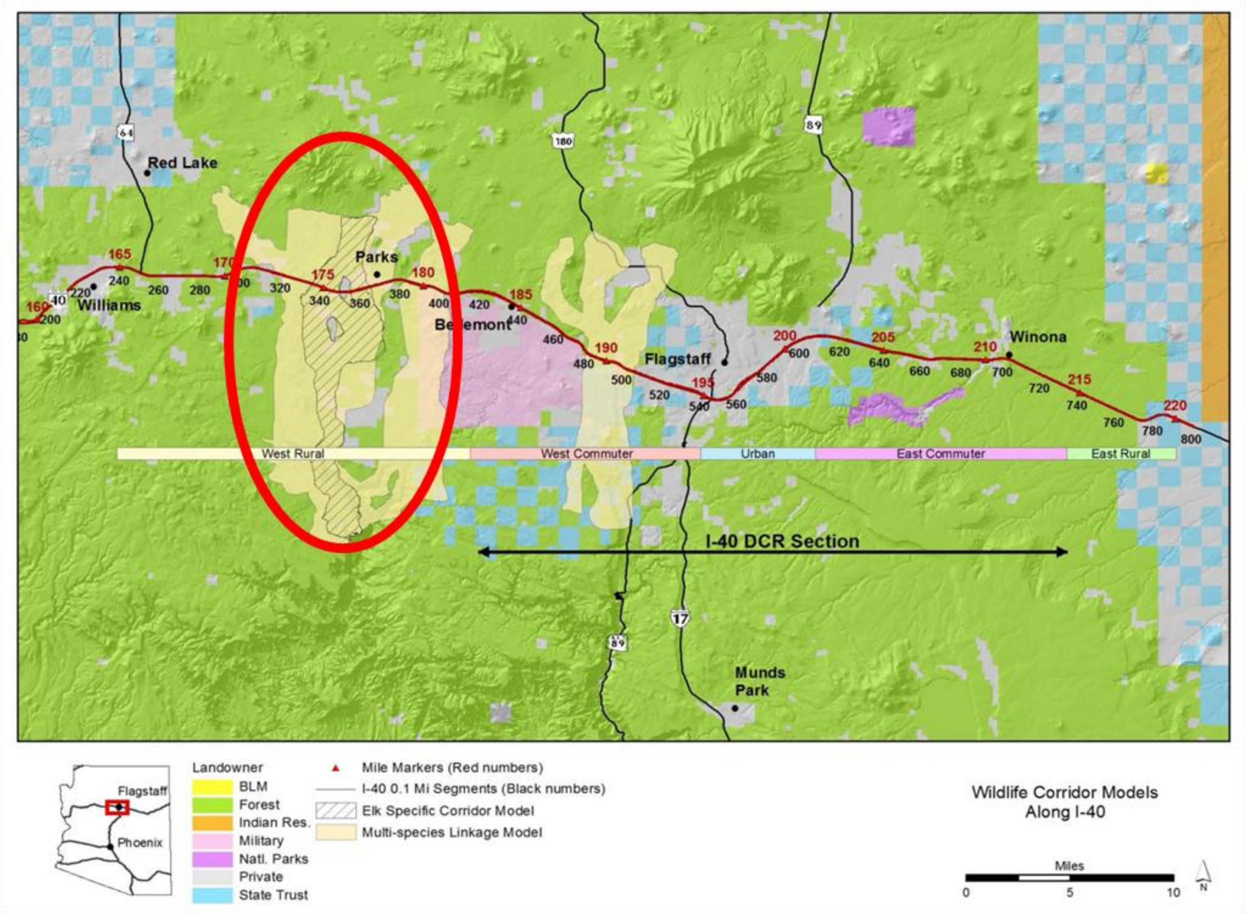

Figure 10: Linkage design and biologically-best corridor for elk (red circle) in relation to Interstate Highway 40 mileposts (red numerals. Source: Gagnon et al. 2012).

Gagnon et al. (2012) provide recommended locations for crossing structures along a stretch of I-40 that spans our linkage design (Figure 11). Recommendations are based on telemetry data, roadkill records, and ground-truthing (e.g. to determine suitability of topography) and indicate locations where existing crossing structures could be modified or new structures created to enhance wildlife movement. We support these recommendations and reproduce them here with permission in hopes that they will be implemented in the future. While based on large mammal datasets these crossings would benefit a wide range of taxa, given their overlap with our multi-species linkage design. It is important to note that in order to realize the maximum benefits from these crossing structures, the permeability to wildlife of the nearby BNSF railway line and of many fences will also need to be assessed and enhanced where possible.

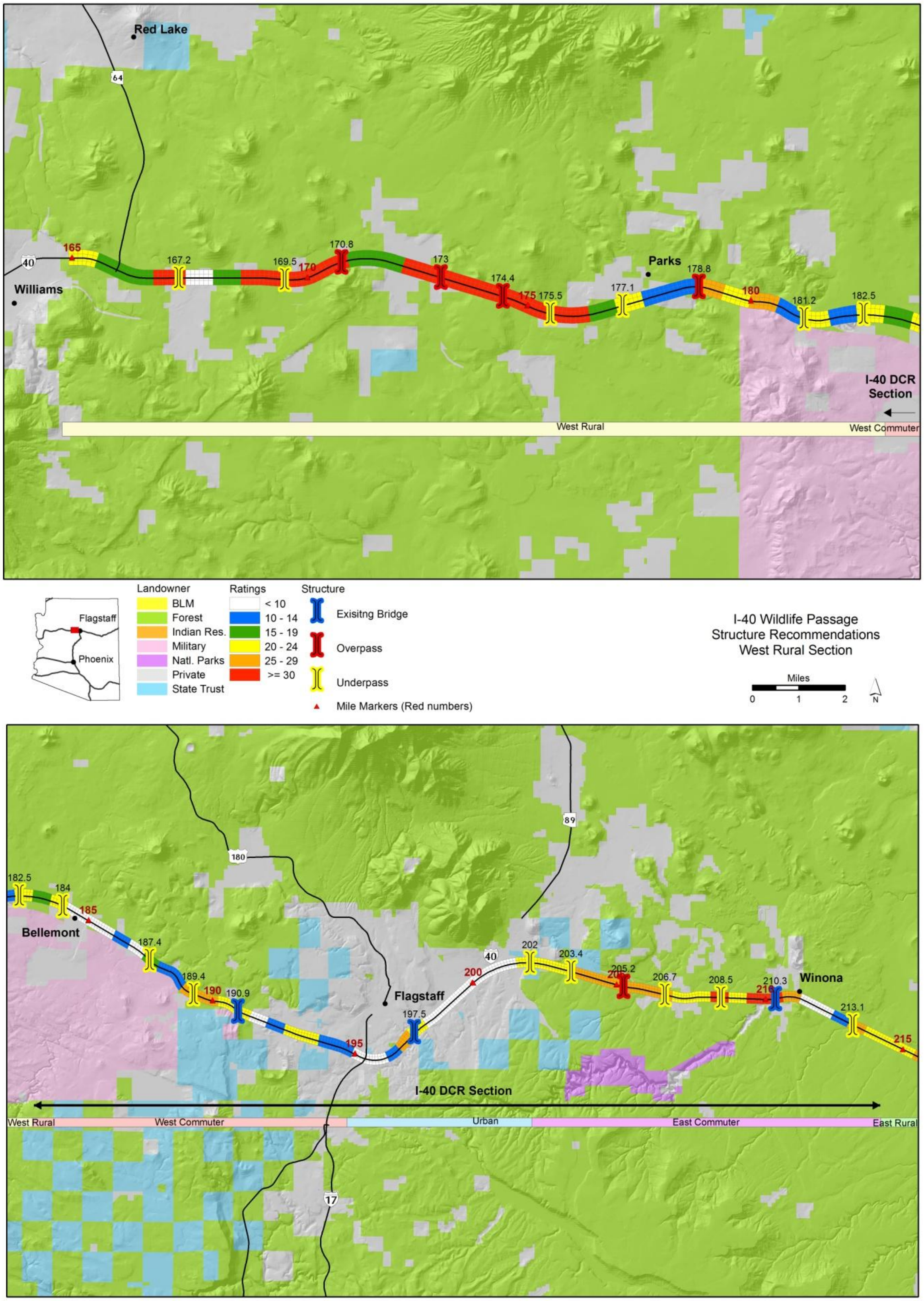

Figure 11: Recommended crossing locations on Interstate Highway 40 (Source: Gagnon et al. 2012).

One of the crossing locations recommended by Gagnon et al. (2012) may have particular value for serving multiple species, including pronghorn and other grassland taxa. This location has been independently recommended by Kaibab National Forest biologists (B. Noble, pers. comm.; Figure 12). The location is found east of milepost 174 in Strand A of the linkage design (marked 174.4 in Figure 11) and is immediately adjacent to our modeled biologically-best corridors for both pronghorn and elk. Here I-40 passes through a roadcut of solid rock and the base material is of similar height on both sides of the highway and in the median between east and westbound lanes. These features could help support a wildlife overpass. Significant grasslands (Government and Garland Prairies) are located north and south of the interstate and the adjacent land is under U.S. Forest Service ownership. A crossing here could play a key role in restoring habitat connectivity for what appear to be increasingly isolated pronghorn populations in this area (Dodd et al. 2011, Theimer et al. 2012). Successful implementation will require significant financial investment and substantial restoration treatments to remove encroached shrubs and create more open grassland habitat on both sides of I-40.

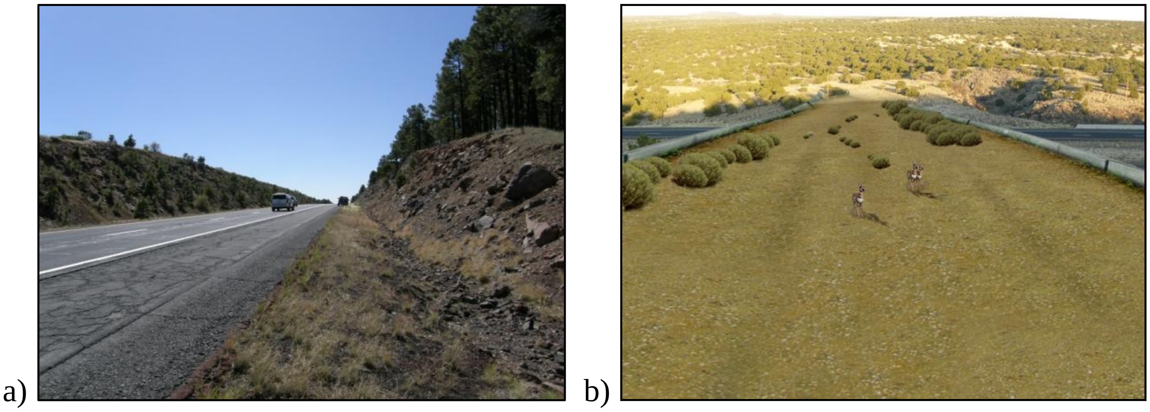
a)
b)

Figure 12: Location photo (a) and possible design (b) of wildlife overpass near milepost 174 on Interstate Highway 40 (Source, b: Norris Dodd).

U.S. Highway 180: While the same level of analysis has not been applied to all roadways in the linkage design, we wish to draw attention to U.S. Highway 180 where it crosses linkage Strand C. High numbers of elk, mule deer and other species have been documented in this vicinity as indicated by Arizona Game and Fish Department elk crossing data (Figure 13). Elk crossings from 2009 to 2012 were highest between mile markers 224 and 226, a segment of Highway 180 which overlaps the middle lobe of linkage Strand C. In addition to providing empirical validation for our linkage design these data reinforce the need to explore potential locations for wildlife crossings and the impact of fencing in this important area.

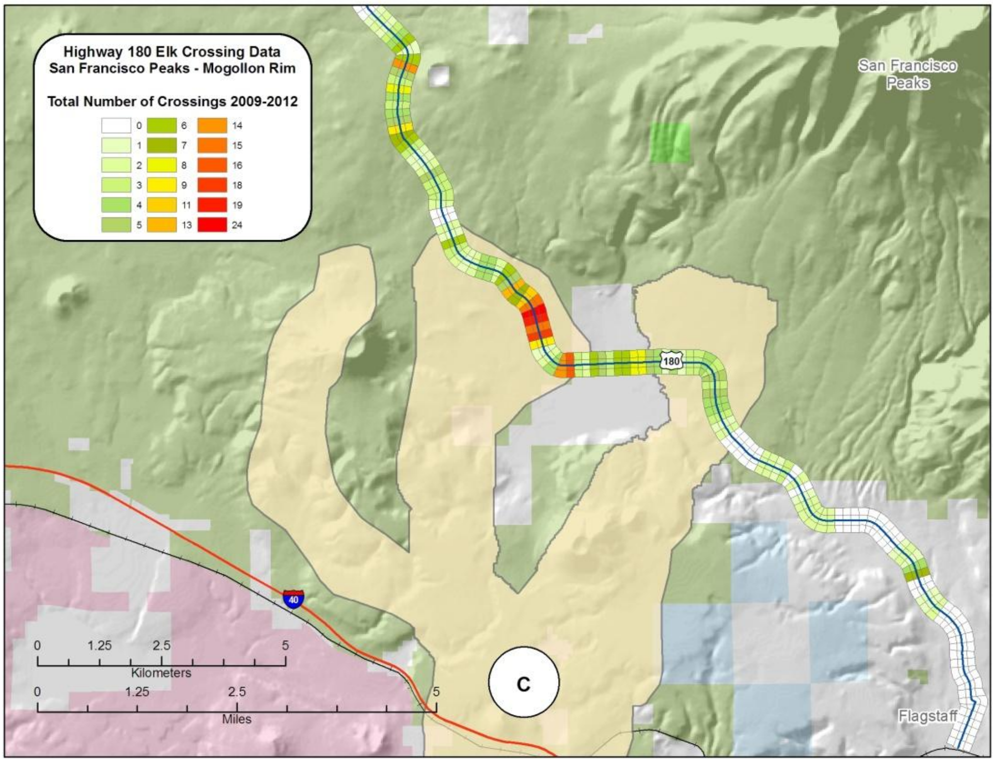

Figure 13: Elk crossings of U.S. Highway 180 northwest of Flagstaff, Arizona. Color reflects total number of crossings in 0.1 mile segments, May 2009 to March 2012. (Source: AGFD Contracts Branch)

Urban and rural development as a barrier to wildlife movement

Urbanization ranges from low-density ranchette development to factories, gravel mines, shopping centers, and high-density residential housing. These diverse land uses can impact wildlife movement in several ways:

- Growth of local road networks. Rural subdivisions require more road length per dwelling than more compact residential areas. Many animals are killed on roads, in some cases at frequencies that significantly affect populations. Some reptiles are repelled even from low-speed 2-lane roads (Findlay and Houlahan 1997). Species that avoid roads may not experience high mortality but instead may become isolated by habitat fragmentation.
- Loss and fragmentation of natural vegetation. Conservation Biology Institute (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County: percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation >30 meters from non-natural land cover), and mean core area per patch at 7 housing density levels (Figure 14). Fragmentation was negligible in areas with <1 dwelling unit per 80 acres and severe in areas with >1 dwelling unit per 40 acres. Similar patterns with a dramatic threshold at 1 unit per 40 acres were evident in 4 measures of fragmentation across 60 landscapes studied (CBI 2005).

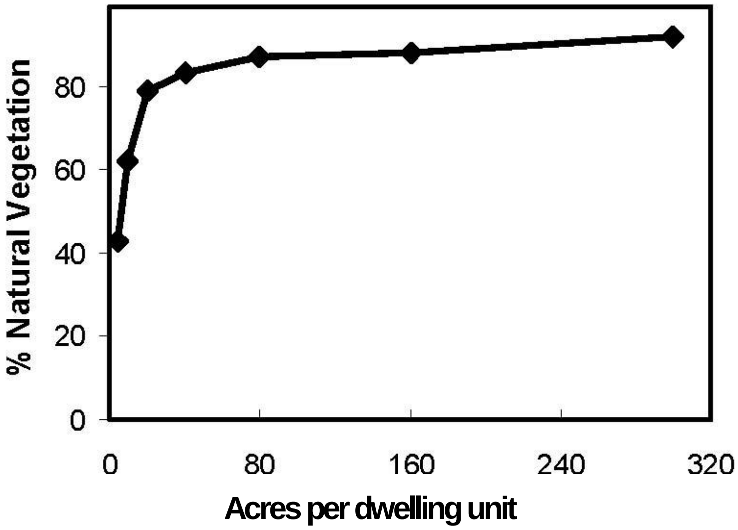

Figure 14: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

- Decreased abundance and diversity of native species and replacement by non-natives (Reed et al. 2012). In Arizona these trends were evident for birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001) and loss of native species increased as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Merenlender et al. 1998, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002, Merenlender et al. 2009), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001, Hastings et al. 2006), and migratory birds in Ontario (Friesen et al. 1995). Negative effects of urbanization were evident at densities as low as 1 dwelling unit per 40-50 acres, with less impact below this threshold on birds and small mammals.
- Increased vehicle traffic, increasing mortality and repellent effects of roads (Van der Zee et. al 1992).
- Increased numbers of dogs, cats, and other pets that kill millions of wild animals each year (May and Norton 1996, Courchamp and Sugihara 1999).
- Increased numbers of wild predators removed for killing pets or hobby animals (Woodroffe and Frank 2005).
- Subsidized “suburban native predators” such as raccoons, foxes, and crows that exploit garbage and other sources to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- Spread of non-native plants that thrive on roadsides and other disturbed ground or are deliberately introduced by humans.
- Perennial water in formerly ephemeral streams making them more hospitable to bullfrogs and other non-native aquatic species that displace natives and reduce species richness (Forman et al. 2003).
- Mortality of native plants and animals via pesticides and rodenticides, which kill not only target species such as domestic rats but also secondary victims, e.g. raccoons and coyotes that feed on poisoned rats, and tertiary victims, e.g. mountain lions that feed on raccoons and coyotes (Riley et al. 2007).

- Artificial night lighting which can impair the ability of nocturnal species to navigate (Beier 1995, 2006) and negatively affect reptile populations (Perry and Fisher 2006).
- Conflicts with native herbivores feeding on landscape plants (Knickerbocker and Waithaka 2005).
- Noise, which may disturb or repel some animals and present a barrier to movement (Liddle 1997).
- Disruption of natural fire regimes by: increasing wildfire ignitions, especially outside the natural burning season; increasing the need to suppress potentially beneficial fires that can maintain natural ecosystem structure; and requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites.

Guidelines for mitigating impacts of urban and rural development

Unlike road impacts which can be mitigated with fencing and crossing structures, urban and rural development create barriers to movement which often cannot be easily mitigated; avoidance is the best way to manage these impacts in a wildlife linkage. Although some species such as lizards and small mammals will occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. Where development does occur, the following guidelines can help reduce the barrier effects of urban and rural development and maintain habitat connectivity:

1. Use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the linkage design.
2. Encourage small building footprints on large (>40 acre) parcels with a minimal road network.
3. Encourage conservation easements, innovative cooperative agreements, and acquisition of land from willing land owners in the linkage design.
4. Combine habitat conservation with compatible public goals e.g. recreation and protection of water quality.
5. Plan trail systems in the linkage design to minimize resource damage and disturbance of wildlife. Encourage users to stay on trails, keep dogs leashed, and travel in groups in areas used by mountain lions or bears, and discourage visitors from collecting reptiles.
6. Where housing or other low-density development occurs enlist landowners as stewards of the linkage. This can include landscaping with natural vegetation, managing fire risk, keeping pets indoors or in enclosures (especially at night), maximizing personal safety with respect to large carnivores by appropriate behaviors, using pesticides and rodenticides carefully, and directing outdoor lighting toward houses and walkways and away from the linkage area.
7. Develop a public education campaign to inform those living and working within the linkage area about living with wildlife and the importance of maintaining ecological connectivity.
8. Discourage residents and visitors from feeding or providing water for wild mammals or otherwise allowing wildlife to lose their fear of people.
9. Install wildlife-proof trash and recycling receptacles and encourage secure garbage storage.
10. Do not install night lighting on rural roads passing through the linkage design. Reduce vehicle speeds in sensitive locations by speed bumps, curves, artificial constrictions, etc.
11. Encourage use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around yards with domestic pets and potential wildlife attractants e.g. gardens.
12. Discourage the killing of ‘threat’ species such as rattlesnakes.

13. Respect the property rights of people living in wildlife corridors. Work with homeowners and residents to manage residential areas for wildlife permeability. Develop innovative programs that respect the rights of residents and enlist them as stewards of the linkage area.

The Arizona Game and Fish Department has created documents outlining wildlife-friendly design and building practices which can help maintain and enhance habitat connectivity in the linkage planning area, including research-based design specifications. These include guidelines for the design of wildlife-friendly bridges (AGFD 2008), culverts (AGFD 2006b), community planning and project development (AGFD 2009a), and fencing (AGFD 2011c).

Mitigating barriers from urban and rural development in the linkage planning area

While developed areas currently account for a small proportion of the land cover within the linkage design, residential and commercial development could increase in the future. Much of the area in all three linkage strands is under the ownership of the Kaibab and Coconino National Forests and is expected to remain protected in the future, but private inholdings are scattered throughout. Future growth in these pockets, particularly if in proximity to proposed wildlife crossings along I-40, could compromise the long-term integrity of the linkage and the mitigation actions proposed above. Proactive planning, open space management, and wildlife-friendly design of future housing developments will help maintain habitat connectivity. Significant portions of Strands B and C are under Department of Defense and Arizona State Land Department ownership, respectively. Collaborative multiparty conservation efforts and future protection of some of these lands as protected open space will likely be necessary.

Land management and acquisition in each strand of the linkage design

Strand A traverses the most rural portion of the linkage design but may present a unique conservation challenge. This strand includes the biologically best corridor for pronghorn, probably the most barrier-sensitive of the species we modeled. Developed areas in Strand A include Pittman Valley and Parks adjacent to Interstate 40, and Parks is located between the grasslands of Government Prairie to the north and Garland Prairie south of I-40. Extensive fencing also exists for livestock and property boundaries. Fences may be designed or retrofitted to be more wildlife-permeable but this will require significant investment. To optimize use of the proposed I-40 overpass at mile 174.4 (described above) by pronghorn and other grassland species, extensive thinning in adjacent areas of National Forest will likely be required.

Land ownership in Strand B is primarily divided between National Forest (Kaibab and Coconino) and U.S. Army Camp Navajo, with a small portion of the NAU Centennial Forest included at its southern terminus. These areas are not under immediate threat from development, and stakeholder collaboration can help to ensure that future changes to training operations or land use on the Camp are compatible with landscape permeability for wildlife, in particular bobcat, black bear and mule deer. The U.S. Army is also exploring future acquisition of conservation easements for private inholdings on the western side of the Camp through its Army Compatible Use Buffer (ACUB) program.

Strand C includes two areas of potential vulnerability to future development. Small private inholdings exist adjacent to the U.S. Naval Observatory where the BNSF railroad line passes beneath Interstate 40. This underpass likely represents a bottleneck in Strand C where telemetry and wildlife camera data have documented a variety of species traveling under the highway. There is also a cluster of Arizona State Trust Land parcels south and west of the Naval Observatory and east of Camp Navajo which include developable lands. Key parcels in both of these areas should be prioritized for future acquisition.

City and County discretionary permitting and land use planning

Design features which maintain wildlife movement areas can be incorporated into individual projects including residential subdivisions. Coconino County's award-winning Comprehensive Plan is grounded in a conservation framework that integrates consideration of natural resource features including wildlife corridors into land use decisions and project planning (CCCPP 2003). Coconino County promotes the use of integrated conservation design for residential subdivisions whereby wildlife corridors, wetlands and springs, and other sensitive habitat features are conserved while developers are given flexibility in the siting and density of homesites. Recent studies indicate that such developments are most effective when the ecosystem context and the relation of the conserved open space to the surrounding landscape are considered during project planning (Wortman-Wunder 2012). We hope that this linkage design and report will be incorporated as a supporting resource for the forthcoming revision of the Comprehensive Plan.

The City of Flagstaff has incorporated goals and policies for promoting wildlife habitat connectivity in the "Environmental Planning and Conservation" and "Open Space" elements of its revised Draft Regional Land Use Plan currently in review (City of Flagstaff 2013). The "Open Space" element promotes use of tools such as conservation easements, transfer of development rights, and prioritizing parcels that overlap wildlife corridors for future acquisition as open space. The Draft Plan also includes Arizona Game and Fish Department wildlife corridor GIS data as a layer in its composite map of important natural resources, proposed to be considered in project permitting and planning, and the City assessed potential impacts to mapped corridors in modeling the consequences of various development patterns during Plan development.

Summary: Using the linkage design as a planning tool

This San Francisco Peaks-Mogollon Rim linkage design is a biologically-based plan for conservation action in central Coconino County. It can be integrated into local and regional planning efforts by government planners, state and federal land managers, and conservation organizations as a recommendation to protect habitats and landscape connections that maintain regional biodiversity and ecosystem processes. The Coconino County Comprehensive Plan and the City of Flagstaff's Regional Land Use Plan acknowledge the importance of wildlife movement areas and include policies and planning tools aimed at their conservation. The U.S. Forest Service, managing the Coconino and Kaibab National Forests and the majority of the linkage planning area, has incorporated existing Arizona Game and Fish Department linkage data into its resource management and wilderness plans for the region, and into proposed treatment prescriptions developed for the ambitious multiple stakeholder Four Forests Restoration Initiative. The Forest Service can use this linkage design to further refine elements of its plans and prescriptions that address the maintenance of wildlife habitat connectivity.

This linkage design may inform barrier mitigation, including the crossing structures recommended above, and habitat improvement efforts such as removing and retrofitting fencing to "wildlife-friendly" specifications. The Arizona Department of Transportation is providing considerable financial support to Arizona Game and Fish Department biologists to determine movement patterns of large mammals and identify locations for wildlife crossings along Interstate Highway 40. Our linkage design is being used to reinforce this research and to identify species not studied directly that may benefit from proposed crossings. This linkage design can also inform habitat restoration projects to maximize wildlife benefits. A partnership between the Arizona Wildlife Federation, National Forest Foundation, Arizona Game and Fish Department, and U.S. Forest Service has used this linkage design to guide fence removal and road closures in support of Four Forests Restoration Initiative goals for improving wildlife habitat. This linkage designs may also guide and support regional land acquisition, conservation easements, open space management, and zoning. The City of Flagstaff, Coconino County, and U.S. Department of Defense are pursuing various open space acquisitions and easements in the linkage area.

Finally, it is important to remember that the benefits of wildlife linkages can only be fully realized if the habitat blocks they connect also remain protected and effectively managed for wildlife. It is our hope that over time this project and others will contribute to a more complete picture of connected habitats in northern Arizona, and facilitate planning at multiple scales that recognizes the importance of interconnected habitats for the benefit of both wildlife and society.

APPENDIX A: LINKAGE DESIGN METHODS

Our goal was to identify continuous corridors of land that, if conserved with appropriate mitigation of potential barriers, will best maintain or restore habitat linking two protected wildland blocks. We call these proposed corridors the *linkage design*.

To create the linkage design we employed GIS-based techniques and a focal species approach, integrated with the best available data and wildlife expertise, to model optimal travel routes for species representing the ecological community of the region[3]. By carefully selecting a diverse group of focal species the linkage design should ensure the long-term viability of all species in the study area, including those for which we did not develop models. Our approach followed these general steps:

1) Select focal species
2) Create habitat suitability models for each focal species
3) Identify potential breeding patches and potential population cores of suitable habitat in each wildland block
4) Identify the biologically best corridor (BBC) through which each focal species could move between cores in the wildland blocks; join these BBCs for all focal species
5) Ensure that the union of BBCs includes enough population patches and is wide enough to accommodate all focal species
6) Carry out field visits to identify barriers to movement and potential mitigation sites

Focal species selection

The focal species concept assumes that a carefully selected set of diverse species will represent the needs of an entire biological community (Lambeck 1997). Biologists familiar with the region's taxa identified species meeting one or more of the following criteria:

- Habitat specialists, especially of habitats that may be relatively rare in the potential linkage area.
- Barrier sensitive species averse to highways, canals, urbanization, or other potential barriers in the potential linkage area, especially species with limited movement ability.
- Species with large home ranges requiring expansive and well-connected landscapes to maintain a viable population and genetic diversity.
- Ecologically-important and keystone species such as top predators, important seed dispersers, and species that affect vegetation, soil structure, or other ecosystem processes.
- Species of concern to management agencies, such as those listed as threatened or endangered by the US Fish and Wildlife Service under the Endangered Species Act and species of special concern to the Arizona Game and Fish Department or US Forest Service.

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[3] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute "truth" but rather an estimate or prediction of the optimal wildlife corridor. Despite this limitation, there are several reasons to use models instead of maps hand-drawn by species experts or other intuitive approaches. (1) Developing the model forces important assumptions into the open. (2) Using the model makes us explicitly deal with interactions (e.g., between species movement mobility and corridor length) that might otherwise be ignored. (3) The model is transparent, with every algorithm and model parameter available for anyone to inspect and challenge. (4) The model is easy to revise when better information is available.

Information on each focal species is presented in Appendix B. As indicated in the footnote to Table 1, we created models for species for which we had an adequate understanding of habitat associations specific to our region and could obtain reliable GIS data on which to base models. Selected species have been documented using habitat in both wildland blocks and the potential linkage area. We did not model species for which these criteria were not met or species likely to travel (e.g., by flying) across unsuitable habitat. We designated focal species requiring multiple generations to traverse the distance between wildland blocks as “corridor dwellers.” For these species we created habitat suitability and patch models but did not model corridors, and ensured that our final linkage design included adequate breeding and dispersal habitat for each. Our selection process resulted in a set of 11 focal species on which the linkage design is based.

Habitat suitability models

We created habitat suitability models for each species (Appendix B) using ArcGIS tools and GIS datasets developed by Dr. Paul Beier and colleagues at Northern Arizona University (CorridorDesign.Org). We modified some GIS datasets as described immediately below, and created a fifth habitat layer, perennial water, *de novo* from several existing datasets to model suitable habitat for northern leopard frog. Models were parameterized by estimating how the species responded to classes of the following five habitat factors that were mapped at a 30x30 m level of resolution (Figure 15):

- Vegetation and land cover. We used the Southwest Regional GAP Analysis (ReGAP) data provided by CorridorDesign.Org, which merges some classes to create 46 vegetation and land cover classes (Appendix D). We edited this layer to better reflect current land cover using a) an improved parcels dataset provided by Coconino County and b) a pipeline dataset held by Arizona Game and Fish.
- Elevation. We used the USGS National Elevation Dataset digital elevation model.
- Topographic position. We characterized each pixel as ridge, canyon bottom, flat to gentle slope, or steep slope.
- Straight-line distance from the nearest paved road or railroad. Distance from roads reflects risk of being struck by vehicles as well as noise, lights, pets, pollution, and other related human-caused disturbances. We edited the roads dataset provided by CorridorDesign.org by adding a line feature for the Burlington Northern Santa Fe railroad before creating the road-distance layer.
- Distance from perennial water. We created a perennial water dataset from several base datasets including both natural and human-created (e.g. stock tank) sources and used distance from water to create the northern leopard frog habitat model. Methods for creating the perennial water dataset are detailed in Appendix E.

To create a habitat suitability map for each species, we assigned each of the 46 vegetation classes (and each of 4 topographic positions, and each of several elevation classes and distance-to-road or –to-perennial water classes) a score from 10 (best) to 0 (worst), where 8-10 is optimal habitat, 6-7 is suboptimal but usable habitat, 3-5 may be occasionally used but cannot sustain a breeding population, and 0-2 is strongly avoided. When available we used habitat suitability scores provided by CorridorDesign.Org[4] and enlisted Arizona Game and Fish biologists with regional species expertise to review and adjust these scores to better reflect habitat associations in the linkage planning area (see also “Identifying biologically best corridors”). Suitability scores for 4 focal species (Abert’s squirrel, Arizona black rattlesnake, Gunnison’s prairie dog, and northern leopard frog) were created anew for this linkage design based on input solicited electronically from recognized agency and academic experts. For northern leopard frog we convened an expert team of agency and academic biologists for an in-person meeting and follow-up conversations to parameterize this species’ habitat suitability model. Experts also provided a relative factor weight for each of the factors (land cover, elevation, topographic position, distance from roads, and/or distance from water) to indicate influence on habitat selection. Factor weights summed to 100%. Only northern leopard frog species experts were asked to weight and score the distance from water factor, so this factor has no weighting for all other species (see Table 3).

This scoring produced up to 5 factor scores for each pixel, each score being a number between 0 and 10. We calculated a weighted geometric mean using the (up to 5) weighted factor scores to produce an overall habitat suitability score that was also scaled 0-10 (USFWS 1981). For each pixel of the landscape, the weighted geometric mean was calculated by raising each factor score by its weight, and multiplying the factors:

$$HabitatSuitabilityScore = Veg^{W1} * Elev^{W2} * Topo^{W3} * Road^{W4} * Water^{W5}$$

We used these habitat suitability scores to create a habitat suitability map for the linkage planning area that formed the foundation for the later modeling steps.

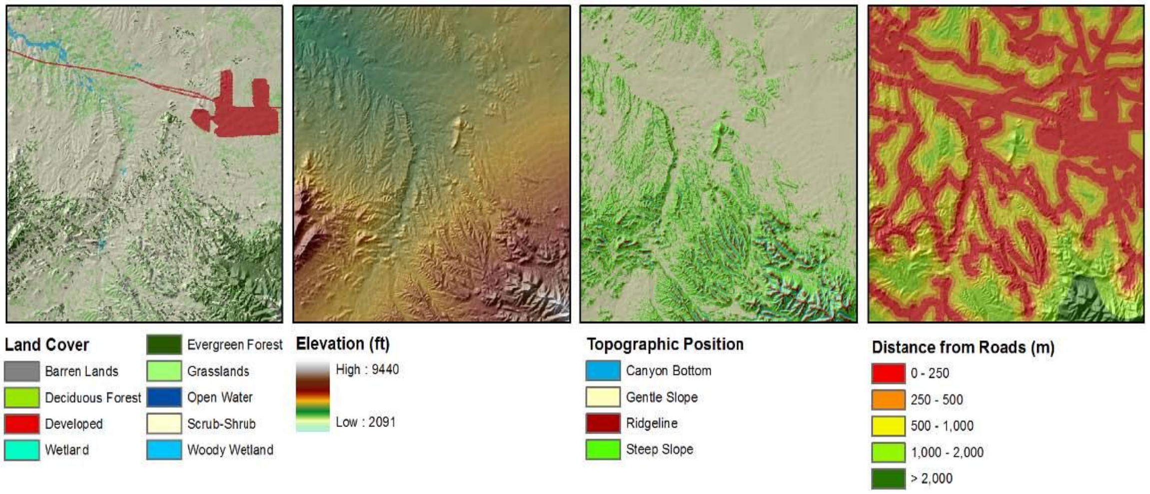

Figure 15: Habitat factors used to create habitat suitability models. Inputs included land cover, elevation, topographic position, distance from roads, and distance from perennial water (distance from water layer not shown. Source: Beier et al. 2007a).

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[4] CorridorDesign.Org recruited external biologists with expertise in each species to assign scores whenever possible, otherwise three CD biologists independently assigned scores, discussed differences, adjusted their scores, and the results were averaged. In either case scorers first reviewed the literature on habitat selection by the focal species. Clevenger et al. (2002) found that literature review significantly improved the fit between expert scores and later empirical observations of animal movement.

Identifying potential breeding patches and potential population cores

The habitat suitability map provides scores for each 30x30-m pixel. For our analyses, we also needed to identify – both in the wildland blocks and in the potential linkage area – areas of good habitat large enough to support reproduction. Specifically, we wanted to identify:

- Potential breeding patches: areas large enough to support a breeding unit (individual female with young, or a breeding pair) for one breeding season. Such patches could be important stepping-stones for species that are unlikely to cross a potential linkage area within a single lifetime.
- Potential population cores: areas large enough to support a breeding population of the focal species for about 10 years.

To do so, we first calculated the suitability of any pixel as the average habitat suitability in a neighborhood of pixels surrounding it (Figure 16). We averaged habitat suitability within a 3x3-pixel neighborhood (90 x 90 m^2, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[5]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score $\geq$ 6) into polygons that represented potential breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

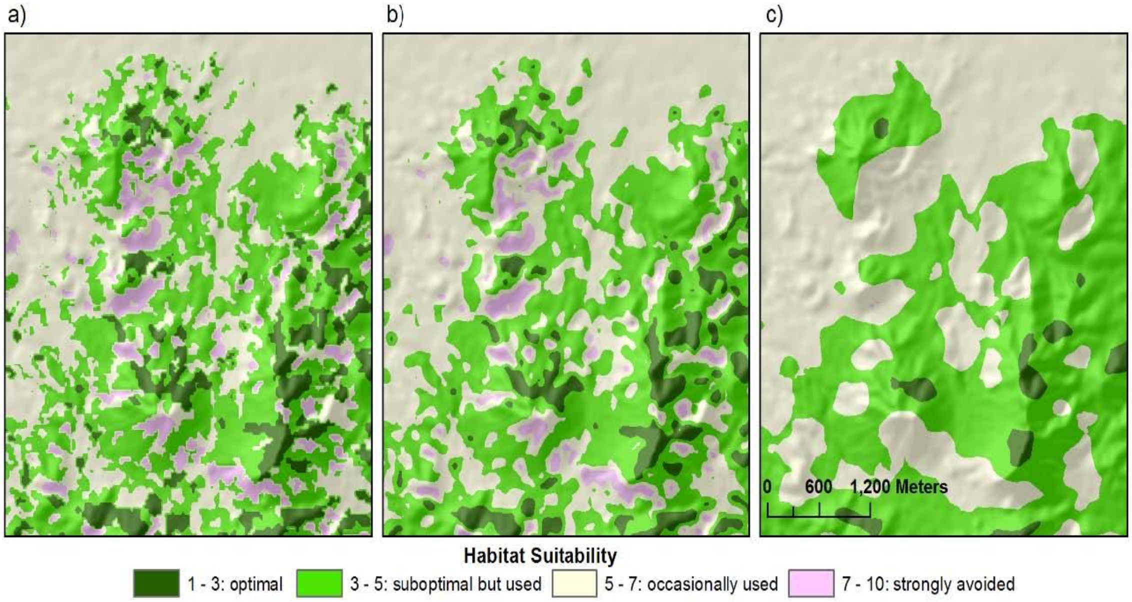

Figure 16: Example moving window analysis used to calculate the average habitat suitability surrounding

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[5] An animal that moves over large areas for daily foraging perceives the landscape as composed of relatively large patches, because the animal readily moves through small swaths of unsuitable habitat in an otherwise favorable landscape (Vos et al. 2001). In contrast, a less-mobile animal has a more patchy perception of its surroundings. Similarly, a small island of suitable habitat in an ocean of poor habitat will be of little use to an animal with large daily spatial requirements, but may be sufficient for the animal that requires little area.

a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window. (Source: Beier et al. 2007a). [*NOTE: Numeric scoring ranges shown are those used in prior CorridorDesign.Org linkage reports and do not reflect the opposite 10-0 scaling used in this design, but the color scheme and conceptual illustration accurately reflect the methods we used*].

Identifying biologically best corridors

The *biologically best corridor*[6] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one wildland block to a potential population core in the other wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero. Travel cost and permeability reflect the scores created during habitat suitability modeling, such that high suitability equals high permeability (and conversely, low travel cost).

We developed BBCs only for those focal species that can move between wildland blocks in a single generation, and thus in less time than disturbances such as fire or climate change will make the current vegetation map obsolete. For focal species that did not meet this criterion (the 4 “corridor dwellers”) we conducted patch configuration analysis (next section).

We created a pair of wildland blocks encompassing relatively protected lands in our analysis area on the Kaibab and Coconino National Forests north and south of Interstate Route 40. The relatively close proximity of these blocks would cause our GIS procedure to identify BBCs in those areas where they nearly touch, even though the resulting corridor would not necessarily include the best habitat for the species being modeled[7]. A BBC drawn this way could be unrealistic, and could serve small wildlife populations near the road while failing to serve much larger populations in the rest of the wildland block. To address these problems for purposes of BBC analyses we redefined the blocks so that their facing edges were parallel to each other, making the distances between their edges a nearly uniform 21 km (13 mi).

We next identified potential population cores and potential breeding patches that fell completely within each wildland block. If potential population cores existed within each block we used these as the starting and ending points for creating BBCs. Otherwise, the start-end points were potential breeding patches within the wildland block, or (for a wide-ranging species with no potential breeding patch entirely within a wildland block) any suitable habitat within the wildland block.

To create each biologically best corridor, we used the modeled habitat suitability score as an estimate of the cost of movement through each pixel[8]. For each pixel we then calculated the lowest *cumulative cost* to that pixel from a starting point in one wildland block. We similarly

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[6] This approach has often been called Least Cost Corridor Analysis (Beier et al. 2006) because it identifies areas that require the least cost of travel (energetic cost, risk of mortality) to the animal. However, CorridorDesign.Org recommends avoiding use of the term “least cost” because this is easily misunderstood as referring to the dollar cost of conserving land or building an underpass.

[7] The GIS algorithm will almost always select a corridor 100 m long (width of a freeway) over a corridor 5 miles long, even if the habitat is much better in the longer corridor.

[8] Levey et al. (2005) provide evidence that animals make movement decisions based on habitat suitability.

calculated the lowest cumulative travel cost to the pixel from the second wildland block, and added these 2 cumulative travel costs to calculate the *total travel cost* for each pixel. The total travel cost reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a species-specific minimum functional width (Figure 17). While we used 1000m as a general minimum width as per prior CorridorDesign.Org linkage designs (see Beier et al. 2008), we increased this for some wide-ranging species (e.g. black bear) for which a greater width would better ensure the BBC's long-term integrity. If a species had two or more distinct strands in its biologically best corridor we eliminated any strand markedly worse than the best strand (e.g. narrower than the desired minimum width), but otherwise we retained multiple strands if they had roughly equal travel cost overall.

We shared our intial BBCs with local species experts and utilized location and telemetry data when available to validate and refine the models. We also referenced aerial imagery to identify potential errors in the model output. Model results that could not be supported by formal and informal evaluation were further investigated. We were able to correct any issues by revising the underlying species parameters based on local information to better reflect habitat associations in our analysis area (see "Habitat suitability models").

For a number of species the BBC models created with our initially-defined wildland blocks included corridor strands only to the west of Camp Navajo, even though empirical data and expert opinion indicated that most of these species also used Woody Ridge as a movement corridor. In order to capture known connectivity for populations using the San Francisco Peaks and moving down through Woody Ridge, we defined a smaller northern habitat block within the larger block with western edge defined primarily by the Coconino National Forest boundary. We then created a second set of BBCs between this smaller northern block and the Mogollon Rim Block, and integrated these with BBCs created using the original larger northern block in the next and final step.

After developing a biologically best corridor for each species, we combined all biologically best corridors to form a union of biologically best corridors (UBBC). The UBBC for this linkage design was based on corridor models created for badger, black bear, bobcat, elk, mule deer, porcupine, and pronghorn.

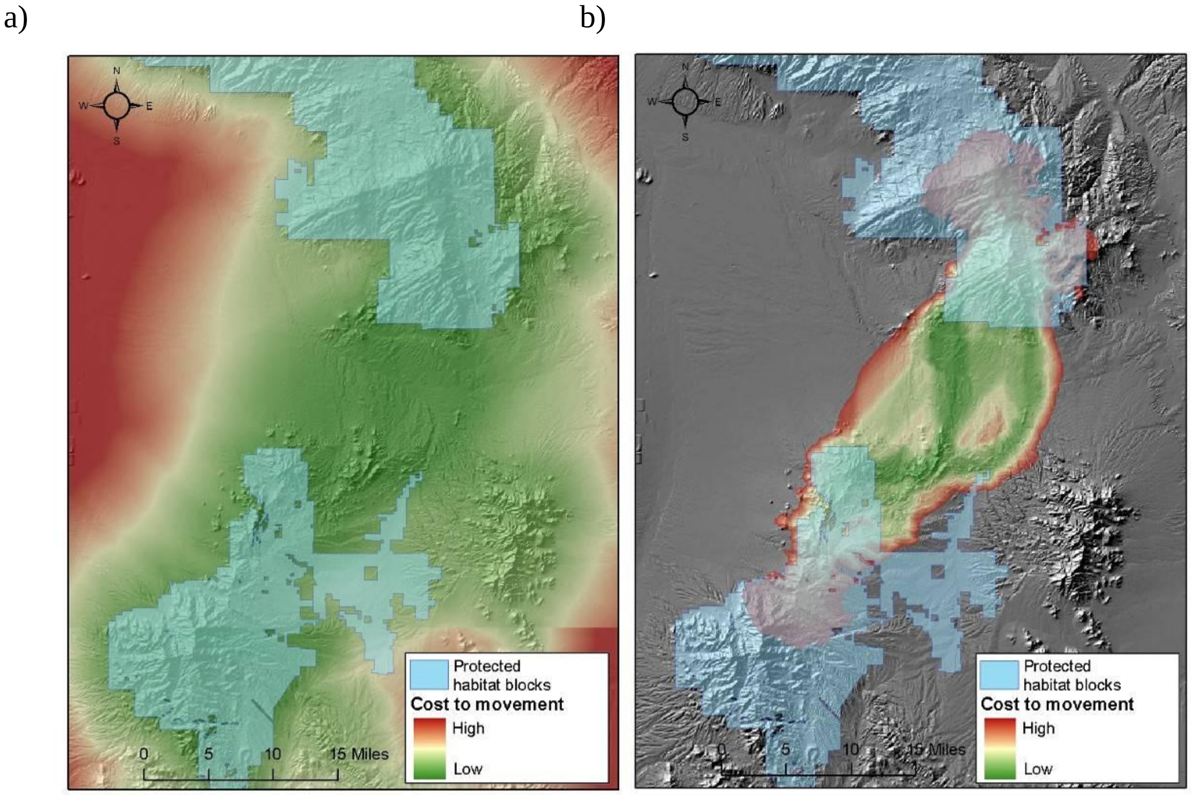

Figure 17: Creation of biologically best corridors. a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape. (Source: Beier et al. 2007a).

Patch configuration analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, biologically best corridors were not modeled for some focal species (see previous section). To address these issues we examined whether the UBBC encompasses adequate potential breeding patches and potential population cores for each focal species, including species for which a BBC was estimated. For species requiring multiple generations to move between wildland blocks (corridor dwellers) we compared the distance between neighboring cores and patches to the species' dispersal[9] distance, because a patch of habitat beyond dispersal distance will not promote connectivity. We also verified that each linkage strand was at least twice the home range width for corridor dwellers to minimize the likelihood that territorial interactions would limit the ability of individuals to move through the corridor.

For species with limited suitable habitat within the UBBC (Gunnison's prairie dog and northern leopard frog) we looked for potential habitat patches within the potential linkage area but outside of the UBBC. For northern leopard frog, when such patches overlapped the UBBC or were within the species' dispersal distance from patches within it, we merged these polygons to the

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[9] Dispersal distance is how far an animal moves from its birthplace to its adult home range. We used dispersal distances reported by species experts and in published literature.

UBBC (see Appendix B for explanation of why this step was not taken for Gunnison's prairie dog). This widened the strands of the UBBC only slightly but allowed us to accommodate additional high quality habitat for this species.

Minimum linkage width

Wide linkages are beneficial for several reasons. They (1) provide adequate area for development of metapopulation structures necessary to allow corridor-dwelling species (individuals or genes) to move through the landscape; (2) reduce pollution into aquatic habitats; (3) reduce edge effects such as pets, lighting, noise, nest predation & parasitism, and invasive species; (4) provide an opportunity to conserve natural fire regimes and other ecological processes; and (5) improve the opportunity of biota to respond to climate change. To address these concerns, we established a minimum width of 1 km (0.62 mi) along the length of each strand of the preliminary linkage design. We widened any bottlenecks where possible by adding natural habitats that included high-quality habitat for one or more focal species. In some areas the preliminary linkage design was considerably wider than 1 km due to the partial overlap of individual BBCs. Because we had used relatively generous minimum widths in developing BBCs, we were able to narrow the preliminary linkage design in these areas and still maintain a minimum 1 km width for both individual BBCs and the overall linkage design. The result of these adjustments was the final linkage design.

Field investigations and empirical validation

We examined areas of the modeled corridor where data were scarce or we had concerns about the model output through targeted field visits. Based on these investigations we wish to highlight the following issues for possible future mitigation and restoration:

- Fencing poses significant barriers to pronghorn and other species. While portions of Garland Prairie are particularly impacted, fencing is prevalent throughout the linkage analysis area. Where practicable, fencing might be removed or upgraded to wildlife-friendly specifications (see "Guidelines for mitigating impacts from urban and rural development" for further discussion).
- Several small communities within the linkage have potential for future growth. Strategic development should accommodate wildlife movement to the greatest extent possible.

As detailed above (see "Recommendations for crossing structures in the linkage design") we also relied on telemetry data and field investigations conducted by the Arizona Game & Fish Department, Wildlife Contracts Branch to guide our recommendations for wildlife crossing structures along key roadways.

Finally, we referenced a number of regional empirical datasets which allowed us to both validate and refine our initial BBC models for selected species. These included the following:

- Camera-trap black bear occurrence data on Camp Navajo provided by Janet Lynn of the Camp.
- Arizona Department of Transportation collision data for elk and mule deer along Interstate Route 40.

- Telemetry locations and maps for elk, mule deer, and pronghorn provided by the Arizona Game and Fish Department Research and Contracts Branches.
- Arizona black rattlesnake occurrence data provided by Erika Nowak of Northern Arizona University.
- Northern leopard frog historical locations provided by Susan MacVean of the Arizona Game and Fish Department Nongame Branch.
- Mexican spotted owl occurrence data acquired from the Arizona Game and Fish Department's Heritage Database Management System

See individual species sections in Appendix B for a description of how we integrated these various data sources into the development and validation of our linkage design. A number of these datasets were proprietary and focused on sensitive species, thus we do not present all spatially-explicit location data herein in order to protect the welfare of the species involved.

Creating a final linkage design

To create the final linkage design, we combined biologically best corridors for all passage focal species modeled and made several minor edits to the union of biologically best corridors:

- We widened the UBBC where necessary to ensure the minimum functional width for all species served by each strand (1.2 – 2 km).
- We trimmed excess width where aerial imagery indicated developed land or poor habitat for the species served, or where BBCs were wider than the species-specific minimum functional width.
- We eliminated gaps in the strands where habitat was suitable for all focal species served in that area and land was undeveloped.
- We expanded the UBBC to capture significant areas of optimal habitat for corridor dwellers, particularly northern leopard frog, where these overlapped or were within the species' dispersal distance of UBBC strands.

APPENDIX B: INDIVIDUAL SPECIES ANALYSES

Table 3: Habitat suitability scores and factor weights for each focal species. Scores range from 10 (best) to 0 (worst), with 8-10 indicating optimal habitat, 6-7 suboptimal but usable habitat, 3-5 occasionally used but not breeding habitat, and 0-2 avoided.

	Abert's squirrel	Arizona black rattlesnake	Badger	Black bear	Bobcat	Elk
Factor weights						
Land Cover	90	45	65	75	80	75
Elevation	5	15	7	10	5	0
Topographic position	0	30	15	10	15	0
Distance from Roads	5	10	13	5	0	25
Distance from Water	-	-	-	-	-	-
Land Cover						
Mixed Conifer Forest and Woodland	8	6	5	8	9	10
Pine-Oak Forest and Woodland	5	10	5	10	9	10
Pinyon-Juniper Woodland	4	7	7	8	9	10
Ponderosa Pine Woodland	10	8	5	7	9	10
Spruce-Fir Forest and Woodland	4	2	5	7	9	9
Aspen Forest and Woodland	4	2	5	5	9	10
Juniper Savanna	0	4	9	3	7	10
Montane-Subalpine Grassland	0	0	9	7	5	10
Semi-Desert Grassland and Steppe	0	3	10	5	7	7
Chaparral	0	7	5	10	9	7
Creosotebush-White Bursage Desert Scrub	0	0	9	1	7	1
Desert Scrub (misc)	0	5	8	8	7	2
Gambel Oak-Mixed Montane Shrubland	2	8	5	10	9	8
Mesquite Upland Scrub	0	2	8	7	7	3
Riparian Woodland and Shrubland	0	9	5	10	8	10
Mixed Bedrock Canyon and Tableland	0	5	1	0	4	1
Playa and High-Elevation Ephemeral Wetland	0	0	2	0	3	10
Volcanic Rock Land and Cinder Land	0	1	1	0	7	5
Developed, Medium - High Intensity	3	1	1	0	2	7
Developed, Open Space - Low Intensity	6	4	3	0	8	8
Open Water	0	0	1	0	0	0
Elevation (ft)						
	0-5000: 0	0-5000: 8	0-5500: 10	0-2500: 2	0-7500: 10	
	5000-7000: 9	5000-7000: 10	5500-8000: 8	2500-4000: 4	7500-10000: 5	
	7000-9000: 10	7000-15000: 8	8000-15000: 5	4000-6500: 9	10000-15000: 1	
	9000-15000: 2			6500-8500: 8		
				8500-15000: 7		
Topographic Position						
Canyon Bottom		9	5	8	10	
Flat - Gentle Slopes		7	10	4	8	
Steep Slope		8	2	8	4	
Ridgetop		7	3	7	3	
Distance from Roads (m)						
	0-250: 6	0-250: 3	0-250: 5	0-100: 4		0-100: 1

	250-500: 7	250-500: 6	250-15000: 10	100-500: 7		100-200: 2
	500-1000: 8	500-1000: 9		500-15000: 10		200-400: 4
	1000-15000: 10	1000-15000: 10				400-1000: 5
						1000-2000: 8
						2000-15000: 10

	Gunnison's prairie dog	Mule deer	Northern leopard frog	Porcupine	Pronghorn
Factor Weights					
Land Cover	45	65	15	87	45
Elevation	25	0	0	0	0
Topographic position	30	30	25	3	37
Distance from Roads	0	5	10	10	18
Distance from Water	-	-	50	-	-
Land Cover					
Mixed Conifer Forest and Woodland	2	8	8	9	5
Pine-Oak Forest and Woodland	1	8	8	10	4
Pinyon-Juniper Woodland	4	8	8	9	8
Ponderosa Pine Woodland	3	8	8	10	7
Spruce-Fir Forest and Woodland	0	5	8	10	3
Aspen Forest and Woodland	0	10	8	10	4
Juniper Savanna	7	7	8	5	8
Montane-Subalpine Grassland	8	2	8	4	10
Semi-Desert Grassland and Steppe	9	2	8	5	10
Chaparral	3	10	8	6	2
Creosotebush-White Bursage Desert Scrub	0	4	8	5	8
Desert Scrub (misc)	7	4	8	5	7
Gambel Oak-Mixed Montane Shrubland	0	7	8	7	7
Mesquite Upland Scrub	2	8	8	6	4
Riparian Woodland and Shrubland	0	8	1	8	2
Mixed Bedrock Canyon and Tableland	0	3	1	4	3
Playa and High-Elevation Ephemeral Wetland	1	4	1	0	3
Volcanic Rock Land and Cinder Land	0	2	1	1	3
Developed, Medium - High Intensity	7	1	1	1	3
Developed, Open Space - Low Intensity	8	5	8	3	4
Open Water	0	0	1	0	3
Elevation (ft)					
	0-4000: 0				
	4000-5000: 6				
	5000-7000: 10				
	7000-15000: 10				
Topographic Position					
Canyon Bottom	2	5	10	10	3
Flat - Gentle Slopes	9	7	8	9	10
Steep Slope	3	8	2	10	2
Ridgetop	0	9	3	9	4
Distance from Roads (m)					
		0-250: 7	0-100: 3	0-250: 2	0-100: 1
		250-15000: 9	100-250: 8	250-500: 5	100-250: 4
			250-15000: 10	500-1000: 9	250-1000: 8
				1000-15000: 10	1000-15000: 10
Distance from Water (m)					
			0-100: 10		
			100-500: 3		
			500-15000: 0		

Abert's squirrel (*Sciurus aberti*)

Justification for Selection

Three subspecies of Abert's squirrel, also called the tassel-eared squirrel, are found in Arizona: Abert's (*S. a. aberti*), Kaibab (*S. a. kaibabensis*), and Abert's Chuska (*S. a. chuscensis*). This arboreal mammal is closely associated with pine forest in the Four Corners region. This species was included because its habitat needs represent those of many coniferous forest specialists. It is a Forest Service Management Indicator Species as it is locally abundant, is an obligate forest dweller, responds to changes in forest structure, is economically important as game, and is prey for the northern goshawk (*Accipiter gentilis*), a Federal Species of Concern.

Distribution

The tassel-eared squirrel is found within forests dominated by ponderosa pine (*Pinus ponderosa*) on the Colorado Plateau and in the southern Rocky Mountains in Arizona, Utah, Colorado, New Mexico, Wyoming, and northern Mexico. These dry forests occur at elevations from 1,800 to 2,600 meters (5,900 to 8,500 feet), however introduced Abert's squirrel populations occur up to 10,400 feet in Arizona's Pinaleño mountains. This squirrel is common throughout most of its range, although rare in parts of the periphery.

Habitat Associations

The primary food source for tassel-eared squirrels is ponderosa pine, along with fungi (truffles and mushrooms), acorns, and mistletoe (States et al. 1988; Hutton et al. 2003). Pine stands with interlocking crowns provide nest trees and travel cover (Patton et al. 1985). Optimal habitat, according to Dodd et al. (1998), includes large seed trees (30-74 cm diameter at breast height [dbh]) and interlocking canopies, while marginal habitat is dominated by trees 2.5-30.3 cm dbh. Nest trees are generally taller and larger than surrounding trees (19.0 ± 2.7 m versus 13.5 ± 5.1 m tall and 37.5 ± 7.5 cm versus 28.9 ± 11.6 cm dbh) (Halloran and Beckoff 1994). Quaking aspen stands and meadows are considered non-habitat.

Prather et al. (2006) found that local basal area explained squirrel density in 9 northern Arizona studies, while basal area and canopy cover greater than 50% at the 160-ha scale explained recruitment. Canopy cover of 40-50% probably represents a threshold for optimal tree squirrel habitat (Prather et al. 2006; Loberger et al. 2011). Optimal basal area is greater than 35 m^2/ha (150 ft^2/ac) (Dodd et al. 1998). Habitat patchiness, particularly in regards to fuels reduction treatments, is probably important for foraging, nesting, and escaping predators. Large trees with interlocking crowns are selected for nest sites, while smaller "jack pines" are associated with hypogeous fungi (Dodd et al. 1998).

While ponderosa pine-dominated forests represent optimal habitat, Abert's squirrels utilize other tree species for various habitat needs. Occasionally squirrels feed on Douglas fir (*Pseudotsuga* *menziesii*) or pinyon pine (*Pinus edulis*) cones. Gambel's oak (*Quercus gambelii*) provides acorns and occasionally nesting cavities. Hutton et al. (2003) documented Abert's squirrels in Arizona foraging, feeding, chasing, and nest building in mixed conifer and spruce-fir forests.

Spatial Patterns

Estimates for individual home ranges vary from less than 4 ha for females in the non-breeding season (Farentinos 1979) to 26 ha (Lema 2001) to greater than 70 ha, depending on habitat quality. Estimated population densities vary even more widely seasonally and year-to-year (Dodd et al. 1998; Dodd 2003; Keith 2003). Abert's squirrels are non-territorial, occasionally nesting in pairs or groups (Lema 2001). Farentinos (1972) recorded juvenile dispersal distances between 840 and 1,440 meters (0.5-0.89 miles).

Conceptual Basis for Model Development

Habitat suitability model – Forest structure and composition is probably the most important habitat attribute for tassel-eared squirrels. Elevation is important to the degree that it influences vegetation and also the severity of winter snow, a major cause of mortality. Individuals seem to readily cross roads, but are also commonly killed in collisions. They have been observed traveling several hundred meters to drink from streams (Farentinos 1979). Land cover received an importance weight of 90%, while elevation, topography, and distance from roads received weights of 5%, 0%, and 5%, respectively. For specific scores of classes within each of these factors see Table 3.

Patch size & configuration analysis – Towry (1984) estimated a minimum viable population would require 30 individuals and 174 ha of optimal habitat. In 2006, Prather et al. concluded that high quality habitat over a 160-305 ha area is likely needed to facilitate recruitment. Wood et al. (2007) modeled population viability for several tree squirrel species, synthesizing the available literature for *Sciurus spp*. Under various environmental conditions, they estimated a minimum population of 15-45 Abert's squirrels could persist for 100 years. Most (13 of 14) tree squirrel introductions begun with at least 10 individuals have been successful over 50 years. Based on the input of species experts we defined minimum potential breeding patch size as 10 ha, and minimum potential population core size as 116 ha. To determine potential breeding patches and population cores, the habitat suitability model for this species was first averaged using a 3 x 3 pixel square neighborhood moving window analysis.

Biologically best corridor analysis – We did not model a biologically best corridor for this species. Based on dispersal distance data Abert's squirrel is considered a "corridor dweller" requiring more than a generation to traverse the distance between wildland blocks.

Results & Discussion

Union of biologically best corridors – While we did not model a biologically best corridor for this species, the habitat suitability model indicates that significant high-quality habitat exists for Abert's squirrel in both wildland blocks and in the linkage design itself, in particular in the more upland forested habitats within the western portion of Strand A and most of Strands B and C (Figure 18). Similarly, abundant population cores exist throughout much of both wildland blocks and the strands of the linkage design within the species' dispersal distance, indicating that the linkage design should facilitate successful movement of Abert’s squirrel between wildland blocks over multiple generations.

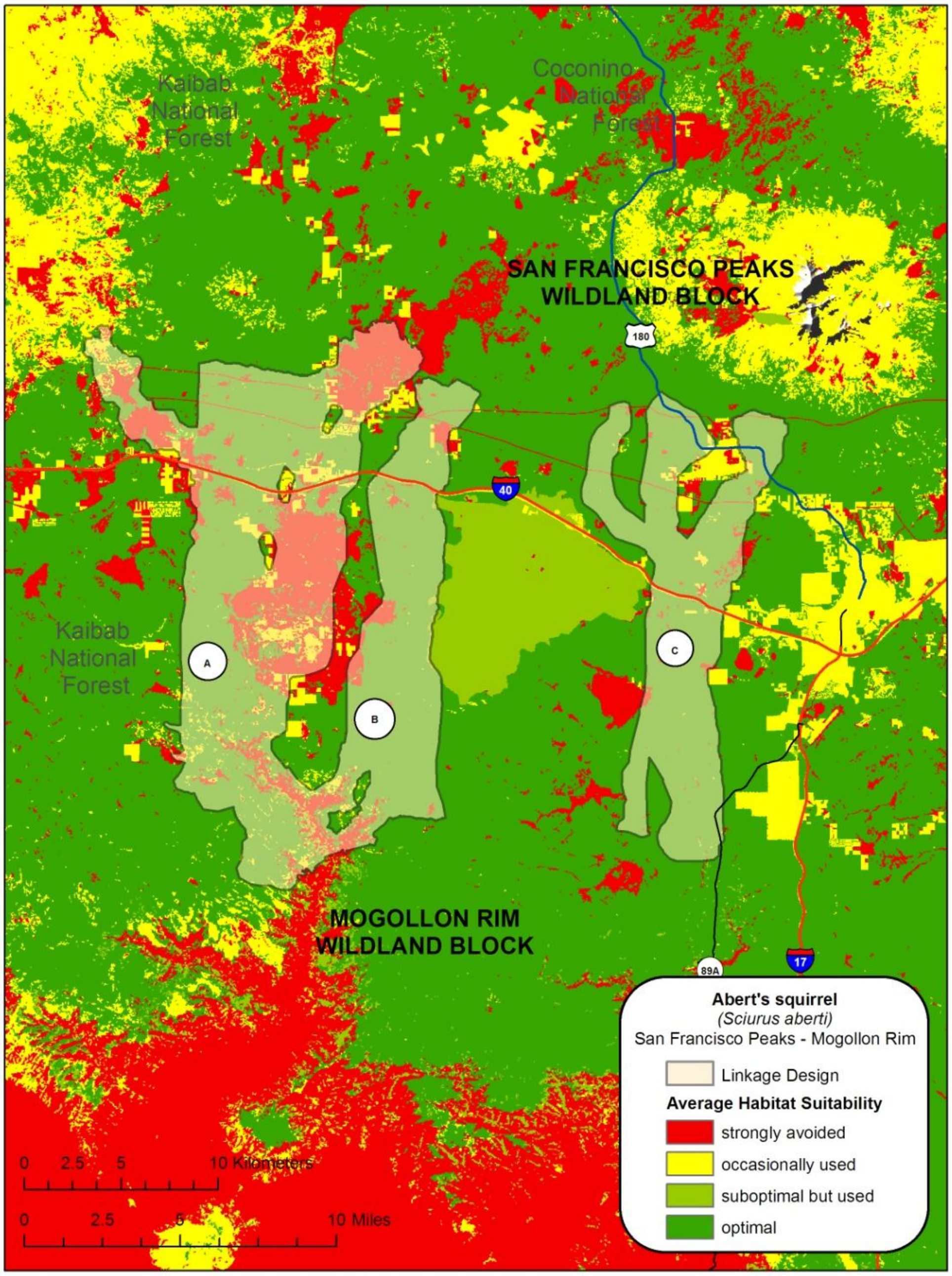

Figure 18: Modeled habitat suitability for Abert’s squirrel in the San Francisco Peaks – Mogollon Rim Linkage

Arizona black rattlesnake (*Crotalus cerberus*)

Justification for Selection

The Arizona black rattlesnake (*C. cerberus*), previously considered a subspecies of the Western rattlesnake (*C. viridis*) has recently been recognized as a distinct species (Crother et al. 2008). Due to its unique habitat requirements and distribution almost entirely within the state of Arizona, *C. cerberus* is an important focal species for wildlife connectivity.

Distribution

C. cerberus is found in mid- and high-elevation forested mountains in Arizona and New Mexico. Nickerson and Mays (1969) reported specimens and reliable accounts of individuals from 1,340 to 3,050 meters (4,400 to 10,000 ft) elevation, however individuals in Tonto National Monument were observed between 880 to 1,010 meters (2,880 and 3,310 ft) (Nowak 2005). The species' habitat selection is not well understood and the majority of available information is based upon anecdotal observation and limited radio-telemetry data. Nonetheless, reliable observations have been made in both habitat blocks and hibernation sites have been identified in the greater Flagstaff area (E. Nowak, pers. comm.).

Habitat Associations

Habitat types associated with *C. cerberus* include chaparral, Great Basin conifer woodland, Madrean evergreen woodland, Petran montane conifer forest, and occasionally Arizona upland desertscrub (Brennan and Holycross 2006). Relative to other rattlesnakes at Tonto National Monument, *C. cerberus* utilizes more mesic, dense upland habitats in remote areas (Nowak and Arundel 2009). Telemetry studies in the Monument indicate that individuals spend most of their time within Arizona sycamore and desert riparian scrub (Nowak 2005; Nowak and Arundel 2009). Individuals were also found within jojoba-mixed scrub. Mixed-grass mixed-scrub was also used by *C. cerberus*, but not significantly more than expected based on habitat availability. These two non-riparian habitat types were used for hibernation sites. Important microhabitat includes rock outcroppings, boulders, and woody debris for thermoregulation, ecdysis, and foraging (Schofer 2007). Prey includes birds, lizards, and small mammals. Telemetry locations in Tonto National Monument were more often located on north- or east-facing aspects with a mean slope of approximately 23% (range for 2005 study was 8-35%). However, seasonal shifts in aspect probably reflect thermoregulation. Hibernation sites were generally in north- or west-facing rocky talus slopes associated with washes (Nowak and Arundel 2009).

Spatial Patterns

Based on limited spatial studies of the species, *C. cerberus* occupies larger home ranges than other rattlesnake species (Schofer 2007; Nowak and Schofer 2005). This is thought to reflect sparseness of mates (females) across the landscape, rather than habitat or forage limitations (Schofer 2007). Average home range size in Schofer's 2007 telemetry study of 5 males was 25 ha with one individual utilizing 56 ha. Nowak (2009) documented annual home range sizes of 2.63 ha for a non-pregnant female, and averages of 1.99 ha for a pregnant female (over several years) and 27.15 ha for males, with a maximum of 91.2 ha for a male. She recommends that any animal that must be translocated be moved no more than 100 meters within the same habitat type of its original location.

Conceptual Basis for Model Development

Habitat suitability model – Individuals will move through more developed areas of National Parks and Monuments where they have been studied, but do not remain in populated areas. Important topographical features include canyon bottoms, dry rocky slopes, and rock slides (Brennan and Holycross 2006). Nowak (2009) estimated meaningful distance-to-feature classes based on her experience with this species and other herpetofauna. *C. cerberus* probably responds to human developed areas, free water, and rock outcroppings differentially at distances of 1-10m, 10-50m, 50-100m, 100-250m, and greater than 250 meters. Land cover received an importance weight of 45%, while elevation, topography, and distance from roads received weights of 15%, 30%, and 10%, respectively. For specific scores of classes within each of these factors see Table 3. Species experts also noted that the Arizona black rattlesnake depends on rocky outcroppings in basalt and other substrates for hibernacula. We were not able to develop an adequate data layer to capture these microhabitat features at our scale of interest, but species experts indicated that a model based on available data layers, while likely overestimating suitable habitat, would still be of value and enhance our linkage design (E. Nowak, personal comm.).

Patch size & configuration analysis – No data were found in the literature; model parameters were provided by regional species experts. Based on the input of species experts we defined minimum potential breeding patch size as 10 hectares, and minimum potential population core size as 116 hectares. To determine potential breeding patches and potential population cores, the habitat suitability model for this species was first averaged using a 3 x 3 pixel square neighborhood moving window analysis.

Biologically best corridor analysis – We did not model a biologically best corridor for this species. Based on expert opinion regarding likely dispersal distance data Arizona black rattlesnake is considered a “corridor dweller” requiring more than a generation to traverse the distance between wildland blocks.

Results & Discussion

Union of biologically best corridors – While we did not model a biologically best corridor for this species, the habitat suitability model indicates that significant high-quality habitat exists for Arizona black rattlesnake in both wildland blocks and in the linkage design itself, in particular in upland forested habitats within the western portion of Strand A and most of Strands B and C (Figure 19). Similarly, abundant population cores exist throughout much of both wildland blocks and the strands of the linkage design within the species’ dispersal distance, indicating that the linkage design should facilitate successful movement of Arizona black rattlesnakes between wildland blocks over multiple generations.

Our suitability model likely overestimates the amount of suitable habitat in the linkage planning area for this species since we were unable to incorporate a data layer for rocky outcroppings. We obtained georeferenced occurrence data from species expert Erika Nowak and her colleagues in an effort to validate our model; these data are sensitive and thus not presented here. The occurrence dataset included a relatively small number of observations, all of which were outside the potential linkage area. There are however 7 rattlesnake locations within or very close to the Mogollon Rim wildland block, and the data generally validate our suitability model. A majority of locations within the overall analysis area are associated with high-quality modeled habitat (13/20 locations within pixels with modeled habitat suitability $\geq$6.0, 5/20 in pixels with suitability $\geq$8.0). Creation of a rocky outcrop layer would provide a necessary refinement of our suitability model for this species in the future.

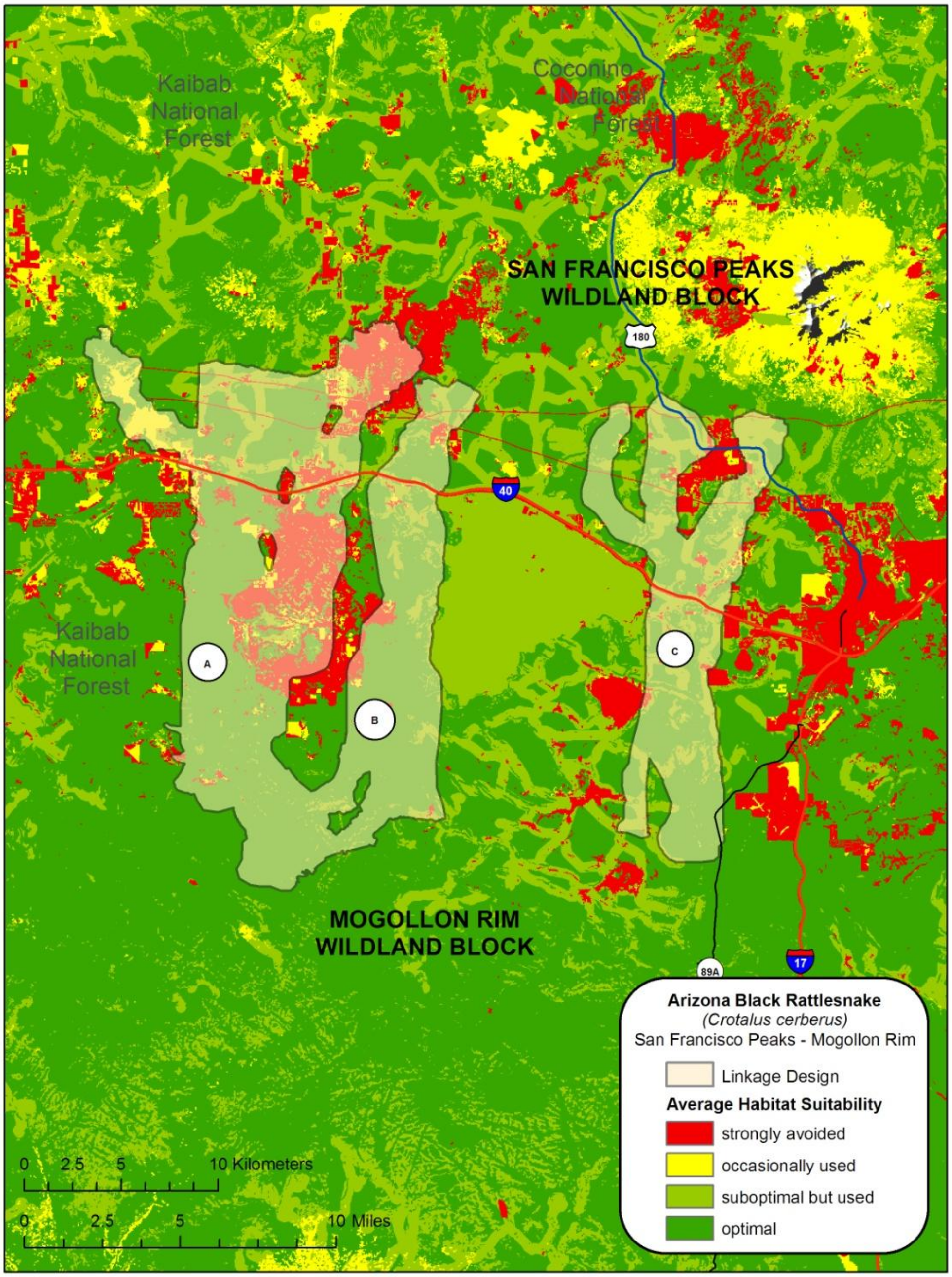

Figure 19: Modeled habitat suitability for Arizona black rattlesnake in the San Francisco Peaks – Mogollon Rim Linkage

Badger (*Taxidea taxus*)

Justification for Selection

Because of their large home ranges, many parks and protected lands are not large enough to ensure protection of a badger population, or even an individual (NatureServe 2005). Consequently, badgers have suffered declines in recent decades in areas where grasslands have been converted to intensive agricultural areas, and where prey animals such as prairie dogs and ground squirrels have been reduced or eliminated (NatureServe 2005). Badgers are also threatened by collisions with vehicles while attempting to cross highways intersecting their habitat (New Mexico Department of Game and Fish 2004, NatureServe 2005).

Distribution

Badgers are found throughout the western United States, extending as far east as Illinois, Wisconsin, and Indiana (Long 1973). They are found in open habitats throughout Arizona.

Habitat Associations

Badgers are primarily associated with open habitats such as grasslands, prairies, and shrublands, and avoid densely wooded areas (NMGF 2004). They may also inhabit mountain meadows, marshes, riparian habitats, and desert communities including creosote bush, juniper and sagebrush habitats (Long & Killingley 1983). They prefer flat to gentle slopes at lower elevations, and avoid rugged terrain (Apps et al. 2002).

Spatial Patterns

Overall yearly home range of badgers has been estimated as 8.5 km^2 (Long 1973). Goodrich and Buskirk (1998) found an average home range of 12.3 km^2 for males and 3.4 km^2 for females, found male home ranges to overlap more than female ranges (male overlap = 0.20, female = 0.08), and estimated density as 0.8 effective breeders per km^2. Messick and Hornocker (1981) found an average home range of 2.4 km^2 for adult males and 1.6 km^2 for adult females, and found a 20% overlap between a male and female home range. Nearly all badger young disperse from their natal area, and natal dispersal distances have been recorded up to 110 km (Messick & Hornocker 1981).

Conceptual Basis for Model Development

Habitat suitability model – Badgers prefer grasslands and other open habitats on flat terrain at lower elevations. They do not show an aversion to roads (Apps et al. 2002), which makes them sensitive to high road mortality. Vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received weights of 7%, 15%, and 13%, respectively. For specific scores of classes within each of these factors, see Table 3.

Patch size & configuration analysis – We defined minimum potential breeding patch size as 200 hectares, which is an average of the home range found for both sexes by Messick and Hornocker (1981), and equal to the female home range estimated by Goodrich and Buskirk (1998), minus 1 standard deviation. Minimum potential population core size was defined as 1000 hectares, approximately enough area to support 10 effective breeders, allowing for a slightly larger male home range size and 20% overlap of home ranges (Messick and Hornocker 1981). To determine potential breeding patches and population cores, the habitat suitability model for this species was first averaged using a 200m-radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that optimal and suitable habitat for badger is concentrated within the western portion of the potential linkage area in grassland habitats of Garland and Government Prairies and Pittman Valley, and to a lesser extent in the area south of Camp Navajo and Rogers Lake (Figure 20). Most of the highest quality habitat in this area is encompassed by the BBC. Population cores exist throughout most of the area encompassed by Strand A, and in grassland habitats in both wildland blocks, though these are generally restricted in the Mogollon Rim block to its northern portions.

Union of biologically best corridors – The additional area encompassed by the linkage design captures a small amount of additional suitable and optimal habitat for badger primarily in the portion of Strand B that intersects Garland Prairie. The primary threats to this species' connectivity and persistence are most likely Interstate 40 and future housing development in its relatively flat grassland habitats.

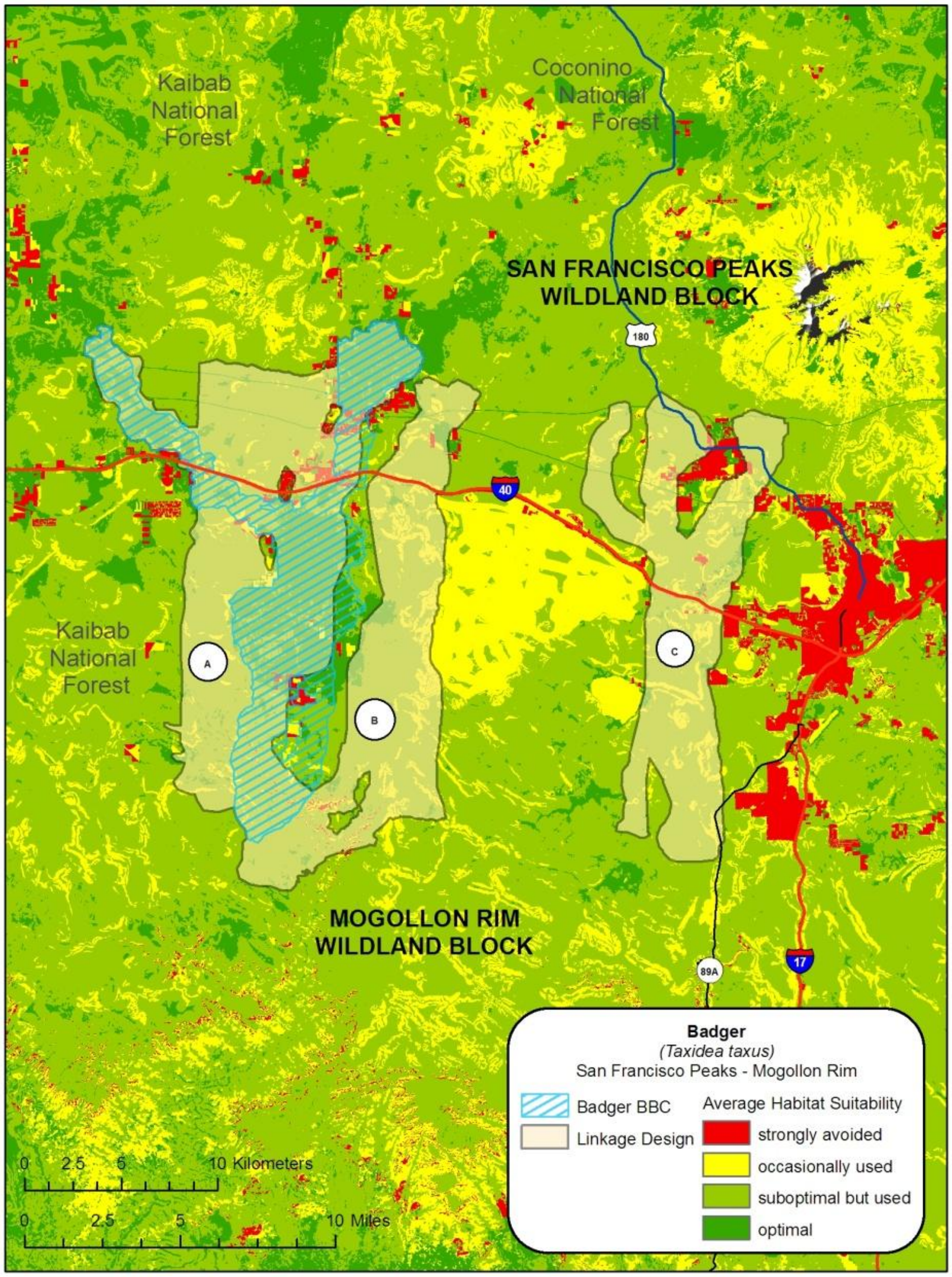

Figure 20: Modeled habitat suitability and biologically best corridor for badger in the San Francisco Peaks – Mogollon Rim Linkage

Black bear (*Ursus americanus*)

Justification for Selection

Black bears require a variety of habitats to meet seasonal foraging demands and have naturally low population densities, making them especially vulnerable to habitat fragmentation (Larivière 2001).

Distribution

Black bears are widely distributed throughout North America, ranging from Alaska and Canada to the Sierra Madre Occidental and Sierra Madre Oriental of Mexico (Larivière 2001). In Arizona, they are found primarily in forested areas from the South Rim of the Grand Canyon to mountain ranges in the southeastern part of the state (Hoffmeister 1986).

Habitat Associations

Black bears are primarily associated with mountainous ranges throughout Arizona. Within these areas they use a variety of vegetation types, ranging from semidesert grasslands to encinal woodlands and montane conifer forests (Hoffmeister 1986). Encinal woodlands and conifer-oak woodlands are optimal habitat, providing food such as acorns (LeCount 1982; LeCount et al. 1984; Cunningham and Ballard 2004). In autumn, black bears use grass and shrub mast as well as prickly pear found in desert scrub (S. Cunningham, personal comm.). In many locations throughout Arizona, black bears are found in riparian communities (Hoffmeister 1986), and prefer to bed in locations with 20-60% slopes (S. Cunningham, personal comm.).

Spatial Patterns

Individual black bears do not have territorial interactions, and home ranges of both sexes commonly overlap. Home ranges are generally larger in locations or years of low food abundance, and smaller when food is plentiful and have been observed to range from 2 - 170 km^2 (Larivière 2001). Daily foraging movements are also dependent on food supply, and have been observed to range from 1.4 – 7 km (Larivière 2001). Males have larger dispersal distances than females, as females stay close to their natal range, and males must migrate to avoid larger males as their mother comes back into estrus (Schwartz and Franzmann 1992). Depending on vegetation, females may disperse up to 20 km, while males often move 20-150 km (S. Cunningham, personal comm.).

Conceptual Basis for Model Development

Habitat suitability model – Cover is the most important factor for black bears, so vegetation was assigned an importance weight of 75%. Elevation and topography each received a weight of 10%, and distance from roads received a weight of 5%. Lee Luedeker of the Arizona Game and Fish Department reviewed the factor weights and suitability scores obtained from CorridorDesign.Org and adjusted these to reflect regional habitat associations for this species.

For specific scores of classes within each of these factors, see Table 3 for habitat suitability scores.

Patch size & configuration analysis – We defined minimum potential breeding patch size as 1000 hectares, since this is the minimum amount of optimum habitat necessary to support a female and cub (Bunnell & Tait 1981; S. Cunningham, personal comm.). Minimum potential population core size was defined as 5000 hectares, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m-radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that optimal and suitable habitat for black bear is found throughout the potential linkage area, with the highest quality habitat found in forested areas with high topographic relief such as the head of Sycamore Canyon (southern portion of Strands A & B), the western portion of Camp Navajo around Volunteer Mountain (Strand B), and Woody Ridge (Strand C; Figure 21). Most of the highest quality habitat is encompassed by the three strands of the BBC. Potential population cores were identified throughout the potential linkage area including within the BBC and in both habitat blocks.

A large portion of Camp Navajo between Strands B and C was modeled as not suitable due to its classification as "developed – medium to high intensity" in the land cover layer, although black bear have regularly been observed in the western and eastern/southeastern areas of the Camp. We obtained trail camera data from Janet Lynn of Camp Navajo to validate the black bear BBC (shown in Figure 21). The middle strand of the BBC captured all of the observations collected on the forested western uplands on the Camp, while not surprisingly those collected from the Camp's southern and eastern areas were not included in the BBC which avoids highly developed areas. It is also worth noting that Rogers Lake is classified as "playa" in the land cover layer, a class which was rated as non-habitat for black bear by species experts, though black bear are known to use forested upland habitats surrounding this feature and may utilize this area to move between Woody Ridge and Camp Navajo (see "Non-modeled areas important to wildlife movement").

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Union of biologically best corridors – The additional area encompassed by the linkage design captures additional suitable habitat for black bear: in scattered areas of Strand A; in the southern end of Strand B and the area where this strand overlaps Volunteer Canyon; and in several high-relief areas of Strand C, such as along Woody Ridge and near Wing Mountain in this strand's northwestern "lobe." Given that black bear is a wide-ranging species vulnerable to human conflict, the greatest threats to connectivity and persistence of black bear populations in the linkage planning area are most likely Interstate 40, continued habitat fragmentation due to urban and rural housing development within the linkage strands, and potential changes in training activities on Camp Navajo.

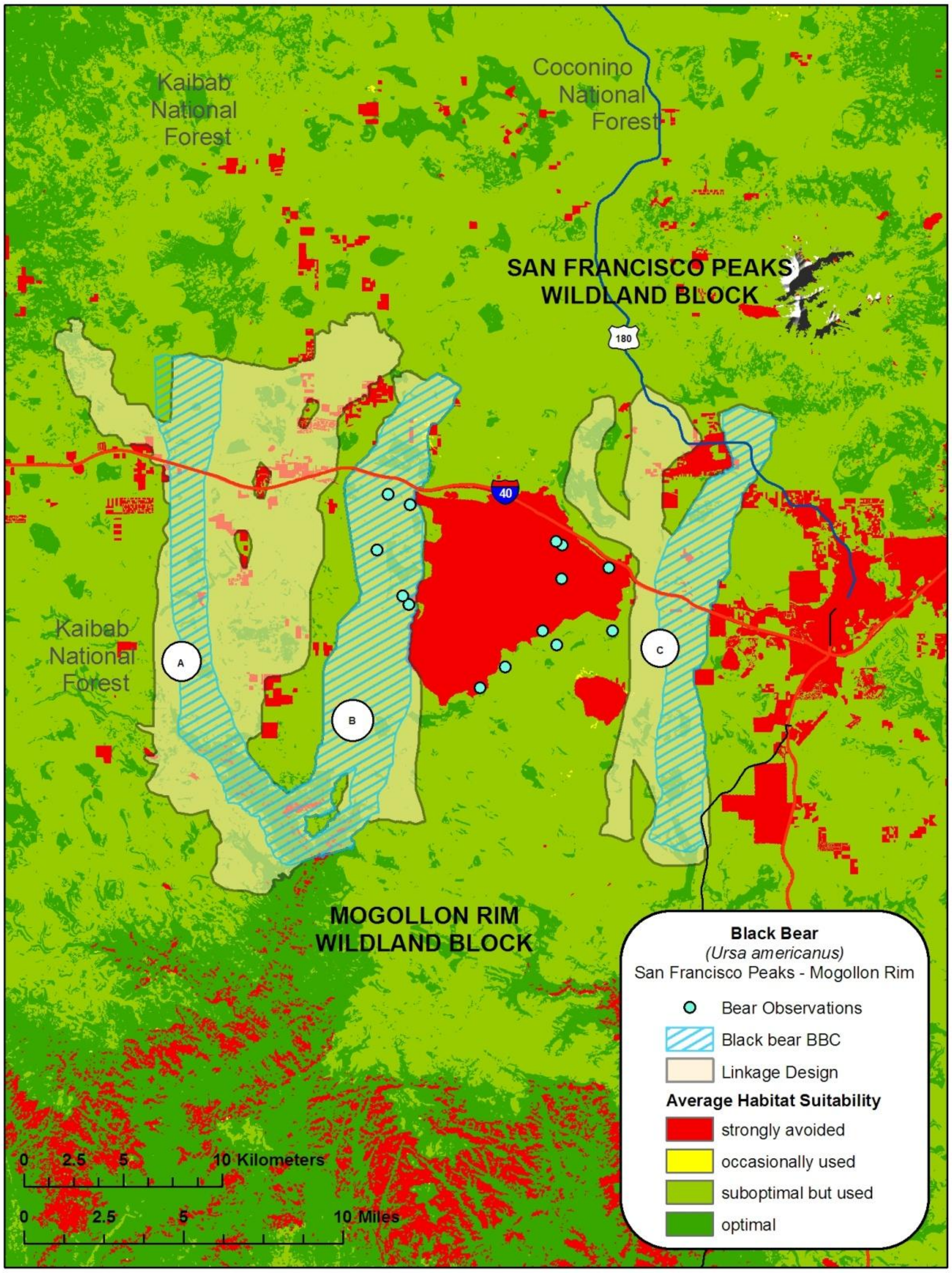


Figure 21: Modeled habitat suitability and biologically best corridor for black bear in the San Francisco Peaks – Mogollon Rim Linkage. Blue points represent locations of Camp Navajo black bear observations. (Note: Much of Camp Navajo is designated "developed" in the land cover layer and thus was modeled as "avoided" for this species).

Bobcat (*Lynx rufus*)

Justification for Selection

Bobcats are the most common felid in North America. Fur trapping remains an important cause of mortality for the species. They are also susceptible to vehicle collisions, intraspecific competition, and disease (Fuller et al. 1995). Bobcats are known habitat generalists that sometimes utilize residential areas adjacent to large undeveloped areas (Harrison 1998). They may be able to coexist with some development when a minimum amount of functional natural habitat remains (Riley et al. 2003). However, rampant urbanization can be detrimental to populations. For example, the disappearance of bobcats in Illinois coincided with human settlement and associated habitat loss (Woolf and Hubert 1998).

Distribution

Bobcats occur over a broad geographic range, including most of the U.S., as far north as Canada, and south into Mexico. They are found throughout Arizona (Hoffmeister, 1986), though they are probably rare on the eastern plains and at higher altitudes in the northern mountains (Findley et al., 1975).

Habitat Associations

Bobcats are primarily associated with broken country where cliffs and rock outcrops are interspersed with open grassland, woods, or desert. In Arizona, they occur from the base to the tops of most desert ranges, in mesquite woods, in arrowweed thickets, among cottonwoods, in open desert miles from "typical" habitat, and in juniper woodland, oak-manzanita, and ponderosa pine (Hoffmeister, 1986). Bobcats are very flexible in their habitat requirements, needing only adequate prey and cover for hunting and escape (Harrison, pers. comm.).

Spatial Patterns

Bobcats are generally solitary and territorial (Riley 2006). Observed home ranges for one breeding pair ranged from 2 to over 50 km^2. Home range size varies greatly with prey density and habitat quality (Harrison, pers. comm.). In Marin County, California, Riley (2006) found that roads represented home range boundaries for 75% of radio-collared bobcats that lived near them, males had larger average home range requirements than females, and the spatial requirements for both genders varied widely according to whether they were located in an urban or rural landscape (mean home range size (MCP 95%) of males: urban zone 6.4 km^2, rural zone 13.5 km^2, females: urban zone 1.3 km^2, rural zone5.3 km^2). Dispersal distances for young bobcats average near 25 km, while they have been recorded up to 182 km (Kamler and Gipson 2000).

Conceptual Basis for Model Development

Habitat suitability model – Bobcats occur across a wide spectrum of vegetation types. While bobcats show some unwillingness to cross major roads, there is a dearth of information on their use of habitat in relation to distance to roads, though Riley (2006) found that roads frequently represented their home range boundaries. Vegetation received an importance weight of 80%, elevation 5%, topography 15%, and distance from roads 0%. Lee Luedeker of the Arizona Game and Fish Department reviewed the factor weights and suitability scores obtained from CorridorDesign.Org and adjusted these to reflect regional habitat associations for this species. For specific scores of classes within each of these factors, see Table 3.

Patch size & configuration analysis – We defined minimum potential breeding patch size as 2,000 hectares (Anderson and Lovallo 2003). Minimum potential population core size was defined as 30,000 hectares (Harrison, pers. comm.), approximately enough area to support 20 effective breeders over a 10 year period provided the population is not harvested.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that optimal and suitable habitat for bobcat is found throughout the potential linkage area for this generalist species (Figure 22). Much of the highest-quality habitat is included within the three strands of the BBC. Most of the potential linkage area was identified as a potential population core including within the BBC as were most areas of both habitat blocks.

Union of biologically best corridors – The additional area encompassed by the linkage design is almost entirely comprised of high-quality habitat for bobcat, save for larger open grassland habitats in Strand A (Garland Prairie and Pittman Valley in the strand’s northwestern “lobe”). Because there is ample habitat for this species and it can coexist with moderate levels of human activity, the greatest threats to its connectivity and persistence are most likely Interstate 40 and habitat fragmentation in the event of significant future housing development within the linkage design.

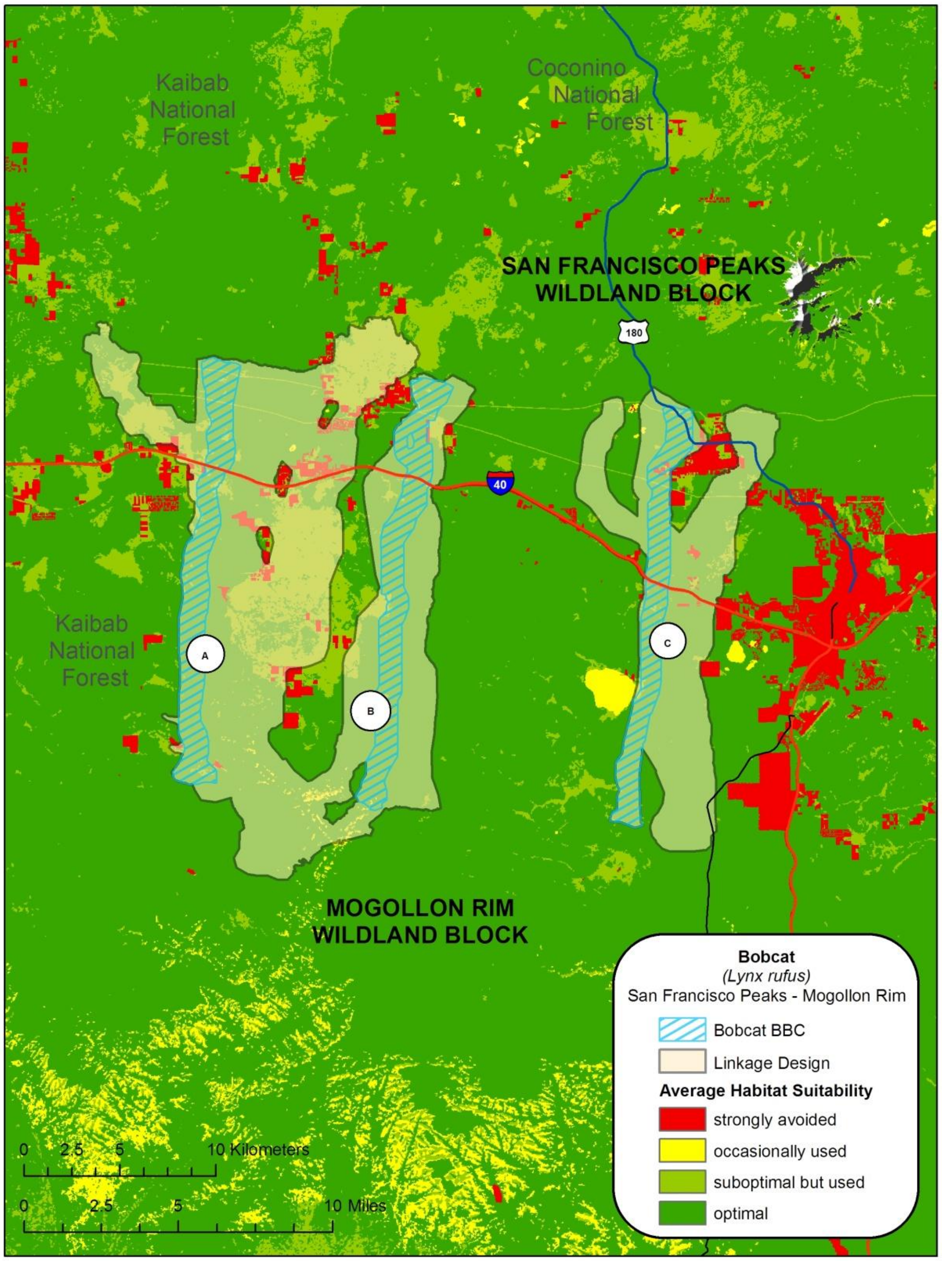


Figure 22: Modeled habitat suitability and biologically best corridor for bobcat in the San Francisco Peaks – Mogollon Rim Linkage

Elk (*Cervus elaphus*)

Justification for Selection

Elk are seasonal migrants that require large tracts of land to support viable populations. They are prey for large carnivores such as mountain lion, and are susceptible to human disturbance and busy roads.

Distribution

By the late 1800's, native elk (*Cervus elaphus merriami*) were believed to be extinct in Arizona. Re-introduction efforts in the early 1900's established stable populations of non-indigenous Rocky Mountain elk (*Cervus elaphus nelsoni*) in virtually all historic elk habitat in the state (Britt and Theobald 1982). Arizona elk populations have expanded to an estimated total of 35,000 post-hunt adult animals (Arizona Game and Fish Department 2009b). Elk are most commonly found in woodlands and forests of northern Arizona extending from the Hualapai Reservation south and eastward along the Mogollon Rim to the White Mountains and into western New Mexico (Severson and Medina 1983). Within the linkage planning area, elk occur within the juniper and shrub oak habitat types.

Habitat Associations

Elk are "intermediate feeders" capable of utilizing a mix of grasses, herbs, shrubs, and trees depending on the season and availability. Although capable of living in a range of habitats from desert chaparral and sagebrush steppe to tundra, elk are most commonly associated with forest parkland ecotones that offer a mix of forage and cover (Thomas et al. 1988; O'Gara and Dundes 2002). Elk are negatively impacted by roads, and have shown avoidance behavior up to 400 m (Ward et al. 1980), 800 m (Lyon 1979) and 2.2 km (Rowland et al. 2004) from roads. Telemetry data from the Arizona Game and Fish Department indicate significant avoidance of high-volume roadways including Interstate Routes 17 and 40 in the linkage planning area (Gagnon et al. 2007, AGFD 2010, 2011a, 2012a).

Spatial Patterns

In Arizona, elk move annually between high elevation summer range (7,000 to 10,000 ft) and lower elevation winter range (5,500 to 6,500) (Arizona Game and Fish Department 2009b). Elk avoid human activity unless in an area secure from predation in which they are tolerant of human proximity (Morgantini and Hudson 1979, Geist 2002, Lyon and Christensen 2002).

Conceptual Basis for Model Development

Habitat suitability model –Vegetation received an importance weight of 75%, elevation and topography were each weighted 0%, and distance from roads received a weight of 25%. Tom McCall of the Arizona Game and Fish Department reviewed the factor weights and suitability scores obtained from CorridorDesign.Org and adjusted these to reflect regional habitat associations for this species. For specific scores of classes within each of these factors, see Table 3.

Patch size & configuration analysis – Home ranges are highly variable for elk (O'Gara and Dundes 2002). In Montana, one herd had an average summer home range of 15 km^2 (Brown et al. 1980), while a herd in northwestern Wyoming had a winter range of 455 km^2 and a summer range of 4,740 km^2 (Boyce 1991). In our analyses, minimum patch size for elk was defined as 60 km^2 or 6,000 ha and minimum core size as 300 km^2 or 30,000 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m-radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that optimal and suitable habitat for elk is found throughout the potential linkage area and in both habitat blocks for this generalist species (Figure 23). Most of the habitat within the single strand of the biologically best corridor was modeled as optimal. Most of the potential linkage area and each habitat block was identified as a potential population core, including nearly all the area encompassed by the BBC. While Figure 23 suggests that the main features compromising habitat quality for elk in the potential linkage area are roads and development, it is worth noting that many of the roads in this area are lower-volume and unpaved forest roads which likely have less impact on elk movement than major highways such as Interstate 40.

As detailed under "Model validation" we obtained wildlife-vehicle collision data from the Arizona Department of Transportation for the period 1989 through 2006 to validate our biologically best corridor model for elk (Figure 5). While elk collisions occurred with some frequency along most of the included length of I-40, collisions within the potential linkage area (roughly encompassing mileposts 167-195) peaked in the segment between mileposts 174-178, with the greatest number recorded at milepost 175 which lies within the western "lobe" of the modeled BBC for elk.

Union of biologically best corridors – The UBBC provides significant additional optimal and suitable habitat for elk in all three strands. Arizona Game and Fish telemetry data illustrated in Figure 9 (see "Recommendations for crossing structures" above) validate that Strand C, though based on BBCs for other species, encompasses an area of high elk movement across U.S. Highway 180. Given that elk can utilize a range of habitats and tolerate moderate levels of human disturbance the main threat to connectivity for this species will likely continue to come from Interstate 40. Ongoing efforts by the Arizona Department of Transportation and Arizona Game and Fish Department described above aim to mitigate this barrier for elk and many other species.

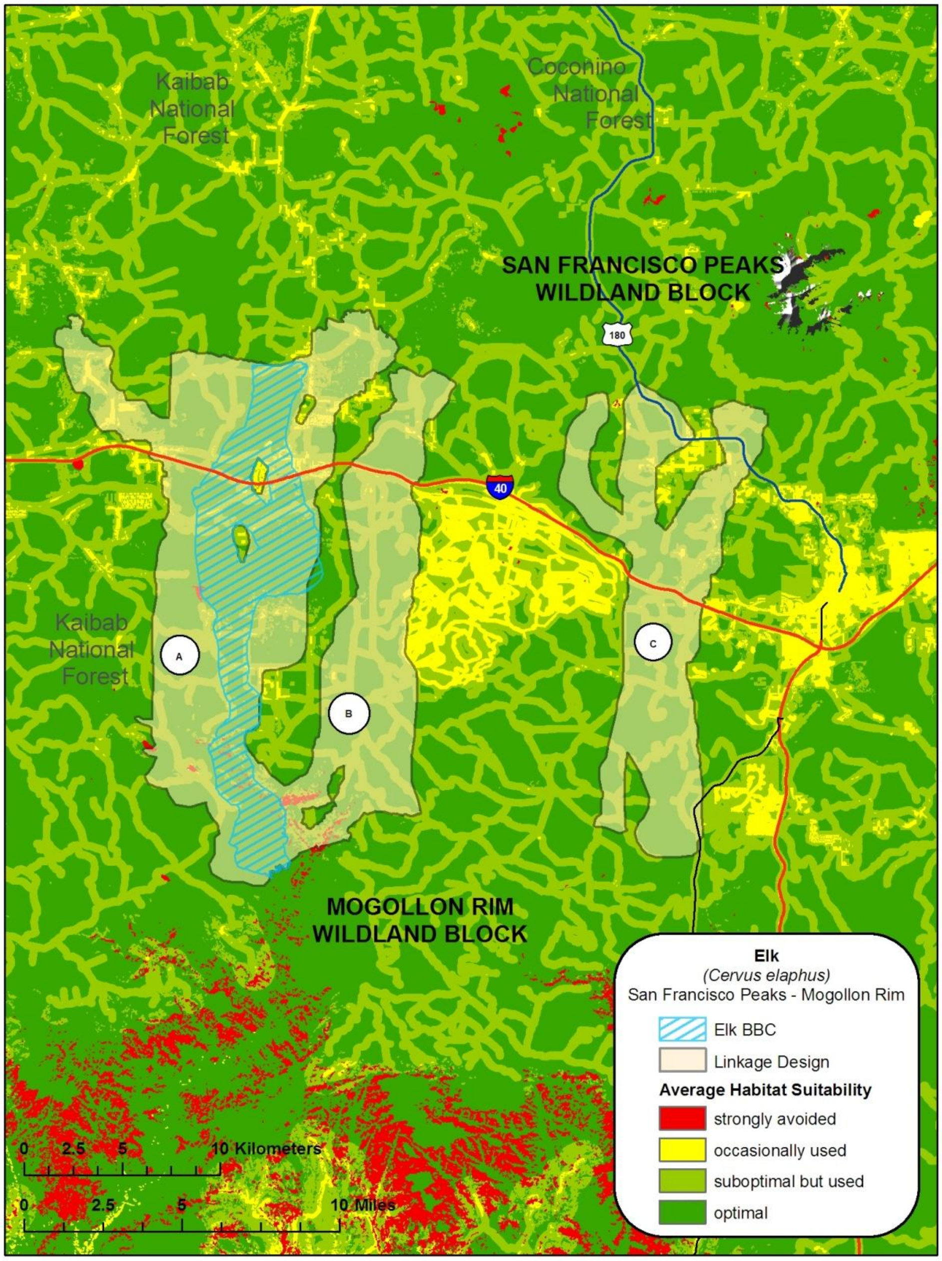


Figure 23: Modeled habitat suitability and biologically best corridor for elk in the San Francisco Peaks – Mogollon Rim Linkage

Gunnison's prairie dog (*Cynomys gunnisoni*)

Justification for Selection

Gunnison's prairie dog is one of five extant prairie dog species, relatives of the ground squirrel that live colonially. As a burrowing ecosystem engineer, the Gunnison's prairie dog (GPD) provides and enhances habitat for a number of grassland species including endangered black-footed ferrets (*Mustela nigripes*), burrowing owls (*Athene cunicularia*), reptiles, invertebrates, and raptors. GPD is an appropriate focal species for wildlife linkages because it represents connectivity for a broader suite of grass- and shrubland species.

Distribution

Gunnison's prairie dog is found in the Four Corners region that includes northern Arizona, southwestern Colorado, northwestern New Mexico, and southeastern Utah. Currently, GPDs are found at elevations of 1,370 m (4,500 ft) in high desert grasslands to 3,650 m (12,000 ft) in the mountains. A 2004 petition to federally list the species was denied due to insufficient information. A number of conservation assessments were produced as a result, and state management has increased (Seglund et al. 2005; Underwood 2007). In 2008, US Fish & Wildlife Service announced that while some GPD populations in Colorado and New Mexico would be considered for listing, those in Arizona and Utah did not warrant listing. The GPD is an Arizona Species of Greatest Conservation Need (Arizona Game and Fish Department 2012b). Major threats include plague (*Yersinia pestis*), poisoning and other methods of extirpation, recreational shooting, and habitat loss.

Habitat Associations

Generally, GPD are found in grasslands, shrublands, and subalpine meadows (particularly in northern Arizona). Relatively little habitat research has focused on this species of prairie dog, which forms smaller, less dense groups than black-tailed prairie dogs (*C. ludovicianus*) in more varied vegetation types. In a statewide study of GPD and pocket gopher (*Thomomys bottae*) habitats, Gallie (2001) found prairie dog colonies in fine (high in clay) to medium coarse (high in sand) textured soils. Well-drained soil is important for burrow integrity. Wagner and Drickamer (2004) found Arizona's GPD colonies in association with deep soils (mean = 1.26m), flat slopes, and low rock cover. These conditions allow burrow construction and hibernation below the frost layer in winter. Fitzgerald and Lechleitner (1974) found colonies in Colorado only where slopes were less than 15%.

Gunnison's prairie dogs feed primarily on grasses (Fitzgerald and Lechleitner 1974) as well as forbs, sedges, and occasionally insects (Underwood 2007). Species commonly found within GPD colonies include *Bromus tectorum, Oryzopsis hymenoides, Aristida purpurea, Muhlenbergia spp., Sporobolus aeroides, Scleropogon brevifolius, Bouteloa gracilis, Hilaria jamesii, Agropyron smithii, A. trachycaulum, Koleria cristata, Festuca spp., Atriplex jonesii, A.*

canescens, Artemesia tridenta, A. frigida, Sarcobatus verminculatus, Potentilla fruticosa, Chrysothmnus spp., Descurainia spp., Cardaria draba, Lepidium virginicum, Cryptantha spp., Senecio spp., Sisymbrium altissimum, Penstemon spp., and *Lappula redowski.* Shalaway and Slobodchikoff (1988) found that prairie dogs in northern Arizona feed on locally abundant plants, switching species seasonally with plant phenology. Diverse plant communities ensure year-round food availability.

GPD can obtain water exclusively from moist vegetation (Vorhies 1945, cited in Underwood 2007), but will drink from artificial or natural sources when they are available (Fitzgerald and Lechleitner 1974). Colonies associated with moist vegetation or wetlands tend to be more productive (Seglund et al 2005). However, GPD colonies are not found in basins that experience periodic flooding (Belitsky 1991). Crocker-Bedford (1976) found a negative correlation between animal density and elevation, attributing this trend to the relationship between vegetative productivity and elevation (cited in Underwood 2007).

Seglund et al. (2005) modeled potential habitat based on elevations 1,500-3,700m (4,921-12,139 ft), 0-20% slope, and 23 landcover classes. The authors considered forest, woodland, dense shrubland, marshland, and wetland to be unsuitable habitats.

Spatial Patterns

This species lives in somewhat territorial clans; a network of associated clans is referred to as a colony. In a statewide study of GPD in Arizona, Wagner and Drickamer (2003) found 76 active colonies from 1.2 to 959.1 ha in size (mean = 59.6 ha, most were <20 ha). Belitsky (1991) found colonies in the Aubrey Valley, AZ from 10 to 4,400 ha in size. In Arizona's Petrified Forest National Park, Hoogland (1999) studied a colony with 21-23 clans (from year to year), each 0.16-1.82 ha in area with 1 to 19 individuals. Juvenile dispersal was generally to an adjacent clan, but up to 529 meters. The black-tailed prairie dog, a better studied species, has an estimated maximum travel distance of 10 km (Knowles 1985, cited in Wagner and Drickamer 2003). The species experts consulted for this effort assigned a mean dispersal distance of 300m for GPD. Colonies may have as many as 50 individuals (Hoffmeister 1986), but populations fluctuate with outbreaks of plague, poisoning, or drought events.

Conceptual Basis for Model Development

Habitat suitability model – Agricultural lands can be considered very poor habitat because GPD are usually eradicated there. However, high density colonies have been found in the productive areas surrounding agricultural lands (Seglund et al. 2005). Livestock grazing can diminish habitat quality and is similarly associated with eradication efforts (Arizona Game and Fish Department 2012b). Roads increase access for recreational shooters (Reading and Matchett 1997), however some developed areas are thought to provide refuge from predators. Black-tailed prairie dogs will use primitive roads for dispersal, but Reading and Matchett (1997) found no relationship between distance to roads and animal density or colony area. Lands open to mining and energy exploration can be directly degraded but also can be so disturbed or noisy as to inhibit GPD vocal communication (Clark 1986). Belitsky (1991) observed that GPD colonies in his study area were not located within highway or railroad right-of-ways. Land cover and topography seem to be important for GPD habitat quality, while proximity to standing water does not seem to directly determine habitat suitability. Steep slopes may serve as barriers to movement. Land cover received an importance weight of 45%, while elevation, topography, and distance from roads received weights of 25%, 30%, and 0%, respectively. For specific scores of classes within each of these factors see Table 3.

Patch size & configuration analysis – Gunnison's prairie dogs currently tend to occur in isolated metapopulations (Wagner and Drickamer 2003). Distance to nearest clan is likely an important factor in local range expansion. Based on the input of species experts we defined minimum potential breeding patch size as 0.07 hectares, and minimum potential population core size as 1.5 hectares. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3 x 3 pixel square neighborhood moving window analysis.

Biologically best corridor analysis – We did not model a biologically best corridor for this species. Based on expert opinion regarding likely dispersal distance Gunnison's prairie dog is considered a "corridor dweller" requiring more than a generation to traverse the distance between wildland blocks.

Results & Discussion

Union of biologically best corridors – The habitat suitability model indicates that significant areas of high-quality habitat for Gunnison's prairie dog exist in the linkage area, primarily in the western portion in Garland and Government Prairies and Pittman Valley, and more centrally on Camp Navajo (Figure 24). Most optimal and suitable habitat in the western portion is encompassed by Strands A and B of the linkage design, with the exception of a relatively developed portion of Garland Prairie lying between them. High-quality habitat on Camp Navajo was not included in the linkage design; much of the land on Camp is classified as "developed medium-high" though sizeable prairie dog colonies exist there. Suitable habitat in the wildland blocks is more limited and somewhat isolated, especially in the Mogollon Rim block where it is restricted to relatively small and scattered grassland areas near the block's northern boundary. Population cores exist and overlap these same areas of high-quality habitat, however there are many areas within Strand A where the distance between breeding patches and population cores exceeds the species' estimated 300m mean dispersal distance. Thus Gunnison's prairie dog is vulnerable in the linkage area to habitat fragmentation from human development. The results also illustrate the critical importance of human-occupied areas such as Camp Navajo and Garland Prairie to GPD. An educational program stressing landowner tolerance of Gunnison's prairie dog colonies and conservation-oriented policies in the Flagstaff and Coconino County land use plans will be essential to ensuring to the species' long-term persistence and dispersal between wildland blocks.

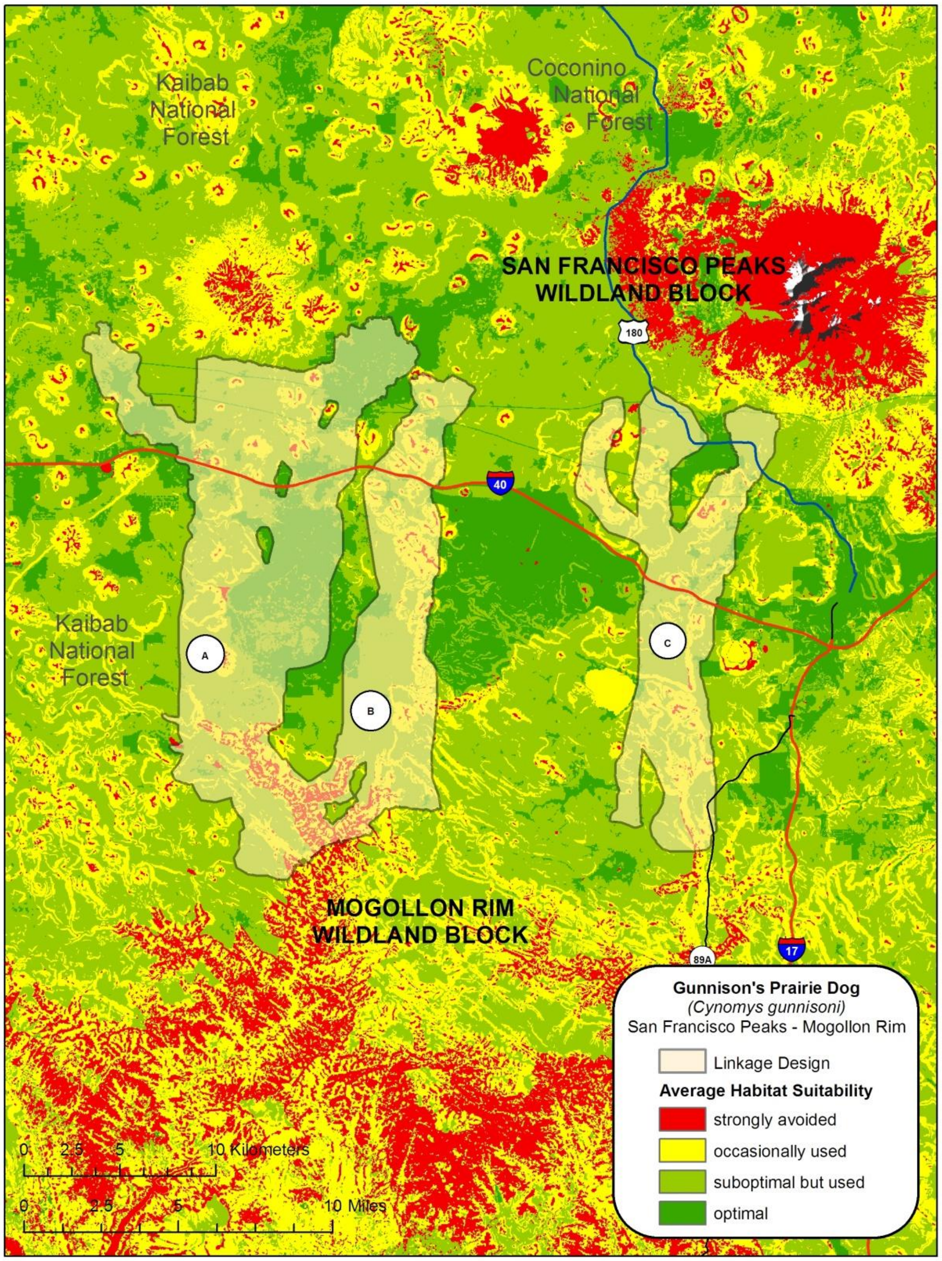


Figure 24: Modeled habitat suitability for Gunnison’s prairie dog in the San Francisco Peaks – Mogollon Rim Linkage

Mule deer (*Odocoileus hemionus*)

Justification for Selection

Mule deer are widespread throughout Arizona, and are an important prey species for carnivores such as mountain lion, jaguar, bobcat, and black bear (Anderson & Wallmo 1984). Road systems may affect the distribution and welfare of mule deer (Sullivan and Messmer 2003, Dodd et al. 2010).

Distribution

Mule deer are found throughout most of western North America, extending as far east as Nebraska, Kansas, and western Texas. In Arizona mule deer are found throughout the state, except for the Sonoran desert in southwestern Arizona where mule deer numbers are very low (Anderson and Wallmo 1984).

Habitat Associations

Mule deer in Arizona are categorized into two groups based on the habitat they occupy. In northern Arizona mule deer inhabit yellow pine, spruce-fir, buckbrush, snowberry, and aspen habitats (Hoffmeister 1986). The mule deer found in the pine and spruce-fir live there from April to the beginning of winter, when they move down to the pinyon-juniper zone (Hoffmeister 1986). Elsewhere in the state, mule deer live in desert shrub, chaparral or even more xeric habitats, which include scrub oak, mountain mahogany, sumac, skunk bush, buckthorn, and manzanita (Wallmo 1981; Hoffmeister 1986).

Spatial Patterns

The home ranges of mule deer vary depending upon the availability of food and cover (Hoffmeister 1986). Swank (1958) reports that home ranges of mule deer vary from 2.6 to 5.8 km^2, with bucks' home ranges averaging 5.2 km^2 and females' home ranges slightly smaller (Hoffmeister 1986). Average home ranges for desert mule deer are larger. Deer that require seasonal migration movements use approximately the same winter and summer home ranges in consecutive years (Anderson & Wallmo 1984). Dispersal distances for male mule deer have been recorded from 97 to 217 km, and females have moved 180 km (Anderson & Wallmo 1984). Two desert mule deer yearlings were found to disperse 18.8 and 44.4 km (Scarbrough & Krausman 1988).

Conceptual Basis for Model Development

Habitat suitability model – Vegetation has the greatest role in determining deer distributions in desert systems followed by topography (J. Marshal, pers. comm.). A similar pattern holds for mule deer in forested areas of northern Arizona, though different associations with vegetation types are observed (C. Lutch, pers. comm.). Carl Lutch of the Arizona Game and Fish Department reviewed the factor weights and suitability scores obtained from CorridorDesign.Org and adjusted these to reflect regional habitat associations for this species. Land cover received an importance weight of 65%, while elevation, topography, and distance from roads received weights of 0%, 30%, and 5%, respectively. For specific scores of classes within each of these factors, see Table 3.

Patch size & configuration analysis – Minimum breeding patch size for mule deer was defined as 9 km^2 or 900 hectares and minimum population core size as 45 km^2 or 4,500 hectares. To determine potential breeding patches and population cores, the habitat suitability model for this species was first averaged using a 200m-radius moving window analysis given the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that large areas of optimal and suitable habitat for mule deer are found throughout the potential linkage area and in both habitat blocks (Figure 25). The biologically best corridor included three strands of comparable habitat quality, and nearly all of this was modeled as optimal or suitable except for scattered small and generally isolated areas in each strand. Most of the potential linkage area and of each habitat block was identified as a potential population core, including nearly all the area encompassed by the BBC. Areas modeled as low suitability were the more open habitats of Garland and Government Prairies and a number of small areas classified as medium- or highly-developed, and these areas, along with Rogers Lake and the north-central portion of Camp Navajo, were not included as population cores.

As detailed under "Model validation" above we obtained mule deer telemetry data from biologists in the Arizona Game and Fish Department Contracts Branch in an effort to validate our initial biologically best corridor model. While this dataset was based on only 13 individuals collected as part of a study of mule deer movements north and west of Flagstaff (Dodd et al. 2010), there is considerable overlap between the telemetry fixes obtained in the potential linkage area and the easternmost strand of the mule deer biologically best corridor (Figure 4). In order to create a more functional mule deer corridor and support future highway mitigation efforts, we appended a small polygon encompassing additional mule deer telemetry points adjacent to the initial BBC north and south of U.S. Highway 180. This adjustment was added to the northwestern lobe of the easternmost strand of the initial mule deer BBC (Figure 25).

We also obtained wildlife-vehicle collision data from the Arizona Department of Transportation for the period 1989 through 2006 to validate our mule deer biologically best corridor (see Figure 5a in "Model validation" section). While mule deer collisions occurred with some frequency along most of the included length of I-40, collisions within the potential linkage area (roughly encompassing mileposts 167- 195) peaked in the segment at mileposts 190-191, which lies within the easternmost strand of the modeled BBC for mule deer.

Union of biologically best corridors – The UBBC provides significant additional optimal and suitable habitat for mule deer in all three strands and large additional areas that could serve as potential population cores. The westernmost of the three northern "lobes" of Strand C also includes additional mule deer telemetry points (Figure 25). The main threats to connectivity for this species in the planning area will likely come from Interstate 40 and future urban and rural development. Ongoing efforts by the Arizona Department of Transportation and Arizona Game and Fish Department described above to develop crossing structures along I-40 aim to mitigate this barrier for mule deer. Also, the underpass where the BNSF Railroad passes south under Interstate 40 near the U.S. Naval Observatory in Strand C, which corresponds to a large cluster of mule deer telemetry locations just north of this highway, may represent a potential bottleneck for this and other species. Future efforts should focus on maintaining and possibly improving this underpass to maintain connectivity in Strand C.

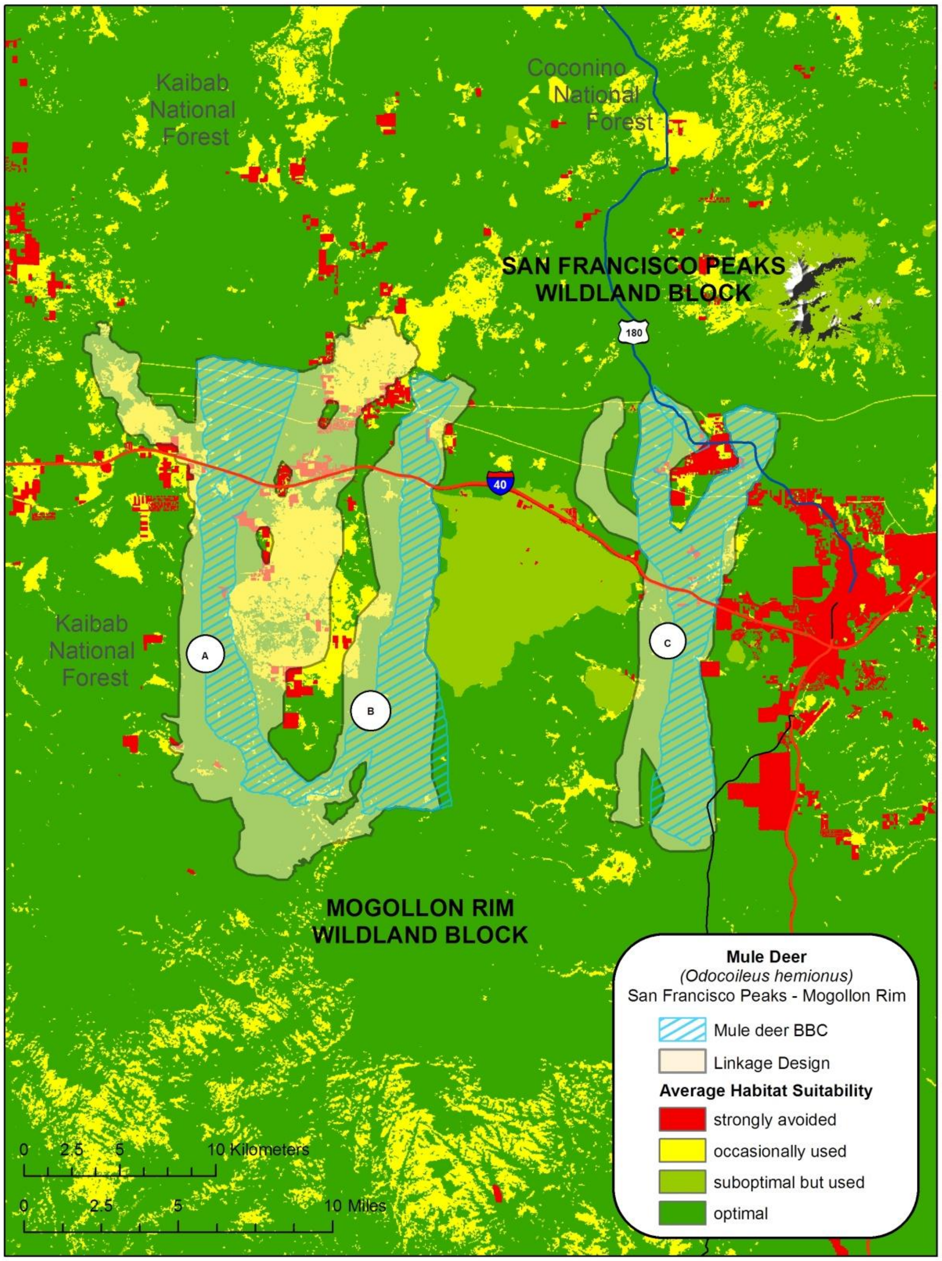


Figure 25: Modeled habitat suitability and biologically best corridor for mule deer in the San Francisco Peaks – Mogollon Rim Linkage

Northern leopard frog (*Rana pipiens*)

Justification for Selection

Leopard frogs are aquatic species that require habitat connectivity for dispersal. The northern leopard frog, the most widespread of Arizona's six leopard frog species, is experiencing population decline, likely due to drought and groundwater depletion, predation and competition by nonnative species, habitat loss, and other human impacts (Blomquist and Sredl 2002; Stebbins 2003; Smith and Keinath 2004; AGFD 2012b). Pope et al. (2000) found that this species relies on habitat complementation, a variety of habitat types with connectivity between, for its various life stages. With its broad geographic distribution and sensitivity to human disturbance, the northern leopard frog is an appropriate focal species for connectivity modeling.

Distribution

The northern leopard frog is found in the Great Basin region of northern and central Arizona, west to Nevada and Washington, north to southern and southeastern Canada, and east to New Jersey (AGFD 2002a). In several states throughout its range, the northern leopard frog is a species of special concern. While the northern leopard frog is not federally listed, US Fish & Wildlife Service reviewed a petition to list the species as threatened in the western United States in 2009 (Federal Register 2009). The Southern Mountain population is listed in Canada and several Canadian provinces.

Habitat Associations

Northern leopard frogs are commonly found in grassland, brushland, woodland, forests, and high-elevation forests. These vegetation types may occur within Great Basin desertscrub, Plains and Great Basin grassland, Great Basin conifer woodland, and Petran montane conifer forests, Madrean Evergreen forest, Mohave desertscrub, semidesert grassland, subalpine grassland, Petran subalpine conifer forest, and all aquatic/riparian habitats (Brennan and Holycross 2006; AGFD 2006a). Inhabited areas usually include permanent waters with rooted vegetation and/or lakes, ponds, canals, cattle tanks, ditches, marshes, springs, and streams (AGFD 2002a; Brennan and Holycross 2006).

Habitat needs may change seasonally; winter habitat includes lakes, streams, and ponds, summer habitat includes more upland foraging for adults, and breeding habitat requires shallow ponds (Smith and Keinath 2004). Another common name for the species is "meadow frog" because it often occurs in grasslands or fields of perennial forage crops in the non-breeding season (Stebbins 2003; Merrell 1977). Vegetative cover probably reduces predation as well as moisture loss through their permeable skin (Mazerolle and Desroches 2005). Ephemeral waters are likely used for dispersal as well as non-breeding habitat (Blomquist and Sredl 2002).

Northern leopard frogs are found at elevations of 0 to 3353 meters (0-11,000 ft) throughout their range (Stebbins 2003), while AGFD has observed them at elevations from 805-2,790 meters (2,640 to 9,155 ft) in Arizona (unpublished data). Northern leopard frogs escape to water when disturbed and use deep water for hibernation in the winter (Stebbins 2003; Brennan and Holycross 2006). In modeling suitable habitat, Southwest ReGAP used the following topographical features preferred: valley flats; toe slopes, bottoms, and swales; gently sloping ridges and hills; nearly level plateau or terrace (http://fws-nmcfwru.nmsu.edu/swregap/). Young frogs use drainages and vegetated lands for dispersal movements (Seburn et al. 1997).

Spatial Patterns

Northern leopard frogs are solitary outside the breeding season, and may or may not be territorial during the breeding season (Harding 1997; Rorabaugh 2005). Few studies have estimated home ranges.

Conceptual Basis for Model Development

Habitat suitability model – Roads contribute directly to mortality by vehicle collisions (Merrell 1970), but also have indirect impacts that include siltation and water pollution from runoff (Smith and Keinath 2007). Carr and Fahrig (2001) found that roads within 1.5 km of breeding ponds negatively affected leopard frog population density. Mazerolle and Desrochers (2005) found that undisturbed substrates with vegetative cover facilitated northern leopard frog movements through the landscape. Conversely, barren and agricultural lands created by peat-mining were avoided, decreased homing success, and accelerated desiccation in frogs. Species experts consulted to parameterize the suitability model for this species stressed the importance of including a perennial water layer in modeling (e.g. S. MacVean, pers. comm.). Thus land cover received an importance weight of 15%, while elevation, topography, distance from roads, and distance from water received weights of 0%, 25%, 10%, and 50%, respectively. For specific scores of classes within each of these factors see Table 3.

Patch size & configuration analysis – Studies of typical dispersal distances for this species have yielded varying results. In Minnesota, adults traveled up to 1.6 km from hibernation sites to breeding sites (Merrell 1970). Dole (1971) found that young frogs usually settle within 800 m of natal sites, although he recorded one individual 5.2 km away, while Seburn et al. (1997) found dispersal distances of up to 8 km in Canada. According to Smith and Keinath (2007), research gaps include causes of mortality, juvenile dispersal, and effects of human disturbance on individuals. Based on the input of species experts we defined minimum potential breeding patch size as 0.01 hectares, and minimum potential population core size as 0.1 hectares. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3 x 3 pixel square neighborhood moving window analysis.

Biologically best corridor analysis – We did not model a biologically best corridor for this species. Based on expert opinion regarding likely dispersal distance northern leopard frog is considered a “corridor dweller” requiring more than a generation to traverse the distance between wildland blocks.

Results & Discussion

Union of biologically best corridors – As expected given the scattered distribution of perennial water in the linkage planning area, optimal and suitable habitat for northern leopard frog is restricted to isolated patches in both the potential linkage area and the two wildland blocks (Figure 26). High-quality habitat is largely associated with stock tanks and small lakes and to a much lesser extent drainages, and somewhat more suitable habitat is found in Strand A than in the other two strands. All areas of high-quality habitat are associated with population cores, given the small spatial requirements of the species. Given the wide variation in dispersal distances reported in prior studies (from 0.8 to 8.0 km), an important unanswered question is whether the average distance between habitat patches in the linkage design is adequate to ensure movement between wildland blocks across multiple generations. Interpatch distances in the linkage design vary greatly, from as little as .1 km to 4 km. Given that this species is being actively considered for reintroduction efforts within the linkage planning area it will be important to collect further data on northern leopard frog dispersal distance in the region, and compare this to the distribution of potential habitat patches when considering relocation sites. Northern leopard frogs are also vulnerable to predation from non-native aquatics and their successful reintroduction will depend on eradication and exclusion of such species.

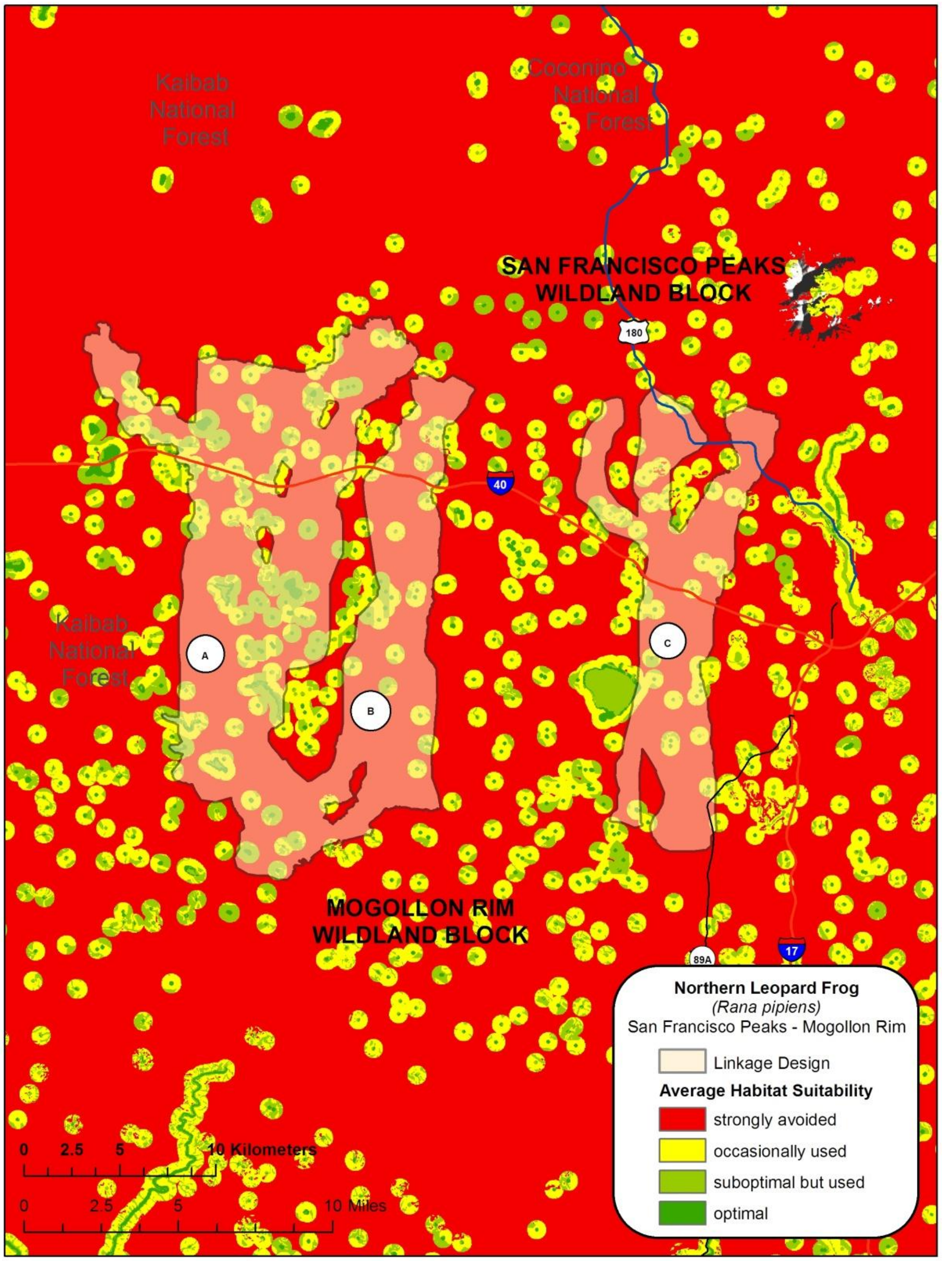


Figure 26: Modeled habitat suitability for northern leopard frog in the San Francisco Peaks – Mogollon Rim Linkage

Porcupine (*Erethizon dorsatum*)

Justification for Selection

The porcupine's range has been reduced in some areas due to changes in human distribution and land use (Woods 1973). Porcupines are frequently killed by automobiles while crossing roads (Woods 1973).

Distribution

Porcupines are widespread in much of North America, from Alaska and northern Canada to parts of northern Mexico (Woods 1973). The porcupine's range includes most of Arizona in forested, mountainous regions of the state as well as riparian areas in lower elevations; they are considered absent or rare in desert areas (Hoffmeister 1986).

Habitat Associations

Porcupines inhabit montane and subalpine forests that include ponderosa pine, spruce-fir, aspen, pinyon, juniper, and oak in higher elevations. They also live in cottonwood-willow forests of riparian areas and mesquite thickets of semidesert shrublands (New Mexico Department of Game and Fish 2004). In Arizona, they also occur in grassland, chaparral or desert scrub (Hoffmeister 1986). Porcupines consume bark from trees in these areas, as well as mistletoe, pine needles, oak leaves, acorns, fungi, buckbrush, and the fruit of prickly pear cactus (New Mexico Department of Game and Fish 2004). Porcupines seek out rock piles, rocky slopes, mine shafts, and caves for shelter (Hoffmeister 1986).

Spatial Patterns

Home ranges of porcupines are restricted, with summer range larger than winter range (Woods 1973). Average summer home range is 14 hectares (Marshall et al. 1962), while winter home range is up to 5 hectares (Smith 1979). Average yearly home range has been estimated as 70 ha (Roze 1989). They will occupy the same dens for many years and even generations (Hoffmeister 1986). Individuals move an average of 1.5 kilometers to and from their winter den (Woods 1973). Dispersal among porcupines is female-biased, with juvenile female porcupines dispersing an average of 3.7 km while juvenile males generally remain within their natal ranges (Sweitzer and Berger 1998).

Conceptual Basis for Model Development

Habitat suitability model – Land cover received an importance weight of 87%, while elevation, topography, and distance from roads received weights of 0%, 3%, and 10%, respectively. For specific scores of classes within each of these factors see Table 3.

Patch size & configuration analysis – Minimum patch size for porcupine was defined as 50 ha and minimum core size as 250 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 pixel square neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that abundant optimal habitat for porcupine is found throughout the potential linkage area and in both habitat blocks (Figure 27). Only open habitats (e.g. Garland and Government Prairies, Rogers Lake) and areas classified as developed (e.g. north-central areas of Camp Navajo, areas with developed housing) were modeled as not suitable. The great majority of the habitat within both strands of the biologically best corridor was modeled as optimal. Most of the potential linkage area and of each habitat block was identified as a potential population core including nearly all of the area encompassed by the BBC. Areas not modeled as potential population cores corresponded to areas modeled as not suitable as described immediately above.

Union of biologically best corridors – The UBBC provides significant additional optimal and suitable habitat for porcupine in all three strands. The main threat to persistence and connectivity for this species is likely major roadways (Interstate 40) and habitat fragmentation from future housing and other development. It will be important to consider the needs of smaller species such as porcupines when developing and maintaining crossing structures in the linkage design area.

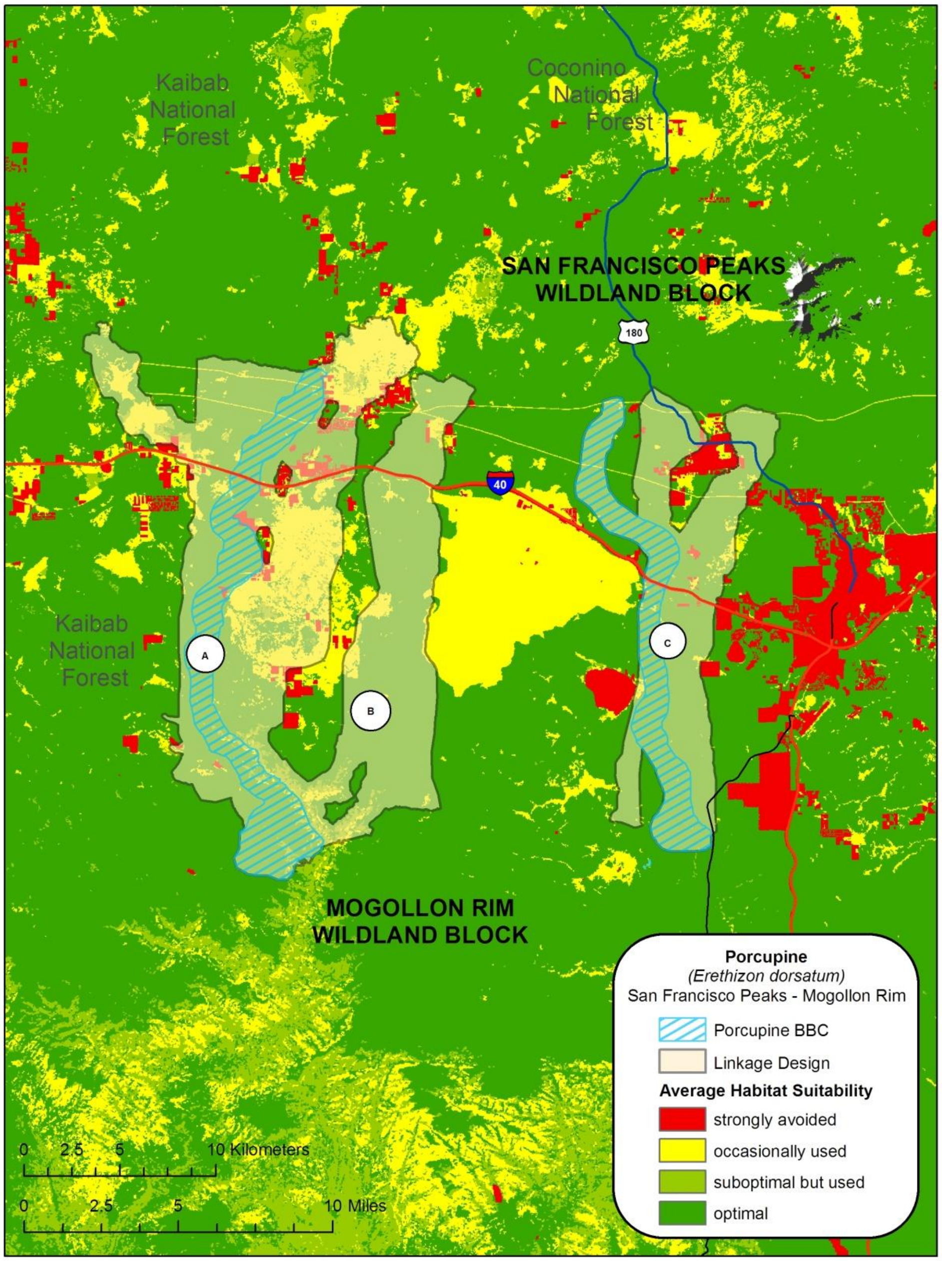


Figure 27: Modeled habitat suitability and biologically best corridor for porcupine in the San Francisco Peaks – Mogollon Rim Linkage

Pronghorn (*Antilocapra americana*)

Justification for Selection

Pronghorn are known to be susceptible to habitat degradation and human development (AGFD 2002b). One example of harmful development is right of way fences for highways and railroads, which are the major factor affecting pronghorn movements across their range (Ockenfels et al. 1997). Existence of migration corridors is critical to pronghorn survival for allowing movement to lower elevation winter ranges away from high snowfall amounts (Ockenfels et al. 2002).

Distribution

Pronghorn range through much of the western United States, and are found throughout the grasslands of Arizona (A. Munig, personal comm., Hoffmeister 1986).

Habitat Associations

Pronghorn are found in areas of grasses and scattered shrubs with rolling hills or mesas (Ticer and Ockenfels 2001, New Mexico Department of Game and Fish 2004). They inhabit shortgrass plains as well as riparian areas of sycamore and rabbitbrush, and oak savannas (New Mexico Department of Game and Fish 2004). In winter, pronghorn rely on browse, especially sagebrush (O’Gara 1978). Pronghorn prefer gentle terrain, and avoid rugged areas (Ockenfels et al. 1997). In many areas woodland and coniferous forests are also generally avoided, especially when high tree density obstructs vision (Ockenfels et al. 2002). In northern Arizona somewhat different associations with vegetation types have been observed, with pronghorn sometimes utilizing and moving through ponderosa pine or other forest types with significant cover (T. McCall, pers. comm., J. Lynn, pers. comm.). Also for visibility, pronghorn prefer slopes that are less than 30% (Yoakum et al. 1996).

Spatial Patterns

In northern populations, home range has been estimated to range from 0.2 to 5.2 km^2, depending on season, terrain, and available resources (O’Gara 1978). However, large variation in sizes of home and seasonal ranges due to habitat quality and weather conditions make it difficult to apply data from other studies (O’Gara 1978). Other studies report home ranges that average 88 km^2 (Ockenfels et al. 1994) and 170 km^2 in central Arizona (Bright & Van Riper III 2000), and in the 75 – 125 km^2 range (n=37) in northern Arizona (Ockenfels et al. 1997). The Sonoran pronghorn subspecies is known to require even larger tracts of land to obtain adequate forage (AGFD 2002c). One study of collared Sonoran pronghorn found the home range of 4 males to range from 64 km^2 – 1,214 km^2 (avg. 800 km^2), while females ranged from 41 km² - 1,144 km^2 (avg. 465.7 km^2) (AGFD 2002c). Another study of Sonoran pronghorn found home range to range from 43 to 2,873 km^2, with mean home range size of 511 + 665 SD km^2 (n=22), which is much larger than other pronghorn subspecies (Hervert et al. 2005). One key element in pronghorn movement is distance to water. One study found that 84% of locations were less than 6 km from water sources (Bright & Van Riper III 2000), and another reports collared pronghorn locations from 1.5 – 6.5 km of a water source (Yoakum et al. 1996). Habitats within 1 km of water appear to be key fawn bedsite areas for neonate fawns (Ockenfels et al. 1992).

Conceptual Basis for Model Development

Habitat suitability model – Tom McCall of the Arizona Game and Fish Department reviewed the factor weights and suitability scores obtained from CorridorDesign.Org and adjusted these to reflect regional habitat associations for this species. Vegetation received an importance weight of 45%, while elevation, topography, and distance from roads received weights of 0%, 37%, and 18%, respectively. For specific scores of classes within each of these factors see Table 3.

Patch size & configuration analysis – Minimum patch size for pronghorn was defined as 50 km^2 or 5,000 ha and minimum core size as 250 km^2 or 25,000 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m-radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate that significant amounts of optimal and suitable habitat for pronghorn exist throughout the potential linkage area and in both habitat blocks, with the highest quality habitat concentrated in grassland areas such as Garland and Government Prairies and lands south of Camp Navajo (Figure 28). Suitable habitat is generally limited in the Mogollon Rim block to its northern portion where topographic relief is less pronounced. Large areas of potential population cores also exist throughout the analysis area and their distribution mirrors that of optimal and suitable habitat, and includes most of the area encompassed by the BBC except where this traverses the developed areas of Parks and Spring Valley just north of Interstate 40.

Union of biologically best corridors – The UBBC provides significant additional optimal and suitable habitat for pronghorn in all three strands. Pronghorn are highly vulnerable to habitat fragmentation from roads, fencing, and housing development and are threatened in the area of the linkage design by all of these. Interstate 40 represents perhaps the greatest single threat to persistence and connectivity for this species. As discussed in detail above (see "Recommendations for crossing structures") there may be an opportunity in the future to develop a wildlife overpass for pronghorn on I-40 within the modeled BBC, but this will depend upon significant funding and habitat restoration to realize. Pronghorn would also benefit from removal and retrofitting of fencing to wildlife-friendly specifications throughout the linkage planning area, particularly in more open grassland areas including areas not encompassed by the strands of the linkage design where significant additional habitat exists for this species.

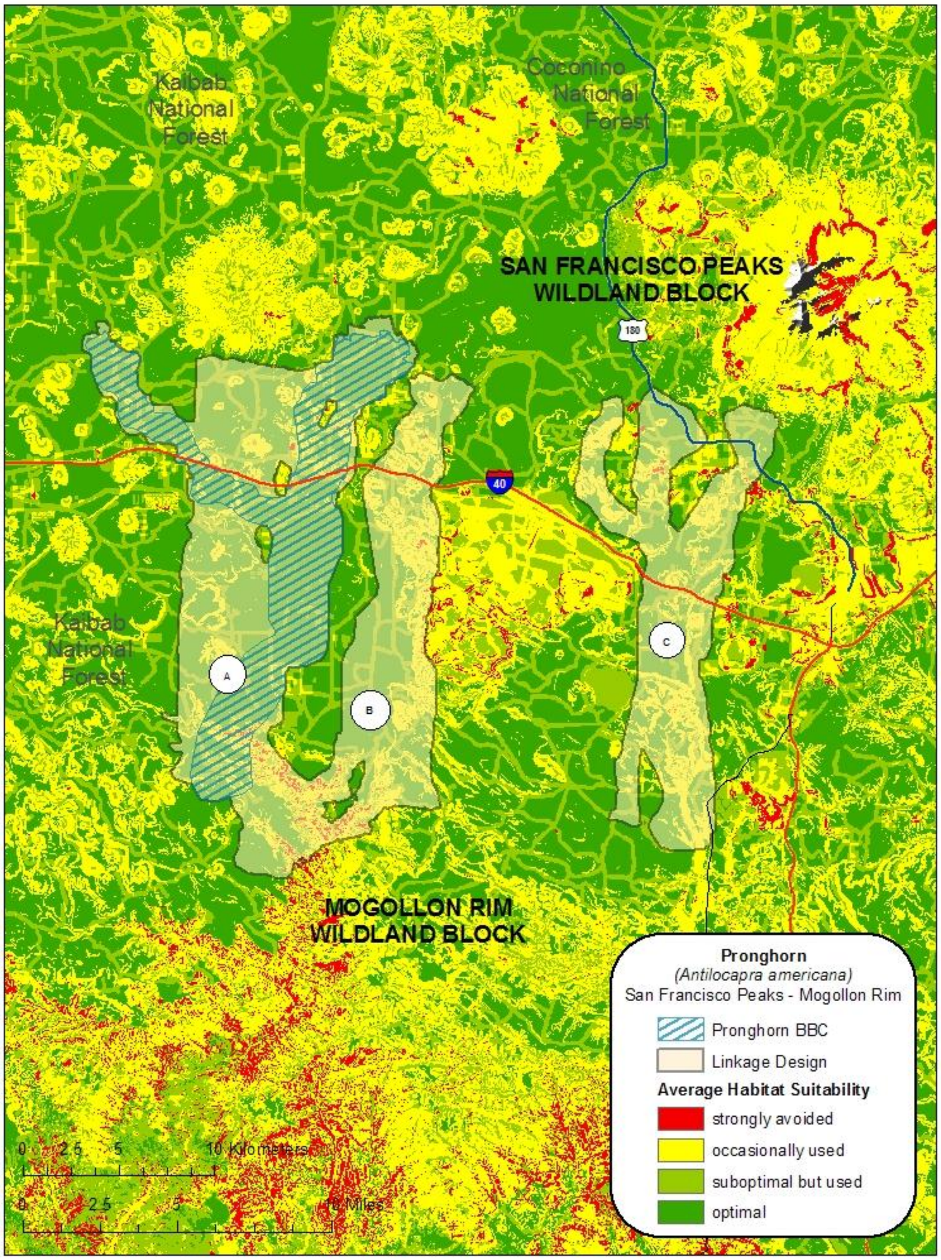
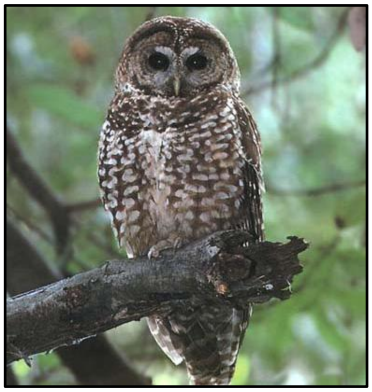


Figure 28: Modeled habitat suitability and biologically best corridor for pronghorn in the San Francisco Peaks – Mogollon Rim Linkage

APPENDIX C: NON-MODELED SPECIES WITHIN LINKAGE DESIGN



The linkage design provides habitat for many species not modeled which are of conservation concern to state and federal management agencies, such as the Mexican spotted owl (*Strix occidentalis lucida*), listed threatened under the Endangered Species Act. Table 4 reflects the diverse ecological benefits to plants, animals, and the ecosystems on which they depend that can result from conservation efforts within the linkage design. We recommend integrating this linkage design into agency land management plans and conservation programs to help realize these benefits.

Table 4: Non-modeled species occurring in the linkage design which are of conservation concern to state and federal management agencies (Source: Heritage Database Management System, Arizona Game and Fish Department). Key: ESA = Endangered Species Act, USFS = US Forest Service, BLM = US Bureau Of Land Management, State = Arizona Game And Fish Department, SC = Species Of Concern, LT = Listed As Threatened, S = Sensitive, WSC = Wildlife Species Of Concern, SR = Salvage Restricted, Collection Only With Permit.

CATEGORY	NAME	COMMON NAME	ESA	USFS	BLM	STATE
Vertebrate	*Idionycteris phyllotis*	Allen's lappet-browed bat	SC	S		
Vertebrate	*Myotis occultus*	Arizona myotis	SC			
Vertebrate	*Haliaeetus leucocephalus*	(wintering) bald eagle	SC	S	S	WSC
Vertebrate	*Eptesicus fuscus*	big brown bat				
Vertebrate	*Tadarida brasiliensis*	Brazilian free-tailed bat				
Vascular plant	*Cystopteris bulbifera*	bulblet fern				
Vascular plant	*Phacelia serrata*	cinder phacelia	SC			
Vascular plant	*Clematis hirsutissima*	clustered leather flower		S		
Vascular plant	*Astragalus troglodytes*	creeping milk vetch				
Vascular plant	*Penstemon nudiflorus*	Flagstaff beardtongue		S		
Vascular plant	*Hedeoma diffusa*	Flagstaff false pennyroyal		S		SR
Vertebrate	*Myotis thysanodes*	fringed myotis	SC			
Vertebrate	*Lasiurus cinereus*	hoary bat				
Vascular plant	*Agrimonia gryposepala*	hook-nosed agrimony				
Vertebrate	*Myotis evotis*	long-eared myotis	SC			
Vascular plant	*Ivesia multifoliolata*	many-leaved ivesia				
Vertebrate	*Strix occidentalis lucida*	Mexican spotted owl	LT			WSC
Vertebrate	*Accipiter gentilis*	Northern goshawk	SC	S	S	WSC
Vertebrate	*Pandion haliaetus*	osprey			S	WSC
Vertebrate	*Antrozous pallidus*	pallid bat				
Vascular Plant	*Hesperochiron pumilus*	pygmy Western waterleaf				
Vascular Plant	*Astragalus rusbyi*	Rusby's milk-vetch		S		
Vertebrate	*Lasionycteris noctivagans*	silver-haired bat				
Vertebrate	*Myotis auriculus*	Southwestern myotis				
Vertebrate	*Cathartes aura*	turkey vulture				
Vascular Plant	*Talinum validulum*	Tusayan flame flower	SC			SR
Vascular Plant	*Rubus leucodermis*	Western raspberry				
Vascular Plant	*Nuphar luteum ssp. polysepalum*	yellow pond lily				

APPENDIX D: DESCRIPTION OF LAND COVER CLASSES

Vegetation classes have been derived from the Southwest Regional GAP analysis (ReGAP) land cover layer. To simplify the layer from 77 to 46 classes, we grouped similar vegetation classes into slightly broader classes by removing geographic and environmental modifiers (e.g. Chihuahuan Mixed Salt Desert Scrub and Inter-Mountain Basins Mixed Salt Desert Scrub got lumped into "Desert Scrub"; Subalpine Dry-Mesic Spruce-Fir Forest and Woodland was simplified to Spruce-Fir Forest and Woodland). What follows is a description of each class found in significant amounts in the linkage planning area (≥.05% of all pixels). Descriptions are taken largely from the document, Landcover Descriptions for the Southwest Regional GAP Analysis Project (Available from http://earth.gis.usu.edu/swgap).

EVERGREEN FOREST (5 CLASSES) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Conifer Forest and Woodland - Comprised of *Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Montane Mesic Mixed Conifer Forest and Woodland* classes. These are mixed-conifer forests occurring on all aspects at elevations ranging from 1200 to 3300 m. The composition and structure of overstory is dependent upon the temperature and moisture relationships of the site, and the successional status of the occurrence.

Pine-Oak Forest and Woodland – This system occurs on mountains and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, Trans-Pecos Texas, southern New Mexico and southern and central Arizona, from the Mogollon Rim southeastward to the Sky Islands. These forests and woodlands are composed of Madrean pines (*Pinus arizonica*, *Pinus engelmannii*, *Pinus leiophylla* or *Pinus strobiformis*) and evergreen oaks (*Quercus arizonica, Quercus emoryi*, or *Quercus grisea*) intermingled with patchy shrublands on most mid-elevation slopes (1500-2300 m elevation). Other tree species include *Cupressus arizonica, Juniperus deppeana.*

Pinyon-Juniper Woodland – These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides. In the southern portion of the Colorado Plateau in northern Arizona and northwestern New Mexico, *Juniperus monosperma* and hybrids of *Juniperus* spp may dominate or codominate tree canopy. *Juniperus scopulorum* may codominate or replace *Juniperus osteosperma* at higher elevations. In transitional areas along the Mogollon Rim and in northern New Mexico, *Juniperus deppeana* becomes common. In the Great Basin, Woodlands dominated by a mix of *Pinus monophylla* and *Juniperus osteosperma*, pure or nearly pure occurrences of *Pinus monophylla*, or woodlands dominated solely by *Juniperus osteosperma* comprise this system.

Ponderosa Pine Woodland – These woodlands occur at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 500 m in British Columbia to 2800 m in the mountains of New Mexico. Occurrences are found on all slopes and aspects, however, moderately steep to very steep slopes or ridgetops are most common. *Pinus ponderosa* is the predominant conifer; *Pseudotsuga menziesii*, *Pinus edulis*, and *Juniperus* spp. May be present in the tree canopy.

Spruce-Fir Forest and Woodland – Engelmann spruce and subalpine fir forests comprise a substantial part of the subalpine forests of the Cascades and Rocky Mountains from southern British Columbia east into Alberta, south into New Mexico and the Intermountain region. They are the matrix forests of the subalpine zone, with elevations ranging from 1525 to 3355 m (5000-11,000 feet). Sites within this system are cold year-round, and precipitation is predominantly in the form of snow, which may persist until late summer. Despite their wide distribution, the tree canopy characteristics are remarkably similar, with *Picea engelmannii* and *Abies lasiocarpa* dominating either mixed or alone. *Pinus contorta* is common in many occurrences and patches of pure *Pinus contorta* are not uncommon, as well as mixed conifer/*Populus tremuloides* stands. Xeric species may include *Juniperus communis, Linnaea borealis, Mahonia repens*, or *Vaccinium scoparium*.

DECIDUOUS FOREST (1 CLASS) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Aspen Forest and Woodland - Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions. Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand, and secondarily is limited by the length of the growing season or low temperatures. These are upland forests and woodlands dominated by *Populus tremuloides* without a significant conifer component (<25% relative tree cover).

GRASSLANDS-HERBACEOUS (3 CLASSES) – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Juniper Savanna – The vegetation is typically open savanna, although there may be inclusions of more dense juniper woodlands. This savanna is dominated by *Juniperus osteosperma* trees with high cover of perennial bunch grasses and forbs, with *Bouteloua gracilis* and *Pleuraphis jamesii* being most common. In southeastern Arizona, these savannas have widely spaced mature juniper trees and moderate to high cover of graminoids (>25% cover). The presence of Madrean *Juniperus* spp. such as *Juniperus coahuilensis*, *Juniperus pinchotii*, and/or *Juniperus deppeana* is diagnostic.

Montane-Subalpine Grassland – This Rocky Mountain ecological system typically occurs between 2200-3000 m on flat to rolling plains and parks or on lower sideslopes that are dry, but may extend up to 3350 m on warm aspects. An occurrence usually consists of a mosaic of two or three plant associations with one of the following dominant bunch grasses: *Danthonia intermedia, Danthonia parryi, Festuca idahoensis, Festuca arizonica, Festuca thurberi, Muhlenbergia filiculmis*, or *Pseudoroegneria spicata*. These large-patch grasslands are intermixed with matrix stands of spruce-fir, lodgepole, ponderosa pine, and aspen forests.

Semi-Desert Grassland and Shrub Steppe – Comprised of *Semi-Desert Shrub Steppe* and *Piedmont Semi- Desert Grassland and Steppe*. Semi-Desert Shrub is typically dominated by graminoids (>25% cover) with an open shrub layer, but includes sparse mixed shrublands without a strong graminoid layer. Steppe Piedmont Semi-Desert Grassland and Steppe is a broadly defined desert grassland, mixed shrub-succulent or xeromorphic tree savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico [Apacherian region], but extends west to the Sonoran Desert, north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is found on gently sloping bajadas that supported frequent fire throughout the Sky Islands and on mesas and steeper piedmont and foothill slopes in the Chihuahuan Desert. It is characterized by typically diverse perennial grasses. Common grass species include *Bouteloua eriopoda, B. hirsuta, B. rothrockii, B. curtipendula, B. gracilis, Eragrostis intermedia, Muhlenbergia porteri, Muhlenbergia setifolia, Pleuraphis jamesii, Pleuraphis mutica*, and *Sporobolus airoides*, succulent species of *Agave, Dasylirion*, and *Yucca*, and tall shrub/short tree species of *Prosopis* and various oaks (e.g., *Quercus grisea*, *Quercus emoryi, Quercus arizonica*).

SCRUB-SHRUB (5 CLASSES) – Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Chaparral – This ecological system occurs across central Arizona (Mogollon Rim), western New Mexico and southwestern Utah and southeast Nevada. It often dominants along the mid-elevation transition from the Mojave, Sonoran, and northern Chihuahuan deserts into mountains (1000-2200 m). It occurs on foothills, mountain slopes and canyons in dryer habitats below the encinal and *Pinus ponderosa* woodlands. Stands are often associated with more xeric and coarse-textured substrates such as limestone, basalt or alluvium, especially in transition areas with more mesic woodlands.

Creosotebush-White Bursage Desert Scrub – This ecological system forms the vegetation matrix in broad valleys, lower bajadas, plains and low hills in the Mojave and lower Sonoran deserts. This desert scrub is characterized by a sparse to moderately dense layer (2-50% cover) of xeromorphic microphyllous and broad-leaved shrubs. *Larrea tridentata* and *Ambrosia dumosa* are typically dominants, but many different shrubs, dwarf-shrubs, and cacti may codominate or form typically sparse understories.

Desert Scrub (misc) – Comprised of Succulent Desert Scrub, Mixed Salt Desert Scrub, and Mid-Elevation Desert Scrub. Vegetation is characterized by a typically open to moderately dense shrubland.

Gambel Oak-Mixed Montane Shrubland – This ecological system occurs in the mountains, plateaus and foothills in the southern Rocky Mountains and Colorado Plateau, including the Uinta and Wasatch ranges and the Mogollon Rim. These shrublands are most commonly found along dry foothills, lower mountain slopes, and at the edge of the western Great Plains from approximately 2000 to 2900 m in elevation, and are often situated above pinyon-juniper woodlands. The vegetation is typically dominated by *Quercus gambelii* alone or codominant with *Amelanchier alnifolia, Amelanchier utahensis, Artemisia tridentata, Cercocarpus* *montanus, Prunus virginiana, Purshia stansburiana, Purshia tridentata, Robinia neomexicana, Symphoricarpos oreophilus*, or *Symphoricarpos rotundifolius*. There may be inclusions of other mesic montane shrublands with *Quercus gambelii* absent or as a relatively minor component. This ecological system intergrades with the lower montane-foothills shrubland system and shares many of the same site characteristics.

<u>Mesquite Upland Scrub</u> – This ecological system occurs as upland shrublands that are concentrated in the extensive grassland-shrubland transition in foothills and piedmont in the Chihuahuan Desert. Vegetation is typically dominated by *Prosopis glandulosa* or *Prosopis velutina* and succulents. Other desert scrub that may codominate or dominate includes *Acacia neovernicosa*, *Acacia constricta*, *Juniperus monosperma*, or *Juniperus coahuilensis*. Grass cover is typically low.

WOODY WETLAND (1 CLASS) – Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

<u>Riparian Woodland and Shrubland</u> – This system is dependent on a natural hydrologic regime, especially annual to episodic flooding. Occurrences are found within the flood zone of rivers, on islands, sand or cobble bars, and immediate streambanks. In mountain canyons and valleys of southern Arizona, this system consists of mid- to low-elevation (1100-1800 m) riparian corridors along perennial and seasonally intermittent streams. The vegetation is a mix of riparian woodlands and shrublands. Throughout the Rocky Mountain and Colorado Plateau regions, this system occurs within a broad elevation range from approximately 900 to 2800 m., as a mosaic of multiple communities that are tree-dominated with a diverse shrub component.

BARREN LANDS (3 CLASSES) – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulation of earthen material. Generally, vegetation accounts for less than 15% of total cover.

<u>Mixed Bedrock Canyon and Tableland</u> – The distribution of this ecological system is centered on the Colorado Plateau where it is comprised of barren and sparsely vegetated landscapes (generally <10% plant cover) of steep cliff faces, narrow canyons, and open tablelands of predominantly sedimentary rocks, such as sandstone, shale, and limestone. Some eroding shale layers similar to Inter-Mountain Basins Shale Badland (CES304.789) may be interbedded between the harder rocks. The vegetation is characterized by very open tree canopy or scattered trees and shrubs with a sparse herbaceous layer.

<u>Playa</u> – This system is composed of barren and sparsely vegetated playas (generally <10% plant cover) found across the Intermountain western U.S. and warm deserts of North America. Playas form with intermittent flooding, followed by evaporation, leaving behind a saline residue. Salt crusts are common throughout, with small saltgrass beds in depressions and sparse shrubs around the margins. Subsoils often include an impermeable layer of clay or caliche. Large desert playas tend to be defined by vegetation rings formed in response to salinity. In northern Arizona

includes less saline high-elevation ephemeral wetlands with >10% plant cover including a mix of grasses and emergent species.

Volcanic Rock Land and Cinder Land – This ecological system occurs in the Intermountain western U.S. and is limited to barren and sparsely vegetated volcanic substrates (generally <10% plant cover) such as basalt lava (malpais), basalt dikes with associated colluvium, basalt cliff faces and uplifted "backbones," tuff, cinder cones or cinder fields. It may occur as large-patch, small-patch and linear (dikes) spatial patterns. Vegetation is variable and includes a variety of species depending on local environmental conditions, e.g., elevation, age and type of substrate. At montane and foothill elevations scattered *Pinus ponderosa*, *Pinus flexilis*, or *Juniperus* spp. trees may be present.

DEVELOPED AND AGRICULTURE (2 CLASSES) –

Developed, Medium - High Intensity – *Developed, Medium Intensity*: Includes areas with a mixture of constructed materials and vegetation. Impervious surface accounts for 50-79 percent of the total cover. These areas most commonly include single-family housing units. *Developed, High Intensity:* Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.

Developed, Open Space - Low Intensity – *Open Space:* Includes areas with a mixture of some construction materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. *Developed, Low intensity*: Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single family housing units.

OPEN WATER (1 CLASS) – All areas of open water, generally with less than 25% cover of vegetation or soil.

APPENDIX E: CREATING A PERENNIAL WATERS DATASET

Northern leopard frogs are dependent upon perennial water sources for breeding and intermittently wet drainages for dispersal. In order to model habitat connectivity for this species, we needed an accurate and up to date spatial dataset for bodies of water within the analysis area. Various data sources were available, but none were complete to a degree that local experts felt comfortable using for the model. Given the stakeholder support for modeling this species, its population decline, and its surrogacy for additional aquatic species, we decided to create a waters dataset for use in developing our corridor model. While other focal species depend on water sources for survival, to adjust the factor weights to include a fifth factor would have required reviews by multiple experts for each species model. It was determined that the suitability models for all but the Northern leopard frog would not be re-run with this additional dataset. The following methods were used to create a perennial waters dataset:

1) Gathered available water datasets from the following parties:
    Arizona Department of Environmental Quality
    Arizona Department of Water Resources
    Arizona Game & Fish Department
    Northern Arizona University
    US Department of Commerce & US Census Bureau
    US Fish & Wildlife Service
    US Geological Survey

2) Clipped all data sources to within 1km of the analysis area and stored in file geodatabase.

3) Surveyed the data for quality by reading metadata, consulting data users, and comparing datasets against maps and against each other. Extracted most reliable and unique perennial waters information.

Notes and decision points:
NHD data was the most comprehensive and was used as a starting point. NHD has separate shapefiles for streams and waterbodies (including tanks, ponds, springs, etc). All other datasets were compared against this one to capture additional water sources. Data sources >7 years old and without metadata were not used. Sources that seemed to include ephemeral water sources and non-unique perennial sources were dismissed. Due to variability in collection techniques and projections, spatial errors seemed extensive. We used a distance of 50 meters between points to determine unique locations. In other words, if two datasets represented a small water body differing by only 30 meters on the ground, we considered these to be representative of a single water feature.

4) Created a single point shapefile including NHD data, AGFD wildlife waters, ADWR springs locations, and AGFD leopard frog locations.

5) Created a single polygon shapefile including NHD waterbodies, TIGER geographic waterbodies, and NHD data for major rivers and creeks.

6) Created a single line shapefile based on ADEQ's perennial waters data.

Creation of single raster file from which distance bands were calculated:

1) Changed all ‘Resolution’ field entries to 2 and used this as value field (added field to PerennialADEQ1kmCLIP). Provided matching data field for subsequent merges.

2) Created separate GRID files for line data, polygon data, and point data at 30 meter cell size.

3) Used “mosaic” tool to combine GRID files into single raster file “Waters_All” in the geodatabase.

APPENDIX F: LITERATURE CITED

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