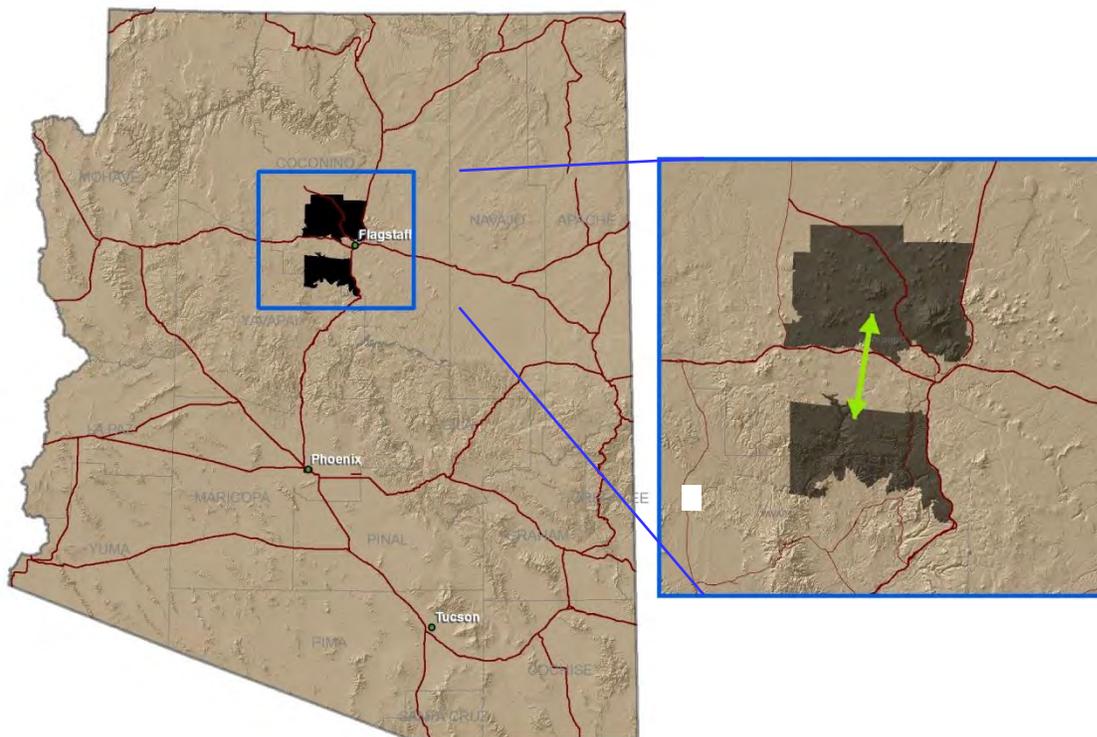


**USING GIS MODELS TO CONSERVE
HABITAT CONNECTIVITY FOR WILDLIFE:
SAN FRANCISCO PEAKS – MOGOLLON RIM LINKAGE DESIGN**

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ABSTRACT

As western communities grow, roads, urbanization, railways, alternative energy facilities, and utility corridors create barriers that can isolate wildlife populations and disrupt critical ecological processes. Habitat fragmentation can be mitigated by conserving large wildland areas connected by wildlife linkages. GIS-based linkage models offer a useful complement to empirical approaches such as telemetry by identifying multispecies movement areas and can help guide siting of crossing structures and other mitigation actions. To maintain wildlife habitat connectivity in northern Arizona the Arizona Game and Fish Department in collaboration with Coconino County developed a linkage design for an area of high conservation priority.

In 2008 and 2009 we convened a diverse group of stakeholders with backgrounds in planning, wildlife biology and management to identify important wildlife movement areas. Stakeholders prioritized grassland and forest habitats linking two large areas of USFS-administered lands between the cities of Flagstaff and Williams, Arizona. We used least-cost corridor modeling (described at www.corridordesign.org) to identify corridors that will maintain wildlife movement between the San Francisco Peaks and the Mogollon Rim across Interstate Highway 40. We identified 11 focal species known to inhabit both wildland blocks and obtained expert information on habitat use to build habitat suitability models in ArcGIS. We then generated least-cost corridors using the habitat suitability outputs. Utilizing field investigations and empirical data we validated and refined the corridor models, united them in a multiple species linkage design, and identified potential locations for mitigation and restoration actions.

Our linkage design includes three strands serving multiple focal species. These strands include lands under diverse ownership including public lands administered by the U.S. Forest Service and other agencies. Comparison of modeled focal species corridors with available location data including Arizona Game and Fish Department large mammal telemetry datasets provided a high degree of validation for our modeling approach and was used to refine our draft model to produce a final linkage design. We are exploring possible applications of our linkage design to regional connectivity conservation and mitigation efforts with government, agency, private, and non-governmental partners.

Our project yielded a linkage design serving diverse species of wildlife including some not easily studied or typically considered in highway connectivity projects. Our results do not supplant but provide an important complement to empirical studies of wildlife movements, and have been integrated with AGFD's ongoing collaboration with the Arizona Department of Transportation to improve wildlife connectivity along Interstate 40 and other major roadways. Integration of empirical data with GIS-based linkage designs provides a powerful way to mutually validate each approach and to extend connectivity planning beyond those species for which data are available. We recommend this synergistic approach to conserving connectivity for wildlife for other important wildlife movement areas which the Arizona Game and Fish Department is actively pursuing in other areas of the state.

RATIONALE

Animals move across the landscape in order to acquire resources necessary for survival such as food, water, protective cover, and mates. While the distance and timing of animal movements can vary considerably, these diverse movement patterns ensure individual survival and help

protect local populations from extinction (Laurance 1991, Beier and Loe 1992), ensure genetic diversity (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 fragment habitat and present barriers to animal movement that can threaten the long-term persistence of wildlife populations and the stability of ecosystems (Noss 1983, Wilcox and Murphy 1985, Noss 1987, Bennett 1999, Henle et al. 2004, Noss and Daly 2006). Habitat fragmentation presents problems for wildlife ranging from roadway mortality to genetic isolation, and can negatively impact human welfare by increasing the risk of vehicle collisions and the frequency of unwanted “close encounters” with wildlife.

The effects of habitat fragmentation can be mitigated by identifying and protecting “linkage” areas that wildlife use for movement (Beier and Noss 1998, Haddad et al. 2003, Eggers et al. 2009, Gilbert-Norton 2010). Ridgelines, canyons, riparian areas, cliffs, swaths of forest or grassland, and other features may function as linkages, and some species may spend their entire lives 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 unfragmented areas of habitat referred to as wildland blocks large enough to sustain healthy wildlife populations and essential ecological processes into the 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 habitats 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). Identification of linkage areas can be approached using telemetry, GIS-based modeling (Clevenger et al. 2002), and other techniques.

Maintaining wildlife linkages also benefits human communities, perhaps most obviously by improving public safety. Wildlife collisions are a significant problem in the area addressed by this linkage design: from 2007 to 2009 more than 190 collisions involving wildlife occurred on Interstate Highway 40 between Williams and Twin Arrows east of Flagstaff, the majority involving elk (Arizona Game and Fish Department 2011b). Identifying wildlife movement areas that intersect transportation corridors permits informed siting of wildlife over- and underpasses that can greatly reduce 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).

Habitat connectivity can be represented at various spatial scales. In Arizona we have identified linkages at statewide, county, and local scales to meet different conservation 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 (e.g. AWLW 2006). The linkage design presented here grew directly out of a collaboration between the Arizona Game and Fish Department and Coconino County to organize stakeholder workshops to create maps of wildlife linkages at a regional scale (Arizona Game & Fish Department 2011a) and list priority linkages for fine-scale GIS modeling. County stakeholders highlighted the San Francisco Peaks to Mogollon Rim linkage area as high priority,

a selection supported by County planners with knowledge of future growth patterns and conservation opportunities.

PEAKS-TO-RIM LINKAGE DESIGN

Study Area

The area addressed by this project spans three ecoregions of central Arizona: Arizona-New Mexico Mountains, Apache Highlands North, and Colorado Plateau (Arizona Game and Fish Department 2006a). The majority lies within the Arizona-New Mexico Mountains Ecoregion which overall covers more than 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 features some of the most dramatic landforms in the state including the Mogollon Rim at its southern boundary and the San Francisco Peaks, the highest point in Arizona. Together these ecoregions span arid grasslands, chaparral, pinyon-juniper, desert scrub, ponderosa pine, mixed conifer, and evergreen oak woodland communities. Diverse wildlife including federally-protected species such as Mexican spotted owl, bald eagle, and San Francisco Peaks groundsel (USFWS 2013) are found in the planning area, as well as important game species and state species of concern. Our linkage design does not directly address connectivity for riparian species but the perennial portions of Sycamore and Oak Creek drainages in the Mogollon Rim block support native aquatics including speckled dace, desert sucker, Sonora sucker, narrow-headed garter snake, and lowland leopard frog and potential reintroduction sites for northern leopard frog.

Methods

Delineation of Wildland Blocks

We defined two wildland blocks we named the San Francisco Peaks and Mogollon Rim blocks after prominent landscape features. Each is primarily administered by the US Forest Service—the Kaibab National Forest to the west and the Coconino National Forest to the east. The blocks span a broad elevational range, provide habitat for a diversity of wildlife, and consist of lands expected to remain in good ecological condition for the foreseeable future contiguous with hundreds of thousands of additional acres of National Forest. We used major highways and National Forest and Wilderness boundaries to delimit the blocks. We retained small private inholdings where development is low-density and good wildlife habitat remains, and included state-owned parcels in the Mogollon Rim block managed by Northern Arizona University's Centennial Forest. The blocks are separated by Interstate 40, the Burlington Northern Santa Fe railroad, and a matrix of private, state, and federal land developed to various degrees (Figure 1).

The northern San Francisco Peaks wildland block encompasses 430,500 acres and includes a number of prominent volcanic mountains including the San Francisco Peaks and Kendrick Peak. Elevation ranges from approximately 1,750 to 3,850 meters (5,760 to 12,633 feet) supporting high-elevation grassland, pinyon-juniper woodland, ponderosa pine, aspen, mixed conifer, and alpine tundra vegetation types. This block includes the Kachina Peaks (18,616 acres) and Kendrick Mountain (6,510 acres) Wilderness Areas administered by the U.S. Forest Service. 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 and Oak Creeks leave the Rim in this

block via deep canyons. Elevation ranges from 1,090 to 2,325 meters (3,575 to 7,630 feet) supporting chaparral, grassland, pinyon-juniper woodland, ponderosa pine forest, and riparian plant communities at lower elevations. This block includes Sycamore Canyon (55,937 acres) and Red Rock-Secret Mountain (47,194 acres) Wilderness Areas and is immediately adjacent to the Munds Mountain Wilderness Area (24,411 acres), all administered by the U.S. Forest Service.

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. They include 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 require 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. Four species, marked in Table 1 by an "*", are "corridor dwellers" requiring multiple generations to move between blocks (see "Modeling methods" below). The focal species thus 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		Herps
Abert's squirrel*	Gunnison's prairie dog*	Arizona black rattlesnake*
badger	mule deer	northern leopard frog*
black bear	porcupine	
bobcat	pronghorn	
elk		

Modeling Methods

For each focal species we created a habitat suitability model based on expert rankings of habitat use of classes within 5 factors: land cover, elevation, topography, distance to roads, and perennial water. Suitability was modeled in ArcGIS using www.corridordesign.org tools to produce a weighted overlay of data layers corresponding to each factor, yielding 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, then used least-cost corridor techniques to model biologically-optimal corridors between the blocks. We refined individual species' models with empirical data as available, then combined species-specific corridors to produce the linkage design. For "corridor dwellers" requiring multiple generations to traverse wildland blocks we did not model corridors, but instead examined the distribution of suitable habitat to verify that the linkage design included high quality habitat and patches of adequate size. Our linkage design (Figure 1) includes three strands linking core habitats for focal species in the San Francisco Peaks and Mogollon Rim blocks. Through field investigation and the work of colleagues (Gagnon et al. 2012) we identified potential locations for highway crossing structures and other mitigation at critical points in the modeled linkage.

Results

Linkage Design

The final linkage design (Figure 1) is composed of three terrestrial strands, labeled A, B, and C from west to east, providing habitat for wildlife to move between wildland blocks north and south of Interstate 40. Strands A and B overlap at their southern end near where each enters the Mogollon Rim block. 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).

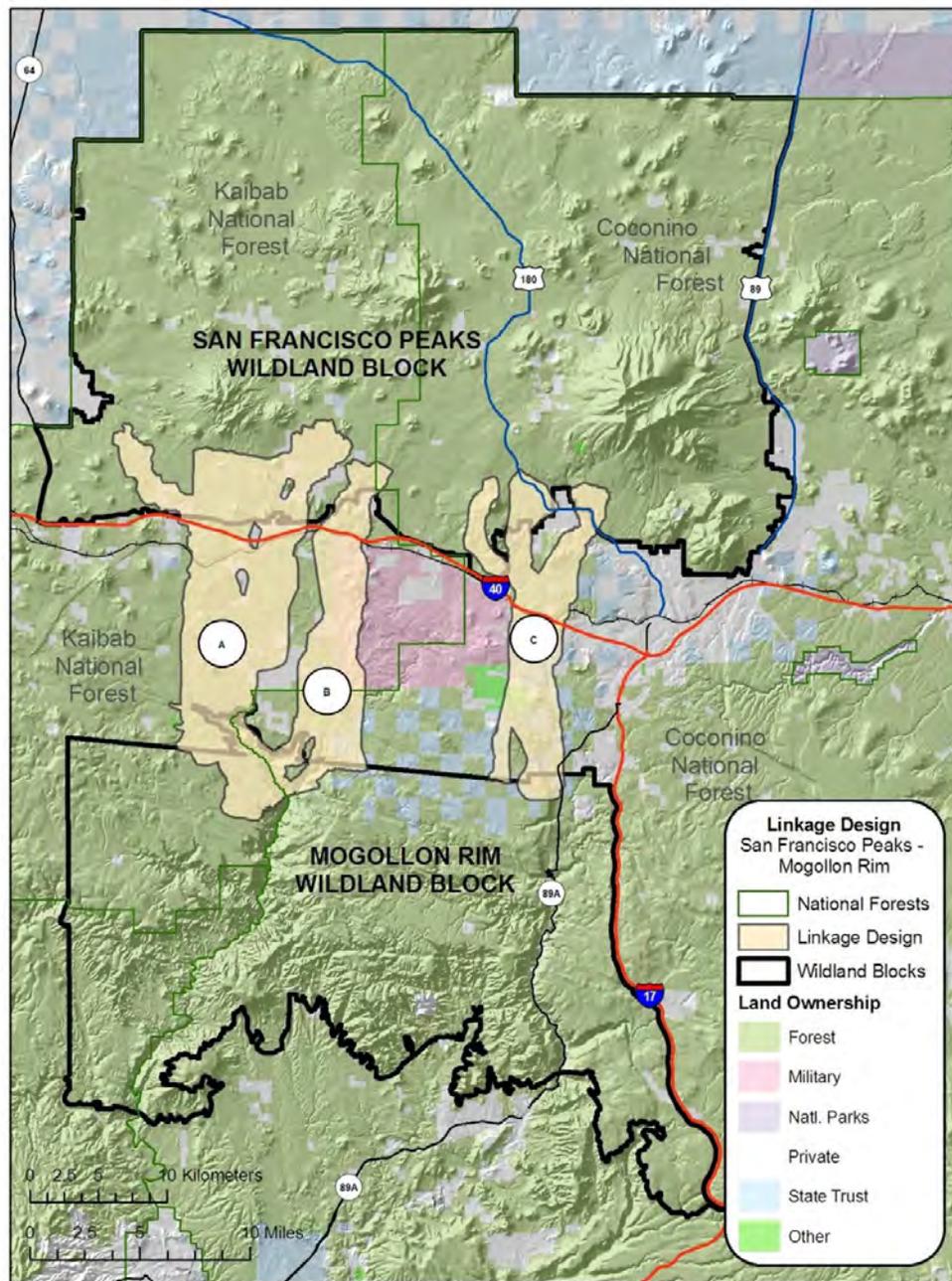


FIGURE 1 San Francisco Peaks to Mogollon Rim linkage design.

Strand A 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 ~30 km long at its greatest extent and 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. The strand includes relatively flat meadows including Government and Garland Prairies, gentle forested slopes in its western half, and overlaps the Sycamore Canyon Wilderness at its southern terminus.

Strand B follows wooded highlands on the western edge of the Army National Guard's Camp Navajo facility and is dominated by ponderosa pine forest with small areas of pinyon-juniper and grassland at its southern and western edges, respectively. It is ~23 km long. 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. It includes steep slopes on its eastern flank including Volunteer Mountain and relatively gentle terrain along its western portion at Garland Prairie. This strand includes rugged terrain at its southern terminus including portions of the Sycamore Canyon Wilderness and Volunteer Canyon.

Strand C encompasses most of north-south trending Woody Ridge east of Camp Navajo. This area is predominantly ponderosa pine forest and rugged. The Strand is ~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 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 at the western edge of Flagstaff and includes a "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.

Model Validation

We used available data to inform and validate our linkage design. Camp Navajo Army Depot provided 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. Mule deer locations obtained from biologists in AGFD's Contracts Branch strongly overlapped the easternmost strand of our modeled corridor for this species, and also guided a small extension of this strand where it crosses US Highway 180 just inside the San Francisco Peaks block (Figure 2, mule deer corridor shown in white and telemetry locations in green).

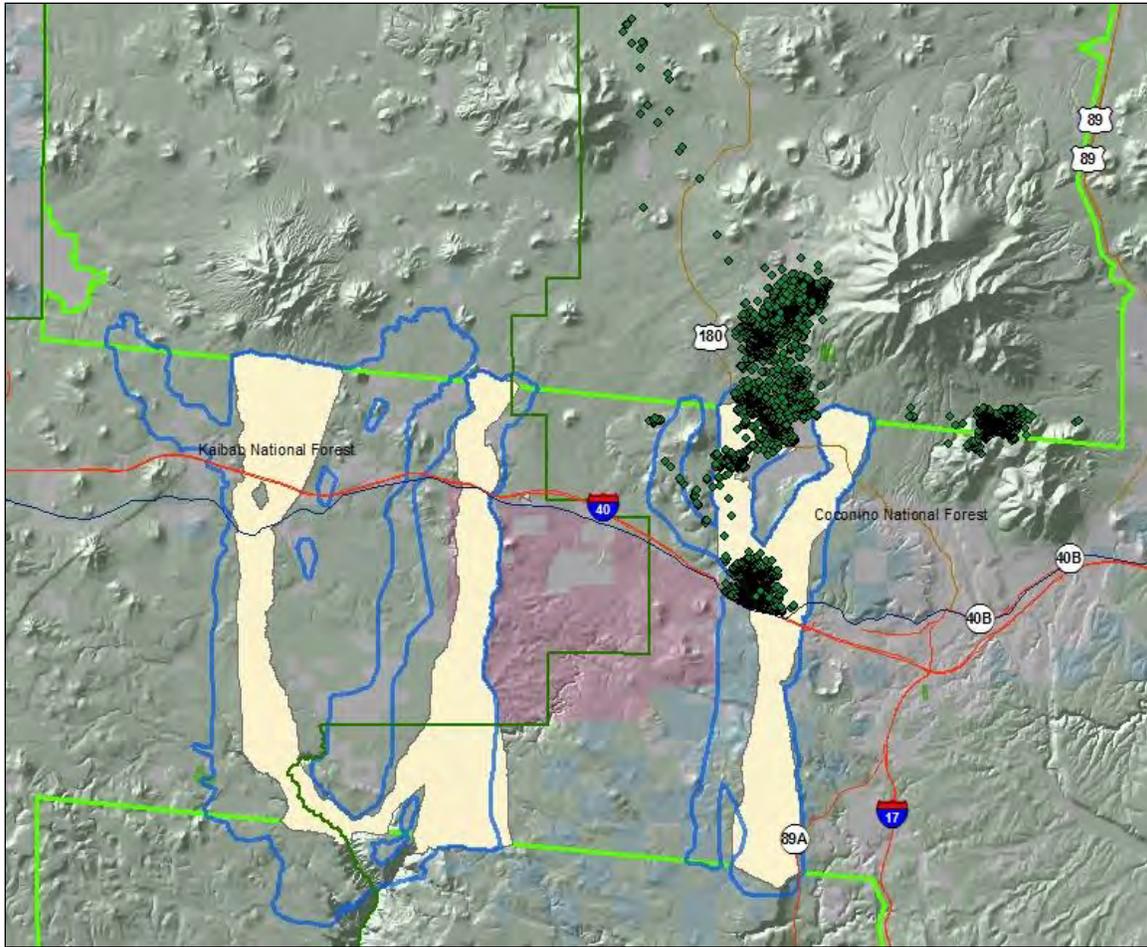
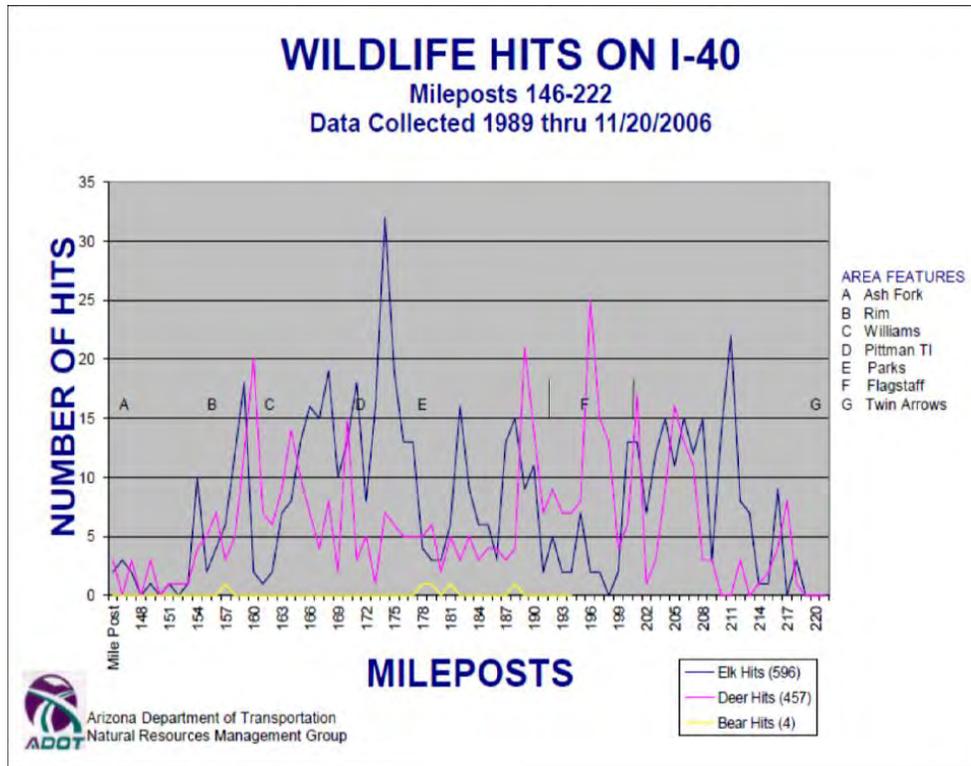


FIGURE 2 Mule deer telemetry data validate modeled corridor.

We also compared wildlife-vehicle collision data obtained data from the Arizona Department of Transportation for Interstate Route 40 with our modeled corridor for elk. As shown in Figure 3, these data also provide good support for our modeling approach. While significant numbers of elk collisions were reported at several areas along I-40 for the study period (blue curve in Figure 3-A), a clear peak is evident in the vicinity of milepost 175. This milepost is included within our modeled biologically-best corridor for elk (salmon polygon in Figure 3-B).

A.



B.

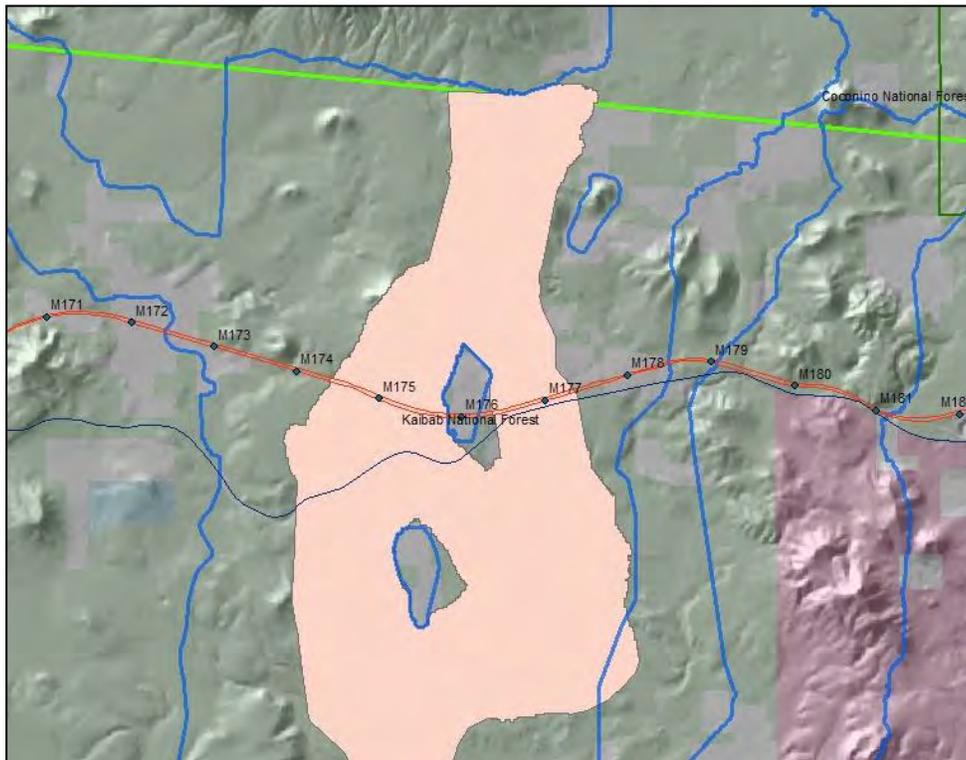


FIGURE 3 Relation of elk-vehicle collisions on Interstate 40 to elk corridor model. A. Wildlife-vehicle collisions between Ash Fork and Twin Arrows, AZ 1989-2006. B. I-40 mileposts and modeled elk corridor.

Non-Modeled Areas Important to Wildlife Movement

The linkage planning area includes several additional areas important for maintaining connectivity that are not part of the modeled linkage design (Figure 4). 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. Rogers Lake is an ephemeral wetland and surrounding grasslands and forested uplands support a diversity of birds including migrant passerines, raptors, and Mexican spotted owls. Coconino County has acquired State Trust parcels around Rogers Lake, and future collaborative efforts with Camp Navajo may augment the amount of protected land. **Volunteer Canyon** originates on Camp Navajo and connects directly to Strand B at its southern end, and provides an important linkage between Rogers Lake, habitats on the Camp, and the head of Sycamore Canyon in the Mogollon Rim block. It includes breeding habitat for Mexican spotted owl and is used for seasonal movements by turkey. **Government Prairie** overlaps Strand A and constitutes important grassland habitat used by a range of species. It connects to other areas of grassland and ponderosa pine forest further north within the San Francisco Peaks wildland block. Future efforts here should focus on removing and improving fencing for wildlife and restoring grasslands.

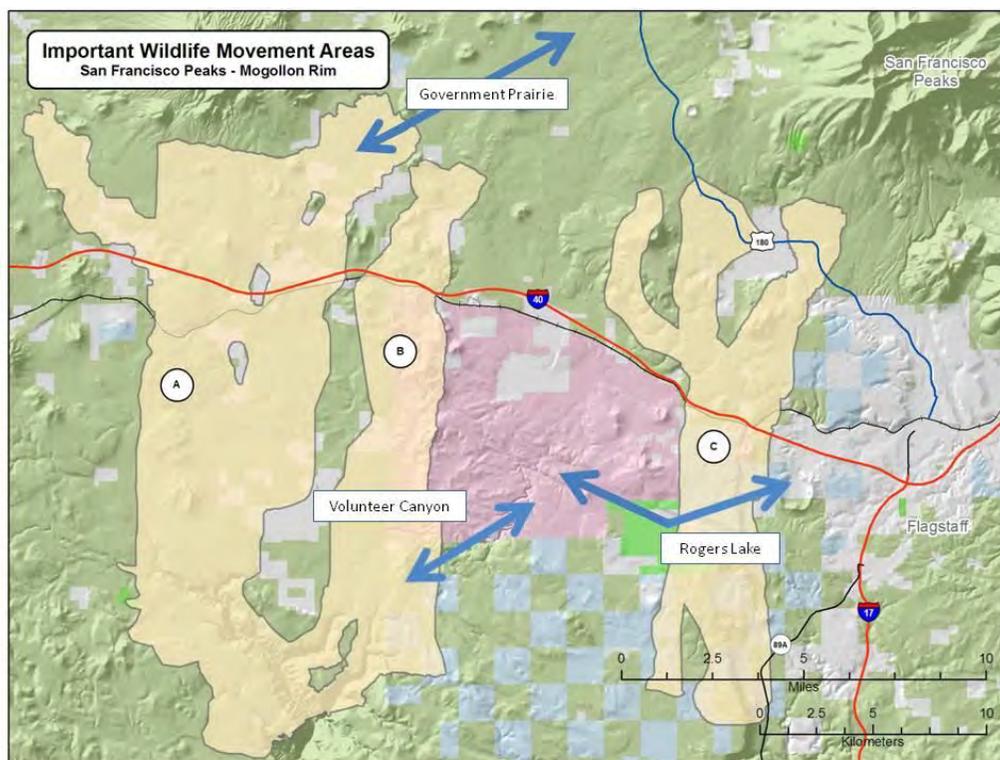


FIGURE 4 Non-modeled areas important to wildlife movement.

MITIGATING BARRIERS TO MOVEMENT

Roads, rail lines, and urban areas occupy only a small fraction of the linkage design but their impacts threaten to impede animal movement between the wildland blocks. Here we identify specific barriers within the linkage design and suggest appropriate mitigations.

Existing Roads

The principal roadway in the linkage area is Interstate 40 which crosses all three strands of the linkage design for a total length of ~10.5 miles. The Burlington Northern Santa Fe railroad, also a major barrier, roughly parallels I-40 for a total distance of ~17 miles across the three linkage strands. Other roadways impacting the linkage are over 7 miles of U.S. Highway 180 in the northern portion of Strand C and ~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 and thus may have a positive effect on wildlife connectivity within the strands of the linkage design.

Recommendations for Crossing Structures

Interstate Highway 40

Research biologists with the Arizona Game and Fish Department's Contracts Branch in collaboration with and supported by the Arizona Department of Transportation have been conducting telemetry studies of large mammal movements along many of Arizona's major highway corridors, including Interstate 40, to determine optimal locations for wildlife crossing structures (AGFD 2011b, AGFD 2012, Gagnon et al. 2012). Their findings for the I-40 corridor support our modeling results and inform their recommended locations for wildlife crossing structures (Figure 5). These recommendations are based on telemetry data, roadkill records, and ground-truthing, indicating locations where existing crossing structures could be modified or new structures implemented to enhance wildlife movement in the linkage planning area. While informed primarily by data on large mammals, the implementation of the recommended crossings should benefit a wide range of species as indicated by their overlap with our linkage design. It is important to note that in order to realize maximum benefits of these crossing structures, the permeability of the nearby BNSF railway line and many fences will likely also need to be assessed and enhanced where possible.

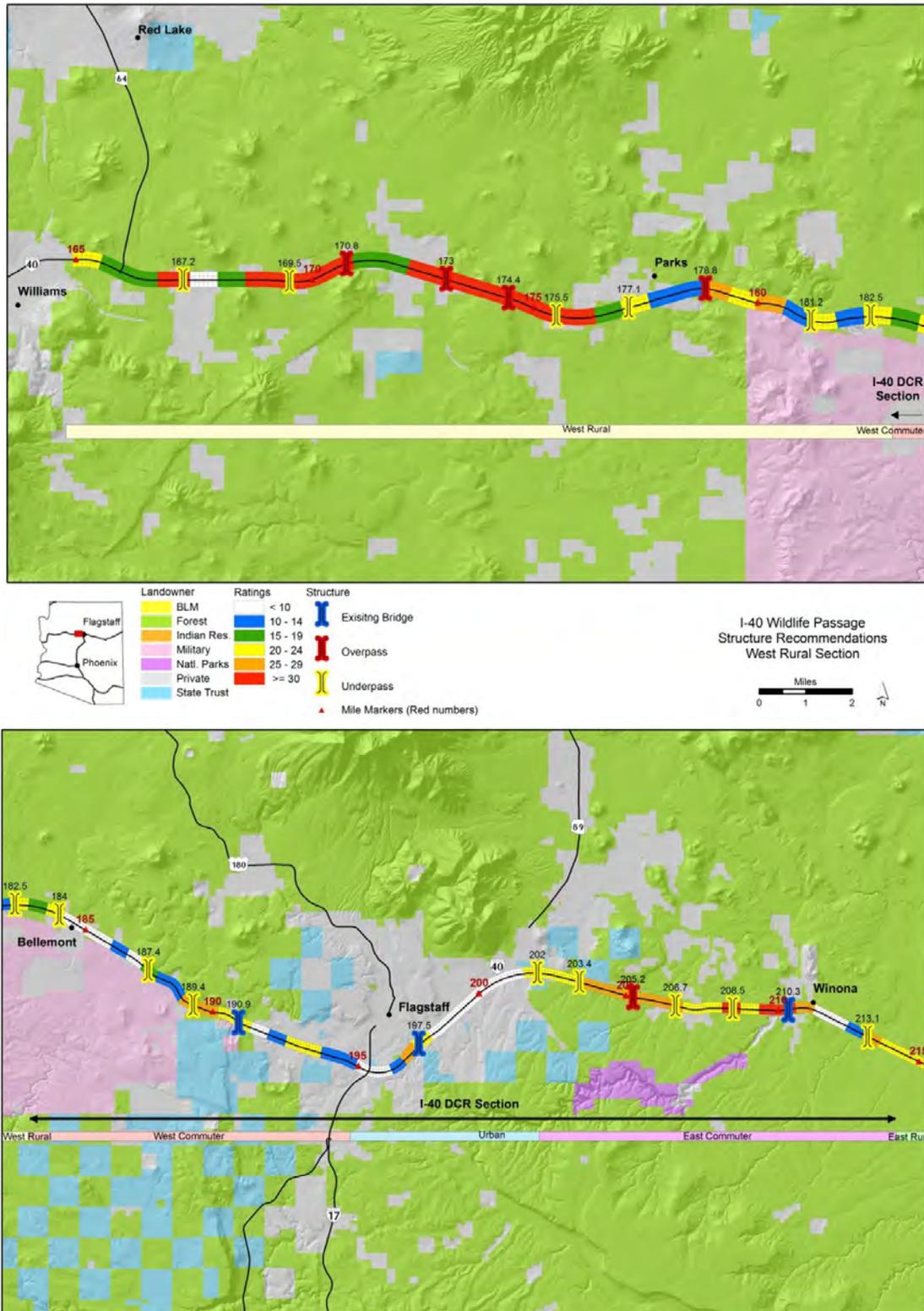


FIGURE 5 Existing and recommended crossing structure locations on Interstate Highway 40 (Used by permission from Gagnon et al. 2012).

Gagnon et al. (2012) emphasize the potential for strategically placed elk overpasses to serve multiple species, including pronghorn. They echo recommendations we received from Kaibab National Forest biologists to locate a wildlife overpass designed to accommodate pronghorn and other grassland species along Interstate 40 (B. Noble, pers. comm.). This location is found at mile 174.4 of I-40 (shown in top panel of Figure 5 above), is located within Strand A of the linkage design, and is immediately adjacent to the modeled biologically best corridor for pronghorn. Here I-40 passes through a roadcut of solid rock; the rock base material occurs at about the same height on both sides of the Interstate, including the median area between the east and westbound lanes (Figure 6). An overpass could possibly be constructed atop these existing features. The highway currently divides Government and Garland Prairie grasslands north and south of the interstate and bisects U.S. Forest Service lands on either side of the highway. A crossing here could play a key role in restoring habitat connectivity for what appear to be increasingly isolated pronghorn populations in this area of northern Arizona (Dodd et al. 2011, Theimer et al. 2012). However, successful implementation would require both a significant financial commitment and substantial restoration treatments to remove encroached shrubs and create more open grassland habitat on both sides of I-40.

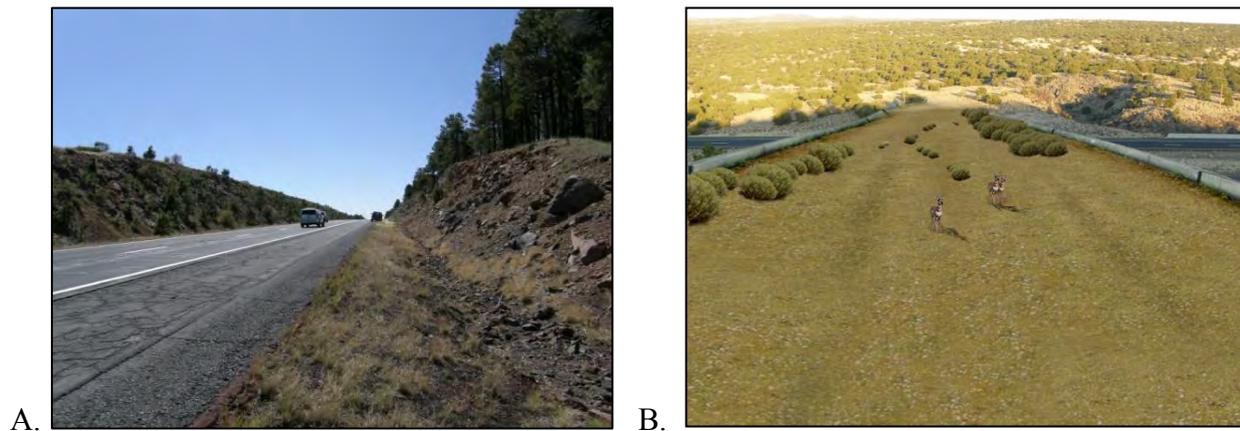


FIGURE 6 Location photo (A) and design (B) of potential pronghorn overpass on Interstate Highway 40 (Source, B: Norris Dodd).

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 7). 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 our linkage Strand C. In addition to providing empirical validation for our linkage design in this area, these data reinforce the need to explore potential locations for wildlife crossings and the impact of fencing in this important area.

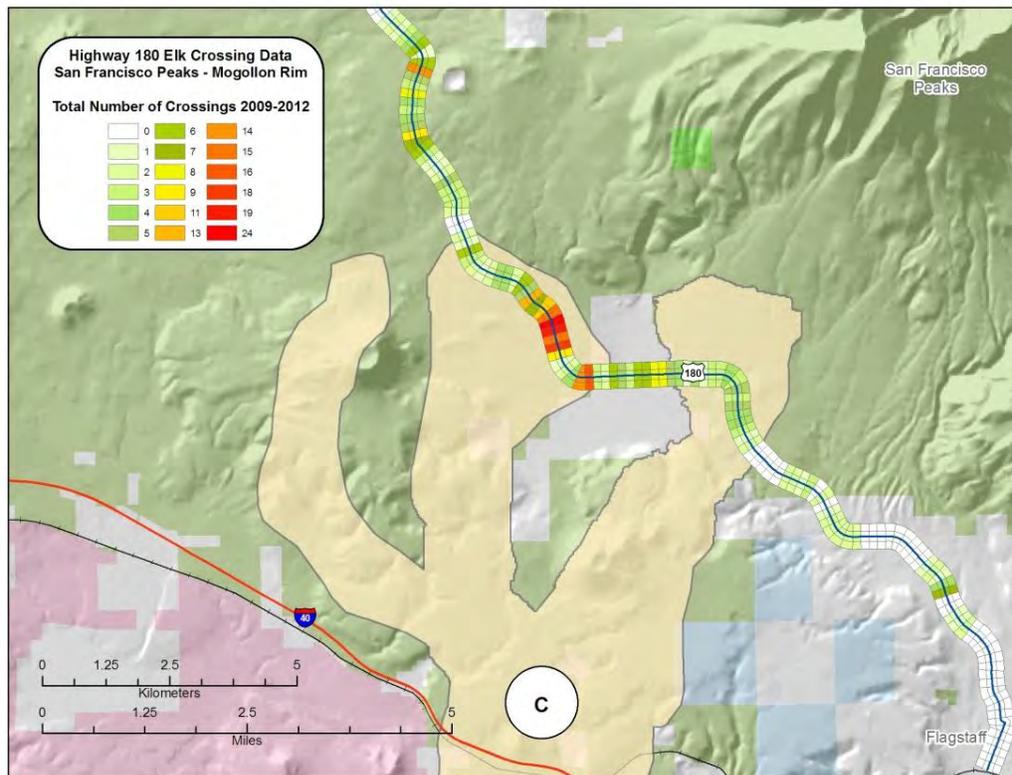


FIGURE 7 Elk crossings of U.S. Highway 180 near Flagstaff, Arizona. Color reflects total number of crossings within 0.1 mile highway segments from May 2009 to March 2012. (Source: AGFD Contracts Branch).

Mitigating Urban Barriers in the Linkage Area

While developed areas currently account for a small proportion of the land cover within the linkage design urban and rural residential development could increase rapidly in some areas, particularly along the I-40 corridor. Much of the area of all three linkage strands is under the ownership of the Kaibab and Coconino National Forests and expected to remain protected into 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 inclusion of wildlife-friendly design features in 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, including future acquisitions of some of these lands as protected open space, will likely be necessary.

Strand A, while traversing perhaps the most rural portion of the linkage design, may present a unique conservation challenge. This strand includes the biologically best corridor for pronghorn, probably the most barrier-sensitive of those modeled. Developed areas in Strand A include Pittman Valley and Parks which may both see increased growth in the future, and Parks is located in an area of this strand which connects grasslands of Government Prairie to the north

with those of Garland Prairie south of I-40. Extensive fencing also exists for livestock and property boundaries. These can be designed or retrofitted to be more wildlife-permeable but would 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 shrub removal 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 Camp Navajo, with a small portion of the NAU Centennial Forest included at its southern terminus. While these areas are under little immediate threat from urban or rural development, 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 Department of Defense is also exploring the 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, some of which should be prioritized for future acquisition.

At the level of project permitting, design features which maintain wildlife movement areas can be incorporated into residential subdivisions and other projects. Coconino County's Comprehensive Plan is grounded in a conservation framework integrating natural resources including wildlife corridors into land use decisions and project planning (CCCPP 2003). An important element of Coconino County's approach is 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. The City of Flagstaff's draft revised Regional Plan (City of Flagstaff, In preparation) incorporates similar policies and includes spatially explicit wildlife corridor data. The County's Plan will also be revised soon, and we expect our linkage design to be integrated in the updated plans of both City and County to guide regional- and project-scale planning and design as well as open space acquisition and management.

Summary: Using this 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 described above, and habitat improvement efforts such as removing and retrofitting fencing to “wildlife-friendly” specifications. As described above, the Arizona Department of Transportation is providing considerable financial support to Arizona Game and Fish Department research biologists to determine movement patterns of large mammals and identify locations for wildlife crossings along Interstate Highway 40. Our linkage design is being used both to validate 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 benefits for wildlife. For example, 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.

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.

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This paper is excerpted from the following report, which interested readers can request for greater detail regarding methodology and results: *Arizona Game and Fish Department. 2013. Coconino County Wildlife Connectivity Assessment: Detailed Linkages. San Francisco Peaks – Mogollon Rim Linkage Design. Phoenix, Arizona.*

GIS DATA

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

BIOGRAPHICAL SKETCHES OF AUTHORS

Jessica Gist is a Research Specialist II for the Arizona Game & Fish Department in Flagstaff, Arizona. In her 5 years with the Department, Jessica has served on several planning teams for projects led by Arizona Department of Transportation, Coconino National Forest, and other agencies in northern Arizona. Working closely with these agencies and Coconino County, she is engaged in planning for wildlife habitat connectivity, open space acquisition and management, and community-based watchable wildlife opportunities. Jessica completed her M.S. in Environmental Sciences and Policy at Northern Arizona University and B.S. in Ecology & Evolutionary Biology at the University of California, Santa Cruz.

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