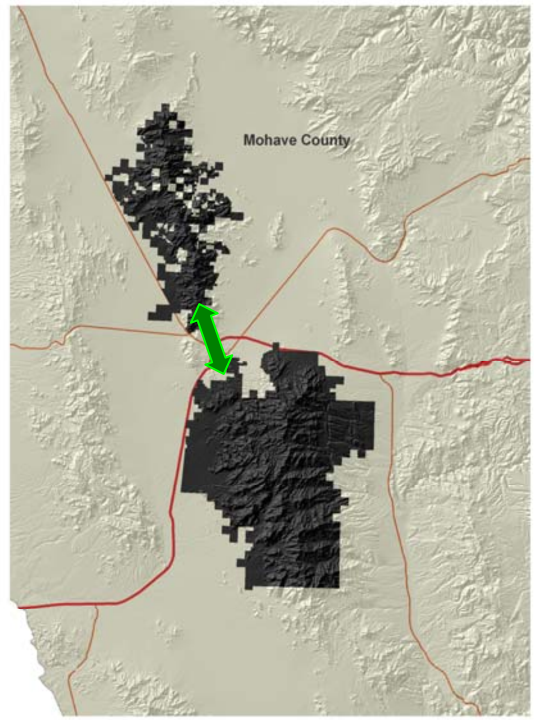
ARIZONA MISSING LINKAGES

Hualapai - Cerbat Linkage Design

Paul Beier, Emily Garding, Dan Majka
2008

HUALAPAI - CERBAT LINKAGE DESIGN



Acknowledgments
This project would not have been possible without the help of many individuals. We thank Dr. Phil Rosen, Matt Good, Chasa O'Brien, Dr. Jason Marshal, Ted McKinney, and Taylor Edwards for parameterizing models for focal species and suggesting focal species. Catherine Wightman, Fenner Yarborough, Janet Lynn, Mylea Bayless, Andi Rogers, Mikele Painter, Valerie Horncastle, Matthew Johnson, Jeff Gagnon, Erica Nowak, Lee Luedeker, Allen Haden, Shaula Hedwall, and Martin Lawrence helped identify focal species and species experts. Robert Shantz provided photos for many of the species accounts. Shawn Newell, Jeff Jenness, Megan Friggens, and Matt Clark provided helpful advice on analyses and reviewed portions of the results.

Funding
This project was funded by a grant from Arizona Game and Fish Department to Northern Arizona University.

Recommended Citation
Beier, P, E. Garding, and D. Majka. 2008. Arizona Missing Linkages: Hualapai-Cerbat Linkage Design. Report to Arizona Game and Fish Department. School of Forestry, Northern Arizona University.

Table of Contents

List of Tables & Figures

List of Tables

List of Figures

Terminology

Key terminology used throughout the report includes:

Biologically Best Corridor: A continuous swath of land expected to be the best route for one focal species to travel from a potential population core in one wildland block to a potential population core in the other wildland block. In some cases, the biologically best corridor consists of 2 or 3 *strands*.

Focal Species: Species chosen to represent the needs of all wildlife species in the linkage planning area.

Linkage Design: The land that should – if conserved – maintain or restore the ability of wildlife to move between the *wildland blocks*. The Linkage Design was produced by joining the biologically best corridors for individual focal species, and then modifying this area to delete redundant strands, avoid urban areas, include parcels of conservation interest, and minimize edge.

Linkage Planning Area: Includes the wildland blocks and the *Potential Linkage Area*. If the Linkage Design in this report is implemented, the biological diversity of the entire Linkage Planning Areawill be enhanced

Permeability: The opposite of travel cost, such that a perfectly permeable landscape would have a travel cost near zero.

Pixel: The smallest unit of area in a GIS map – 30x30 m in our analyses. Each pixel is associated with a vegetation class, topographic position, elevation, and distance from paved road.

Potential Linkage Area: The area of private and ASLD land between the wildland blocks, where current and future urbanization, roads, and other human activities threaten to prevent wildlife movement between the wildland blocks. The *Linkage Design* would conserve a fraction 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 models assume that habitat suitability is the best indicator of the cost of movement through the pixel.

Wildland Blocks[1]: Large areas of publicly owned or tribal land expected to remain in a relatively natural condition for at least 50 years. These are the "rooms" that the Linkage Design is intended to connect. The value of these conservation investments will be eroded if we lose connectivity between them. Wildland blocks include private lands managed for conservation but generally exclude other private lands and lands owned by Arizona State Land Department (ASLD, which has no conservation mandate under current law). Although wildland blocks may contain non-natural elements like barracks or reservoirs, they have a long-term prospect of serving as wildlife habitat. Tribal sovereignty includes the right to develop tribal lands within a wildland block.

[1] In the linkage designs we produced in 2006, we used the term Habitat Blocks instead of Wildland Blocks. We changed to Wildland Block to avoid awkwardness in referring to habitat for particular species within a block ('suitable habitat within a habitat block') and patches of suitable habitat in the corridor ('habitat patches outside a habitat block').

Executive Summary

Habitat loss and fragmentation are the leading threats to biodiversity, both globally and in Arizona. These threats can be mitigated by conserving well-connected networks of large wildland areas where natural ecological and evolutionary processes operate over large spatial and temporal scales. Large wildland blocks connected by corridors can maintain top-down regulation by large predators, natural patterns of gene flow, pollination, dispersal, energy flow, nutrient cycling, inter-specific competition, and mutualism. Corridors allow ecosystems to recover from natural disturbances such as fire or flood, and to respond to human-caused disturbance such as climate change and invasions by exotic species.

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between two large areas of BLM-administered wildlands near Kingman, Arizona. Running east-west through this region, Interstate 40 and future urban development present an impediment to animal movement between the Hualapai Mountains to the south, and the Cerbat Mountains to the north. These areas represent a large public investment in biological diversity, and this Linkage Design is a reasonable science-based approach to maintain the value of that investment.

To begin the process of designing this linkage, we asked academic scientists, agency biologists, and conservation organizations to identify focal species in the area that are sensitive to habitat loss and fragmentation, including 2 amphibians, 4 reptiles, 4 birds, 2 fish, and 14 mammals (Table 1). These focal species cover a broad range of habitat and movement requirements. Some require huge tracts of land to support viable populations (e.g. badger, mountain lion). Some species are habitat specialists (e.g. bighorn sheep, Gila Monster), and others are reluctant or unable to cross barriers such as freeways (e.g. elk, mule deer). Some species are rare and/or endangered (Hualapai Mexican Vole), while others like javelina are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of rugged highlands and desert scrub. Together, these 26 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final Linkage Design provides live-in or move-through habitat for each focal species.

The Linkage Design (Figure 1) is composed of 2 strands which together provide habitat for movement and reproduction of wildlife between the Hualapai Mountains area to the south and the Cerbat Mountains area to the north. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The Hualapai and Cerbat Mountain regions provide significant ecological, educational, recreational, and spiritual values as protected wildlands. Our Linkage Design represents an opportunity to protect a functional landscape-level connection. The cost of implementing this vision will be substantial—but reasonable in relation to the benefits and the existing public investments in protected wild habitat. If implemented, our plan would not only permit movement of individuals and genes between the Hualapai and Cerbat Mountain wildland blocks, but should also conserve large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the US Forest Service, Arizona State Parks, Bureau of Land Management, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and other conservancy lands.

Next Steps: This Linkage Design Plan is a science-based starting point for conservation actions. The plan can be used as a resource for regional land managers to understand their critical role in sustaining biodiversity and ecosystem processes. Relevant aspects of this plan can be folded into management plans of agencies managing public lands. Transportation agencies can use the plan to design new projects and find opportunities to upgrade existing structures. Regulatory agencies can use this information to help inform decisions regarding impacts on streams and other habitats. This report can also help motivate and inform construction of wildlife crossings, watershed planning, habitat restoration, conservation easements, zoning, and land acquisition. Implementing this plan will take decades, and collaboration among county planners, land management agencies, resource management agencies, land conservancies, and private landowners.

Public education and outreach is vital to the success of this effort – both to change land use activities that threaten wildlife movement and to generate appreciation for the importance of the corridor. Public education can encourage residents at the urban-wildland interface to become active stewards of the land and to generate a sense of place and ownership for local habitats and processes. Such voluntary cooperation is essential to preserving linkage function. The biological information, maps, figures, tables, and photographs in this plan are ready materials for interpretive programs.

Ultimately the fate of the plants and animals living on these lands will be determined by the size and distribution of protected lands and surrounding development and human activities. We hope this linkage conservation plan will be used to protect an interconnected system of natural space where our native biodiversity can thrive, at minimal cost to other human endeavors.

Table 1: Focal species selected for Hualapai-Cerbat Linkage

<table>
<tr><th>MAMMALS</th><th>AMPHIBIANS & REPTILES</th><th>BIRDS</th></tr>
<tr><td rowspan="3">*Badger
Bats
*Black Bear
Black-footed Ferret
*Black-tailed Jackrabbit
*Desert Bighorn Sheep
*Elk
Gunnison’s Prairie Dog
Hualapai Mexican Vole
*Javelina
*Kit Fox
*Mountain Lion
*Mule Deer
*Pronghorn</td><td rowspan="3">Lowland Leopard Frog
Northern Leopard Frog
Arizona Black Rattlesnake
Black-necked Gartersnake
Chuckwalla
*Gila Monster</td><td>Black-throated Sparrow
Gambel’s Quail
Western Burrowing Owl
Yellow-billed Cuckoo</td></tr>
<tr><th>FISH</th></tr>
<tr><td>Desert Sucker
Longfin Dace</td></tr>
</table>

* Species modeled in this report. The other species were not modeled because there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), because the species does not occur in both wildland blocks, or because the species probably can travel (e.g., by flying) across unsuitable habitat. Appendix C provides rationales for species not modeled.

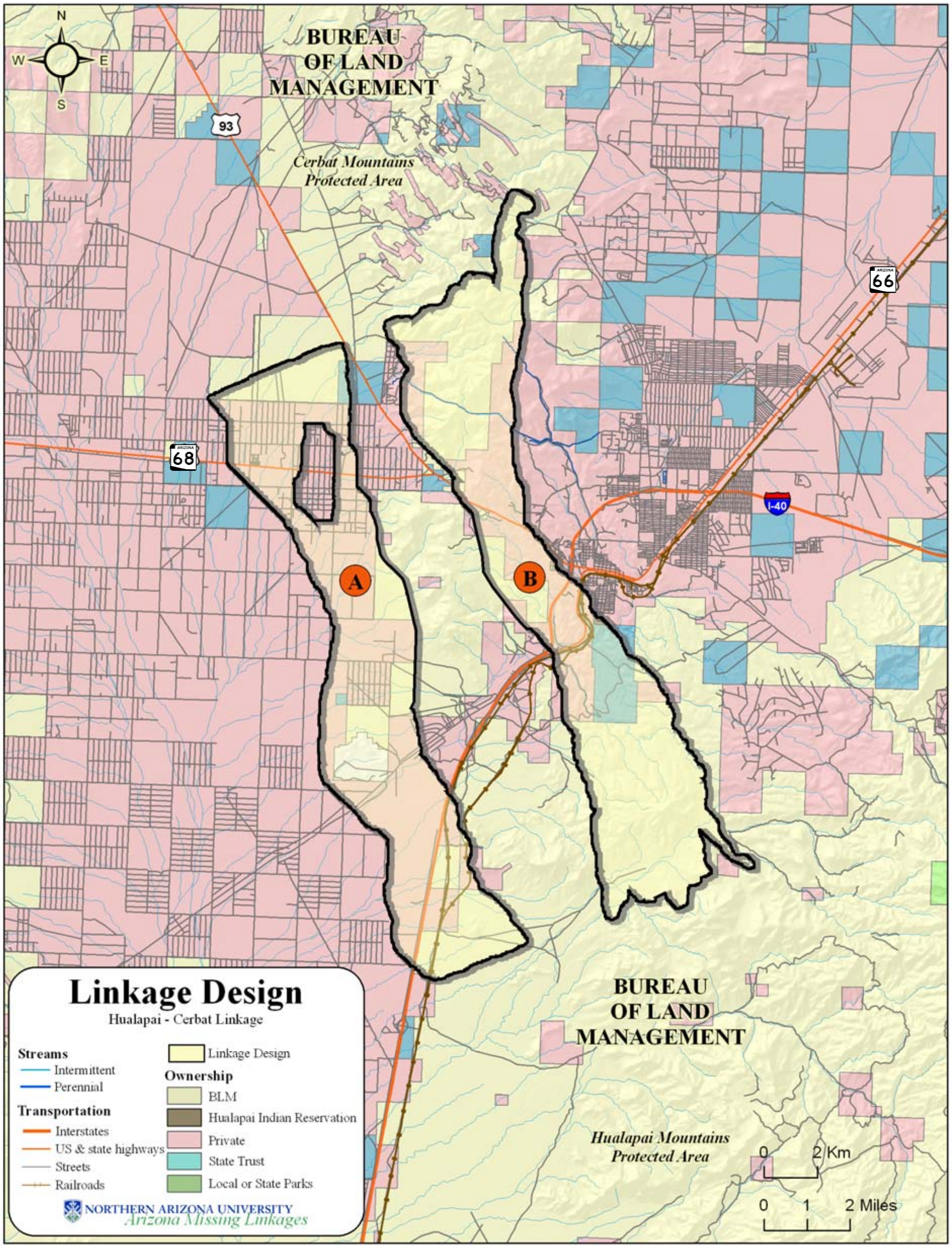


Figure 1: The Linkage Design between the Hualapai and Cerbat Mountain wildland blocks includes two strands, each of which is important to different species.

Introduction

Nature Needs Room to Move

Movement is essential to wildlife survival, whether it be the day-to-day movements of individuals seeking food, shelter, or mates, dispersal of offspring (e.g., seeds, pollen, fledglings) to new home areas, gene flow, migration to avoid seasonally unfavorable conditions, recolonization of unoccupied habitat after environmental disturbances, or shifting of a species' geographic range in response to global climate change.

In environments fragmented by human development, disruption of movement patterns can alter essential ecosystem functions, such as top-down regulation by large predators, gene flow, natural patterns and mechanisms of pollination and seed-dispersal, natural competitive or mutualistic relationships among species, resistance to invasion by alien species, and prehistoric patterns of energy flow and nutrient cycling. Without the ability to move among and within natural habitats, species become more susceptible to fire, flood, disease and other environmental disturbances and show greater rates of local extinction (Soulé and Terborgh 1999). The principles of island biogeography (MacArthur and Wilson 1967), models of demographic stochasticity (Shaffer 1981, Soulé 1987), inbreeding depression (Schonewald-Cox et al. 1983; Mills and Smouse 1994), and metapopulation theory (Levins 1970, Taylor 1990, Hanski and Gilpin 1991) all predict that isolated populations are more susceptible to extinction than connected populations. Establishing connections among natural lands has long been recognized as important for sustaining natural ecological processes and biological diversity (Noss 1987, Harris and Gallagher 1989, Noss 1991, Beier and Loe 1992, Noss 1992, Beier 1993, Forman 1995, Beier and Noss 1998, Crooks and Soulé 1999, Soulé and Terborgh 1999, Penrod et al. 2001, Crooks 2001, Tewksbury et al. 2002, Forman et al. 2003).

Habitat fragmentation is a major reason for regional declines in native species. Species that once moved freely through a mosaic of natural vegetation types are now being confronted with a human-made labyrinth of barriers such as roads, homes, and agricultural fields. Movement patterns crucial to species survival are being permanently altered at unprecedented rates. Countering this threat requires a systematic approach for identifying, protecting, and restoring functional connections across the landscape to allow essential ecological processes to continue operating as they have for millennia.

A Statewide Vision

In April 2004, a statewide workshop called *Arizona Missing Linkages: Biodiversity at the Crossroads* brought together over 100 land managers and biologists from federal, state, and local agencies, academic institutions, and non-governmental organizations to delineate habitat linkages critical for preserving the State's biodiversity. Meeting for 2 days at the Phoenix Zoo, the participants identified over 100 Potential Linkage Areas throughout Arizona (Arizona Wildlife Linkage Workgroup 2006).

The workshop was convened by the Arizona Wildlife Linkage Workgroup, a collaborative effort led by Arizona Game and Fish Department, Arizona Department of Transportation, Federal Highways Administration, US Forest Service, Bureau of Land Management, US Fish and Wildlife Service, Sky Island Alliance, Wildlands Project, and Northern Arizona University. The Workgroup prioritized the potential linkages based on biological importance and the conservation threats and opportunities in each area (AWLW 2006). Eight linkage designs were produced in the Fiscal Year 2005-06. In the Fiscal Year 2006-07, eight additional linkages within 5 miles of an incorporated city were selected for linkage design planning. The Hualapai-Cerbat Linkage is one of these "urban" linkages.

Ecological Significance of the Hualapai-Cerbat Linkage

The Hualapai-Cerbat Linkage Planning Arealies within a unique location in Arizona where four of the state's five ecoregions converge (Figure 2), creating a diverse mix of desert scrublands and forested highlands. As climate change proceeds, these ecoregional boundaries will also shift, and the landscape will need sufficient connectivity to allow species to shift their geographic distributions. The four ecoregions in the Linkage Planning Areaare:

- The southern lowlands of the Linkage Planning Areaare predominantly classified as part of the 55 million-acre **Sonoran Desert Ecoregion** of southwestern Arizona, southeastern California, and northwestern Sonora, Mexico. This ecoregion is the most tropical of North America's warm deserts (Marshall et al. 2000). Bajadas sloping down from the mountains support forests of ancient saguaro cacti, paloverde, and ironwood; creosotebush and bursage desert shrub dominate the lower desert (The Nature Conservancy 2006). The Sonoran Desert Ecoregion is home to more than 200 threatened species, and its uniqueness lends to a high proportion of endemic plants, fish, and reptiles (Marshall et al. 2000; The Nature Conservancy 2006). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of 233 of the earth's most biologically valuable ecoregions.
- The western plains of the linkage zone are part of the 33-million acre **Mojave Desert Ecoregion** of northwestern Arizona, southeastern California, southern Nevada, and southwestern Utah. The Mojave Desert Ecoregion is drier than the Sonoran Desert, averaging less than 5 inches of annual precipitation (TNC 2006). Found within this ecoregion is a diverse array of topography, which supports 250 plant species, 90 of which are endemic to the ecoregion (TNC 2006). In addition to a number of common desert mammals, the Mojave supports 35 fish species, 21 amphibian species, 30 species of snails, and a number of threatened or endangered birds, such as the yellow-billed cuckoo and southwestern willow flycatcher (TNC 2006).
- The middle and eastern portions of the linkage zone are dominated by two high elevation ecoregions. The **Apache Highlands Ecoregion** encompasses 30 million acres of central and southeastern Arizona, northern Sonora, northwestern Chihuahua, and southwestern New Mexico (Marshall et al 2004). This ecoregion spans 7,000 feet in elevation, providing varied ecosystems including sky island forests, grasslands, and riparian corridors. This variation supports a high level of biological diversity, including 110 mammals, 265 birds, and 2000 plant species (TNC 2006). Additionally, this ecoregion is one of the most reptile-rich regions of the country, supporting more than 75 reptiles (TNC 2006).
- The **Colorado Plateau Ecoregion** encompasses nearly 49 million acres of northern Arizona, southern Utah, southwestern Colorado, and northwestern New Mexico. Within this ecoregion, the combination of a large elevation range from 1,200 to 12,700 feet and a unique geological history provide for a high level of diversity and endemism. More than 300 planet species are endemic to the region, and vegetation communities range from semi-arid grasslands and desert scrub in low deserts and canyons, to pinyon-juniper mesas at mid-elevations, and conifer forests and alpine tundra in the high mountains.

Within the Linkage Planning Area, two wildland blocks are separated by Interstate 40, US Highways 93 and 66, State Highway 68, County Highway 10, and a matrix of private, state trust, and BLM land 14 to 16 miles wide (Figure 3). We have named the wildland blocks the Hualapai and Cerbat Mountain Wildland blocks[2]. Both of these areas are administered by the Bureau of Land Management.

[2] Both blocks of BLM land have no formal designation on most maps. We named them after prominent topographic features found in each blocks: the Cerbat Mountains in the northern block, and the Hualapai Mountains in the southern block.

The Cerbat Mountain wildland block encompasses all but the southernmost portion of the Cerbat Mountain range, including the Mount Tipton Wilderness Area (Figure 5). The area supports drainages such as Antelope Canyon, Twentysix Wash, Indian Springs, Marble Canyon and Pine Canyon. Most of this wildland block is located within the Mojave Desert Ecoregion. The vegetation at lower elevations consists of Mohave Desert scrub transitioning to pinyon-juniper and interior chaparral. Ponderosa pine forests occur at the highest elevations. Elevation within this wildland block ranges from 3000 to 7,148 feet at Mount Tipton Peak.

The Hualapai Mountain wildland block encompasses the Hualapai Mountains, which support drainages such as Antelope Wash, Big Sandy River, Cane Springs Wash, Cow Creek, Crow Canyon, Deluge Wash, Kabba Wash, Mackenzie Wash, McGarrys Wash, Moss Wash, Walnut Creek, Wheeler Wash, and Willow Creek. Most of this wildland block is located within the Apache Highlands Ecoregion, with the western foothills and flats falling within the Mojave Desert Ecoregion. Within this wildland block, mid-elevation mixed desert scrub, creosotebush, and paloverde-mixed cacti desert scrub dominate the flats and lowlands, while pinyon-juniper woodlands and chaparral cover the higher elevations. Elevation within this wildland block ranges from 1550 to 8400 ft., providing geologic and topographic variability that contributes to high biological diversity.

Between the wildland blocks, the lowlands of Linkage Planning Areaare dominated by mid-elevation desert scrub. The varied habitat types in the Linkage Planning Areasupport many animal species, home to far-ranging mammals such as pronghorn, mule deer, badger, elk, and mountain lion. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as black-tailed jackrabbits, javelina, kit fox, and Gila monsters also need corridors to maintain genetic diversity, to allow populations to shift their range in response to climate change, and to promote recolonization after fire or epidemics.

Existing Conservation Investments

The proposed Hualapai-Cerbat Linkage is designed to protect and enhance the public investments in conservation in the wildland blocks it would link. It is therefore important to understand the public investments at stake in each wildland block, and in the linkage area.

The wildland blocks are comprised of land federally protected by the Bureau of Land Management. The **northern Cerbat Mountains** wildland block consists of nearly 122,650 acres. The mountains encompass a diverse range of habitats from the Mohave desert scrub and Arizona chaparral communities at lower elevations to a remnant stand of old-growth ponderosa pine near the summit of 7,148 foot Mount Tipton. This varied landscape provides habitat for an array of wildlife species including bobcat, kit fox, several species of raptors, mule deer and Gambel’s quail. Mount Tipton, a 31,320 acre Wilderness area designated in 1990, encompasses much of the northern portion of this wildland block. The Cerbat Pinnacles are a well-known landmark within the Wilderness area. The Cerbat Foothills Recreation Area provides over 1,000 acres of open space and recreational opportunities in the southern portion of the mountains. Grand Canyon National Park, a World Heritage Site and natural landmark encompassing over 1.2 million acres, lies roughly 20 miles northeast of the Cerbat Mountains. Adjacent to the north rim of the Grand Canyon is another 2.7 million acres of federally protected BLM-administered land. To the northwest, Lake Mead National Recreation Area supports an array of desert and riparian species less than 20 miles away (Figure 5).

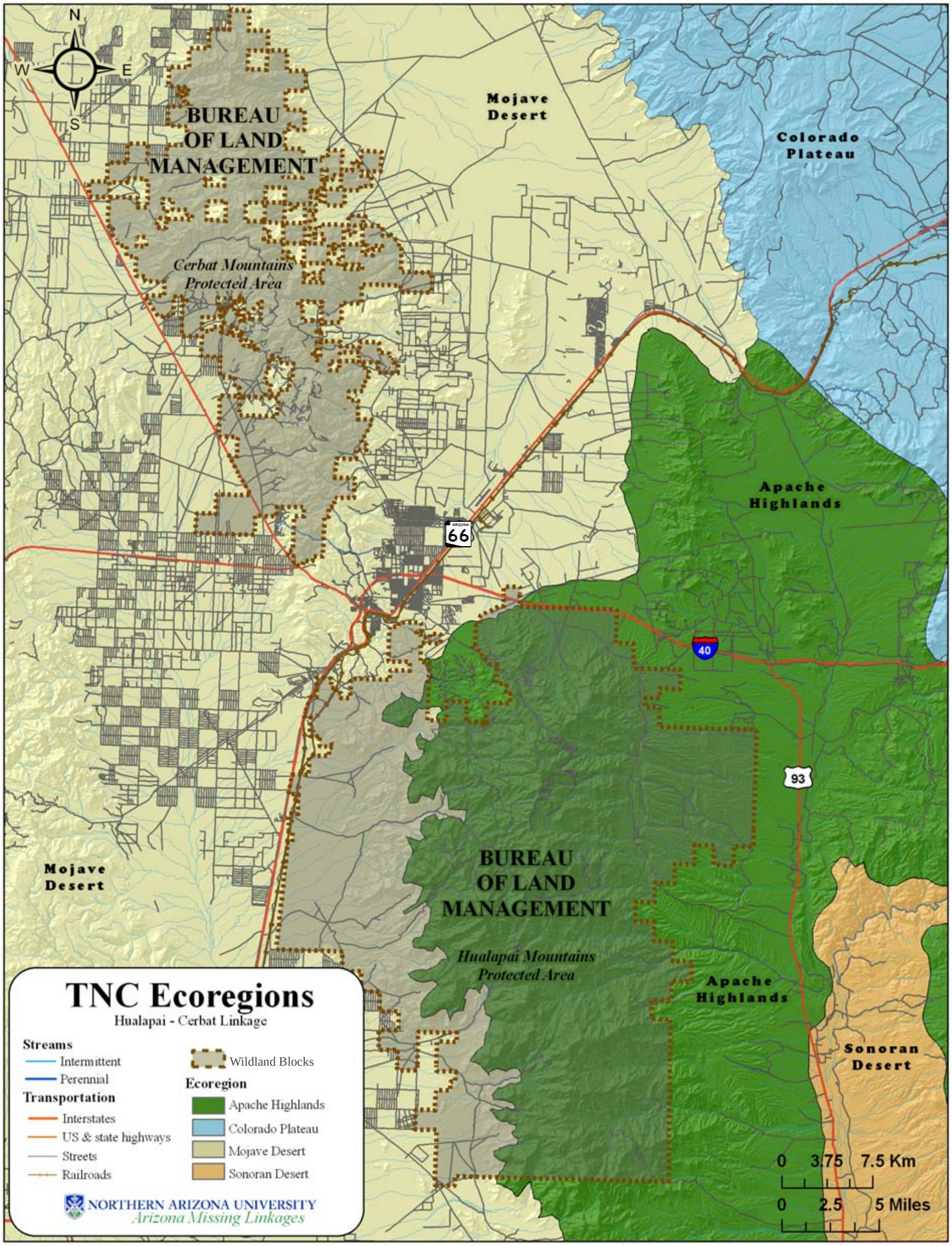


Figure 2: Ecoregions within the Linkage Planning Area. The Linkage Planning Areais in a unique area in Arizona where four of the state's five ecoregions converge.

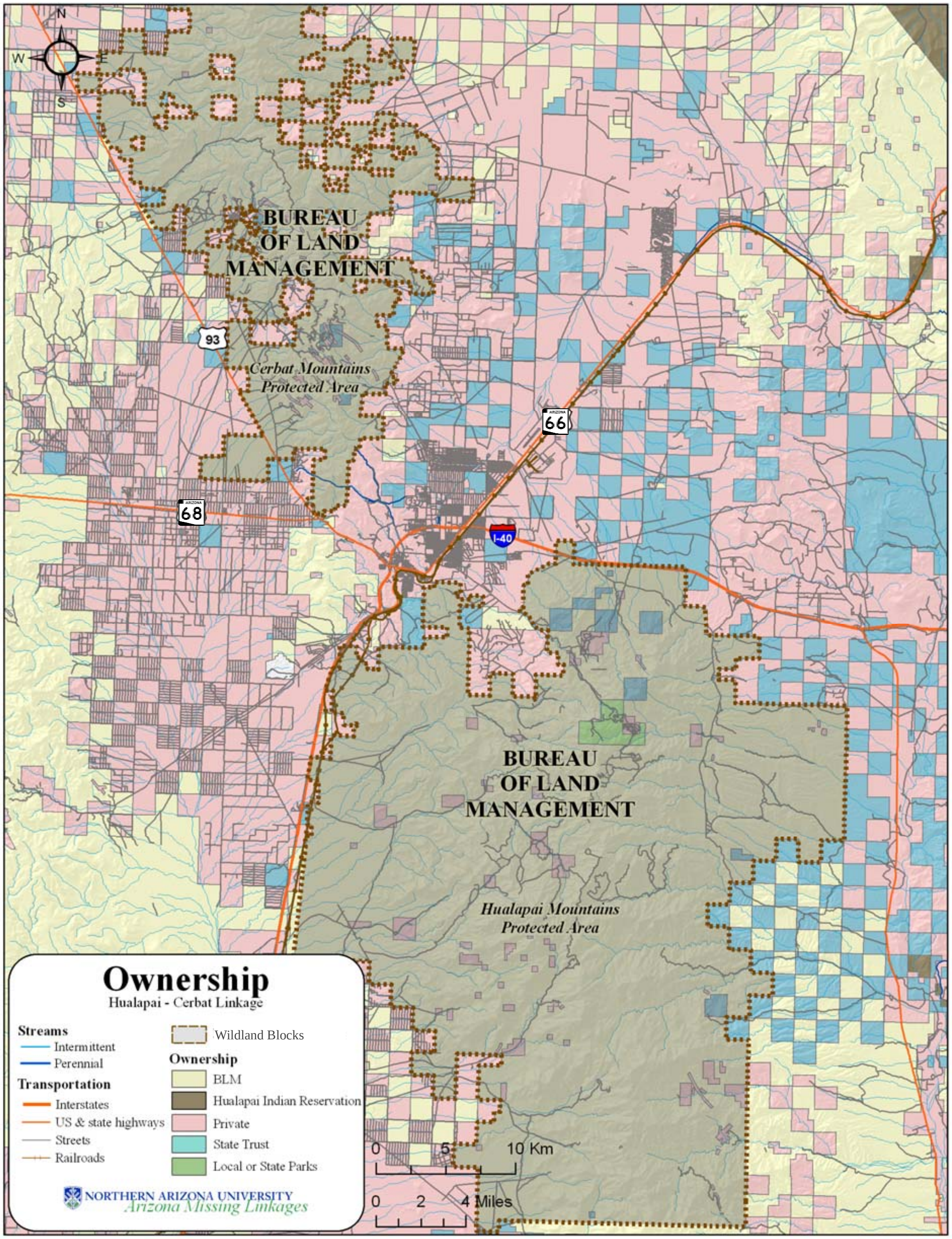


Figure 3: Land ownership within the Linkage Planning Area.

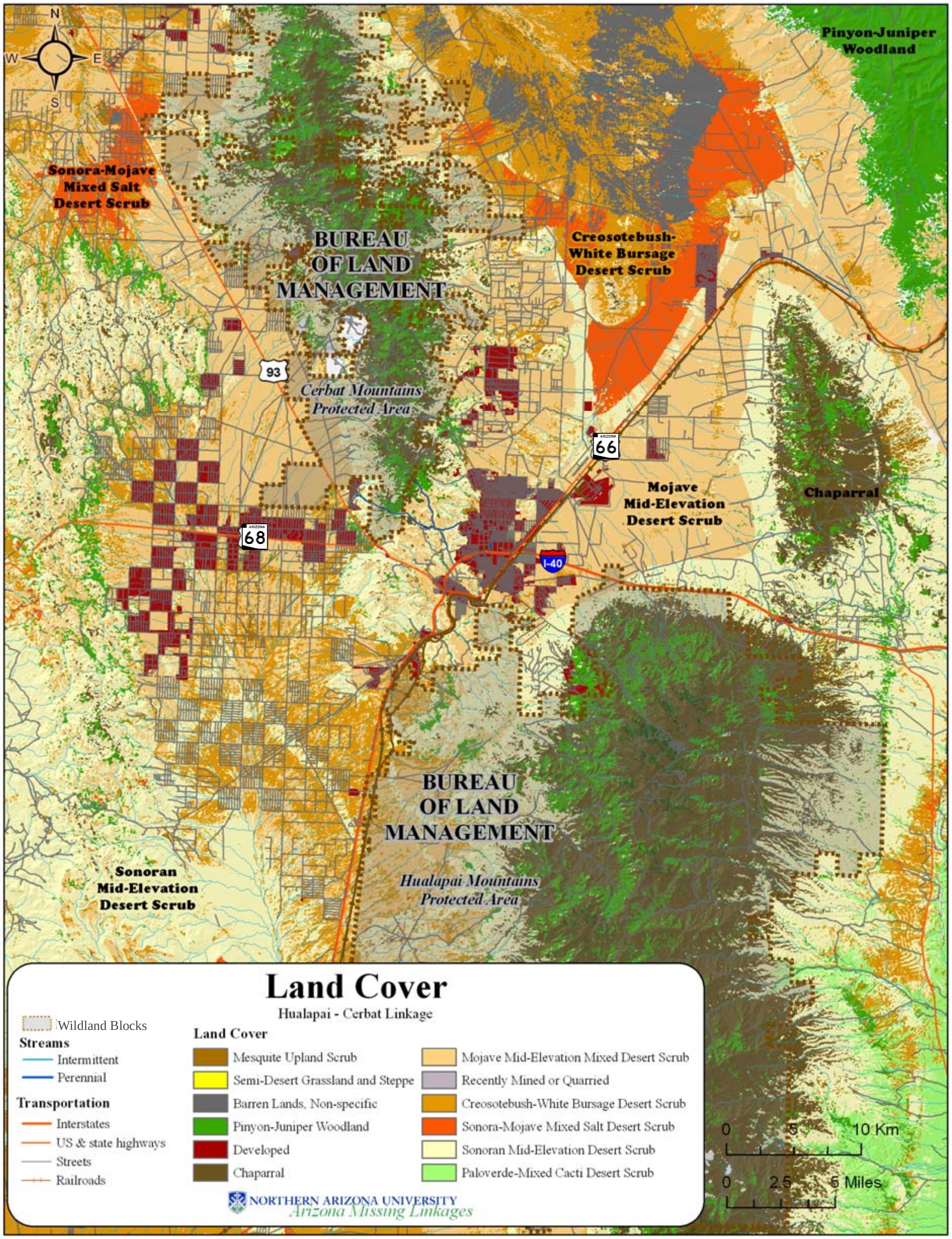


Figure 4: Land cover in the Linkage Planning Area.

The **southwestern Hualapai Mountains** wildland block, made up of approximately 304,000 acres of BLM land, is part of one large block of BLM land encompassing nearly 4.8 million acres in the central and southern areas of western Arizona (Figure 5). Within the block, the Hualapai Mountain County Park provides recreational opportunities and over 2,000 acres of open space. The Hualapai Mountains are home to the 40,000 acre Wabayuma Wilderness Area, established in 1990, where Wabayuma Peak towers above the desert at 7,601 feet. The high elevation ridges make a dramatic plunge to the deserts below, encompassing a range of ecosystems along the elevational gradient. Above, the mountains are home to ponderosa pine and Gambel oak forests that meld into chaparral in the mid-elevation areas. The lowest deserts within the wildland block contain a mixture of Sonoran and Mohave desert vegetation, and are home to the northernmost population of Saguaro cactus.

The potential linkage area between these blocks is mainly private land, with some Arizona State Trust lands and BLM lands (Figure 7). Connectivity between these wildland blocks would provide the continuous habitat necessary to sustain viable populations of sensitive and far ranging species in this ecological transition zone of northwestern Arizona.

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include Interstate 40, U.S. 93, Arizona State Routes 66 and 68, Mohave County roads, and expanding urban development. Parts of the growing Golden Valley and Golden Valley South developments (Figure 6) overlap the western part of our Linkage Design. If not properly mitigated, these roads and urban developments could impede wildlife movement between the Cerbat and Hualapai Mountain wildland blocks.

Providing connectivity is paramount in sustaining this unique area's diverse natural heritage. Recent and future human activities could sever natural connections and alter the functional integrity of this natural system. Creating linkages that overcome barriers to movement will ensure that wildlife in all wildland blocks and the potential linkage area will thrive there for generations to come.

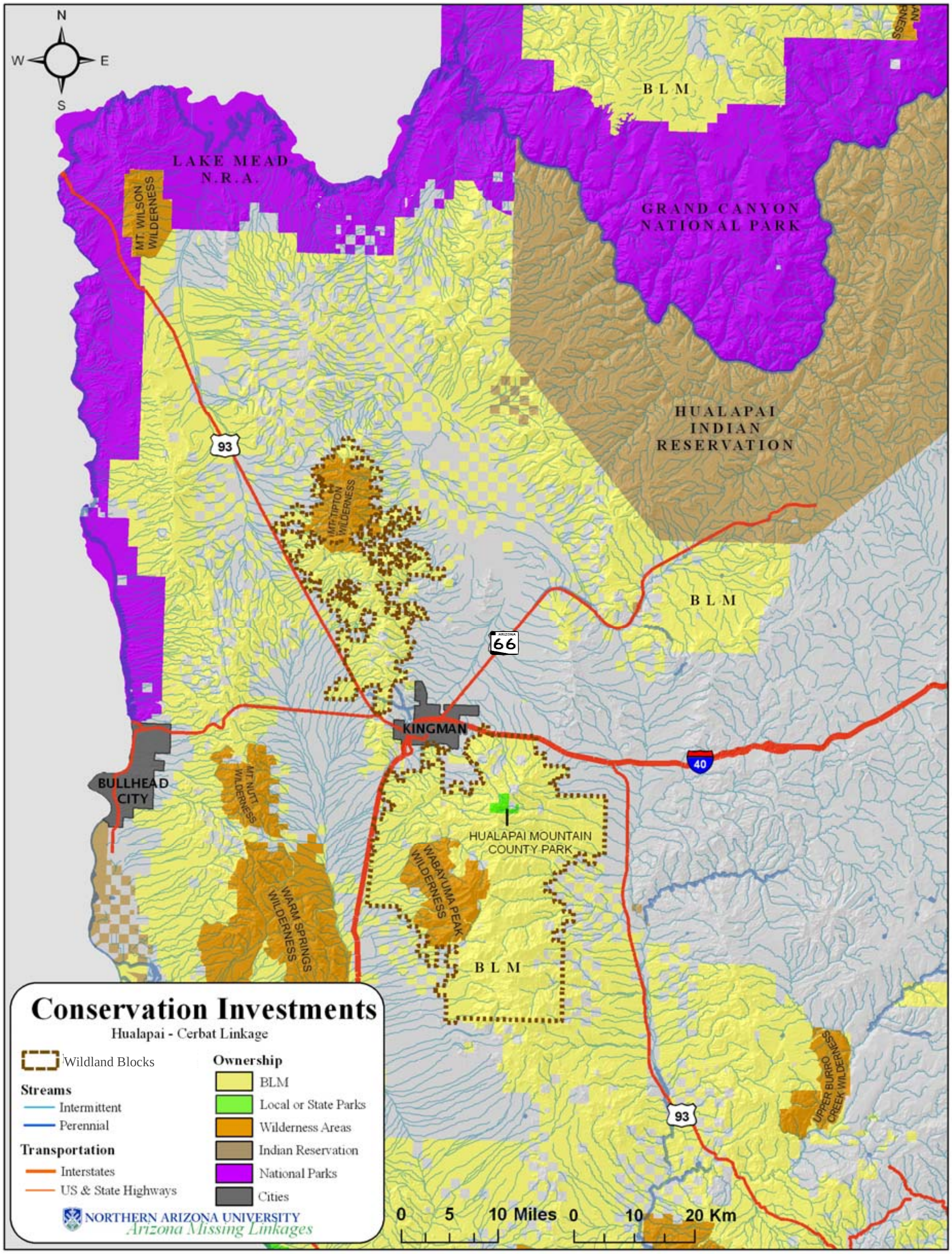


Figure 5: Existing conservation investments within the Linkage Planning Area.

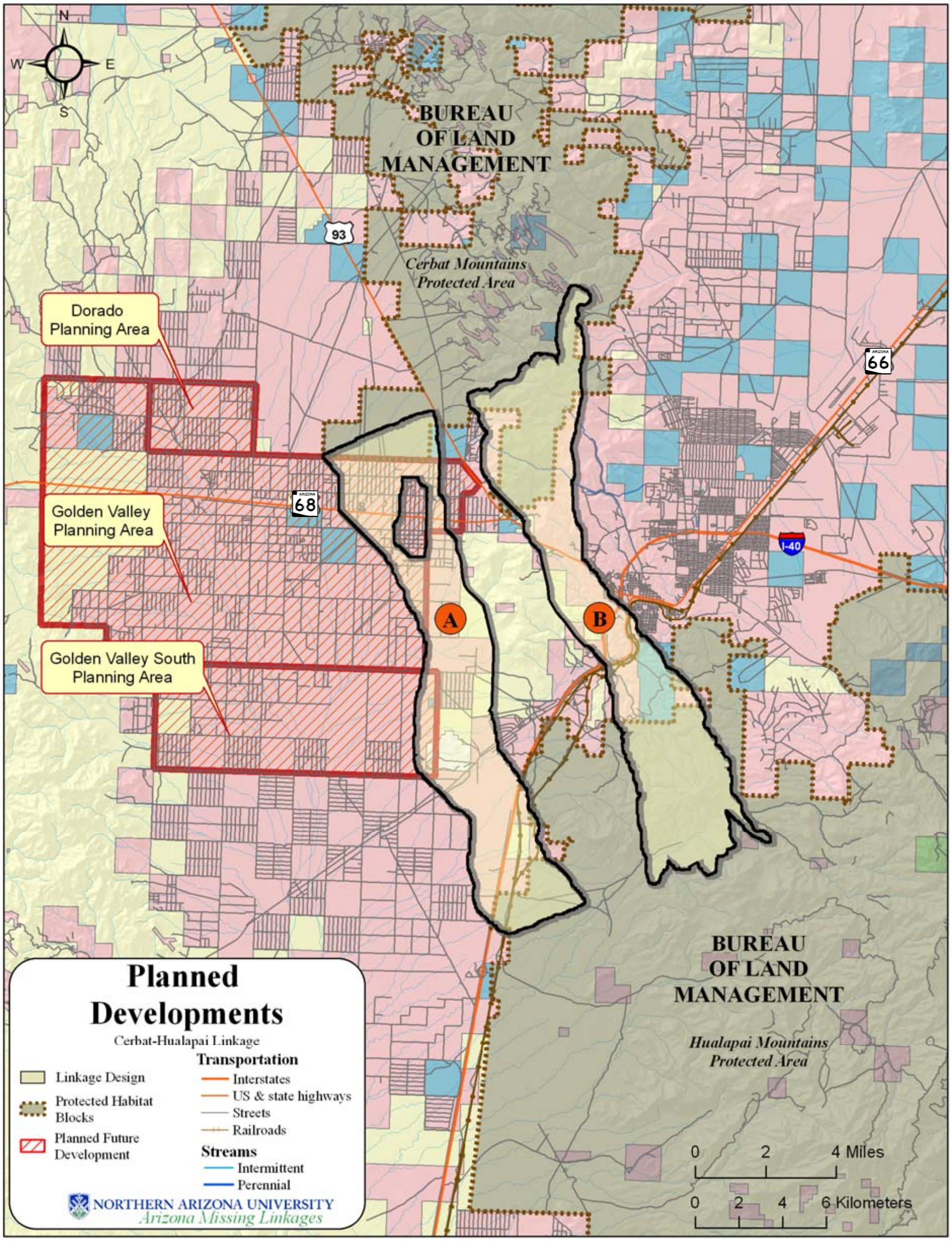


Figure 6: Future and existing residential developments within the Linkage Planning Area.

Linkage Design & Recommendations

The Linkage Design[3] (Figure 1) is composed of two Strands which together provide habitat for movement and reproduction of wildlife between BLM-administered lands adjacent to Kingman. In this section, we describe the land cover and ownership patterns in the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Two Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of two distinct Strands which connect the Cerbat and Hualapai Mountain wildland blocks. We describe these Strands from west to east (A and B respectively).

LINKAGE DESIGN GOALS
• Provide move-through habitat for diverse group of 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 • Provide a buffer protecting aquatic habitats from pollutants • 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 A of the linkage design provides live-in and pass-through habitat for species dependent on desert vegetation and/or gentle topography, including badger, kit fox, and javelina. Strand A spans from Shingle Canyon near the northern side of the Hualapai Mountains to Thirteenmile Wash, west of the Cerbat Mountains. It borders the foothills of the Hualapai Mountains, skirting the Sacramento Valley and crossing Interstate 40, Route 66, County Highway 10, and State Highway 68. The Strand is approximately 23 km long, and is primarily composed of Creosotebush-White Bursage Desert Scrub (43%), Mojave Mid-Elevation Desert Scrub (31%), and Sonoran Mid-Elevation Desert Scrub (19%). This Strand is composed mainly of flat, gentle slopes, with an average slope of 3% (Range: 0-79%, SD: 5) and 96% of the area has a flat topographic position. There is considerable residential development in the northern part of Strand A. A “hole” in the northern part of Strand A excludes the most heavily urbanized area from the linkage design.

Strand B provides live-in and pass-through habitat for species dependent on rugged topography, including desert bighorn sheep, mountain lions, mule deer, and gila monsters. This mountainous strand spans from Cottonwood Canyon along the northern perimeter of the Hualapai Mountains to Cerbat Peak in the southern portion of the Cerbat Mountains. This strand crosses several major transportation routes including Interstate 40, U.S. Highway 93, Route 66, and County Highway 10. This Strand is primarily composed of Sonoran Mid-Elevation Desert Scrub (49%) Mojave Mid-Elevation Desert Scrub (26.4%), and includes smaller areas dominated by chaparral (10.7%) as well as Pinyon Juniper Woodlands (10.7%). Strand B is more topographically varied than Strand A, with an average slope of 26% (Range: 0-112%, SD: 16). Over half (57.7%) of the land within this strand is classified as steep slopes, 13.5% as ridgetops, 12.5% as canyon bottoms, and 16.4% flat, gentle slopes.

Land Ownership, Land Cover, and Topographic Patterns within the Linkage Design

The Linkage Design encompasses 38,206 acres (15,461 ha) of land, the majority of this land is under private ownership (48%) and the Bureau of Land Management (45%), with small fragments (2 and 3%

[3] The reader will note that the strands of the linkage design extend well into each wildland block. As explained in **Error! Reference source not found.**, for modeling purposes we had to redefine the wildland blocks such that the facing edges were parallel lines about 15 km apart.

respectively) of Game and Fish and State Trust lands (Figure 1). Strand A is composed of 69% private land, 27% BLM, 4% Game and Fish, and 1% State Trust Lands. Strand B is composed of 30% private land, 64% BLM, and 6% State Trust Lands.

Eight natural vegetation communities account for 96% of the land cover (Figure 8), and developed land accounts for the other 4% (1550 acres, 600 ha) of the linkage design, occurring primarily in Strand A (Table 2). Natural vegetation is dominated by desert scrub-shrub associations. There is no riparian vegetation in the linkage design.

The Linkage Design captures a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, 55% of the land is classified as gentle slopes, 32% is classified as steep slopes, and 14% is classified as either canyon bottom or ridgetop (Figure 9). The land in the linkage area has predominantly southwestern and western aspects (Figure 9).

Table 2: Approximate land cover found within Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (< 5.9%)			
Pinyon-Juniper Woodland	2259	914	5.9%
Scrub-Shrub (96%)			
Creosotebush-White Bursage Desert Scrub	7751	3137	20.3%
Mojave Mid-Elevation Mixed Desert Scrub	11373	4603	29.8%
Sonoran Mid-Elevation Desert Scrub	12911	5225	33.8%
Chaparral	2194	888	5.7%
Developed and Agriculture (4.1%)			
Open Space-Low Intensity Developed	1340	542	3.5%
Medium-High Intensity Developed	226	92	0.6%

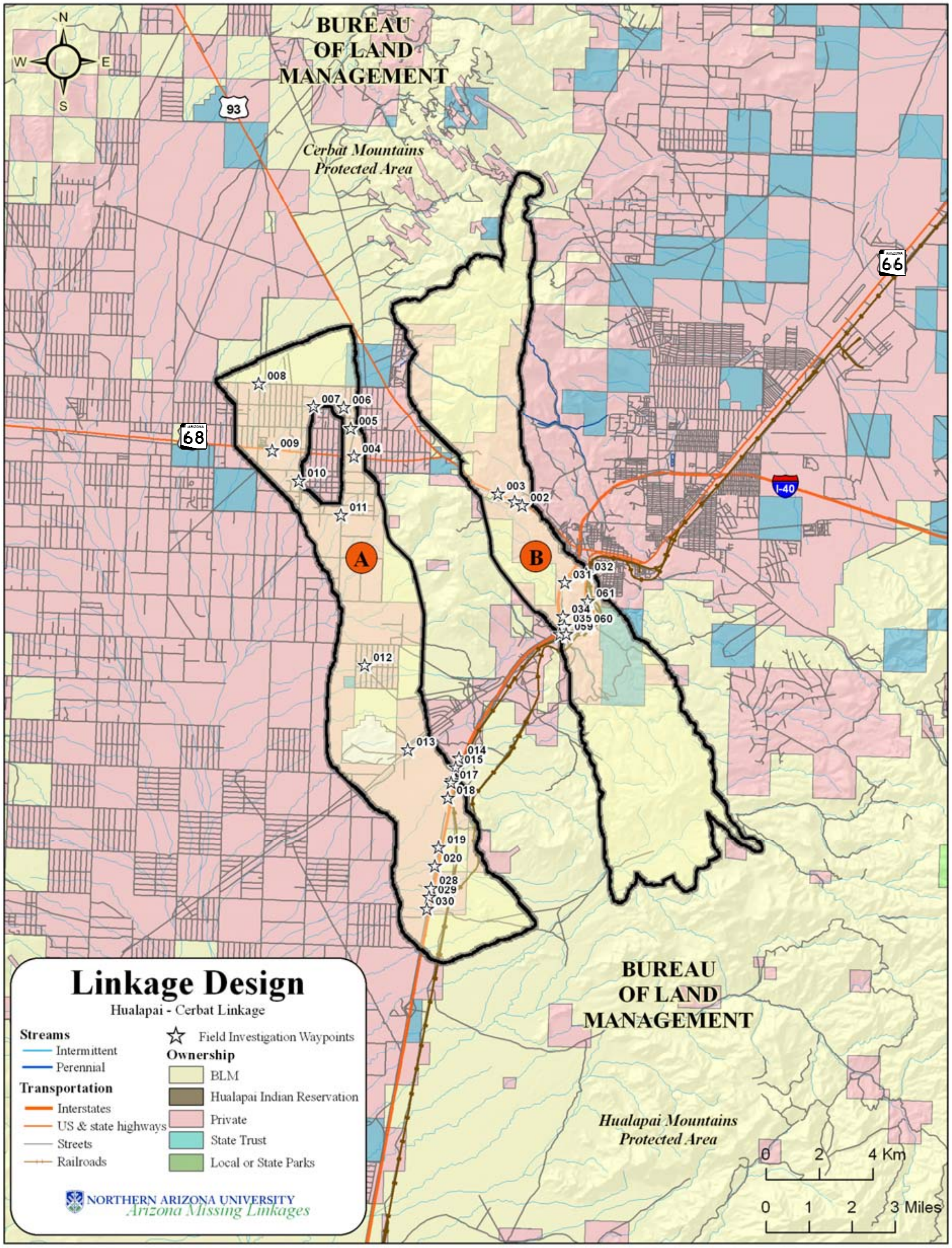


Figure 7: Property ownership and field investigation Waypoints in the Linkage Design. The accompanying CD-ROM includes photographs taken at most Waypoints.

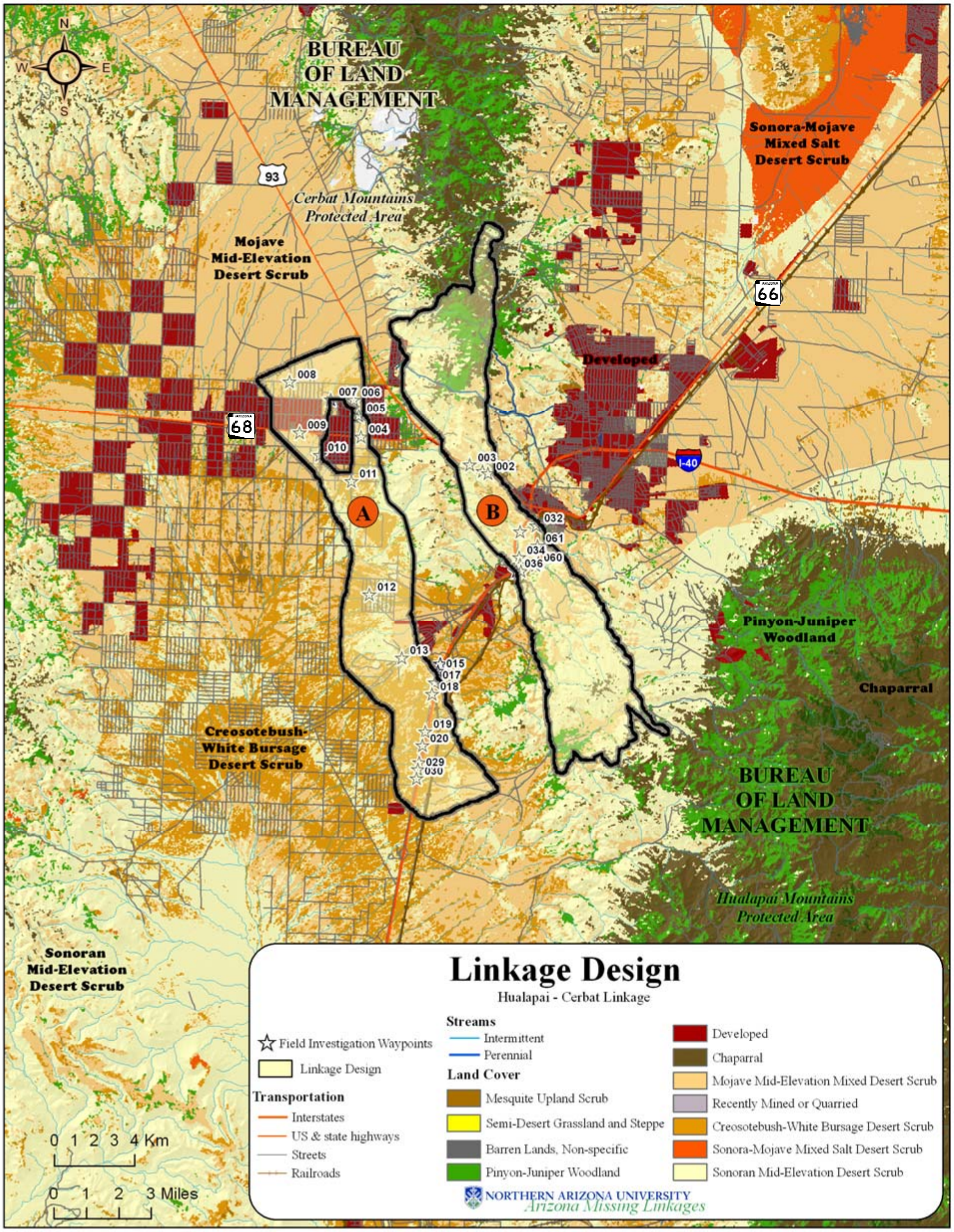


Figure 8: Land cover in the Linkage Design.

a)

b)

c)

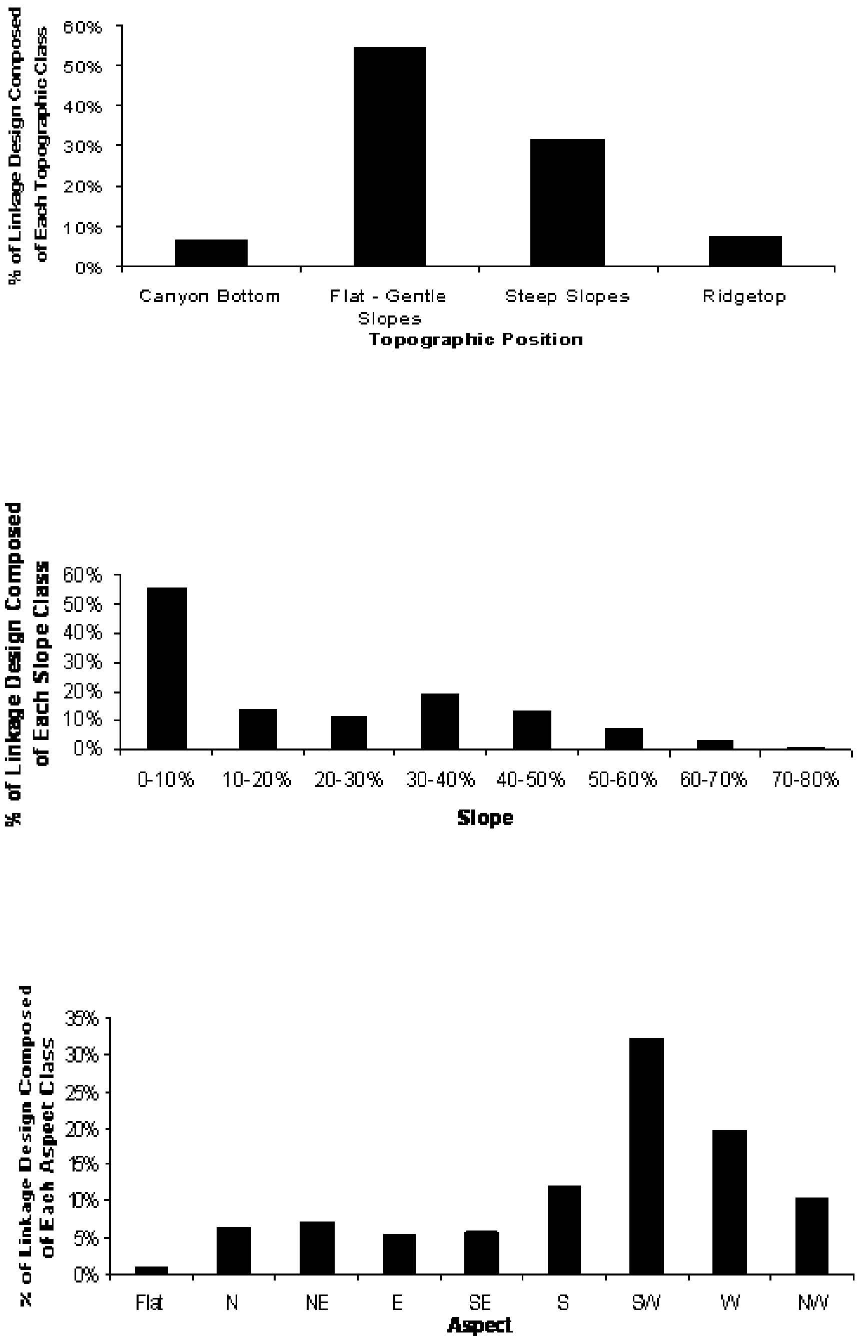


Figure 9: Topographic diversity encompassed in the Linkage Design.

Removing and Mitigating Barriers to Movement

Although roads, rail lines, canals, agriculture, and urban areas occupy only a small fraction of the Linkage Design, their impacts threaten to block animal movement between the wildland blocks. In this section, we review the potential impacts of these features on ecological processes, identify specific barriers in the Linkage Design, and suggest appropriate mitigations. The complete database of our field investigations, including UTM coordinates and photographs, is provided in Appendix G and the Microsoft Access database on the CD-ROM accompanying this report.

While roads, canals, and fences impede animal movement, and the crossing structures we recommend are important, we remind the reader that crossing structures are only part of the overall linkage design. To restore and maintain connectivity between the Hualapai and Cerbat wildland blocks, it is essential to consider the *entire* linkage design, including conserving the land in the linkage. Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either wildland block is lost.

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity, and the severity of these effects depends on the ecological characteristics of a given species (Table 3). Direct **roadkill** affects most species, with severe documented impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the 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 per year killed due to vehicle collisions. Although we may not often think of roads as causing **habitat loss**, a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. Roads cause **habitat fragmentation** because they break large habitat areas into small, isolated habit patches which support few individuals; these small populations lose genetic diversity and are at risk of local extinction.

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 fish, and pollute water sources with roadway chemicals (Forman et al. 2003). Highway lighting also has important impacts on animals (Rich and Longcore 2006).

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 10). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. Approximately 50 overpasses have been built in the world, with only 6 of these occurring in North America (Forman et al. 2003). Overpasses are typically 30 to 50 m wide, but can be as large as 200 m wide. In Banff National Park, Alberta, grizzly bears, wolves, and all ungulates (including bighorn sheep, deer, elk, and moose) prefer overpasses to underpasses, while species such as mountain lions prefer underpasses (Clevenger & Waltho 2005).

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate 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 ft wide by 8 ft high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should 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). A bridge is a road supported on piers or abutments above a watercourse, 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 (instead of concrete or corrugated metal in a culvert) and the area under the bridge is large enough that a semblance of a natural stream channel returns a few years after construction. 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 under bridges. In contrast, vegetation does not grow inside a culvert, 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 located culverts can mitigate the effects of busy roads on 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, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). In south Texas, bobcats most often used 1.85 m x 1.85 m 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 in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Some cases located in fill dirt have openings far above the natural stream bottom. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

Table 3: Characteristics which make species vulnerable to the three major direct effects of roads (from Forman et al. 2003).

	EFFECT OF ROADS		
CHARACTERISTICS MAKING A SPECIES VULNERABLE TO ROAD EFFECTS	Road mortality	Habitat loss	Reduced connectivity
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		
Multiple-resource needs	★		★
Large area requirement/low density	★	★	★
Low reproductive rate	★	★	★
Behavioral avoidance of roads			★

Figure 10: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

Based on the small but increasing number of scientific studies on wildlife use of highway crossing structures, we offer these standards and guidelines for *all* existing and future crossing structures intended to facilitate wildlife passage across highways, railroads, and canals. These recommendations are consistent with AGFD Guidelines for constructing culverts and passage (http://www.azgfd.gov/hgis/guidelines.aspx). In selecting focal species for this report, we solicited experts to identify threatened, endangered, and other species of concern as defined by state or federal agencies, paying attention to those with special needs for culverts or road-crossing structures. At the time of mitigation, we urge planners to determine if additional species need to be considered, and to monitor fish and wildlife movements in the area in order to determine major crossing areas, behaviors, and crossing frequencies. Such data can improve designs in particular locations and provide baseline data for monitoring the effectiveness of mitigations.

Standards and Guidelines for Wildlife Crossing Structures

1) **Multiple crossing structures should be constructed at a crossing point 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). For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and mountain lions, large box culverts with natural earthen substrate flooring are optimal (Evink 2002). For small mammals, pipe culverts from 0.3m – 1 m in diameter are preferable (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 m (Clevenger et al. 2001). For ungulates (deer, pronghorn, bighorn) and large carnivores, larger crossing structures such as bridges, viaducts, or overpasses should be located no more than 1.5 km (0.94 miles) 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 for species should occur on both sides of the crossing structure** (Ruediger 2001; Barnum 2003; Cain et al. 2003; Ng et al. 2004). This applies to both *local* and *landscape* scales. On a local scale, vegetative cover should be present near entrances to give animals security, and reduce negative effects such as lighting and noise associated with the road (Clevenger et al. 2001; McDonald & St Clair 2004). A lack of suitable habitat adjacent to culverts originally built for hydrologic function may prevent their use as potential wildlife crossing structures (Cain et al. 2003). On the landscape scale, "Crossing structures will only be 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* the crossing structure.** This can best be achieved by having a bridge high enough to allow enough light for vegetation to grow under the bridge, and by making sure that the bridge spans upland habitat that is not regularly scoured by floods. Where 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. 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).

In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches, Russian thistle, sand, or garbage that impede animal movement (Beier, personal observation). Bridged undercrossings rarely have similar problems.

6) **Fencing should never block entrances to crossing structures, and instead should direct animals towards crossing structures** (Yanes et al. 1995). In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in roadkill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Fences, guard rails, and embankments at least 2 m high discourage animals from crossing roads (Barnum 2003; Cain et al. 2003; Malo et al. 2004). One-way ramps on roadside fencing can allow an animal to escape if it is trapped on a road (Forman et al. 2003).

7) **Raised sections of road discourage animals from crossing roads, and should be used when possible to 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 each crossing structure**. Clevenger & Waltho (2000) suggest that human use of crossing structures should be restricted and foot trails relocated away from structures intended for wildlife movement. However, a large crossing structure (viaduct or long, high bridge) should be able to accommodate both recreational and wildlife use. Furthermore, if recreational users are educated to maintain utility of the structure for wildlife, they can be allies in conserving wildlife corridors. At a minimum, nighttime human use of crossing structures should be restricted.

9) **Design culverts specifically to provide for animal movement**. Most culverts are designed to carry water under a road and minimize erosion hazard to the road. Culvert designs adequate for transporting water often have pour-offs at the downstream ends that prevent wildlife usage. At least 1 culvert every 150-300m of road should have openings flush with the surrounding terrain, and with native land cover up to both culvert openings, as noted above.

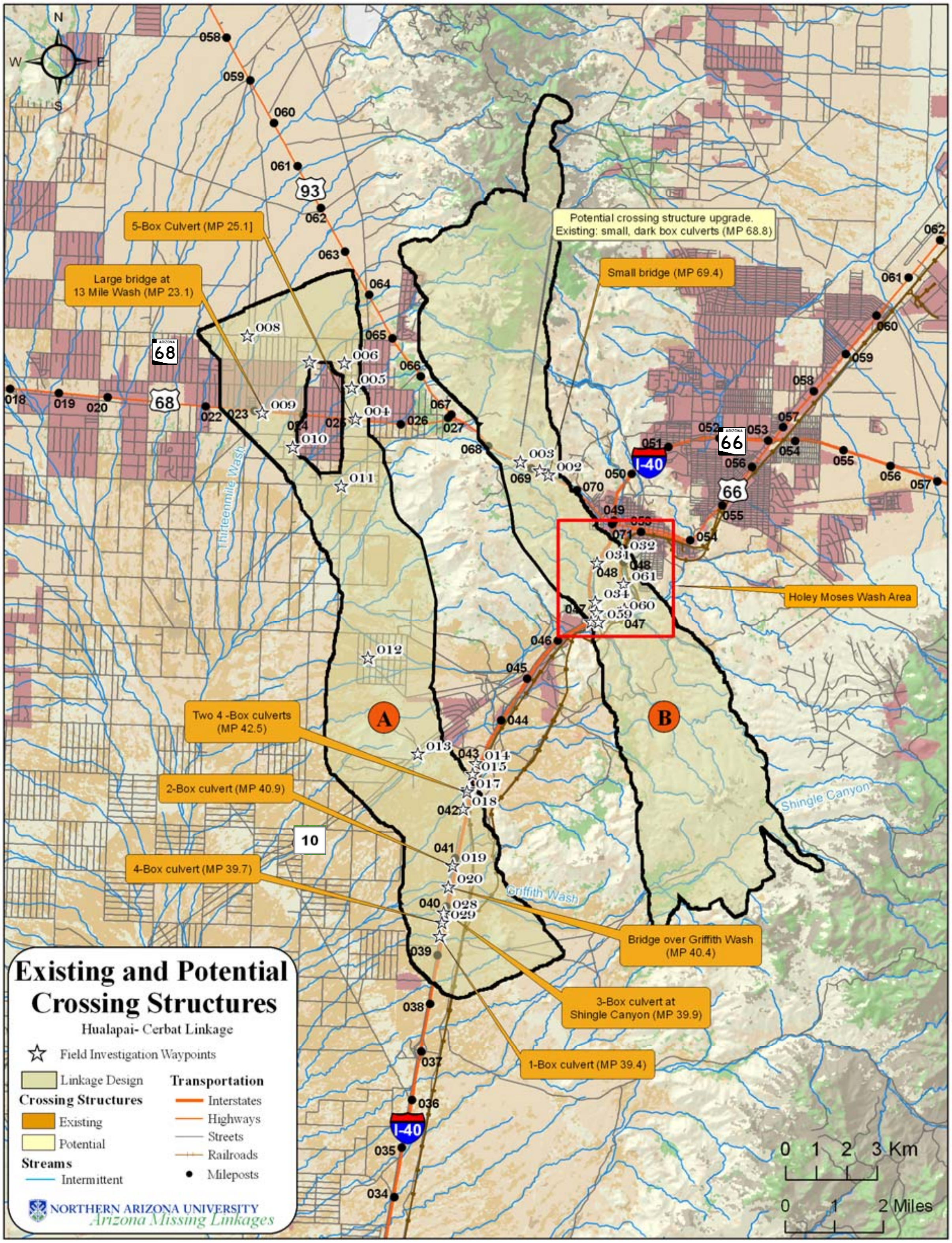


Figure 11. Locations of existing crossing structures, numbered mileposts, and field investigation waypoints in the Linkage Design.

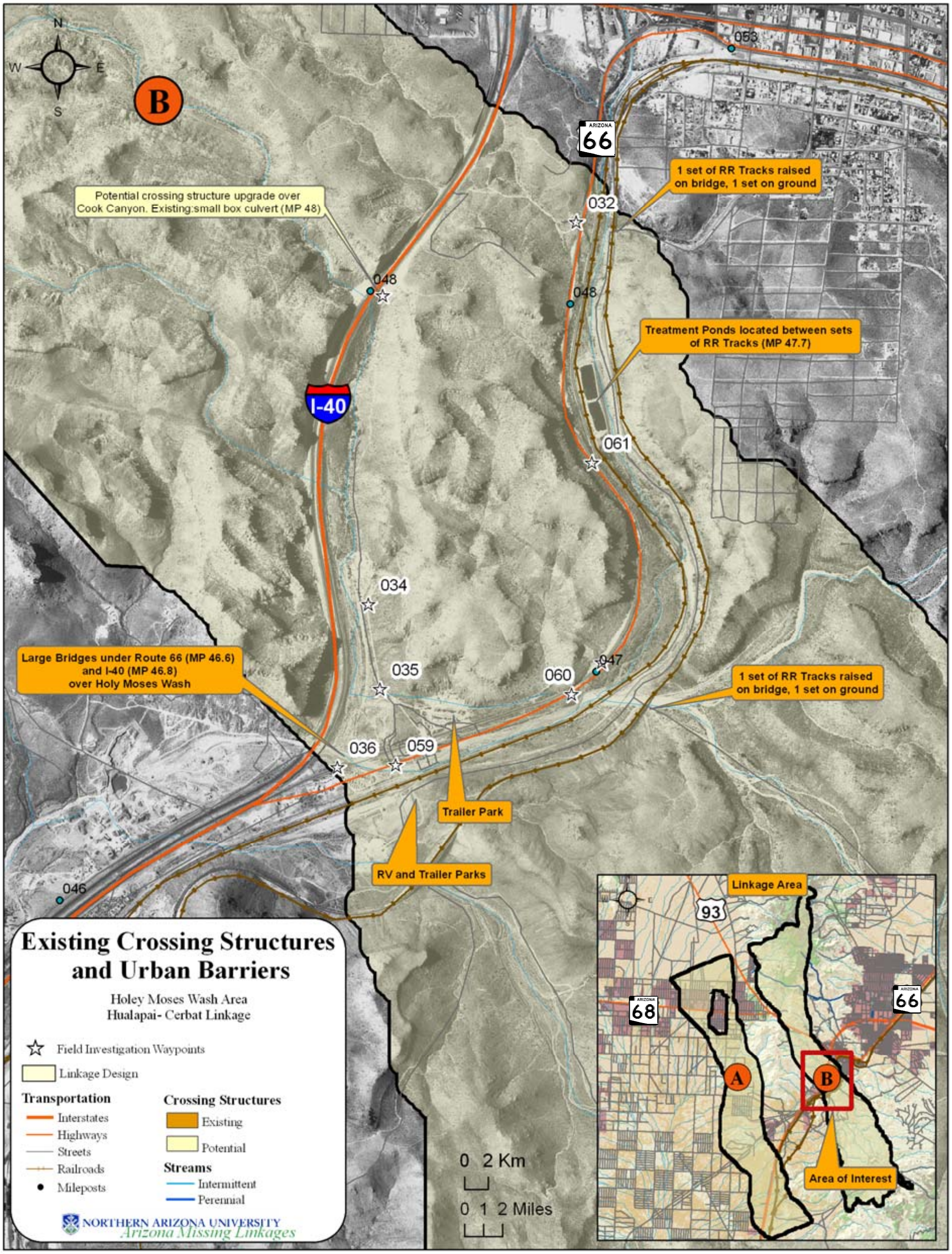


Figure 11: Existing locations of crossing structures and impediments to wildlife movement in Strand B of the Linkage Design, where Route 66 and I-40 converge.

Existing Roads and Rail Lines in the Linkage Design Area

There are approximately 224 km (139.4 mi) of transportation routes in the Linkage Design, including 21 km (13.1 mi) of the Burlington Northern Santa Fe Railroad, 9.5 km (5.9 mi) of Interstate 40, 13.1 km (8.1 mi) of highways including State Highway 68, U.S. Highway 93 and Route 66, and County Highway 10. There are an additional 180.4 km (112.3 mi) of local roads (Table 4). Because some of the major transportation routes occur parallel and/or near one another, they can present a formidable challenge to wildlife attempting to cross the road. We conducted field investigations of many of these roads to document existing crossing structures, and to identify where structures could be modified to enhance wildlife movement through the area.

Table 4: Highways and Railroads (bold) and other roads in the Linkage Design

Road Name	Kilometers	Miles
Burlington Northern Santa Fe Railroad	21.0	13.1
I-40	9.5	5.9
State Highway 68	3.6	2.2
United States Highway 93	3.6	2.2
Route 66	3.4	2.1
Bacobi Rd	7.9	4.9
Old Trails Rd	6.4	4.0
Aqua Fria Dr	5.3	3.3
Frontage Rd	5.3	3.3
Aztec Rd	4.8	3.0
Adobe Rd	4.1	2.6
Bosque Rd	3.9	2.4
Burro Dr	3.9	2.4
Chino Dr	3.5	2.2
Redwall Dr	3.0	1.8
Arrivaca Rd	2.8	1.7
Shipp Dr	2.7	1.7
Apache Rd	2.7	1.7
Aguila Rd	2.7	1.7
Araby Rd	2.7	1.6
Abrigo Dr	2.6	1.6
County Highway 10	2.5	1.6
Bolsa Dr	2.5	1.5
Maverick Rd	2.4	1.5
Shinarump Dr	2.3	1.4
Mobile Rd	2.2	1.4
Yuma Rd	2.0	1.3
Ajo Rd	2.0	1.3
Bibo Rd	2.0	1.2
Ambrigo Rd	2.0	1.2
Roads < 2 km	60.2	37.4
Unnamed Roads	59.2	36.8
Total length of transportation routes	**224**	**139.4**

Existing Crossing Structures on Interstate 40

Interstate 40 is the principal arterial interstate in the area, generating high traffic volumes. It bisects southern portions of both Strand A and Strand B. Exacerbated by two sets of railroad tracks that parallel

I-40, this highway presents a significant barrier to connectivity between the Hualapai and Cerbat mountain ranges. Adequate crossing structures are crucial to the success of this linkage.

In Strand A of the linkage design, we noted many pipe culverts up to 3 feet in diameter, such as the culvert at Waypoint 18 (Figure 12). Although culverts of this size are potential suitable for small animals, the entrances to most culverts were blocked by fencing; many were also not flush with the surrounding terrain, or were choked with sediment.

We documented several larger crossing structures in Strand A (locations shown in Figure 11) that could serve medium or larger sized animals after appropriate modifications.

- Near milepost 39.4 (Waypoint 30), there is a one-box culvert, approximately 5x9 ft. The entrance is blocked by a barbed wire fence.
- At Milepost 39.7 (Waypoint 29), there is a four-box culvert, each approximately 5x9 ft. The bottom of this structure is buried in sediment, rendering the culvert effectively 2.5 to 3' high, and the entrance is also blocked by fence.
- At Shingle Canyon, Milepost 39.9 (Waypoint 28), there is a three-box culvert, each approximately 5x9 ft, also hindered by a large amount of sediment build up.
- Near Milepost 40.4, (Waypoint 20) Griffith Wash has an open box culvert consisting of five boxes approximately 20x9 ft. A barbed-wire fence also blocks the entrance to this structure (Figure 14).
- Near Milepost 40.9 (Waypoint 19) there is a two box culvert that is almost completely blocked by sediment (Figure 13). The entrance is also blocked by a fence.
- Near Milepost 42.5 (Waypoint 17), there are two four-box culverts within roughly 100 meters of one another. Each is equipped with boxes measuring roughly 5x9', and the entrances are blocked by fences.

Where the southern end of Strand B intersects I-40, we documented two existing structures.

- A small cement box culvert near Milepost 48 over Cook Canyon, about 2 km northeast of the Holy Moses Bridge (Waypoint 31) measuring approximately 5x9' (Figure 15).
- A concrete bridge over 200 feet long across Holy Moses Wash (Figure 16) near Milepost 47 (Waypoint 59).

Existing Crossing Structures on Route 66

Route 66 parallels Interstate 40 through Strand B. The only major crossing structure in this area is a 200-ft bridge over Holy Moses Wash (Figure 16).

Existing Crossing Structures on Highway 68

Highway 68 traverses the northern portion of Strand A, where we identified two existing structures.

- A 131' bridge spanning 13 Mile Wash (Figure 19, Waypoint 9), near Milepost 23.1. The entrance is blocked by a fence.
- A 5-box culvert (each box 8x3') over an unnamed Wash near mile 25.1 (Figure 17, Waypoint 4).

Existing Crossing Structures on Highway 93

Highway 93 runs through Strand B from Kingman to the intersection with SR-68. Throughout this stretch of road, **US-93 has** a jersey barrier in the median (Figure 21**). These concrete barriers make it impossible for most non-flying animals to cross the road.**

We documented two existing structures.

- At Waypoint 3, Milepost 68.8, there is a small two- box culvert with boxes measuring about 3x3. The entrance is blocked and the culvert is dark apparently because culvert is not straight.
- A 20-ft long bridge over an unnamed wash near Milepost 69.4. (
- Figure **20**, Waypoint 002).

Existing Crossing Structures on County Highway 10

County Highway 10 runs through the southern portion of Strand A. We did not locate any crossing structures along Highway 10.

Existing Rail lines in the Linkage Design

Two sets of railroad tracks parallel Route 66 in Strand B and I-40 in Strand A. In some areas, one track spans a wash on a bridge, while the second track sits on fill slope of angular rocks and boulders (Figure 22). In many cases culverts or bridges do not align between the 2 tracks, or between the tracks and the nearby highway (Figure 23).

Figure 12: A 3' pipe culvert typical of those found under I-40. Note the fence blocking the entrance, and the pour-off, impeding access to small mammals and reptiles.

Figure 13: At Waypoint 19, two box culverts under I-40 are almost completely blocked by sediment; Hualapai Mountains in background.

Figure 14: Five box culverts at Griffith Wash (Waypoint 20) under I-40.

Figure 15: Cook Canyon passes under I-40 via the small box culvert in the lower left corner of photo (Waypoint 031); this structure should be replaced with a bridged crossing.

Figure 16: Two large multiple-span bridges over Holey Moses Wash (Route 66 in foreground; piers of the I-40 bridge beyond) provide connectivity for wildlife (Waypoint 059); Cerbat Mountains in background.

Figure 17: Five 8x3' box culverts under Highway 68 at an unnamed wash (Waypoint 004).

Figure 18: Urban development upstream from unnamed wash on Highway 68 (Waypoint 005).

Figure 19: Bridge on Highway 68 over 13 Mile Wash (Waypoint 009).

Figure 20: A small bridge provides a good crossing structure under Highway 93 (Waypoint 003.)

Figure 21: A jersey barrier in the US 93 median throughout Strand B of the Linkage Design (Waypoint 002). These concrete barriers make it impossible for most non-flying animals to cross the road.

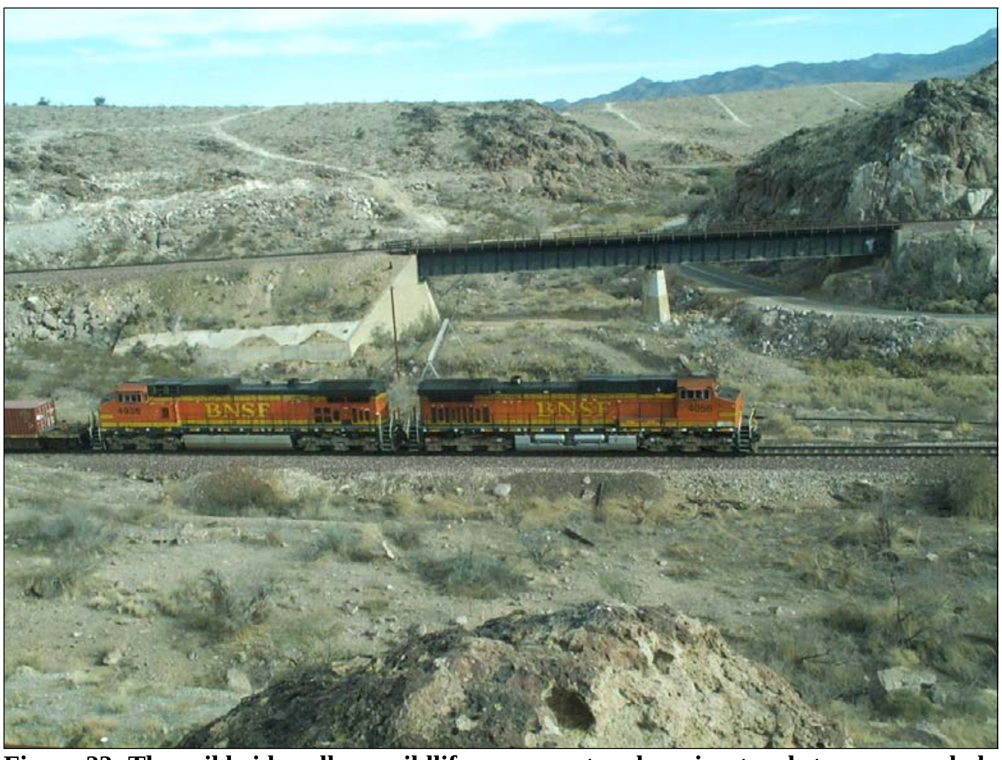


Figure 22: The rail bridge allows wildlife movement and semi-natural stream morphology. In contrast, the rail line in the foreground crosses the wash on fill slopes with small pipe culverts, disrupting animal movement and stream hydrology (Waypoint 032.)

Figure 23: Two rail road lines parallel to I-40 creates additional considerations for placement of crossing structures within the Linkage Design (Waypoint 060). Ideally, crossing structures on the 3 roads should be aligned.

Recommendations for Highway and Railroad Crossing Structures

The existing crossing structures are not adequate to serve the movement needs of wildlife between the BLM lands in the Cerbat and Hualapai mountain ranges. Because every animal moving between these ranges must traverse at least one of the highways, we recommend upgrading existing crossing structures and adding new ones as follows:

- Between Milepost 68 and Milepost 70 on US-93, build two bridged underpasses suitable for use by mule deer, bighorn sheep, and smaller animals. There are currently no crossing structures suitable for mule deer in this 2-mile portion of US-93.
- Between Milepost 46.7 and Milepost 48A on I-40 in Strand B, build two bridged underpasses. One of these could replace the existing box culvert in Cook Canyon (Figure 15).
- Between Holy Moses Bridge and Milepost 48.5 on Route 66, build one new bridged crossing structure. Do not install Jersey barriers on Route 66.
- Between Milepost 38.5 and Milepost 43 on I-40 in Strand A, build one new bridged crossing to supplement the bridged crossing at Griffith Wash (Figure 14).
- Ensure that there are at least two bridged crossing structures on each of the two railroad lines in Strand B, and two bridged structures on each track in Strand A. If a crossing structure is built where the railroad is < 200m from the other track or a major highway (I-40 in Strand A, Route 66 in Strand B), the structures should be aligned so that an animal crossing one linear barrier can readily find the structure to cross the nearby barrier.
- Along every paved road in each Strand of the linkage design, there should be at least one pipe culvert every 300m for passage by small animals. Because we did not attempt to locate small culverts, we do not know how many new culverts will need to be installed. In some dry, flat areas (County highway 10) there are apparently no existing culverts.
- Within Strand A of the linkage design, build three large culverts and one bridged crossing for reptiles, amphibians, and medium-sized and large mammals under County Highway 10 (where there are currently no large culverts). Because javelina are the largest animals expected to use Strand A, one

bridged crossing should be sufficient as long as this remains a 2-lane road. If lanes are added to the road, a second bridge crossing should be added.

- Maintain the two crossing structures on US 68 in Strand A.
- For the existing structures, remove wire fences across structure entrances. Instead use fencing to guide animals toward the crossing structures. Manage these crossings to ensure that they do not become filled with sediments or otherwise impede movement.

Urban Development as Barriers to Movement

Urbanization includes not only factories, gravel mines, shopping centers, and high-density residential development, but also low-density ranchette development. These diverse types of land use impact wildlife movement in several ways. In particular, urbanization causes:

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005)) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure XX). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

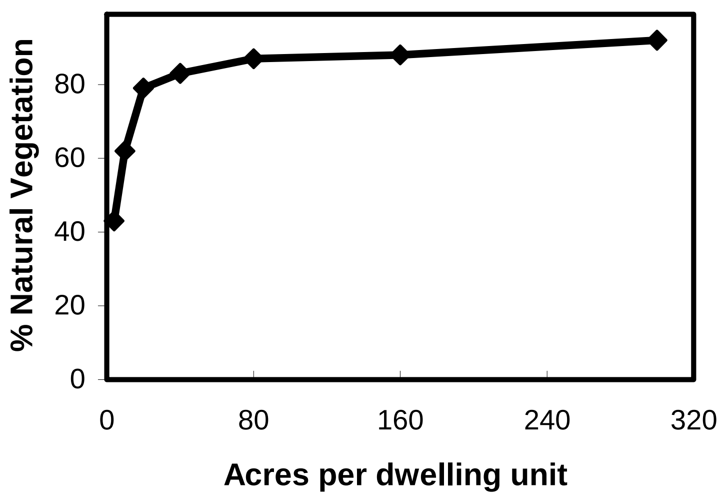


Figure 24: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (CBI 2005).

- decreased abundance and diversity of native species, and replacement by non-native species. 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, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.

- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized “suburban native predators” such as raccoons, foxes, and crows that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms 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 their primary targets, but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).
- increased artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- increased noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- Disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas currently accounts for over 4% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

In the northern portion of Strand A of the linkage design, the development of the Golden Valley, and Golden Valley South areas and associated homes may threaten connectivity (Figure 6 and Figure 25). Biologically best corridors for badger, javelina, and kit fox pass through this strand of the linkage design.

The existing residential development covers about 542 ha in Strand A, near waypoints 004 through 011 (Figure 6). In some areas, active subdivision is occurring. In other areas, old subdivisions seem to have failed. For example, the area near Waypoint 12 (Figure 57) has only about half the roads depicted on USGS topo maps, and few lots have been developed.

Urbanization is less prevalent in Strand B. However, even in this strand, residential and industrial development near Kingman may impede the movement of species such as desert bighorn sheep, mule deer, and Gila monster. Near Waypoint 60, residential development includes two mobile and RV Parks including the Canyon West Mobile Home Park, a few private residences, 2 wastewater treatment ponds, 2 rail lines, and 2 major transportation routes, I-40 and Route 66, are located in close proximity to one another (Figure 27 and Figure 28).

Figure 25: This photo (looking east toward Cerbat Mountains from Waypoint 006) shows residential development abutting Strand A of the Linkage Design.

Figure 26: Residential development in Strand B (looking northeast from Waypoint 013).

Figure 27: Residential and industrial development is a barrier to connectivity in Strand B of the Linkage Design (Waypoint 060). The two large developments in the photo are trailer parks on old Route 66.

Figure 28: Sewage treatment ponds in Strand B of the Linkage Design (Waypoint 061).

Mitigation for Urban Barriers

To reduce the barrier effects of urban development (listed above) we offer the following recommendations:

1) Integrate this Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design.
2) Where development is permitted within the linkage design, encourage small building footprints on large (> 20-acre) parcels with a minimal road network.
3) Integrate this Linkage Design into Habitat Conservation Plans, and conservation plans of nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as open space, recreation, and protection of water quality.
6) One reason we imposed a minimum width on each strand of the linkage design was to allow enough room for a designated trail system without having to compromise the permeability of the linkage for wildlife. Nonetheless, because of the high potential for human access, the trail system should be carefully planned to minimize erosion and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.
7) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.
8) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and focus outside lighting on their houses and walkways (never into the linkage area).
9) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.
10) 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.
11) Discourage residents and visitors from feeding or providing water for wild animals, or otherwise allowing wildlife to lose their fear of people.
12) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.
13) Do not install artificial night lighting on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
14) Encourage the use of wildlife-friendly fencing on land or pasture boundaries.
15) Encourage the use of wildlife-proof fencing around gardens and other potential wildlife attractants.
16) Discourage the killing of ‘threat’ species such as rattlesnakes.

17) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.

In addition, we offer the following recommendations to minimize the impact of urban development on the linkage design:

- Limit urbanization along old Route 66 west of Kingman. There are currently two trailer parks, a water treatment facility, and several older residences in this area. The trailer parks and other parcels in Clack Canyon and Cook Canyon near the I-40 junction are probably at risk of conversion to industrial use. If such conversion occurs, care should be taken to reduce the impact on wildlife movement compared to current condition.
- Discourage development of private land along US-93 in Strand B. There are large stretches of US-93 outside the Linkage Design that have gentler topography and are more suitable to urban and residential development.
- Work with homeowners and residents to manage the residential areas in Strand A for wildlife permeability. Many people already live in this optimal movement corridor for javelina, kit fox, and black-tailed jackrabbit. Although these species are more tolerant of human disturbance than the species for which Strand B was designed, unrestrained dogs and cats, fencing, road kill on neighborhood streets, and artificial night lighting could make this Strand ineffective. We advocate innovative programs that respect the rights of residents and enlist them as steward of the linkage area.
- Discourage further residential development and subdivision of large parcels in the Linkage Design.

Appendix A: Linkage Design Methods

Our goal was to identify a continuous corridor of land which – if conserved and integrated with underpasses or overpasses across potential barriers – will best maintain or restore the ability of wildlife to move between large *wildland blocks*. We call this proposed corridor the *Linkage Design*.

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[4]. By carefully selecting a diverse group of focal species and capturing a range of topography to accommodate climate change, the Linkage Design should ensure the long-term viability of all species in the protected areas. Our approach included six steps:

1) Select focal species.
2) Create a habitat suitability model for each focal species.
3) Join pixels of suitable habitat to identify potential breeding patches & potential population cores (areas that could support a population for at least a decade).
4) Identify the biologically best corridor (BBC) through which each species could move between protected core areas. Join the BBCs for all focal species.
5) Ensure that the union of BBCs includes enough population patches and cores to ensure connectivity.
6) Carry out field visits to identify barriers to movement and the best locations for underpasses or overpasses within Linkage Design area.

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 22 species (Table 1) that had one or more of the following characteristics:

- habitat specialists, especially habitats that may be relatively rare in the potential linkage area.
- species sensitive to highways, canals, urbanization, or other potential barriers in the potential linkage area, especially species with limited movement ability.
- area-sensitive species that require large or well-connected landscapes to maintain a viable population and genetic diversity.
- ecologically important species such as keystone predators, important seed dispersers, herbivores that affect vegetation, or species that are closely associated with nutrient cycling, energy flow, or other ecosystem processes.
- species listed as threatened or endangered under the Endangered Species Act, or species of special concern to Arizona Game and Fish Department, US Forest Service, or other management agencies.

Information on each focal species is presented in Appendix B. As indicated in Table 1, we constructed models for some, but not all, focal species. We did not model species for which there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), or if the species probably can travel (e.g., by flying) across unsuitable habitat. We narrowed the list of identified focal species to 7 focal species that could be adequately modeled using the available GIS layers. For an explanation of why some suggested focal species were not modeled, see Appendix C.

[4] 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.

Habitat Suitability Models

We created habitat suitability models (Appendix B) for each species by estimating how the species responded to four habitat factors that were mapped at a 30x30 m level of resolution (Figure 29):

- *Vegetation and land cover.* We used the Southwest Regional GAP Analysis (ReGAP) data, merging some classes to create 46 vegetation & land cover classes as described in Appendix E.
- *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, light, pets, pollution, and other human-caused disturbances.

To create a habitat suitability map, we assigned each of the 46 vegetation classes (and each of 4 topographic positions, and each of several elevation classes and distance-to-road classes) a score from 1 (best) to 10 (worst), where 1-3 is optimal habitat, 4-5 is suboptimal but usable habitat, 6-7 may be occasionally used but cannot sustain a breeding population, and 8-10 is strongly avoided. Whenever possible we recruited biologists with the greatest expertise in each species to assign these scores (see *Acknowledgements*). When no expert was available for a species, three biologists independently assigned scores and, after discussing differences among their individual scores, were allowed to adjust their scores before the three scores were averaged. Regardless of whether the scores were generated by a species expert or our biologists, the scorer first reviewed the literature on habitat selection by the focal species[5].

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 1 and 10. We then weighted each of the by 4 factors by a weight between 0% and 100%, subject to the constraint that the 4 weights must sum to 100%. We calculated a weighted geometric mean[6] using the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10 (USFWS 1981). For each pixel of the landscape, the weighted geometric mean was calculated by raising each factor by its weight, and multiplying the factors:

$$HabitatSuitabilityScore = Veg^{W_1} * Elev^{W_2} * Topo^{W_3} * Road^{W_4}$$

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

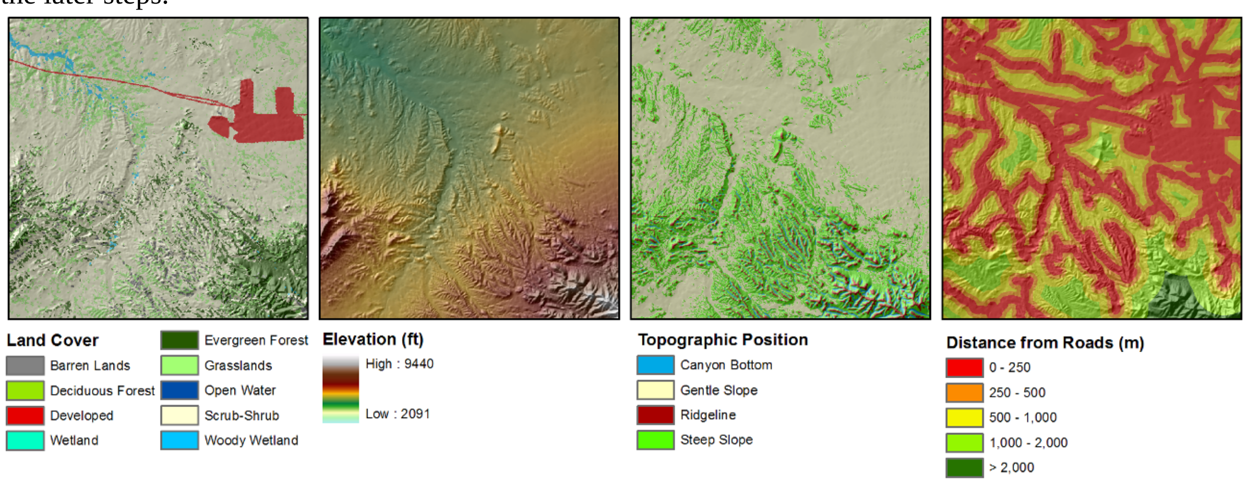


Figure 29: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

[5] Clevenger et al. (2002) found that literature review significantly improved the fit between expert scores and later empirical observations of animal movement.

[6] In previous linkage designs, we used arithmetic instead of geometric mean.

Identifying Potential Breeding Patches & 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 30). 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[7]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) 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.

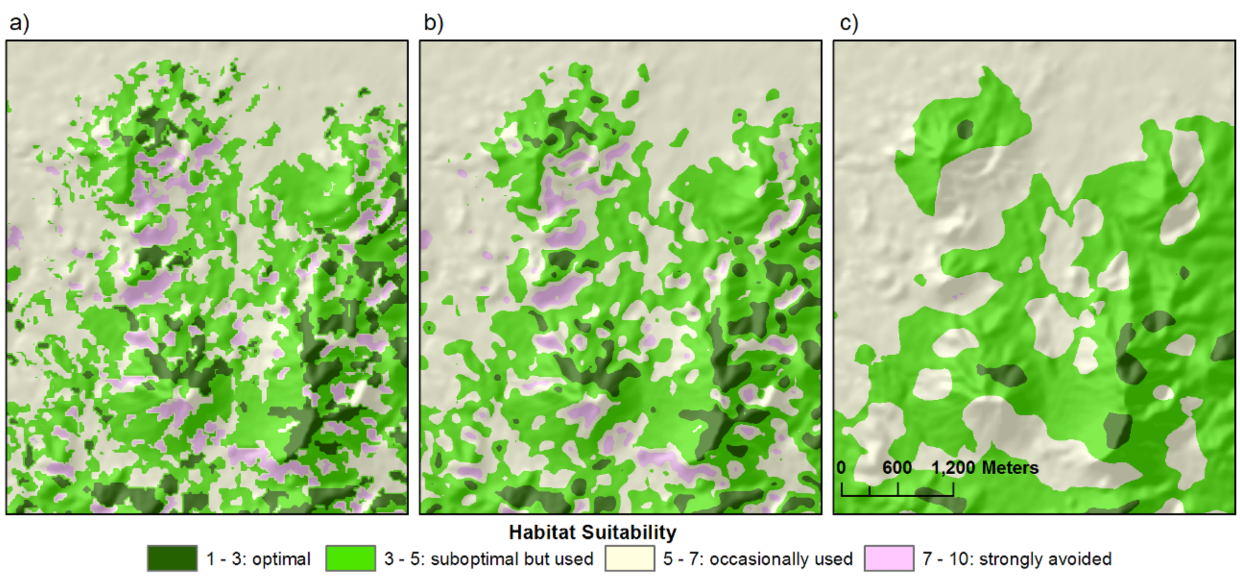


Figure 30: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

Identifying Biologically Best Corridors

The *biologically best corridor*[8] (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

[7] 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 mobile 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.

[8] Our 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, we avoid the words "least cost" because it is easily misunderstood as referring to the dollar cost of conserving land or building an underpass.

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.

We developed BBCs only for some focal species, namely species that (a) exist in both wildland blocks, or have historically existed in both and could be restored to them, (b) can move between wildland blocks in less time than disturbances such as fire or climate change will make the current vegetation map obsolete, and (c) move near the ground through the vegetation layer (rather than flying, swimming, or being carried by the wind), and (d) have habitat preferences that can reasonably be represented using GIS variables. For focal species that did not meet these criteria, we conducted patch configuration analysis (next section).

The two wildland blocks are separated by the city limits of Kingman, as well as I-40 and State, and US Highways (Figure 1, Figure 3). The close proximity of the blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[9]. A BBC drawn in this way has two problems: (1) It could be unrealistic (previous footnote) and (2) It 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, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel to each other, and set back at least 1 mile from the city of Kingman. Thus for purposes of BBC analyses, we redefined the wildland blocks such that the Hualapai wildland block was a minimum of 22.5 km (14 mi) from the Cerbat wildland block.

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

[9] 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.

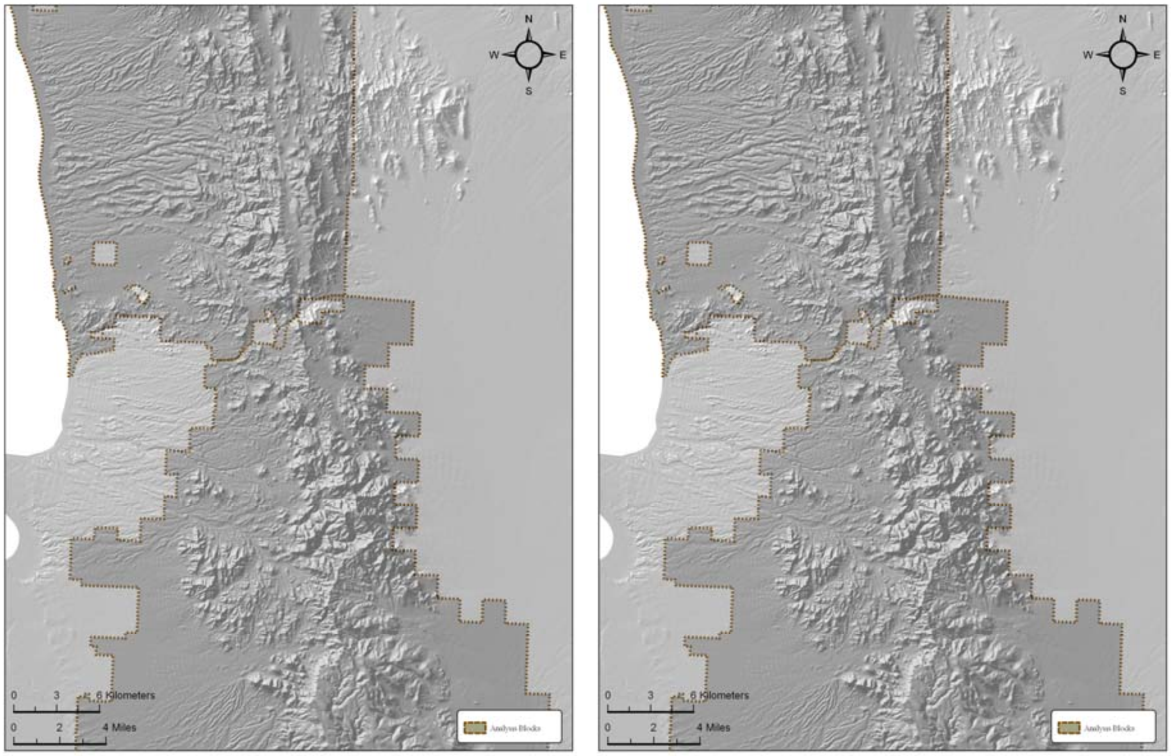


Figure 31: To give our corridors models "room to run," for the purposes of BBC analyses, we modified the wildland blocks used in our analyses, so that the facing edges were parallel lines about 15 km apart. This forces the models to identify corridors with the best habitat; without this modification, the models tend to identify the shortest corridors regardless of habitat quality.

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[10]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus 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 minimum width of 500 m (Figure 32). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

If necessary, we also used additional factors critical for a particular species, such as a minimum slope needed as escape terrain for bighorn sheep, or proximity to water for frogs. To create a habitat suitability model using critical features, we reclassified any pixel beyond a specified threshold distance from the critical feature as unsuitable for breeding (score > 5). This was accomplished using the equation:

New habitat score for pixel beyond threshold distance = (1/2 of original habitat score) + 5

Therefore, if a pixel of habitat located beyond the threshold distance from a critical feature had an original habitat score of 1 (optimal habitat), it received a reclassified score of 5.5 (usable, but not breeding habitat). Likewise, unsuitable habitat located outside of the threshold distance remained unsuitable: an original score of 9 would be reclassified as 9.5. All pixels of habitat within the threshold distance of a

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

critical feature maintained their original habitat score.

After developing a biologically best corridor for each species, we combined biologically best corridors to form a union of biologically best corridors (UBBC). In this linkage planning area, the UBBC was based on models created for Badger, Black-tailed Jackrabbit, Javelina, Kit Fox, Mountain Lion, and Mule Deer. For reasons outlined in the relevant species analyses (Appendix B), we modeled habitat suitability for Black Bear, Desert Bighorn Sheep, Elk, and Pronghorn, and evaluated patch configuration analysis instead of creating a BBC.

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, corridor analyses were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[11] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

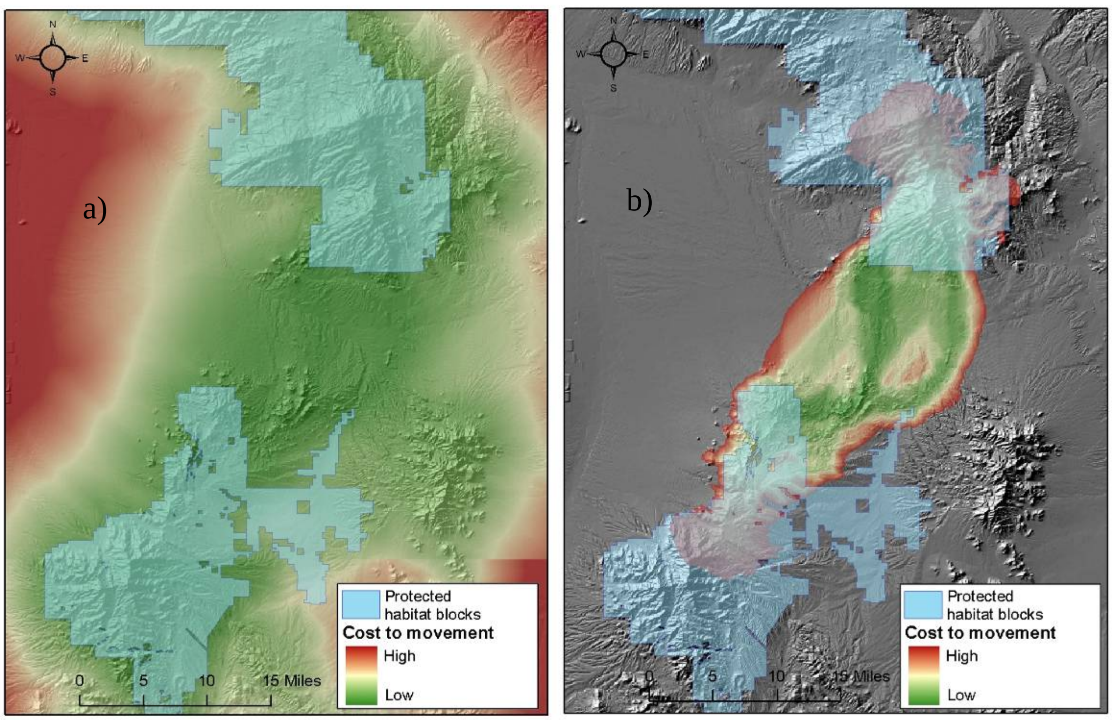


Figure 32: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

[11] Dispersal distance is how far an animal moves from its birthplace to its adult home range. We used dispersal distances reported by the species expert, or in published literature. In some cases, we used dispersal distance for a closely-related 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 and (6) allow enough space for trails and other human recreational uses without compromising suitability for wildlife occupancy and movement.

To address these concerns, we established a minimum width of 1.5 km (0.94 mi) along the length of each terrestrial branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available.

It is especially important that the linkage will be useful in the face of climate change. Climate change scientists unanimously agree that average temperatures will rise 2 to 6.4 C over pre-industrial levels by 2100, and that extreme climate events (droughts and storms) will become more common (Millennium Ecosystem Assessment 2005). Although it is less clear whether rainfall will increase or decrease in any location, there can be no doubt that the vegetation map in 2050 and 2100 will be significantly different than the map of current vegetation used in our analyses. Implementing a corridor design narrowly conforming to current distribution of vegetation types would be risky. Therefore, in widening terrestrial linkage strands, we attempted to maximize local diversity of aspect, slope, and elevation to provide a better chance that the linkage will have most vegetation types well-distributed along its length during the coming decades of climate change. Because of the diversity of focal species used to develop the UBBC, our preliminary linkage design had a lot of topographic diversity, and minimal widening was needed to encompass this diversity.

Expanding the linkage to this minimum width produced the final linkage design.

Field Investigations

Although our analyses consider human land use and distance from roads, our GIS layers only crudely reflect important barriers that are only a pixel or two in width, such as freeways, canals, and major fences. Therefore we visited each linkage design area to assess such barriers and identify restoration opportunities. We documented areas of interest using GPS, photography, and field notes. We evaluated existing bridges, underpasses, overpasses, and culverts along highways as potential structures for animals to cross the highway, or as locations where improved crossing structures could be built. We noted recent (unmapped) housing & residential developments, major fences and artificial night lighting that could impede animal movement, and opportunities to restore native vegetation degraded by human disturbance or exotic plant species. A database of field notes, GPS coordinates, and photos of our field investigations can be found in Appendix G, as well as in a MS Access database on the CD-ROM accompanying this report.

Table 5: Habitat suitability scores and factor weights for each species. Scores range from 1 (best) to 10 (worst), with 1-3 indicating optimal habitat, 4-5 suboptimal but usable habitat, 6-7 occasionally used but not breeding habitat, and 8-10 avoided.

	Badger	Bighorn Sheep	Black Bear	Black-tailed Jackrabbit	Elk
Factor weights					
Land Cover	65	30	75	70	75
Elevation	7	10	10	10	0
Topography	15	50	10	10	0
Distance from Roads	13	10	5	10	25
Land Cover					
Pine-Oak Forest and Woodland	5	9	1	6	1
Pinyon-Juniper Woodland	4	9	6	4	1
Ponderosa Pine Woodland	5	9	4	6	1
Juniper Savanna	2	8	7	3	1
Semi-Desert Grassland and Steppe	1	5	5	4	7
Chaparral	5	9	3	6	4
Creosotebush, Mixed Desert and Thorn Scrub	2	6	6	2	9
Creosotebush-White Bursage Desert Scrub	2	6	9	2	9
Desert Scrub (misc)	3	2	5	1	8
Gambel Oak-Mixed Montane Shrubland	5	9	3	5	2
Mesquite Upland Scrub	3	7	6	4	7
Paloverde-Mixed Cacti Desert Scrub	4	3	5	1	8
Pinyon-Juniper Shrubland	4	8	6	3	1
Riparian Mesquite Bosque	6	9	5	5	3
Riparian Woodland and Shrubland	6	9	5	4	2
Barren Lands, Non-specific	7	8	10	8	10
Bedrock Cliff and Outcrop	9	2	10	8	10
Cliff and Canyon	9	1	10	8	10
Mixed Bedrock Canyon and Tableland	9	2	10	8	9
Warm Desert Pavement	9	9	10	9	10
Recently Mined or Quarried	9	10	10	10	10
Agriculture	6	10	6	6	7
Developed, Medium - High Intensity	10	10	10	9	10
Developed, Open Space - Low Intensity	7	10	10	6	7
Open Water	9	10	10	9	10
Elevation (ft)					
	0-5500: 1	0-2950: 2	0-2500: 8	0-6000: 1	
	5500-8000: 3	2950-3300: 1	2500-4000: 6	6000-8000: 4	
	8000-11000: 6	3300-7000: 3	4000-6500: 2	8000-11000: 8	
		7000-11000: 7	6500-8500: 3		
			8500-11000: 4		
Topographic Position					
Canyon Bottom	5	8	3	3	
Flat - Gentle Slopes	1	7	6	1	
Steep Slope	8	5	3	4	
Ridgetop	7	1	4	4	
Distance from Roads (m)					
	0-250: 6	0-1000: 6	0-100: 10	0-250: 9	0-100: 9
	250-1500: 1	1000-15000: 2	100-500: 4	250-500: 6	100-200: 8
			500-15000: 1	500-1000: 3	200-400: 6
				1000-15000: 1	400-1000: 5
					1000-2000: 2
					2000-15000: 1

	Gila Monster	Javelina	Kit Fox	Mountain Lion	Mule Deer
Factor weights					
Land Cover	10	50	75	70	80
Elevation	35	30	0	0	0
Topography	45	20	15	10	15
Distance from Roads	10	0	10	20	5
Land Cover					
Pine-Oak Forest and Woodland	10	7	8	1	3
Pinyon-Juniper Woodland	6	5	8	1	5
Ponderosa Pine Woodland	10	6	8	4	5
Juniper Savanna	10	7	3	4	4
Semi-Desert Grassland and Steppe	5	2	1	5	2
Chaparral	6	3	6	3	4
Creosotebush, Mixed Desert and Thorn Scrub	3	3	1	6	6
Creosotebush-White Bursage Desert Scrub	7	4	1	6	6
Desert Scrub (misc)	3	2	1	6	6
Gambel Oak-Mixed Montane Shrubland	10	8	5	3	4
Mesquite Upland Scrub	4	2	5	4	3
Paloverde-Mixed Cacti Desert Scrub	1	1	3	7	3
Pinyon-Juniper Shrubland	6	10	4	2	5
Riparian Mesquite Bosque	5	1	4	4	3
Riparian Woodland and Shrubland	5	2	5	2	3
Barren Lands, Non-specific	10	9	9	8	10
Bedrock Cliff and Outcrop	2	8	9	6	8
Cliff and Canyon	2	7	9	6	7
Mixed Bedrock Canyon and Tableland	2	10	9	6	7
Warm Desert Pavement	6	8	9	9	9
Recently Mined or Quarried	10	10	10	8	6
Agriculture	10	7	7	10	6
Developed, Medium - High Intensity	9	7	9	10	10
Developed, Open Space - Low Intensity	1	4	7	8	5
Open Water	10	10	10	9	10
Elevation (ft)					
	0-1700: 4	0-5000: 1			
	1700-4000: 1	5000-7000: 3			
	4000-4800: 4	7000-11000: 10			
	4800-5700: 7				
	5700-11000: 10				
Topographic Position					
Canyon Bottom	1	1	7	1	2
Flat - Gentle Slopes	5	1	1	3	2
Steep Slope	1	7	5	3	4
Ridgetop	1	4	4	4	6
Distance from Roads (m)					
	0-1000: 5		0-50: 7	0-200: 8	0-250: 10
	1000-3000: 3		50-250: 3	200-500: 6	250-1000: 3
	3000-15000: 1		250-500: 2	600-1000: 5	1000-15000: 1
			500-15000: 1	1000-1500: 2	
				1500-15000: 1	

	Pronghorn
Factor weights	
Land Cover	45
Elevation	0
Topography	37
Distance from Roads	18
Land Cover	
Pine-Oak Forest and Woodland	8
Pinyon-Juniper Woodland	6
Ponderosa Pine Woodland	7
Juniper Savanna	4
Semi-Desert Grassland and Steppe	1
Chaparral	8
Creosotebush, Mixed Desert and Thorn Scrub	2
Creosotebush-White Bursage Desert Scrub	2
Desert Scrub (misc)	3
Gambel Oak-Mixed Montane Shrubland	5
Mesquite Upland Scrub	7
Paloverde-Mixed Cacti Desert Scrub	3
Pinyon-Juniper Shrubland	4
Riparian Mesquite Bosque	8
Riparian Woodland and Shrubland	8
Barren Lands, Non-specific	7
Bedrock Cliff and Outcrop	10
Cliff and Canyon	10
Mixed Bedrock Canyon and Tableland	8
Warm Desert Pavement	7
Recently Mined or Quarried	10
Agriculture	8
Developed, Medium - High Intensity	10
Developed, Open Space - Low Intensity	8
Open Water	7
Elevation (ft)	
Topographic Position	
Canyon Bottom	7
Flat - Gentle Slopes	1
Steep Slope	8
Ridgetop	6
Distance from Roads (m)	
	0-100: 10
	100-250: 6
	250-1000: 3
	1000-15000: 1

Species Modeled by Best Biological Corridor Analysis

The biologically best corridors for black-tailed jackrabbit, gila monster, javelina, kit fox, mountain lion, and mule deer were joined into a preliminary union of biologically best corridors (UBBC). In this section, we describe the best biological corridor created for each of these species.

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 5.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 2 km^2, 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 habitat core size was defined as 10 km^2, approximately enough area to support 10 effective breeders, allowing for a slightly larger male home range size and 20% overlap of home ranges (Messick

& Hornocker 1981). 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 significant amounts of suitable habitat for this species within the potential linkage area (Figure 33). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.66 to 5.54, with an average suitability cost of 2.5 (S.D: 0.7). Within the corridor, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 34).

Union of biologically best corridors - Strand A of the UBBC captures additional optimal habitat for badger throughout most of the strand, with the exception of smaller patches of suitable habitat, and a block of unsuitable habitat in a residential development. Strand B consists almost entirely of suitable badger habitat, with some very small patches of optimal habitat, the largest located south of US 93. Nearly all portions of the UBBC, excepting small residentially developed areas, are a potential habitat core for badger. The greatest threat to connectivity and persistence of badger populations is most likely high-traffic roads such as I-40, US 93, and Highway 68, continued habitat fragmentation, and rapid residential development in Strand A.

Biologically Best Corridors

We first present results for the 6 species for which we estimated BBC, namely Badger, Black-tailed Jackrabbit, Javelina, Kit Fox, Mountain Lion, and Mule Deer. We display the Union of Biologically Best Corridors for these species in this section.

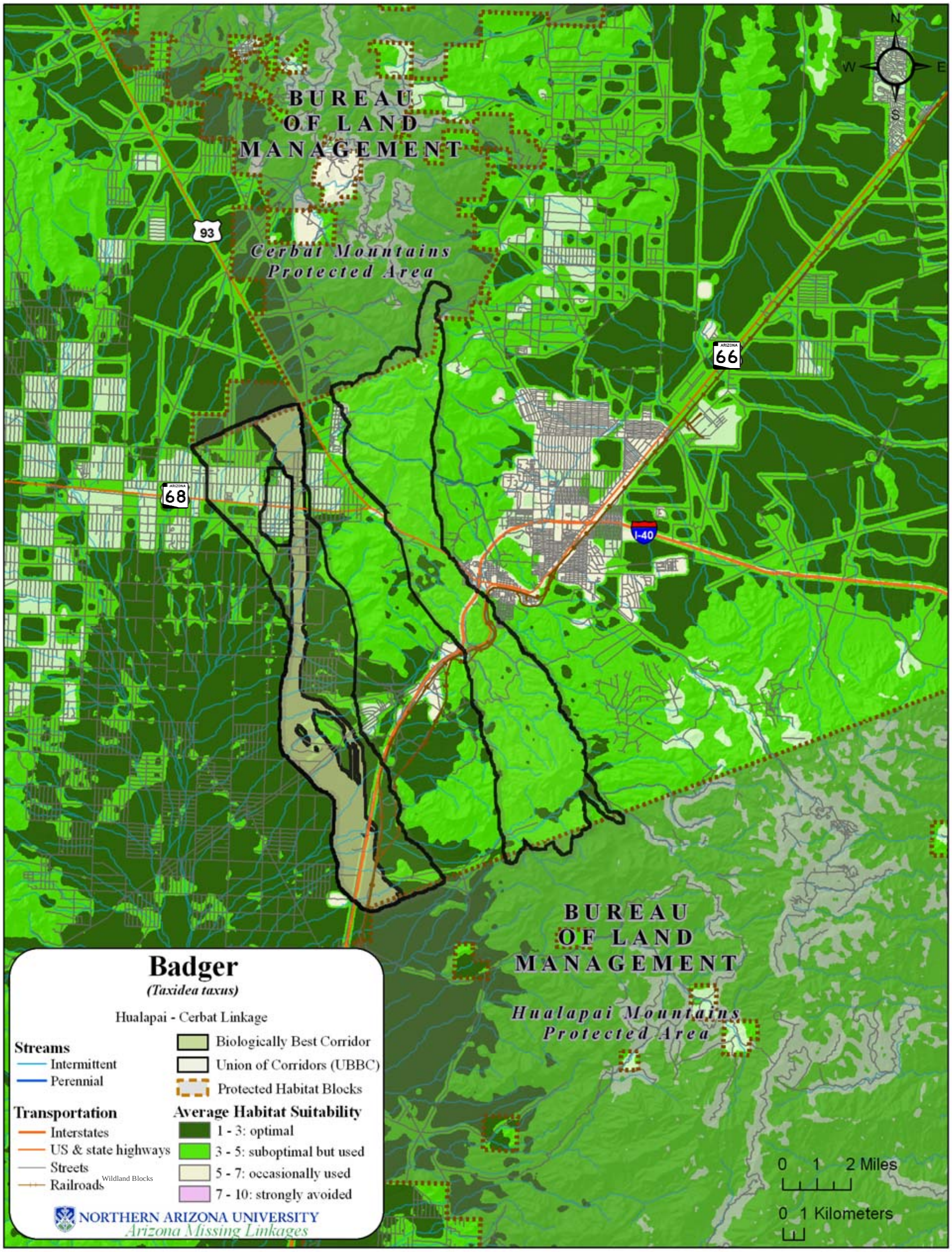


Figure 33: Modeled habitat suitability for badger

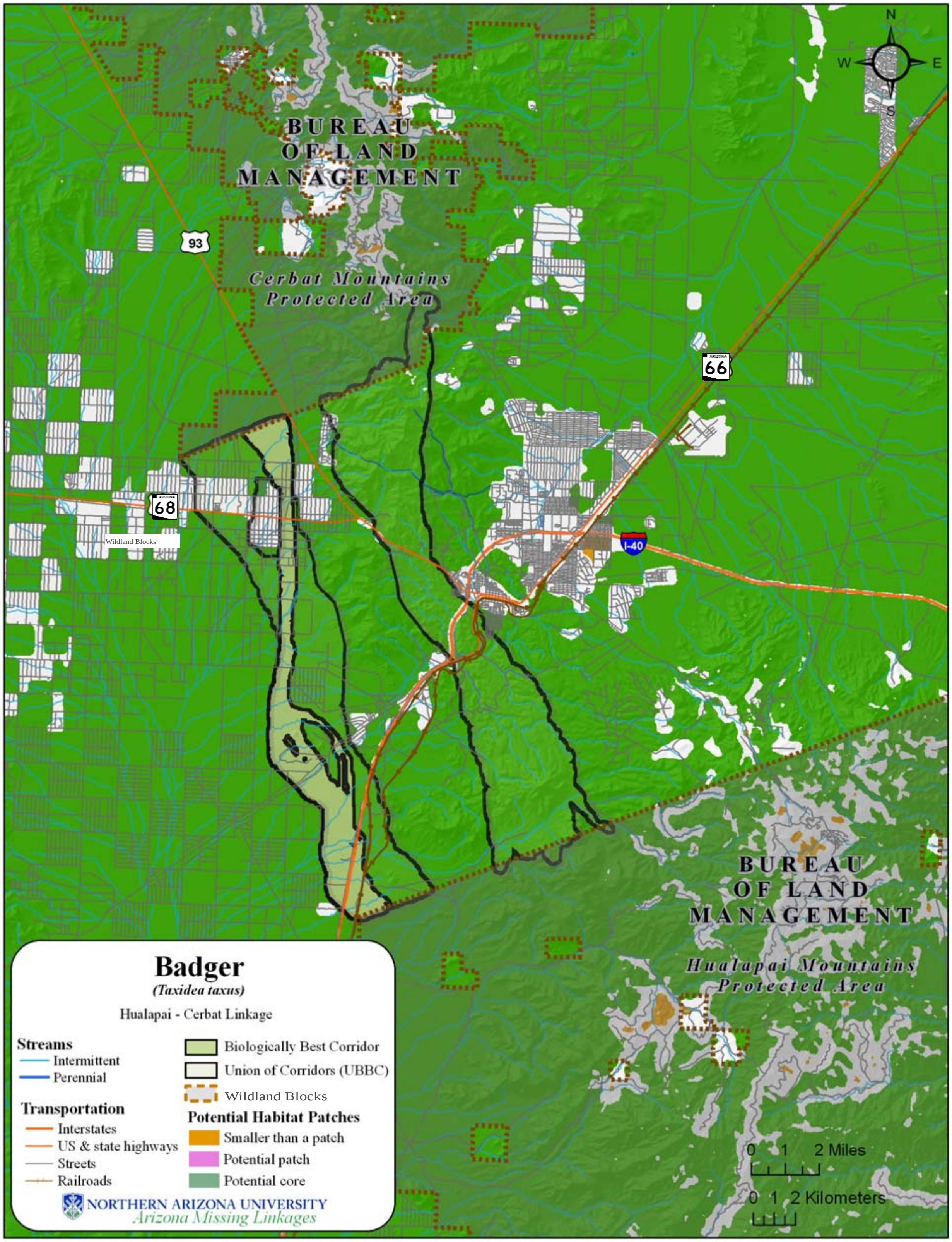


Figure 34: Potential habitat patches and cores for badger

Black-tailed Jackrabbit (*Lepus californicus*)

Justification for Selection
Black-tailed jackrabbits are important seed dispersers (Best 1996) and are frequently killed by roads (Adams & Adams 1959). They also serve as prey for predators such as hawks, eagles, owls, coyotes, badgers, foxes and bobcats (Hoffmeister 1986; Best 1996).

Distribution
Black-tailed jackrabbits are common through western North America. They range from western Arkansas and Missouri to the Pacific Coast, and from Mexico northward to Washington and Idaho (Best 1996). They are found throughout the lower elevations of Arizona (Lowe 1978).

Habitat Associations
This species primarily prefers open country, and will typically avoid areas of tall grass or forest where visibility is low (Best 1996). In Arizona, black-tailed jackrabbits prefer mesquite, sagebrush, pinyon juniper, and desert scrub (Hoffmeister 1986). They are also found in sycamore, cottonwood, and rabbitbrush habitats (New Mexico Department of Fish and Game 2004). Dense grass and/or shrub cover is necessary for resting (New Mexico Department of Fish and Game 2004). Black-tailed jackrabbits are known to avoid standing water, making large canals and rivers possible population barriers (Best 1996).

Spatial Patterns
Home range size varies considerably for black-tailed jackrabbits depending upon distances between feeding and resting areas. Home ranges have been reported from less than 1 sq km to 3 sq km in northern Utah (NatureServe 2005); however, daily movements of several miles to find suitable forage may be common in southern Arizona, with round trips of up to 10 miles each day possible (Hoffmeister 1986). Best (1993) estimated home range size to be approximately 100 ha.

Conceptual Basis for Model Development
Habitat suitability model – Due to this species' strong vegetation preferences, vegetation received an importance weight of 70%, while elevation, topography, and distance from roads each received weights of 10%. For specific costs of classes within each of these factors used for the modeling process, see Table 5.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 100 hectares (Best 1993), and minimum potential habitat core size as 500 ha, or five times the minimum patch size. To estimate potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 ($90x90m^2$) 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 significant amounts of suitable habitat for this species within the potential linkage area (Figure 35). Within the biologically best corridor linking the

wildland blocks, habitat suitability ranged from 1.0 to 8.5, with an average suitability cost of 1.8 (S.D: 0.8). Within the BBC for this species, potential suitable habitat appears to be abundant, and most of the corridor serves as a potential habitat core (Figure 36).

Union of biologically best corridors – The UBBC captures a great deal of both optimal and suitable potential habitat for the black-tailed jackrabbit. Less than optimal habitat occurs near roads, residential developments, and areas with rugged topography such as the northern portion of Strand B. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-40, Route 66, and Highways 68 and 93, continued habitat fragmentation, and residential development.

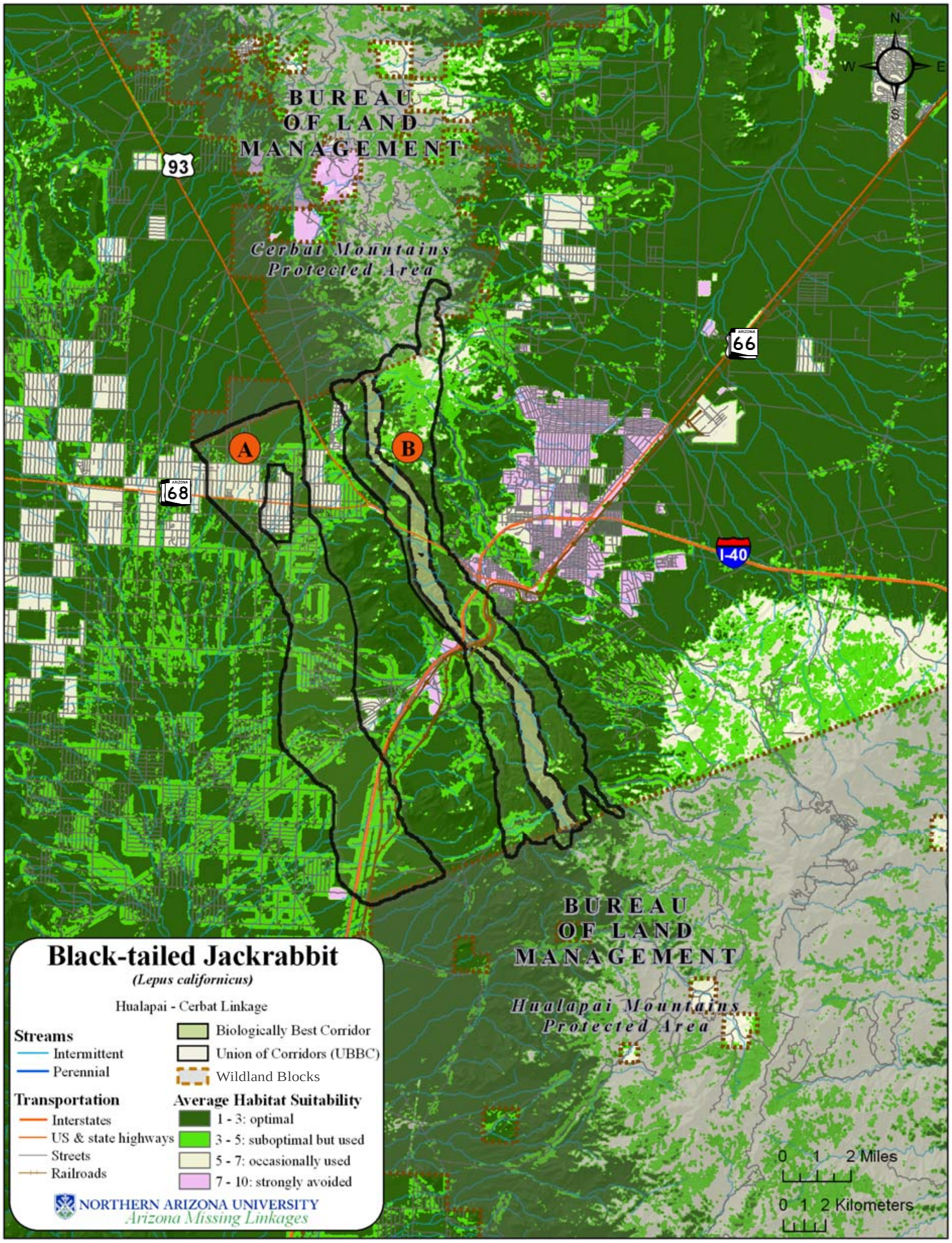


Figure 35: Modeled habitat suitability of black-tailed jackrabbit

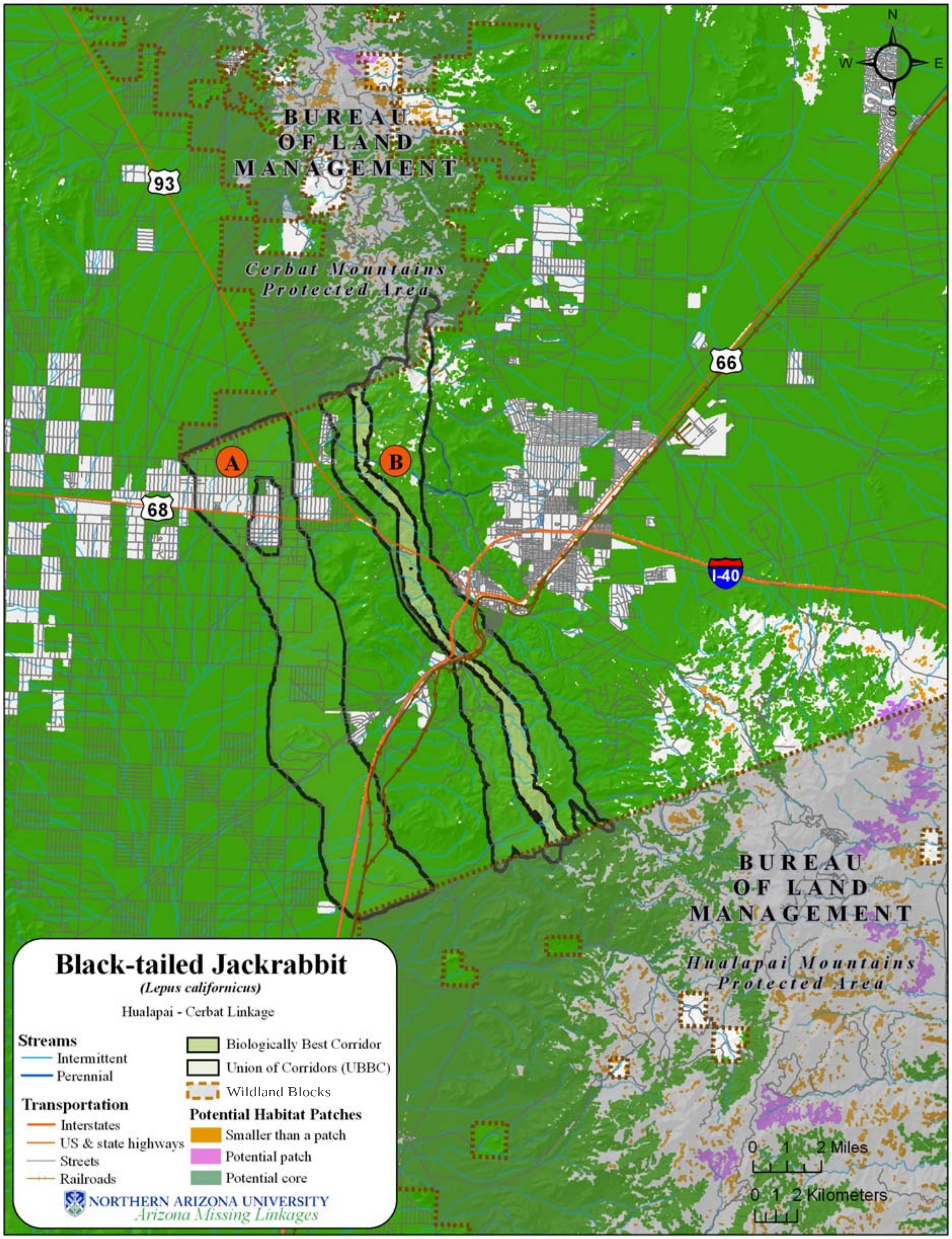


Figure 36: Potential habitat patches and cores for black-tailed jackrabbit

Gila Monster (*Heloderma suspectum*)

Justification for Selection
Gila monsters are state-listed in every state in which they occur, and are listed as Threatened in Mexico (New Mexico Department of Game and Fish 2002). Gila monsters are susceptible to road kills and fragmentation, and their habitat has been greatly affected by commercial and private reptile collectors (AZGFD 2002; NMDGF 2002).

Distribution
Gila monsters range from southeastern California, southern Nevada, and southwestern Utah down throughout much of Arizona and New Mexico.

Habitat Associations
Gila monsters live on mountain slopes and washes where water is occasionally present. They prefer rocky outcrops and boulders, where they dig burrows for shelter (NFDGF 2002). Individuals are reasonably abundant in mid-bajada flats during wet periods, but after some years of drought conditions, these populations may disappear (Phil Rosen & Matt Goode, personal comm.). The optimal elevation for this species is between 1700 and 4000 ft.

Spatial Patterns
Home ranges from 13 to 70 ha have been recorded (Beck 2005). Home ranges 3-4 km long have been recorded. Gila Monsters are widely foraging, and capable of long bouts of exercise, so it is assumed that they can disperse up to 8 km or more (Rose & Goode, personal comm.).

Conceptual Basis for Model Development
Habitat suitability model – Vegetation received an importance weight of 10%, while elevation, topography, and distance from roads received weights of 35%, 45%, and 10%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum potential habitat patch size was defined as 100 ha, and minimum potential core size was defined as 300 ha (Rosen & Goode, personal comm.; Beck 2005). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 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 significant amounts of suitable habitat for this species within the potential linkage area (Figure 37). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.4 to 8.0, with an average suitability cost of 2.0 (S.D: 0.6) Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 38).

Union of biologically best corridors – Strand B, the western strand of UBBC captures potential optimal habitat throughout most of the strand, interspersed with patches of suitable habitat including the northern portion of the strand. Strand A consists of suitable habitat with a few small isolated patches of optimal habitat. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-40, Route 66, and Highways 68 and 93, continued habitat fragmentation, and residential development.

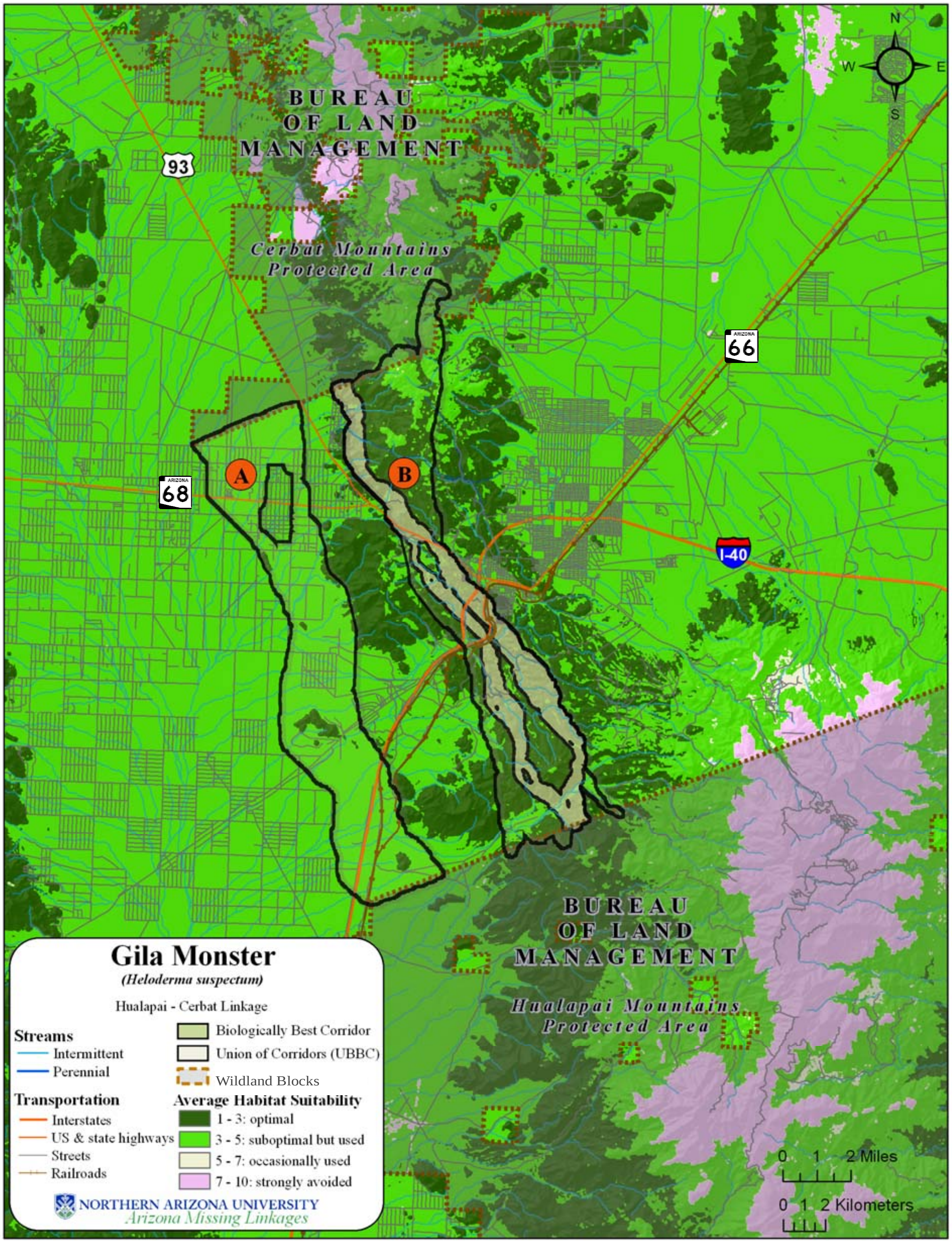


Figure 37: Modeled habitat suitability of gila monster

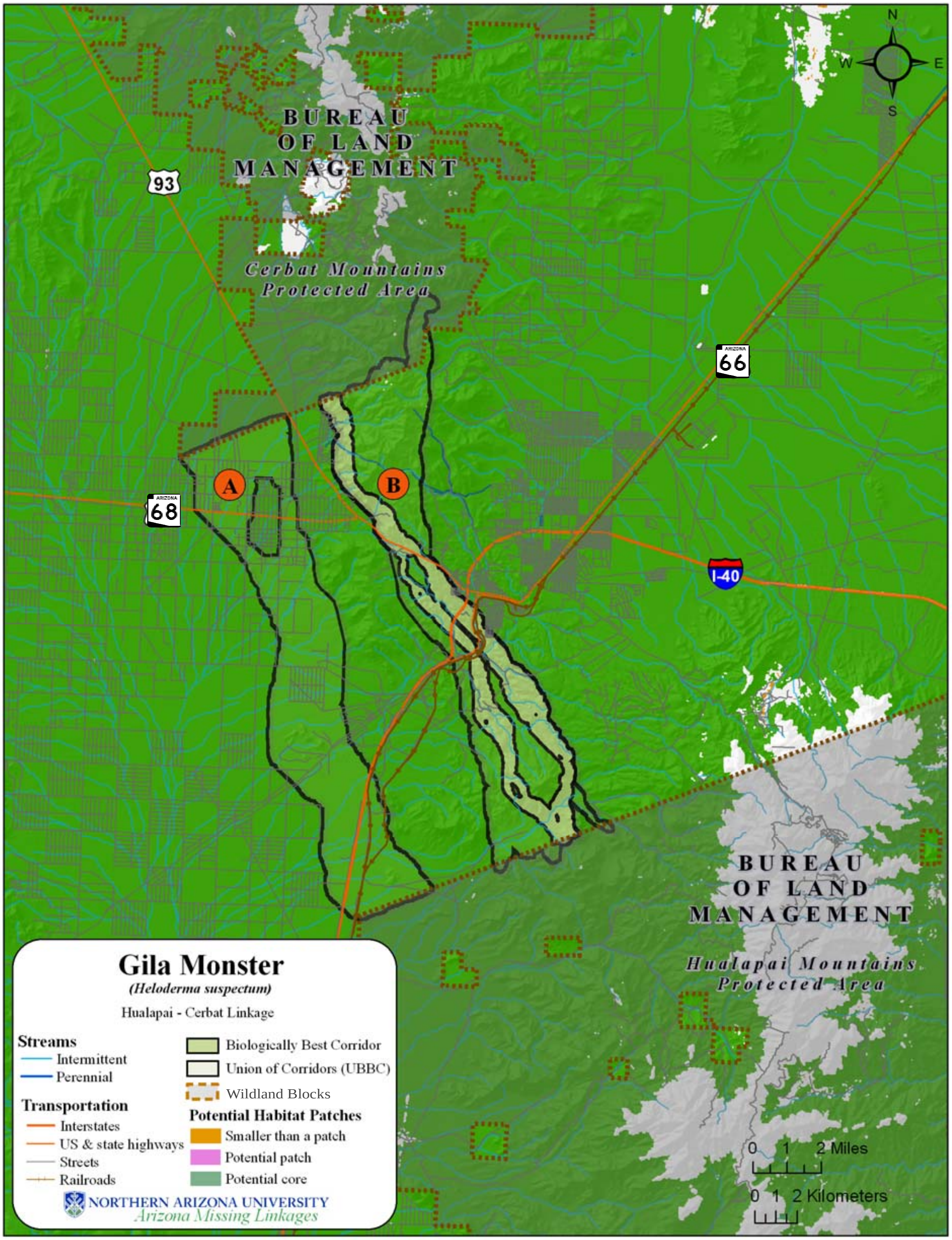


Figure 38: Potential habitat patches and cores for gila monster.

Javelina (*Tayassu tajacu*)

Justification for Selection

Young javelina are probably prey items for predators such as coyotes, bobcats, foxes (Hoffmeister 1986), and jaguars (Seymour 1989). Although they habituate well to human development, their herds require contiguous patches of dense vegetation for foraging and bed sites (Hoffmeister 1986; Ticer et al. 2001; NatureServe 2005). Roads are dangerous for urban dwelling javelina (Ticer et al. 1998). Javelina are an economically important game species (Ticer et al. 2001).

Distribution

Javelina are found from Northern Argentina and northwestern Peru to north-central Texas, northwestern New Mexico, and into central Arizona (NatureServe 2005). Specifically in Arizona, they occur mostly south of the Mogollon Rim and west to Organ Pipe National Monument (Hoffmeister 1986).

Habitat Associations

Javelina have adapted to a variety of plant communities, varied topography, and diverse climatic conditions (Ticer et al. 2001). However, javelina confine themselves to habitats with dense vegetation (Ticer et al. 2001; Hoffmeister 1986; NatureServe 2005), and rarely are found above the oak forests on mountain ranges (Hoffmeister 1986). Javelina prefer habitat types such as areas of open woodland overstory with shrubland understory, desert scrub, and thickets along creeks and old stream beds (Ticer et al. 1998; Hoffmeister 1986). They also will forage in chaparral (Neal 1959; Johnson and Johnson 1964). Prickly pear cactus provides shelter, food, and water (Ticer et al. 2001, Hoffmeister 1986). Other plants in javelina habitat include palo verde, jojob, ocotillo, catclaw, and mesquite (Hoffmeister 1986). Javelina habituate well to human development, as long as dense vegetation is available (Ticer et al. 2001). Their elevation range is from 2000 to 6500 feet (New Mexico Department of Fish and Game 2004).

Spatial Patterns

Javelina live in stable herds, though occasionally some individuals may move out of the herd to join another or establish their own (Hoffmeister 1986). Home ranges for herds have been reported as 4.7 km^2 in the Tortolita Mountains (Bigler 1974), 4.93 km^2 near Prescott (Ticer et al. 1998), and between 1.9 and 5.5 ha in the Tonto Basin (Ockenfels and Day 1990). Dispersal of javelina has not been adequately studied, but they are known to be capable of extensive movements of up to several kilometers (NatureServe 2005).

Conceptual Basis for Model Development

Habitat suitability model – Vegetation as it relates to both forage and cover requirements is very important for javelina. Sowls (1997) lists climate, vegetation, and topography as important factors in javelina habitat use. For this species', vegetation received an importance weight of 50%, while elevation and topography received weights of 30% and 20%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum habitat patch size for javelina was defined as 44 ha, based on an estimate for a single breeding season for one "herd" of one breeding pair. The estimate for minimum habitat core size is 222 ha, based on an estimate of 10 breeding seasons for 1 herd of mean size 9 to 12 animals (Chasa O'Brien, AGFD, personal comm.). The calculation of area is based upon 3 different estimates of density of animals/ha in south-central and southern Arizona. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 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 significant suitable habitat for this species within the potential linkage area (Figure 39). Within the biologically best corridor for this species, habitat suitability ranged from 1.0 to 4.8, with an average suitability cost of 2.0 (S.D: 0.5). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 40).

Union of biologically best corridors – Both strands of the UBBC capture significant amounts of potential habitat for javelina. Strand A is composed almost entirely of optimal javelina habitat, and Strand B encompasses a mixture of optimal and suitable habitat in areas with higher elevations and more rugged topography. Because there is ample habitat for this species, and both strands of the UBBC serve as a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-40, Route 66, and Highways 68 and 93, continued habitat fragmentation, and rapid residential development in Strand A.

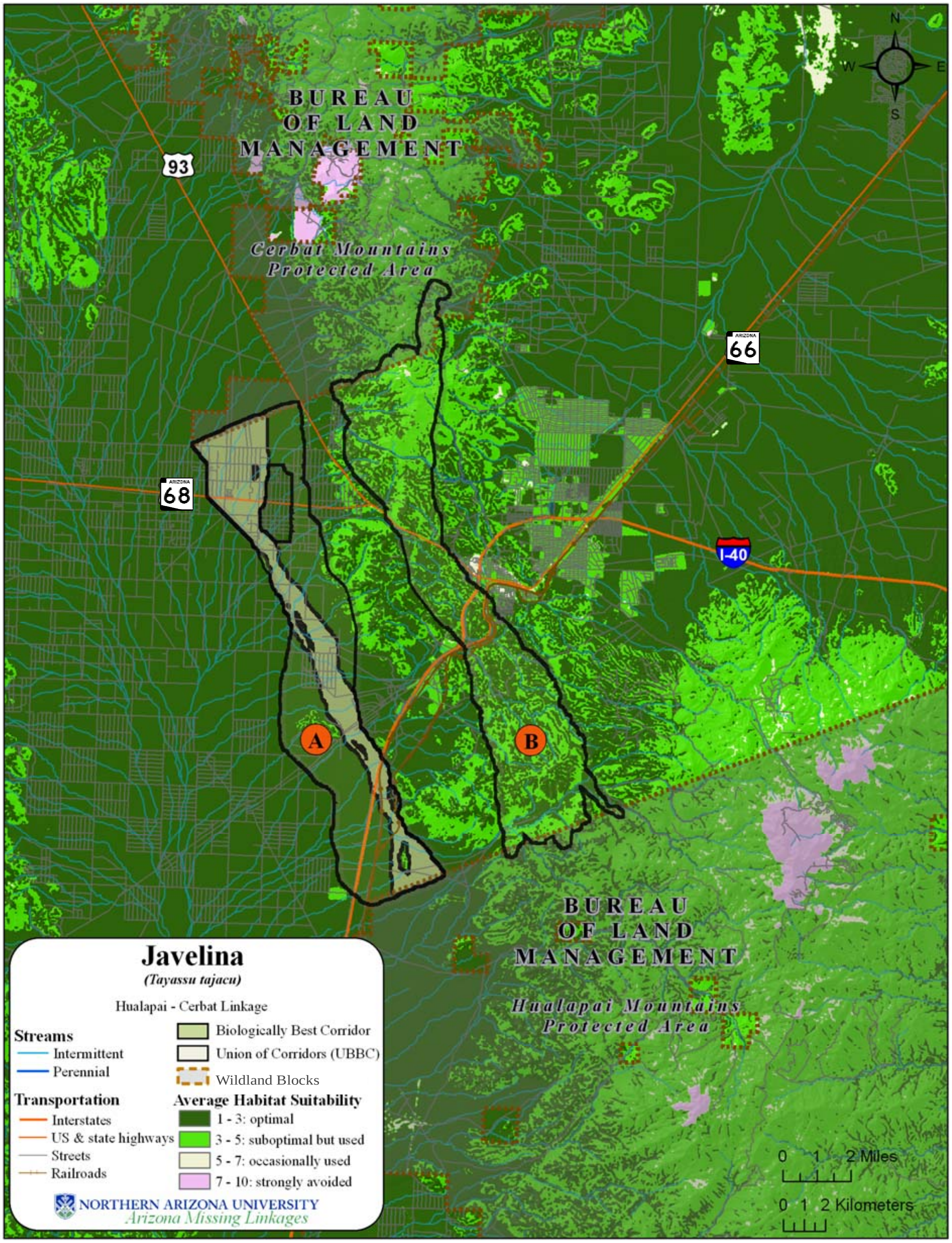


Figure 39: Modeled habitat suitability of javelina.

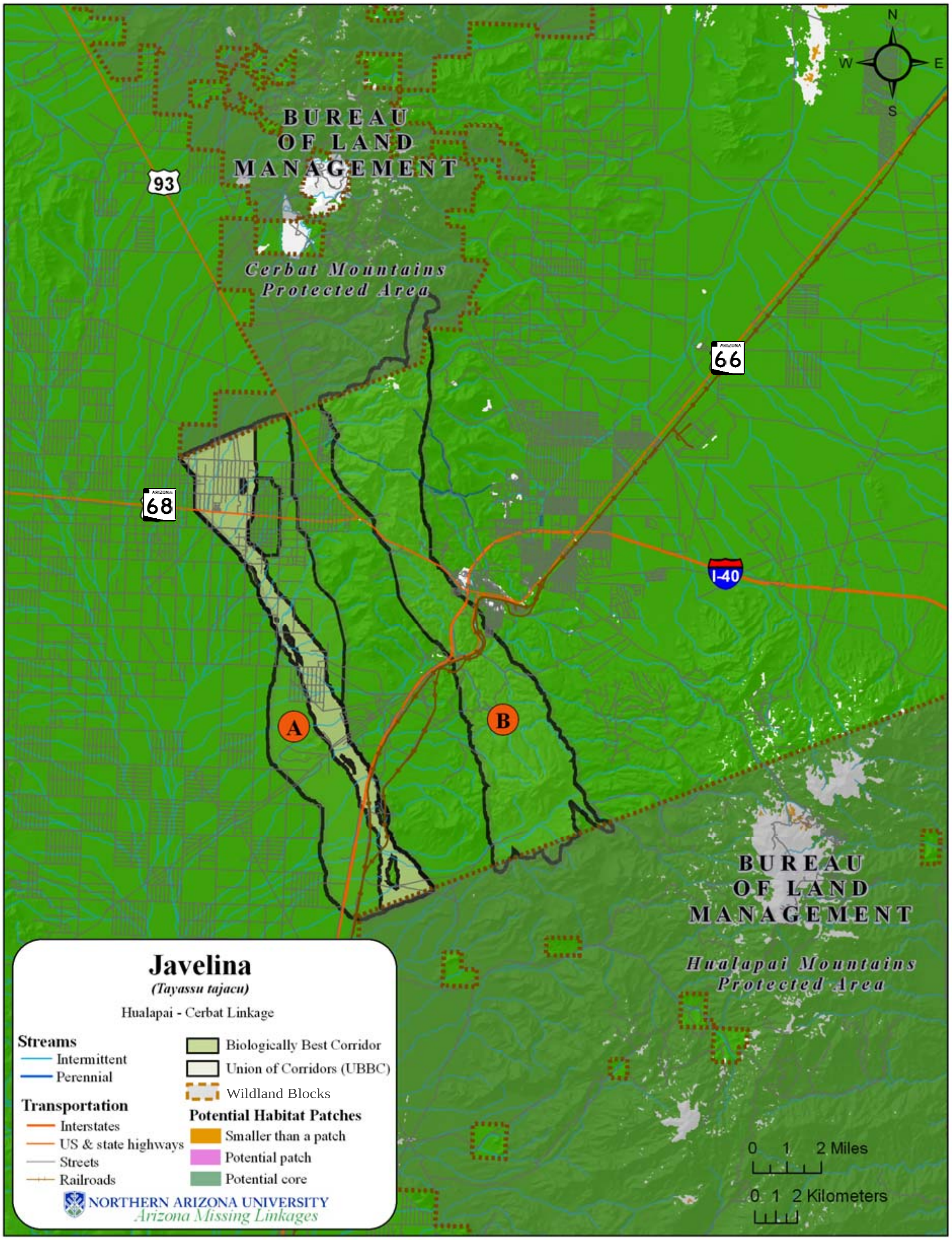


Figure 40: Potential habitat patches and cores for javelina.

Kit Fox (*Vulpes macrotis*)

Justification for Selection
Kit fox are susceptible to habitat conversion and fragmentation due to agricultural, urban, and industrial development.

Distribution & Status
Kit fox are found throughout arid regions of several states in the western U.S., including Arizona, New Mexico, Texas, Utah, Nevada, California Colorado, Idaho, and Oregon (Natureserve 2006). They historically ranged throughout all major desert regions of North America, including the Sonora, Chihuahua, and Mohave Deserts, as well as the Painted Desert and much of the Great Basin Desert (McGrew 1979). Within Arizona, Kit fox are found in desert grasslands and desert scrub throughout much of southern and western parts of the state.

Habitat Associations
Kit fox are mostly associated with desert grasslands and desert scrub, where they prefer sandy soils for digging their dens (Hoffmeister 1986). Most dens are found easily diggable clay soils, sand dunes, or other soft alluvial soils (McGrew 1979; Hoffmeister 1986).

Spatial Patterns
Spatial use is highly variable for kit fox, depending on prey base, habitat quality, and precipitation (Zoellick and Smith 1992; Arjo et al. 2003). One study in western Utah found a density of 2 adults per 259 ha in optimum habitat, while an expanded study in Utah found density to range from 1 adult per 471 ha to 1 adult per 1036 ha (McGrew 1979). Arjo et al. (2003) reported home range size from 1151-4308 ha. In Arizona, one study found an average home range size of 980 ha for females and 1230 ha for males; however, home ranges the authors also reported 75% overlap of paired males and females (Zoellick and Smith 1992).

Conceptual Basis for Model Development
Habitat suitability model –Vegetation received an importance weight of 75%, while topography and distance from roads received weights of 15% and 10%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – In our analyses, we defined minimum patch size for kit fox as 259 ha and minimum core size as 1295 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.

Initial biologically best corridor – Modeling results indicate significant suitable habitat for this species within the potential linkage area (Figure 41). Within the biologically best corridor for this species, habitat suitability ranged from 1.0 to 5.0, with an average suitability cost of 1.4 (S.D: 0.5). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 42).

Results & Discussion

Union of biologically best corridors – Optimal habitat for kit fox is found in the desert scrub vegetation associations between the wildland blocks. Both strands of the UBBC consist of optimal habitat and potential habitat cores for this species, except for the residential area in northern Strand A and the foothills of the Cerbat and Hualapai mountains in Strand B. This species appears to be well-served by the linkage design. The San Joaquin kit fox tolerates moderate urbanization, so the residential development in Strand A may not impair utility for kit fox.

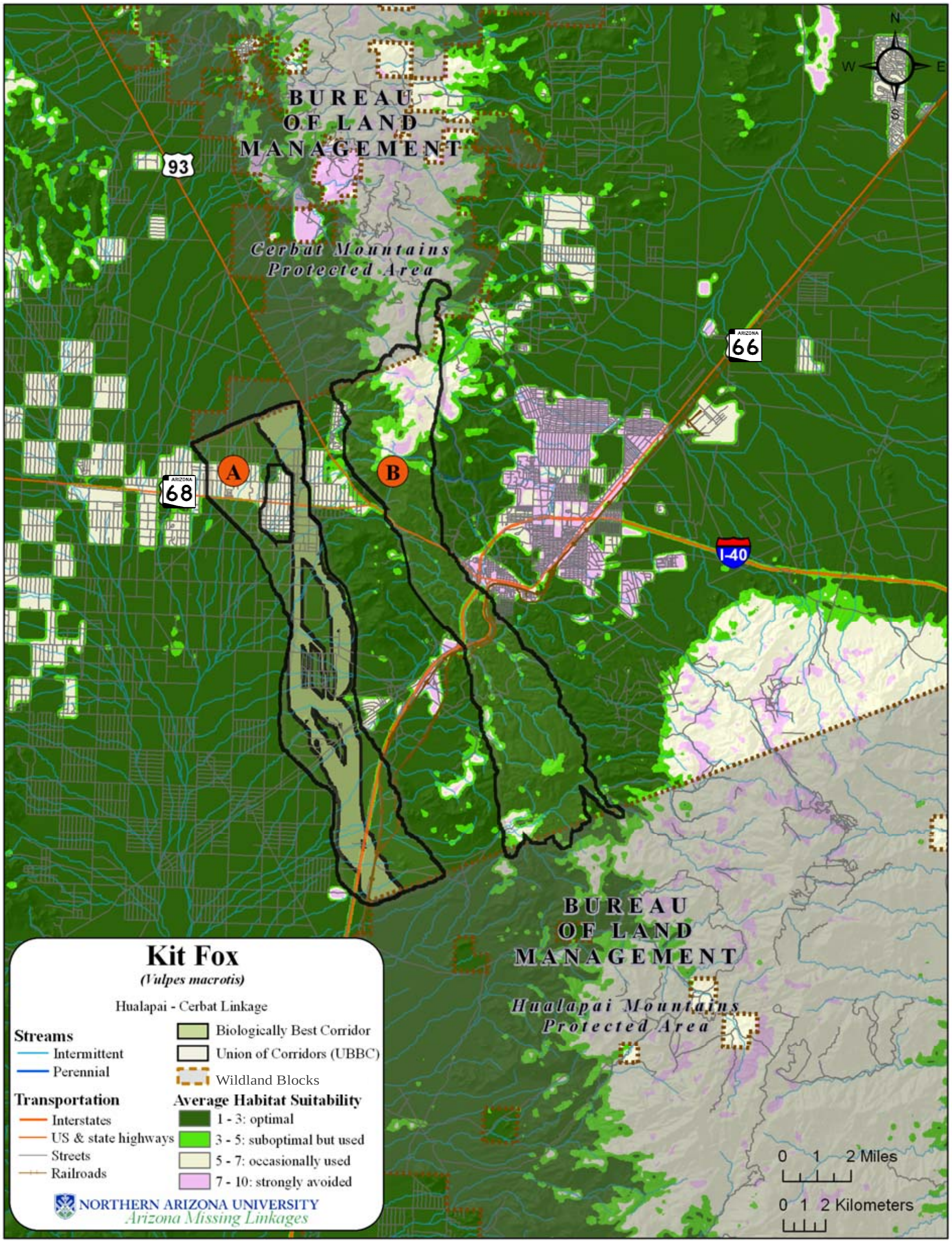


Figure 41: Modeled habitat suitability for kit fox.

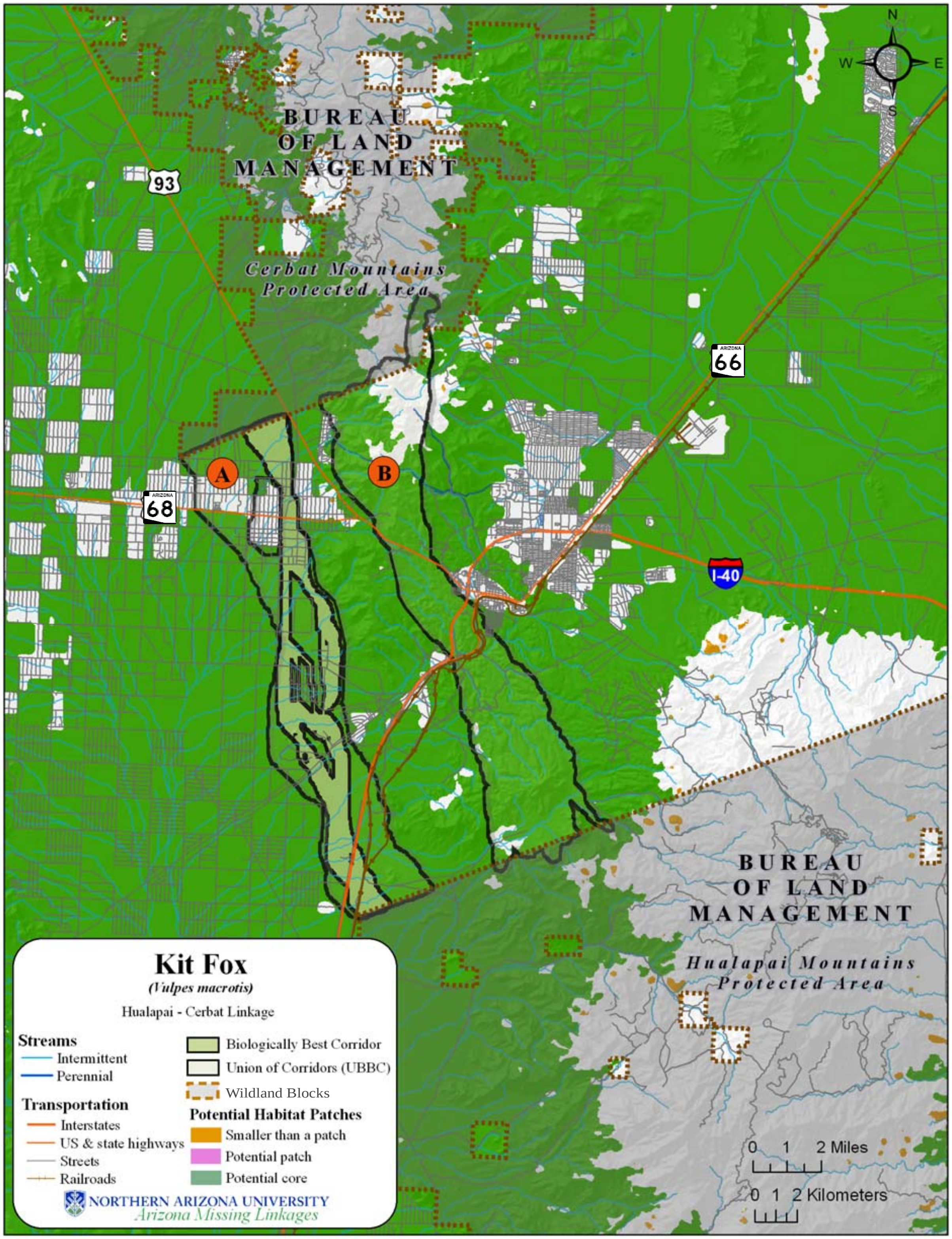


Figure 42: Potential habitat patches and cores for kit fox.

Mountain Lion (*Puma concolor*)

Justification for Selection

Mountain lions occur in low densities across their range and require a large area of connected landscapes to support even minimum self sustaining populations (Beier 1993; Logan and Sweanor 2001). Connectivity is important for hunting, seeking mates, avoiding other pumas or predators, and dispersal of juveniles (Logan and Sweanor 2001).

Distribution

Historically, mountain lions ranged from northern British Columbia to southern Chile and Argentina, and from coast to coast in North America (Currier 1983). Presently, the mountain lion's range in the United States has been restricted, due to hunting and development, to mountainous and relatively unpopulated areas from the Rocky Mountains west to the Pacific coast, although isolated populations may still exist elsewhere (Currier 1983). In Arizona, mountain lions are found throughout the state in rocky or mountainous areas (Hoffmeister 1986). In the linkage planning area, mountain lions occur in all mountainous areas, including the Hualapai and Cerbat Mountains (AZGFD 2006).

Habitat Associations

Mountain lions are associated with mountainous areas with rocky cliffs and bluffs (Hoffmeister 1986; New Mexico Game and Fish Department 2004). They use a diverse range of habitats, including conifer, hardwood, and mixed forests, and shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Game and Fish Department 2004). Mountain lions are found at elevations ranging from 0 to 4000 m (Currier 1983).

Spatial Patterns

Home range sizes of mountain lions vary depending on sex, age, and the distribution of prey. One study in New Mexico reported annual home range size averaged 193.4 km² for males and 69.9 km² for females (Logan and Sweanor 2001). This study also reported daily movements averaging 4.1 km for males and 1.5 km for females (Logan and Sweanor 2001). Dispersal rates for juvenile mountain lions also vary between males and females. Logan and Sweanor's study found males dispersed an average of 102.6 km from their natal sites, and females dispersed an average of 34.6 km. A mountain lion population requires 1000 - 2200 km² of available habitat in order to persist for 100 years (Beier 1993). These minimum areas would support about 15-20 adult cougars (Beier 1993).

Conceptual Basis for Model Development

Habitat suitability model – While mountain lions can be considered habitat generalists, vegetation is still the most important factor accounting for habitat suitability, so it received an importance weight of 70%, while topography received a weight of 10%, and distance from roads received a weight of 20%. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum patch size for mountain lions was defined as 79 km2, based on an average home range estimate for a female in excellent habitat (Logan & Sweanor 2001; Dickson & Beier 2002). Minimum core size was defined as 395 km2, or five times 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 a moderate amount of suitable habitat for this species within the potential linkage area, with a significant amount of suitable habitat within the wildland blocks (Figure 43). Within the linkage area, the average habitat suitability ranged from 1.2 to 9.4 with an average suitability of 4.5 (S.D: 1.6). The Hualapai Mountain protected area provides a habitat core, while the Cerbat Mountain range makes up a smaller habitat patch. The corridor between the wildland blocks includes areas with suitable habitat that are too small to qualify as patches.

Union of biologically best corridors –Strand B captures some small areas of suitable and optimal habitat located in the northernmost and southernmost parts of the strand, however, these areas are not contiguous and likely will not affect connectivity for the species. Because optimal habitat for lions is concentrated within the wildland blocks, the UBBC doesn't capture much additional potential lion habitat (Figure 44). I-40, Route 66, Highway 93, urban barriers and habitat fragmentation appear to be the largest impediments to the mountain lion's ability to successfully traverse between areas of suitable or optimal habitat within the linkage area.

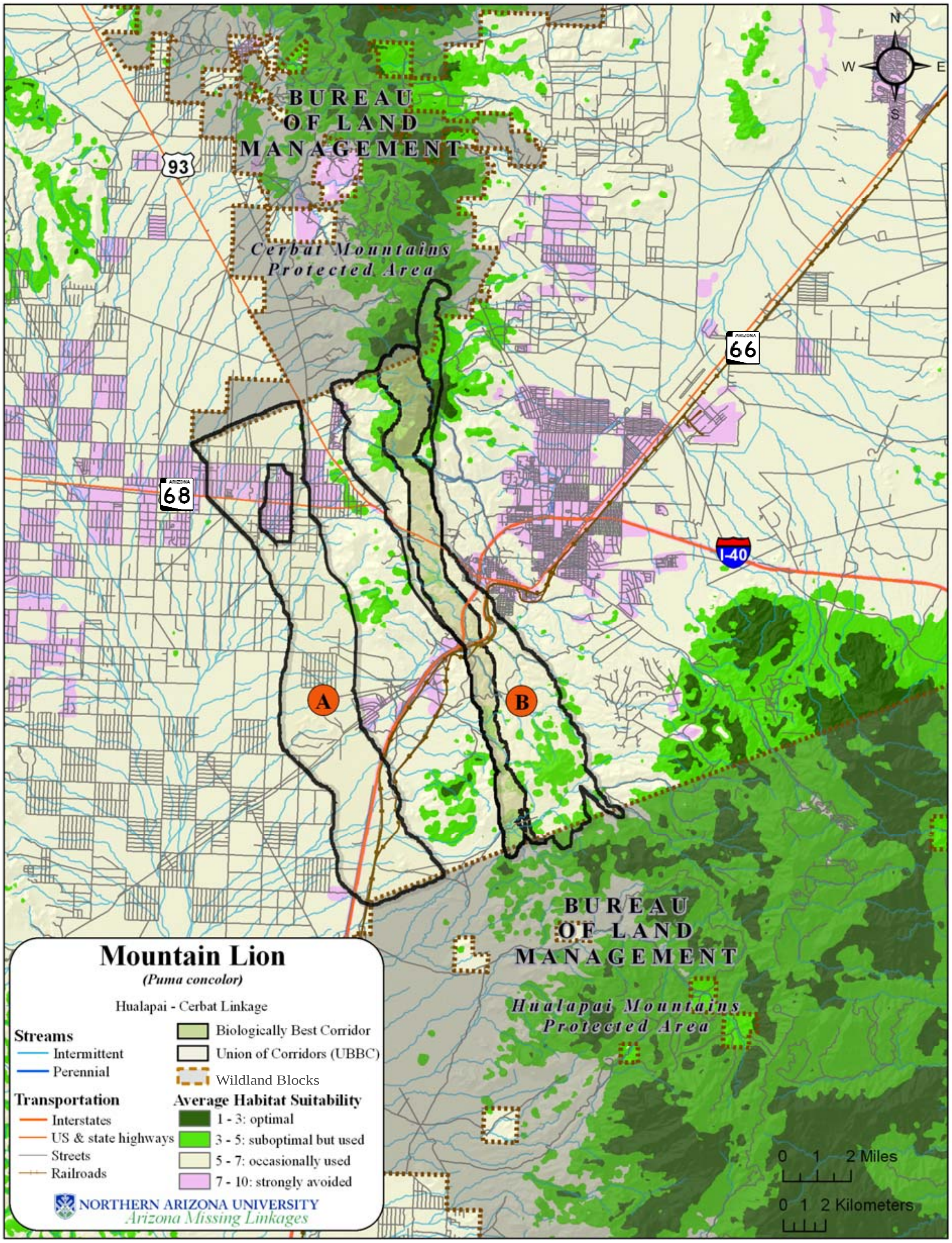


Figure 43: Modeled habitat suitability for mountain lion.

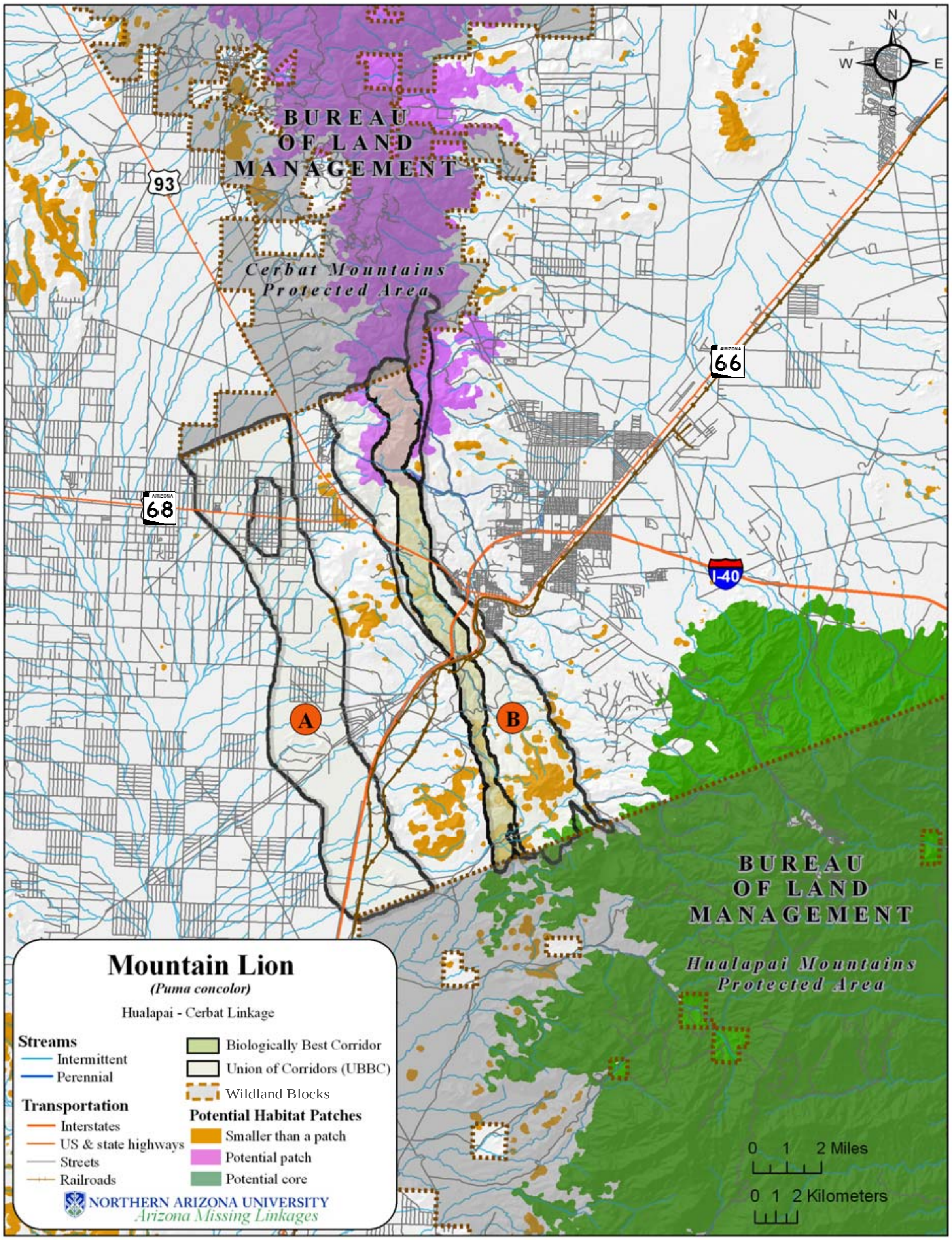


Figure 44: Potential habitat cores and patches for mountain lion.

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

Mule deer are widespread throughout Arizona, and are an important game species in the state. They are also prey species for carnivores such as mountain lion, black bear, jaguar, and gray wolf (Anderson & Wallmo 1984). Road systems may affect the distribution and welfare of mule deer (Sullivan and Messmer 2003).

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 the southwestern part of the state (Anderson & 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). In some parts of Arizona, mule deer migrate between summer range in yellow pine and spruce-fir to winter range in 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). Home ranges of mule deer in Arizona chaparral vary from 2.6 to 5.8 km^2, with bucks' home ranges averaging 5.2 km^2 and does slightly smaller (Swank 1958, as cited by Hoffmeister 1986). Average home ranges for desert mule deer are larger. Deer that migrate seasonally 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 dispersed 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 (Jason Marshal, personal comm.). For this reason, vegetation received an importance weight of 80%, while topography and distance from roads received weights of 15% and 5%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum patch size for mule deer was defined as 9 km^2 and minimum core size as 45 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis reflecting 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 a very little suitable habitat for this species within the potential linkage area (Figure 45). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 3.8 to 8.6, with an average suitability cost of 5.3 (S.D: 0.6). Both wildland blocks serve as habitat cores for the species (Figure 46).

Union of biologically best corridors – Strand B captures some additional suitable habitat at the southern end of the Cerbat Mountain range, while Strand C does not contain any mule deer habitat. Because there is not ample habitat for this species within the Linkage Planning Area, connectivity between the wildland blocks is challenged for this species. Major roads including I-40, Route 66, Highway 93, and urban barriers appear to threaten connectivity for mule deer in the area.

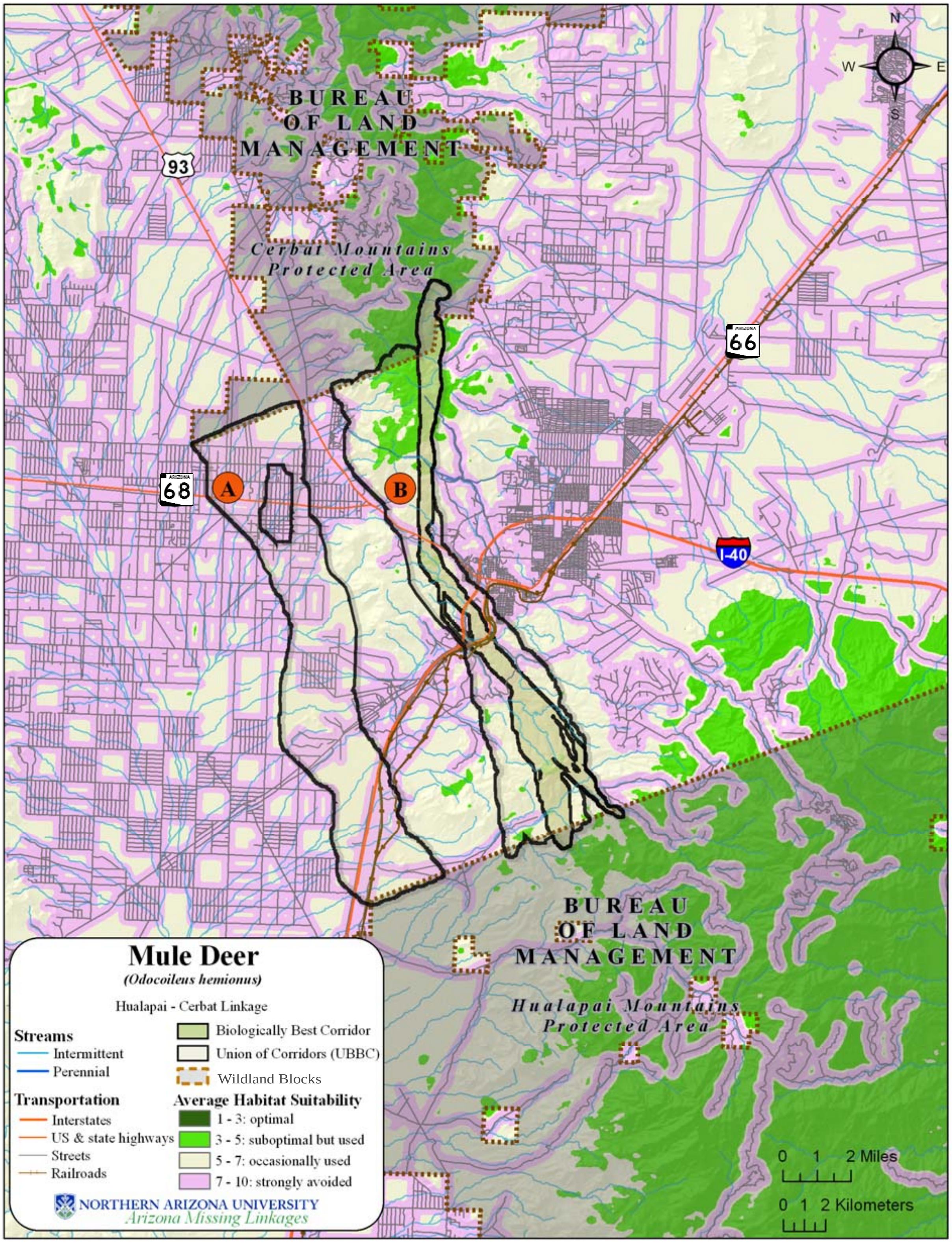


Figure 45: Modeled habitat suitability for mule deer.

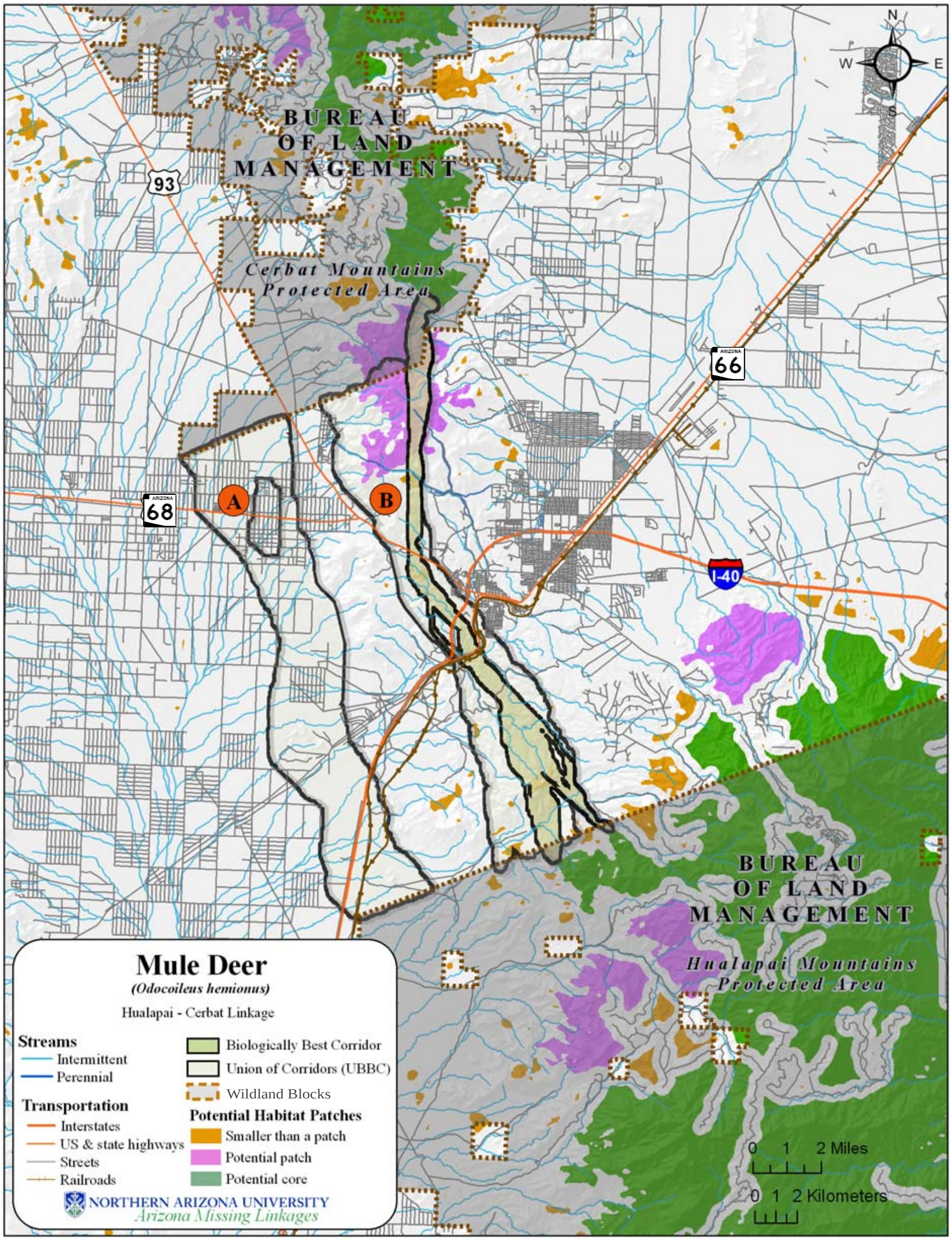


Figure 46: Potential habitat patches and cores for mule deer.

Species Modeled by Patch Configuration Analysis

The biologically best corridors for black-tailed jackrabbit, gila monster, javelina, kit fox, mountain lion, and mule deer were joined into a preliminary union of biologically best corridors (UBBC). We then evaluated how well this union of BBCs served the needs of black bear, desert bighorn sheep, elk, and pronghorn using Patch Configuration Analysis as described in Appendix A. For reasons described on the following pages, we were unable to develop BBC's for these species. In Patch Configuration analysis, we examined whether the preliminary UBBC encompassed adequate potential breeding habitat for the focal species, and made adjustments to the UBBC that would improve connectivity for that species.

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 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 & 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%. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 10 km^2, since this is the minimum amount of optimum habitat necessary to support a female and cub (Bunnell & Tait 1981; S. Cunningham, pers. comm.). Minimum potential habitat core size was defined as 50km^2, 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 – While black bear habitat is limited in the linkage planning area, they are occasionally found in the Hualapai Mountains, the westernmost part of their range in Arizona (Hoffmeister 1986). Because black bear habitat is limited in the linkage area, and they are not known to occur in the Cerbat Mountain range, we did not create a biologically best corridor for this species. Instead, we used the habitat suitability model and patch configuration analysis to assess potential habitat for this species within the union of biologically best corridors (Figure 47).

Results & Discussion

Union of biologically best corridors – The union of biologically best corridors encompasses a large portion of suboptimal but potentially suitable bear habitat. While the most optimal bear habitat occurs in the Hualapai Mountains outside of the linkage design, Strand B captures the edge of large cores comprised of optimal habitat in the foothills of the both the Cerbat and Hualapai mountain ranges. With climate change, this corridor may become important for northward shift of black bear range. Because Strand B serves this species well, we did not modify the UBBC for black bears.

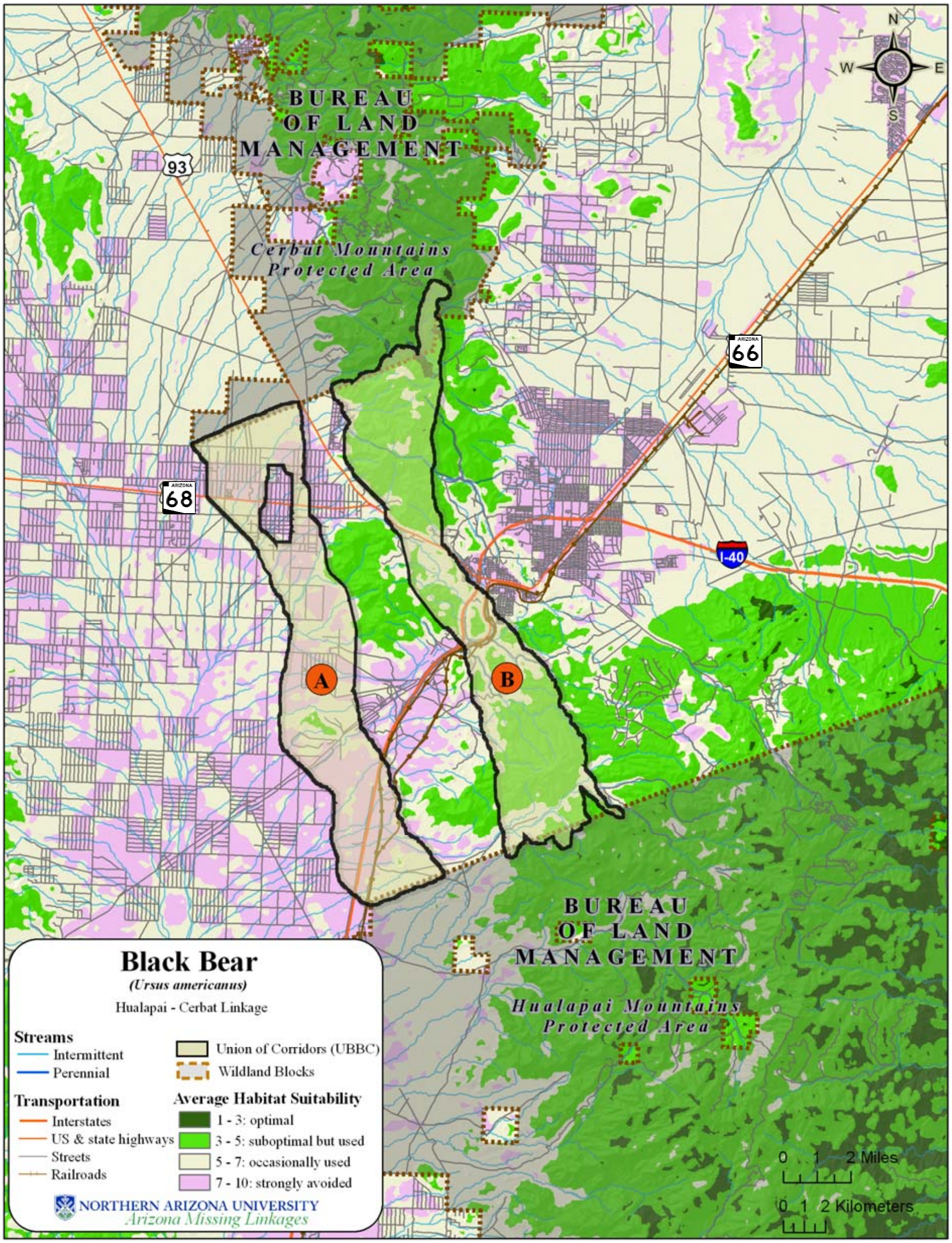


Figure 47: Modeled habitat suitability of black bear with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

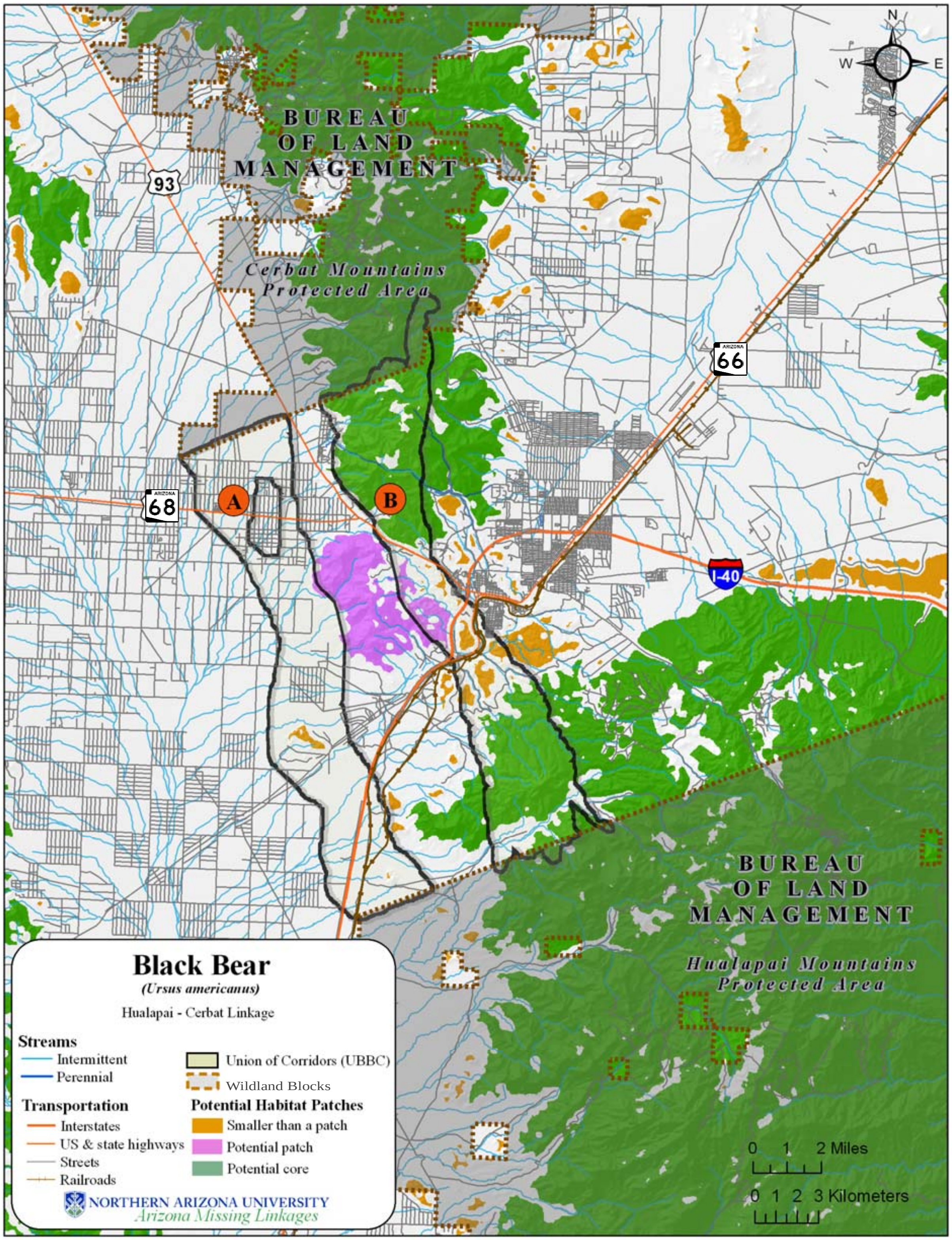


Figure 48: Potential habitat patches and cores for black bear with design; respect to the linkage for reasons described above, we did not estimate the biologically best corridor for this species.

Desert Bighorn Sheep (*Ovis Canadensis nelsoni*)

Justification for Selection

Bighorn sheep populations have suffered massive declines in the last century, including local extinctions. Human activities such as alteration of bighorn sheep habitat, urbanization, and grazing by domestic sheep have been largely responsible for population declines (Johnson and Swift 2000; Krausman 2000). These declines, along with barriers to movement such as roads and range fences, have created small, isolated groups of bighorn sheep with a highly fragmented distribution (Singer et al. 2000; Bleich et al. 1990). Isolated bighorn populations are more susceptible to extirpation than large, contiguous populations due to climate change, fire, or disease, especially introduced diseases from domestic sheep (Gross et al. 2000; Singer et al. 2000; Epps et al. 2004). Bighorn sheep are listed as USFS Sensitive in New Mexico and Arizona (New Mexico Department of Game and Fish 2004).

Distribution

Bighorn sheep are found throughout western North America from the high elevation alpine meadows of the Rocky Mountains to low elevation desert mountain ranges of the southwestern United States and northern Mexico (Shackleton 1985). Specifically, their range extends from the mountains and river breaks of southwestern Canada south through the Rocky Mountains and Sierra Nevada, and into the desert mountains of the southwest United States and the northwestern mainland of Mexico (NatureServe 2005). In Arizona, bighorns can be found from Kanab Creek and the Grand Canyon west to Grand Wash, as well as in westernmost Arizona eastward to the Santa Catalina Mountains (Hoffmeister 1986).

Habitat Associations

Bighorn sheep habitat includes mesic to xeric grasslands found within mountains, foothills, and major river canyons (Shackleton 1985). These grasslands must also include precipitous, rocky slopes with rugged cliffs and crags for use as escape terrain (Shackleton 1985; Alvarez-Cardenas et al. 2001; Rubin et al. 2002; New Mexico Department of Game and Fish 2004). Slopes >80% are preferred by bighorn sheep, and slopes <40% are avoided (Alvarez-Cardenas et al. 2001). Dense forests and chaparral that restrict vision are also avoided (NatureServe 2005). In Arizona, the desert bighorn subspecies (*O. Canadensis nelsoni*) is associated with feeding grounds that include mesquite, ironwood, palo verde, catclaw, coffeeberry, bush muhly, jojoba, brittlebrush, calliandra, and galleta (Hoffmeister 1986). Water is an important and limiting resource for desert bighorn sheep (Rubin et al. 2002). Where possible, desert bighorn will seek both water and food from such plants as cholla, prickly pear, agave, and especially saguaro fruits (Hoffmeister 1986). Bighorn sheep will also occasionally graze on shrubs such as sagebrush, mountain mahogany, cliffrose, and blackbrush (New Mexico Department of Game and Fish 2004). Elevation range for bighorn sheep varies across their range from 0 – 3660 m (New Mexico Department of Game and Fish 2004), but in Arizona the desert bighorn subspecies is found from 100 – 1000m elevation, with the best habitat found from 900 – 1000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

Home ranges for bighorn sheep vary depending upon population size, availability and connectivity of suitable habitat, and availability of water resources (Singer et al. 2001). Home ranges have been reported to range from 6.1 km^2 to 54.7 km^2 (Singer et al. 2001). One desert bighorn sheep study in Arizona reports an average home range of 16.9 ± 3.38 km^2 for ewes, and home ranges for males that increased with age from 11.7 km^2 for a one year old to 37.3 km^2 for a 6 year old (Shackleton 1985). Bighorn sheep that live in higher elevations are known to migrate between an alpine summer range to a lower elevation winter range in response to seasonal vegetation availability and snow accumulation in the higher elevations (Shackleton 1985; NatureServe 2005). Maximum distances for these seasonal movements are about 48 km (Shackleton 1985). Desert bighorns on low desert ranges do not have separate seasonal ranges (Shackleton 1985). Bighorns live in groups, but for most of the year males over 3 years of age live separate from maternal groups consisting of females and young (Shackleton 1985).

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong topographic preferences, topographic position received an importance weight of 50%, while vegetation, elevation, and distance from roads received weights of 30%, 10%, and 10%, respectively. For specific costs of classes within each of these factors used for the modeling process, see Table 5. Because bighorn sheep actively select slopes greater than 40% for escape terrain, any pixel located further than 300 meters from a slope greater than 40% was reclassified to a suitability score between 5 and 10 (see Appendix A for explanation of modeling additional critical factors).

Patch size & configuration analysis – We defined minimum potential habitat patch size as 16.9 km^2 (Shackleton 1985) and minimum potential habitat core size as 84.5 km^2, 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 – Desert bighorn habitat occurs in isolated mountain ranges on the outskirts of the linkage planning area, separated by uninhabitable desert flats. Desert bighorn do not inhabit either the Cerbat or the Hualapai Mountains (AZGFD 2006). Because desert bighorn habitat is limited and discontinuous in the linkage area, and there is no evidence that bighorn occur in the designated wildland blocks, we did not create a biologically best corridor for this species. Instead, we used the habitat suitability model to assess potential habitat and evaluate patch configuration for this species within the union of biologically best corridors (Figure 49).

Results & Discussion

Union of biologically best corridors – Strand B of the UBBC serves bighorn sheep well. The foothills of the Cerbat and Hualapai mountain ranges, along with the rugged topography of Strand B, comprise potential sheep habitat and form part of a large potential habitat core (Figure 49 and Figure 50). Bighorn sheep make seasonal movements up to 48 km (Shackleton 1985), and disperse up to 70 km (Witham & Smith 1979), and therefore could move into the mountain ranges in the wildland blocks. However, we again emphasize that sheep do not occur here, the linkage design may be hypothetical for bighorn. Major highways are barriers to gene flow in bighorn sheep (Epps et al. 2005), so connectivity between these blocks depends on effective crossing structures and maintenance of existing habitat. We did not modify the UBBC for this species.

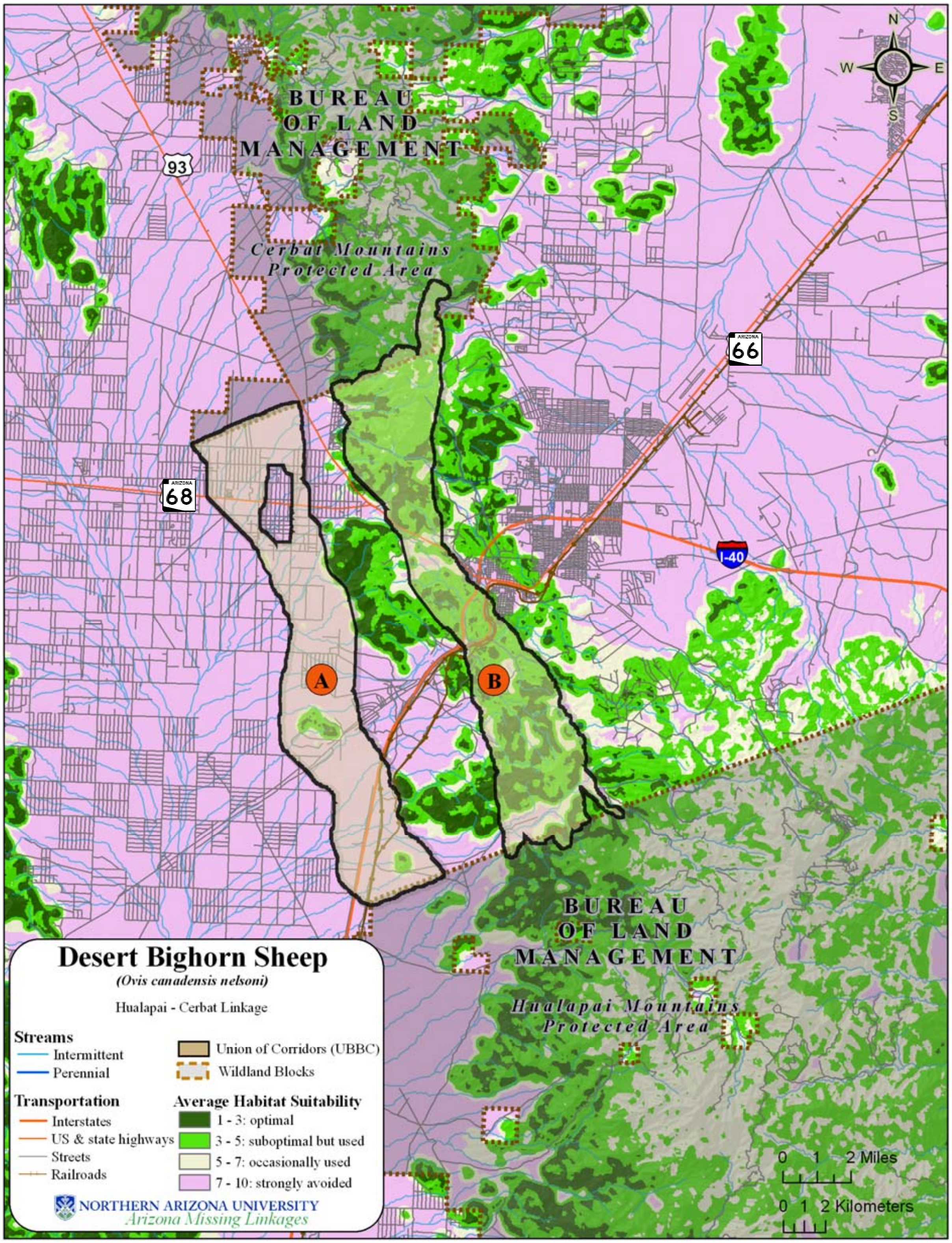


Figure 49: Modeled habitat suitability of desert bighorn sheep with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

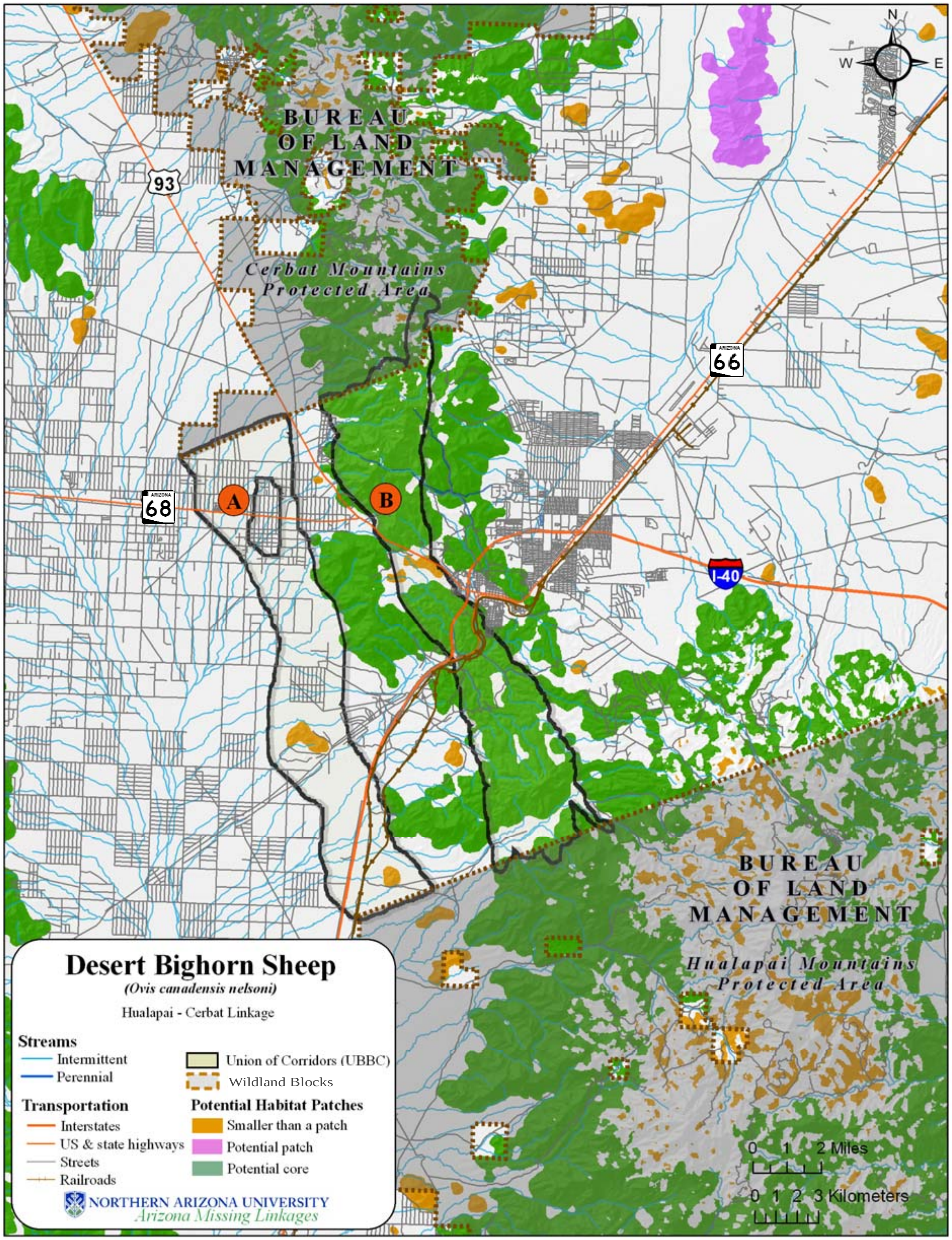


Figure 50: Potential habitat patches and cores for desert bighorn sheep with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

Elk (*Cervus elaphus*)

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

Distribution & Status
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). Populations were also established in the Hualapai Mountains south of Kingman and on the San Carlos Reservation near Cutter, Arizona. Both areas were believed to be previously uninhabited by elk (Severson and Medina 1983). Arizona elk populations have expanded to an estimated total of 35,000 animals (Arizona Department of Game and Fish 2006). Elk are most commonly found in woodlands and forests of northern Arizona extending from the Kaibab Plateau 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 currently occur within the Hualapai, Peacock, and Music mountains.

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 (Brown et al. 1980; Rowland et al. 2004) from roads.

Spatial Patterns
In Arizona, elk move annually between high elevation summer range (7000 to 10000 ft) and lower elevation winter range (5500 to 6500 ft) (Arizona Department of Fish and Game 2006). Elk may move as far as 100 km to lower elevations where there is less snow in the winter (Boyce 1991). Elk avoid human activity unless in an area secure from predation in which they are tolerant of human proximity (Morgantini and Hudson 1979, Lyon and Christensen 2002, Geist 2002).

Conceptual Basis for Model Development
Habitat suitability model –Vegetation received an importance weight of 75%, while distance from roads received a weight of 25%. For specific scores of classes within each of these factors, see Table 5.

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 4740 km^2 (Boyce 1991). In our analyses, minimum patch size for elk was defined as 60 km^2 and minimum core size as 300 km^2. 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 – Elk habitat occurs in isolated mountain ranges throughout the linkage planning area. A small population of elk inhabits the Hualapai Mountains. These mountains are a sky island surrounded by habitat that elk are likely to avoid. Elk do not inhabit the Cerbat Mountains (AZGFD 2006). Because elk habitat is limited and discontinuous in the linkage area, and elk do not occur in both wildland blocks, we did not create a biologically best corridor for this species. Instead, we used the habitat suitability model to assess potential habitat and evaluate patch configuration for this species within the union of biologically best corridors (Figure 51).

Results & Discussion
Union of biologically best corridors – The UBBC provides little suitable habitat for elk, since the majority of optimal habitat is concentrated within the Hualapai Mountain wildland block (Figure 51). Strand B of the linkage does capture some small patches of habitat at the foothills of the Hualapai Mountains, as well as a small potential patch along the southern end of the Cerbat Mountains (Figure 52). Since elk are known to occur only within the Hualapai Mountains and very little suitable habitat for elk exists within the Linkage Planning Area, we did not modify the UBBC for this species.

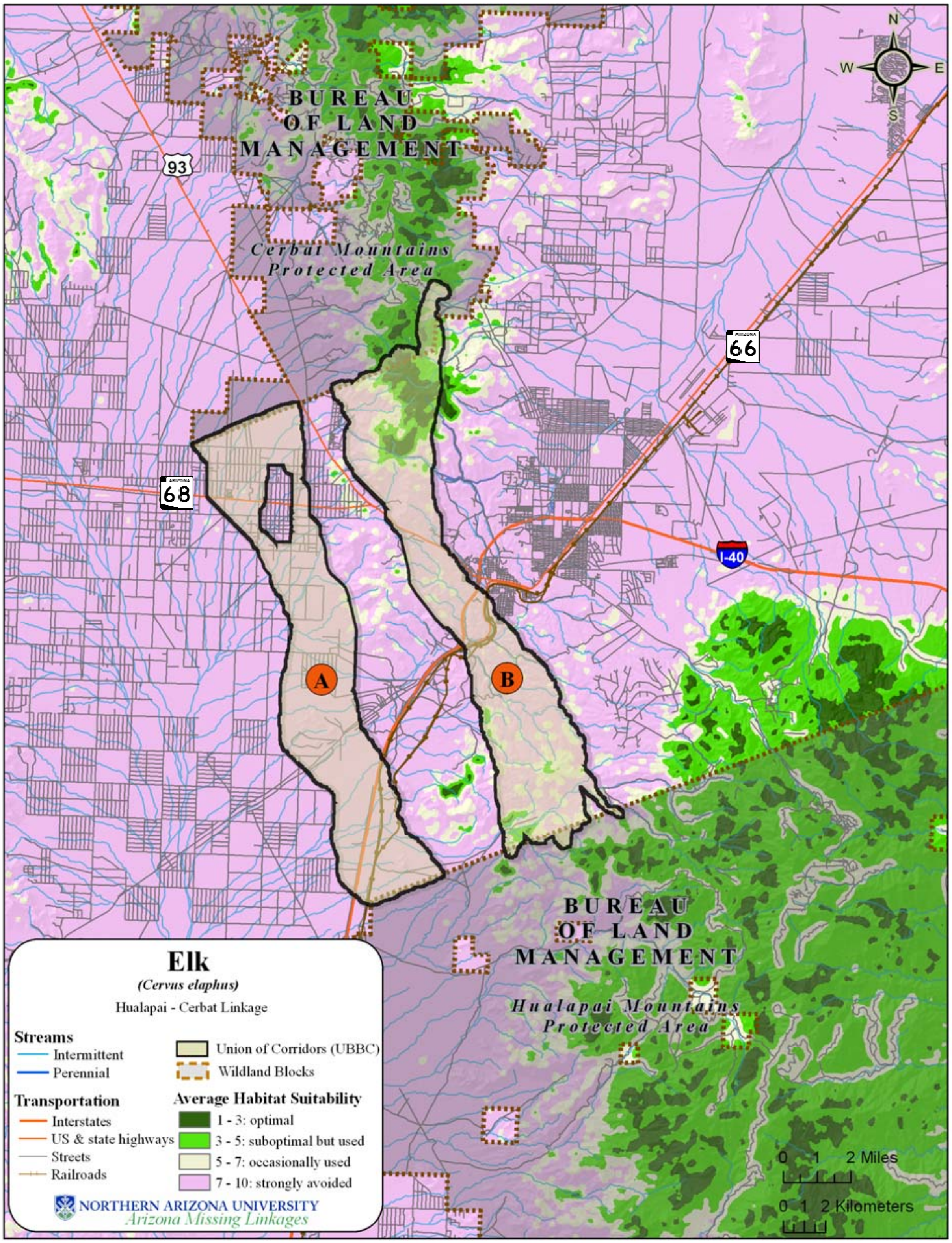


Figure 51: Modeled habitat suitability of elk with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

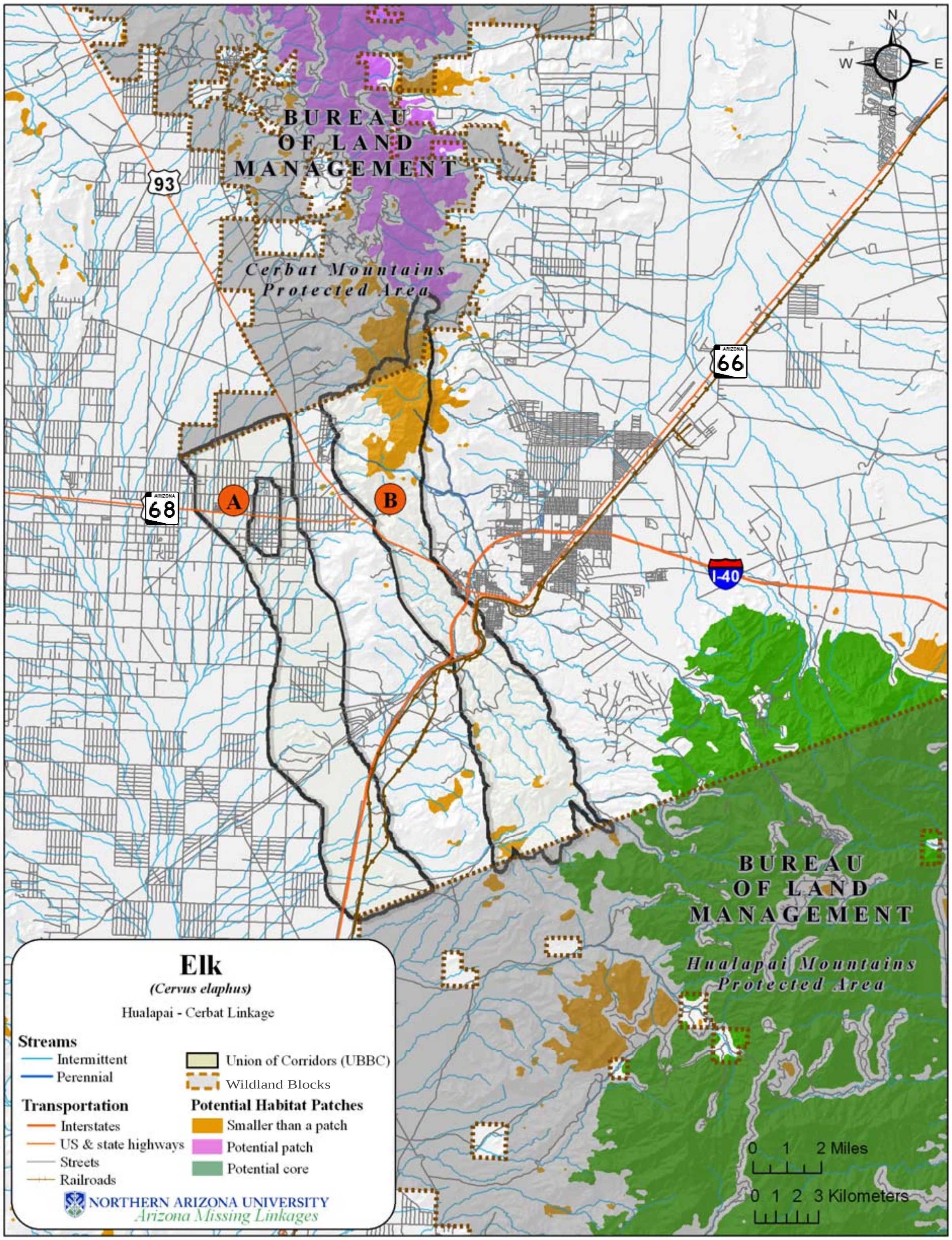


Figure 52: Potential habitat patches and cores for elk with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

Pronghorn (*Antilocapra americana*)

Justification for Selection

Pronghorn are susceptible to habitat degradation and human development (AZGFD 2002a). 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, except in the southeastern part of the state (Hoffmeister 1986). The Sonoran pronghorn subspecies is found in northwest Sonora, Mexico and southwestern Arizona including on the Cabeza Prieta National Wildlife Refuge, the Organ Pipe Cactus National Monument, the Barry M. Goldwater Gunnery Range (AZGFD 2002b). Within the linkage planning area, pronghorn occur in Truxton Flat, Badger Flat, and Airport Flat, between the Hualapai and Peacock-Cottonwood wildland blocks, and within Goodwin Mesa and Bozarth Mesa in the Aquarius wildland block (AZGFD 2006).

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 Fish and Game 2004). They inhabit shortgrass plains as well as riparian areas of sycamore and rabbitbrush, and oak savannas (New Mexico Department of Fish and Game 2004). In winter, pronghorn rely on browse, especially sagebrush (O'Gara 1978). Pronghorn prefer gentle terrain, and avoid rugged areas (Ockenfels et al. 1997). Woodland and coniferous forests are also generally avoided, especially when high tree density obstructs vision (Ockenfels et al. 2002). Also for visibility, pronghorn prefer slopes that are less than 30% (Yoakum et al. 1996). Sonoran pronghorn habitat is described as broad alluvial valleys separated by block-faulted mountains (AZGFD 2002b). Elevations for this subspecies vary from 400 to 1600 feet (AZGFD 2002b). Sonoran pronghorn are found in vegetation types that include creosote bush, bursage/palo verde-mixed cacti, and saguaro (deVos and Miller 2005).

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 (AZGFD 2002b). One study of collared Sonoran pronghorn found the home range of 4 males to range from 64 km^2 – 1214 km^2 (avg. 800 km^2), while females ranged from 41km^2 -1144 km^2 (avg. 465.7 km^2) (AZGFD 2002b). 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 – Vegetation received an importance weight of 45%, while topography and distance from roads received weights of 37% and 18%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum patch size for pronghorn was defined as 50 km^2 and minimum core size as 250 km^2. 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 – Pronghorn habitat occurs in small patches outside of the wildland blocks. Pronghorn do not inhabit either the Cerbat or Hualapai Mountains (AZGFD 2006). Because pronghorn habitat occurs mainly outside of the linkage area, and there is no evidence that they occur in the designated wildland blocks, we did not create a biologically best corridor for this species. Instead, we created a habitat suitability model and evaluated patch configuration for this species within the union of biologically best corridors (Figure 53).

Results & Discussion

Union of biologically best corridors – A fair amount of potential habitat between the Hualapai and Cerbat Mountain wildland blocks is encompassed by the union of biologically best corridors, particularly in the lowlands of Strand A. This strand is comprised mainly of suitable pronghorn habitat although the presence of road networks decreases the suitability scores in this area. While almost all of Strand A serves as part of a large potential habitat core, Strand B captures a few discontinuous, smaller patches of suitable habitat due to its more rugged topography (Figure 54). Because the UBBC seems to serve this species well, particularly in Strand A, we did not modify the UBBC for pronghorn. Connectivity for pronghorn movement is threatened in the linkage area by major roads including I-40, Route 66, Highway 93, urban barriers, right-of-way fencing, and habitat fragmentation.

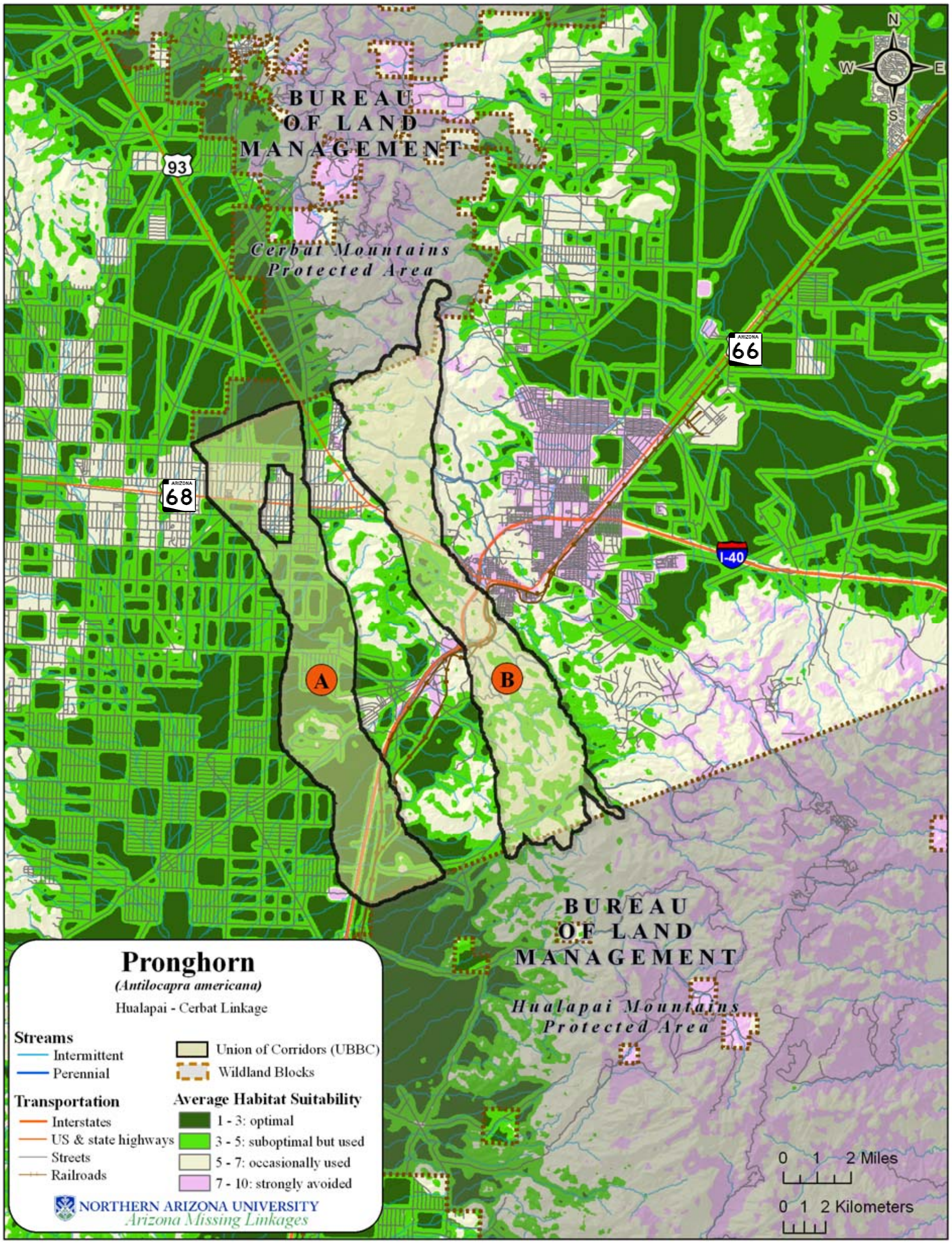


Figure 53: Modeled habitat suitability of pronghorn with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

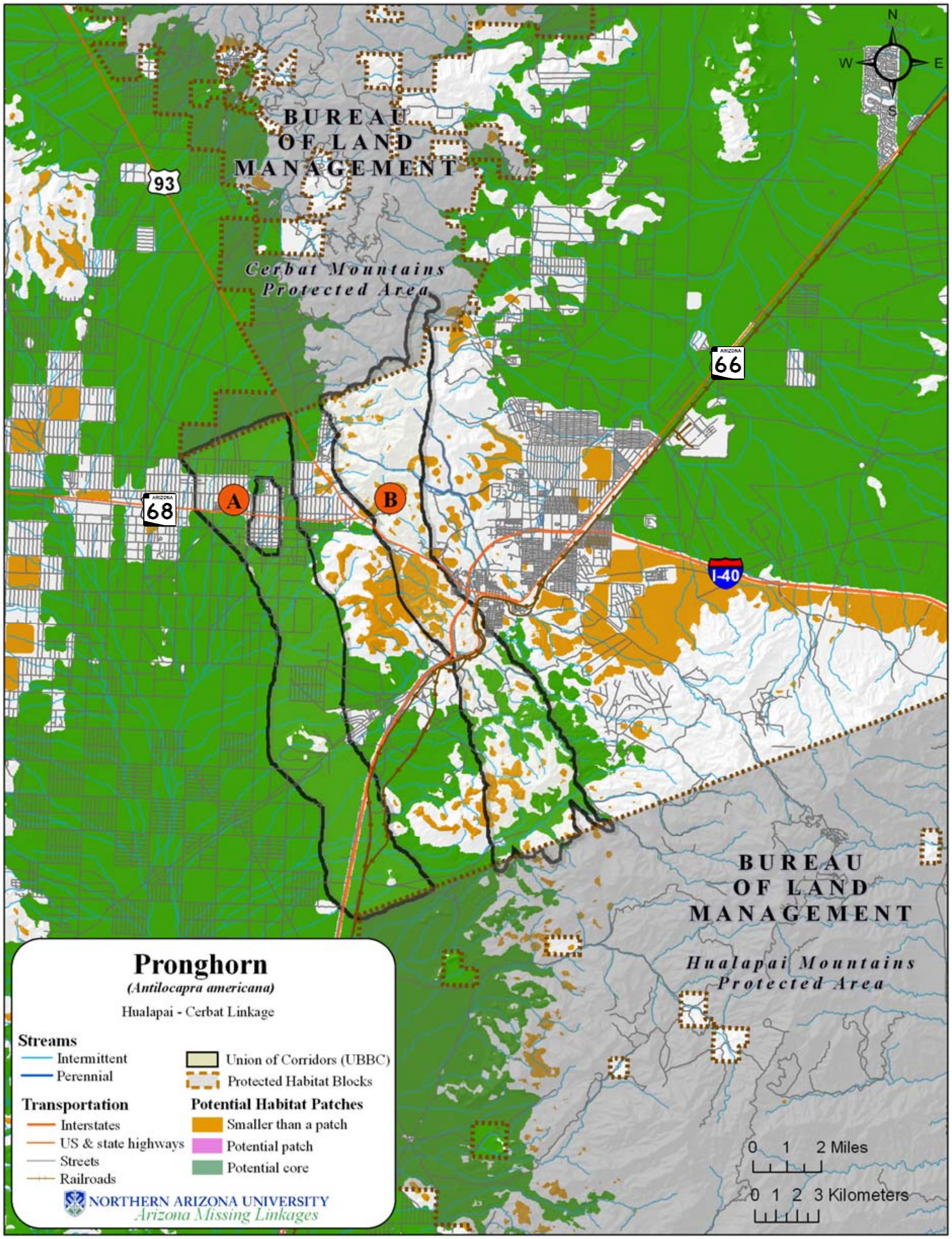


Figure 54: Potential habitat patches and cores for pronghorn with respect to the linkage design; for reasons described above, we did not estimate the biologically best corridor for this species.

Appendix C: Suggested Focal Species Not Modeled

In addition to the riparian and aquatic obligate species listed above, the habitat requirements and connectivity needs of several other suggested focal species were not modeled in this study. A list of these species follows:

Mammals

- Bats – 'Bats' were suggested as a focal taxon; however, their habitat preferences cannot be easily modeled using standard GIS layers, and they are highly mobile.
- Black-footed Ferret (*Mustela nigripes*) – Black-footed ferrets, one of the most endangered mammals in North America, were suggested as a focal species. However, the only population of this species reintroduced to Arizona occurs in Aubrey Valley, significantly east of the linkage planning area.
- Hualapai Mexican Vole (*Microtus mexicanus hualpaiensis*) – The Hualapai Mexican Vole is federally listed as endangered without critical habitat. They are mostly associated with moist grass and forb habitats within Ponderosa Pine dominated forest, and are currently only found along permanent and semipermanent waters (AZGFD 2003). They are mostly only found in the Hualapai Mountains, though a small population may occur in the Music Mountains. This species was not modeled due to the inability to adequately capture their habitat preferences using available GIS data.

Herpetofauna

- Arizona Black Rattlesnake (*Crotalus viridis cerberus*) – Arizona black rattlesnakes are found at high elevations in moist, dense vegetation in Arizona. Insufficient data is available to adequately parameterize a GIS-based habitat model for this species.
- Black-necked gartersnake (*Thamnophis cyrtopsis*) – The black-necked gartersnake occurs throughout Arizona, where there are usually associated with water (NMDGF 2005). There are no riparian systems in the linkage planning area.
- Chuckwalla (*Sauromalus ater*) – Chuckwallas prefer large rock outcrops and crevices within desert scrub vegetation associations (NMDGF 2005). The ReGAP land cover layer does not capture small rocky outcrops which are likely to be habitat for this species (most suitable rocks are smaller than one 30 x 30 m pixel); consequently, the habitat requirements of this species could not be adequately represented by our habitat suitability modeling process.
- Desert Tortoise (*Gopherus agassizii*) – There are two distinct populations of desert tortoise in Arizona: the Sonoran and the Mohave population. There are no Mohave desert tortoises in this zone, and while there may be Sonoran desert tortoise in the southern blocks, they would not and cannot occur in the northern wildland blocks (Rebecca Peck, BLM, personal comm.).
- Lowland Leopard Frog (*Rana yavapaiensis*) – Lowland leopard frog is considered a Species of Concern by the U.S. Fish and Wildlife Service, is USFS Sensitive, and a Wildlife Species of Special Concern in Arizona. There are no riparian systems in the linkage planning area.
- Northern Leopard Frog (*Rana pipiens*) – There are no riparian systems in the linkage planning area.

Birds

Most bird species are not good candidates for connectivity studies, because "either the species are resident and stay in the forested mountains or would simply fly over the inhospitable barriers" (Troy Corman, AZGFD, personal comm.). For this reason, we did not model habitat suitability or perform corridor analyses for birds.

- Black-throated sparrow (*Amphispiza bilineata*) – Black throated sparrows occur in a range of desert habitat dominated by shrubs, including paloverde and creosotebush vegetation associations

(NMDGF 2005). They are also highly mobile. We reasoned they would be well-covered by the remaining suite of focal species.

- Western Burrowing Owl (*Athene cunicularia hypugaea*) – Western burrowing owls are designated a sensitive species by the BLM. They prefer open, well-drained grasslands, steppes, deserts, and prairies (AZGFD 2001). We reasoned they would be well-covered by the remaining suite of focal species.
- Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) – The yellow-billed cuckoo is listed as a candidate for endangered species by the USFWS and is a Wildlife Species of Special Concern in Arizona. This species is associated with riparian areas (AZGFD 2005), which do not occur within the linkage planning area.
- Zone–tailed Hawk (*Buteo albonotatus)* – These hawks occur in a variety of habitat types. They are also highly mobile. We reasoned they would be well-covered by the remaining suite of focal species.
- Gambel's Quail (*Callipepla gambelii*) – Gambel's quail prefer xeric habitats dominated by shrubs (NMGFD 2006). We reasoned they would be well-covered by the remaining suite of focal species.

Fish

- Desert Sucker (*Catostomus clarki*) – There are no riparian systems in the Linkage Planning Areawhere desert suckers may occur.
- Longfin dace (*Agosia chrysogaster*) – Longfin dace is listed as BLM Sensitive, threatened in Mexico, and considered a Species of Concern by the U.S. Fish and Wildlife Service. (AZGFD 2002). There are no riparian systems in the Linkage Planning Areawhere they may occur.

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we first selected focal species. For each species, created habitat suitability models and identified the biologically best corridor (BBC) for each species. We combined biologically best corridors for all focal species modeled to form a union of biologically best corridors (UBBC), and made several minor edits to the UBBC to ensure that it preserves connectivity (Figure 55):

- We filled-in holes that were created as an artifact of the modeling process if they were composed of natural vegetation and not high-density developed land.
- We widened small sections of both strands to increase high-quality habitat. The central portion of both strands was expanded toward the outlying BLM parcel in the southernmost Cerbat Mountains, because this undeveloped, federally-owned parcel presents a good opportunity to conserve existing wildlife habitat.

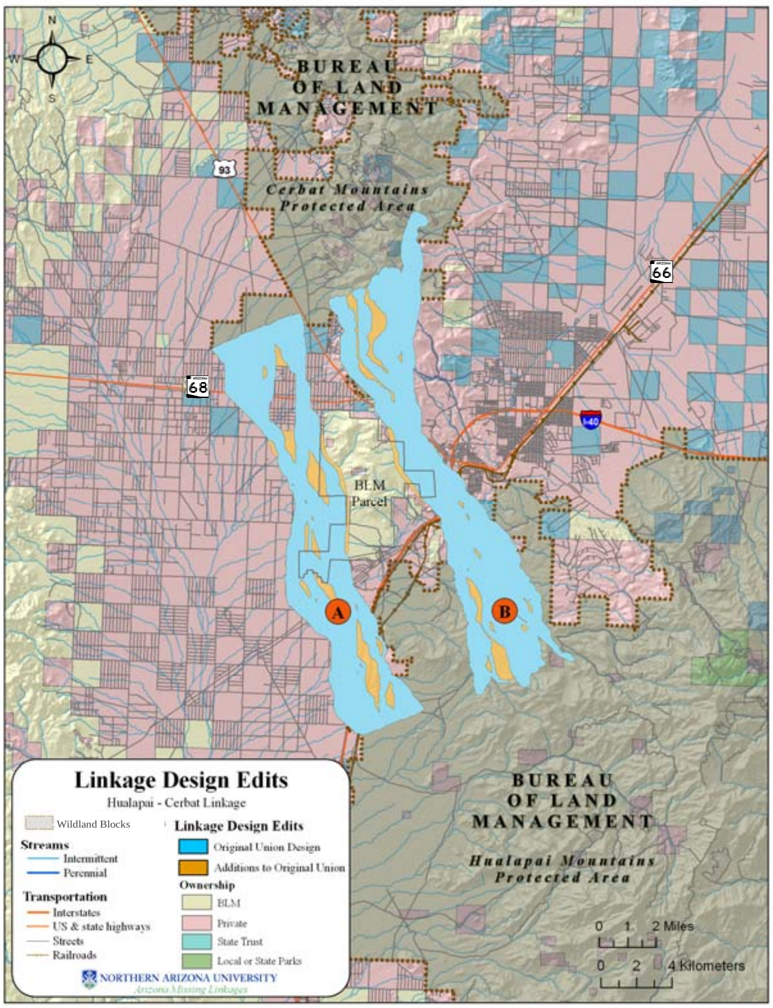


Figure 55: Edits made to union of biologically best corridors to create the final Linkage Design.

Appendix E: 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 the linkage area, taken largely from the document, Landcover Descriptions for the Southwest Regional GAP Analysis Project (Available from http://earth.gis.usu.edu/swgap)

EVERGREEN FOREST (2 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.

> 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 New Mexico mountains. 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.

GRASSLANDS-HERBACEOUS (2 CLASSES) – Areas dominated by grammanoid 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.
>
> 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 a 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.

Mesquite Upland Scrub – 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.

Paloverde-Mixed Cacti Desert Scrub - This ecological system occurs on hillsides, mesas and upper bajadas in southern Arizona. The vegetation is characterized by a diagnostic sparse, emergent tree layer of *Carnegia gigantea* (3-16 m tall) and/or a sparse to moderately dense canopy codominated by xeromorphic deciduous and evergreen tall shrubs *Parkinsonia microphylla* and *Larrea tridentata* with *Prosopis* sp., *Olneya tesota*, and *Fouquieria splendens* less prominent. The sparse herbaceous layer is composed of perennial grasses and forbs with annuals seasonally present and occasionally abundant. On slopes, plants are often distributed in patches around rock outcrops where suitable habitat is present.

WOODY WETLAND (2 CLASSES) – 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.

Riparian Mesquite Bosque – This ecological system consists of low-elevation (<1100 m) riparian corridors along intermittent streams in valleys of southern Arizona and New Mexico, and adjacent Mexico. Dominant trees include *Prosopis glandulosa* and *Prosopis velutina*. Shrub dominants include *Baccharis salicifolia, Pluchea sericea*, and *Salix exigua*.

Riparian Woodland and Shrubland – 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 (2 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.

Barren Lands, Non-specific – 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.

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.

ALTERED OR DISTURBED (1 CLASS) –

Recently Mined or Quarried – 2 hectare or greater, open pit mining or quarries visible on imagery.

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

Developed, Medium - High Intensity – *Developed, Medium Intensity*: Includes areas with a mixture of constructed materials and vegetation. Impervious surface accoutns 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 sesttings 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 F: Literature Cited

Adams, H.B., and L. Adams. 1959. Black-tailed jackrabbit carcasses on the highways in Nevada, Idaho, and California. Ecology 40: 718-720.

Anderson, A.E., and O.C. Wallmo. 1984. Mammalian Species 219: 1-9. Mule deer.

Apps, C.D., N.J. Newhouse, and T.A. Kinley. 2002. Habitat associations of American badgers in southeastern British Columbia. Canadian Journal of Zoology 80: 1228-1239.

Arizona Widllife Linkage Workgroup. 2006. Arizona Wildlife Linkage Assessment. Arizona Department of Transportation, Phoenix.

Arjo, W.M., T.J. Bennett, and A.J. Kozlowski. 2003. Characteristics of current and historical kit fox (Vulpes macrotis) dens in the Great Basin Desert. Canadian Journal of Zoology 81: 96-102.

Arizona Game and Fish Department. http://www.gf.state.az.us/h_f/game_elk.shtml, 2006.

Arizona Game and Fish Department. 2001. *Athene cunicularia hypugaea.* Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 6 pp.

Arizona Game and Fish Department. 2002. *Heloderma suspectum cinctum.* Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 5 pp.

Arizona Game and Fish Departmenet. 2003. Microtus mexicanus hualpaiensis. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 7 pp.

Barnes, T. and Adams, L. 1999. A Guide to Urban Habitat Conservation Planning. University of Kentucky Cooperative Extension Service.

Barnum, S.A. 2003. Identifying the best locations along highways to provide safe crossing opportunities for wildlife: a handbook for highway planners and designers. Colorado Department of Transportation.

Beck, D.E. 2005. Biology of Gila Monsters and Beaded Lizards. University of California Press, Berkeley.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology 7: 94-108.

Beier, P. 2006. Effects of artificial night lighting on terrestrial mammals. Pp 19-42 In C. Rich and T. Longcore, editors, Ecological consequences of artificial night lighting. Island Press, Covelo, California.

Beier, P., and S. Loe. 1992. A checklist for evaluating impacts to wildlife corridors. Wildlife Society Bulletin 20: 434-40.

Best, T. 1996. Lepus californicus. Mammalian Species 530: 1-10.

Blair, R.B. 1996. Land use and avian species diversity along an urban gradient. Ecological Applications 6:506-519.

Blair, R.B. 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity? Ecological Applications 9:164-170.

Blair, R.B., and A.E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. Biological Conservation 80:113-125.

Boyce, M.S. 1991. Migratory behavior and management of elk (Cervus elaphus). Applied Animal Beahviour Science 29: 239-250.

Britt, T.L. and D.P. Theobald, eds. 1982. Provincial, reservation and state status reports. Proceedings of the Western States Elk Workshop. Western Association of Fish and Wildlife Agencies. Phoenix, AZ. 166 p.

Brooks, M.L., and B. Lair. 2005. Ecological effects of vehicular routes in a desert ecosystem. Report prepared for the United States Geological Survey, Recoverability and Vulnerability of Desert Ecosystems Program.

Brown, C.F., and P.R. Krausman. 2003. Habitat characteristics of three leporid species in southeastern Arizona. Journal of Wildlife Management 67: 83-89.

Brown, G., et al. 1980 Elk habitat: timber management relations. Central Zone, Northern Region. USDA Forest Service, Montana Dept. of Fish, Wildlife & Parks, Confederated Salish and Kootenai Tribes.

Brudin III, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. ICOET 2003.

Bunnell, F.L., and D.E.N. Tait. 1981. Population dynamics of bears-implications. Pages 75 - 98 in C. W. Fowler and T. D Smith, Eds. Dynamics of Large Mammal Populations. John Wiley and Sons, New York, New York. USA.

Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114: 189-197.

Clevenger, A.P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121: 453-464.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting

passage by mammals. Journal of Applied Ecology 38: 1340-1349.
Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109: 15-26.
Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503-514.
Conservation Biology Institute. 2005. Analysis of General Plan-2020 San Diego County. Encinitas, Ca. 27pp.
Courchamp, F., G. Sugihara. 1999 .Biological control of introduced predator populations to protect native island species from extinction. Ecological Applications, 9(10), pp.112-123
Crooks K.R., M.E. Soule. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature. 400:563–566 p.
Cunningham, S.C., and W. Ballard. 2004. Effects of wildfire on black bear demographics in cetral Arizona. Wildlife Society Bulletin 32: 928-937.
Currier, M.P. 1983. Felis Concolor. Mammalian Species 200: 1-7.
Degenhardt, W.G., C.W. Painter, and A.H. Price. 1996. Amphibians and Reptiles of New Mexico. UNM Press, Albuquerque, NM. 431 pp.
Dickson, B.G., and P. Beier. 2002. Home range and habitat selection by adult cougars in southern California. Journal of Wildlife Management 66:1235-1245.
Dodd, C.K, W.J. Barichivich, and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.
Donnelly, R., and J.M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. Conservation Biology 18:733-745.
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Washington D.C. Available from www.elistore.org
Evink, G.L. 2002. Interaction between roadways and wildlife ecology. National Academy Press, Washington, D.C.
Findley, C.S., J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation biology 11:1000-1009.
Forman, R.T.T., et al. 2003. Road ecology: science and solutions. Island Press: Washington, D.C.
Friesen, L.E., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.Geist, V. 2002. Adaptive behavioral strategies, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 389-433.
Germaine, S.S., and B.F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229-237.
Germaine, S.S., S.S. Rosenstock, R.E. Schweinsburg, and W.S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson, Arizona. Ecological Applications 8:680-691.
Goodrich, J.M., and S.W. Buskirk. 1998. Spacing and ecology of North American badgers (*Taxidea taxus*) in a prairie-dog (Cynomys leucurus) complex. Journal of Mammalogy 78: 171-179.
Hetherington, T. 2005. Role of the opercularis muscle in seismic sensitivity in the bullfron Rana catesbeiana. Journal of Experimental Zoology 235(1):27-34.
Hoffmeister, D.F. 1986. Mammals of Arizona. The University of Arizona Press and The Arizona Game and Fish Department. 602 pp.
Knickerbocker, T, J. Waithaka. 2005. People and elephants in the Shimba Hills, Kenya. Pp224-238 R. Woodroff, S. Thirgood and A. Rabinowitz, editors. People and Wildlife: Conflict or Coexistence? Cambidge University Press, Cambridge, UK
Krueper, D. J. 1993. Conservation priorities in naturally fragmented and human-altered riparian habitats of the arid West. USDA Forest Service. General Technical Report RM-43. Available online: www.birds.cornell.edu/pifcapemay/krueper.htm.
Lambeck, R. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.
Larivière, S. 2001. Ursus americanus. Mammalian Species 647: 1-11.
LeCount, A.L. 1982. Characteristics of a central Arizona black bear population. Journal of Wildlife Management 46:861-868.
LeCount A.L., R.H. Smith, and J.R. Wegge. 1984. Black Bear habitat requirements in central Arizona. Federal Aid Final Report. Arizona Game and Fish Department. Phoenix. USA.
Levey, D., B.M. Bolker, J.T. Tewksbury, S. Sargent, and N. Haddad. 2005. Effects of Landscape Corridors on Seed Dispersal by Birds. Science 309: 146-148.

Liddle, M. 1997. Recreation ecology: The ecological impact of outdoor recreation and ecotourism. 639 pp. Chapman and Hall: New York.
Little, S.J. 2003. The influence of predator-prey relationships on wildlife passage evaluation. ICOET 2003.
Logan, K.A., and L.L. Sweanor. 2001. Desert Puma: Evolutionary Ecology and Conservation of an Enduring Carnivore. Island Press, Washington D.C. 463 pp.
Long, C.A. 1973. Taxidea taxus. Mammalian Species 26: 1-4.
Long, C.A., and C.A. Killingley. 1983. The badgers of the world. Charles C. Thomas Publishing, Springfield, IL.
Lowe, C.H. 1978. The Vertebrates of Arizona. The University of Arizona Press. Tuscon, Arizona. 270pp.
Lyon, L.J. 1979. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry 77: 658-660.
Lyon, L.J. and A.G. Christianson. 2002. Elk and land management, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 557-581.
Main, M. B., F. M. Roka, and R. F. Noss. 1999. Evaluating costs of conservation. Conservation Biology 13:1262-1272.
Malo, J.E., F. Suarez, and A. Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models. Journal of Applied Ecology 41: 701-710.
Marshall, R.M., S. Anderson, M. Batcher, P. Comer, S. Cornelius, R. Cox, A. Gondor, D. Gori, J. Humke, R. Paredes Aguilar, I.E. Parra, and S. Schwartz. 2000. *An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion.* Prepared by The Nature Conservancy Arizona Chapter, Sonoran Institute, and Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora with support from Department of Defense Legacy Program, Agency and Institutional partners. 146 pp.
Mata, C., I. Hervas, J. Herranz, F. Suarez, and J.E. Malo. 2005. Complementary use by vertebrates of crossing structures along a fences Spanish motorway. Biological Conservation 124: 397-405.
May, S. A., T. W. Norton. 1996. Influence of fragmentation and disturbance on the potential impact of feral predators on native fauna in Australian forest ecosystems. Wildlife Research 15:387–400.
McDonald, W., and C.C. St Clair. 2004. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41: 82-93.
McGrew, J.C. 1979. Vulpes macrotis. Mammalian Species 123: 1-6.
Messick, J.P., and M.G. Hornocker. 1981. Ecology of the badger in southwestern Idaho. Wildlife Monographs 76.
Minton, Jr. S.A. 1968. The fate of amphibians and reptiles in a suburban area. Journal of Herpetology 2:113-116.
Morgantini, L.E., and R.J. Hudson. 1979. Human disturbance and habitat selection in elk in Boyce, M.S. and L.D. Hayden-Wing, eds. North American Elk: Ecology, Behavior and Mgt. University of Wyoming. pp 132-139.
Naiman, R. J., H. Decamps and M. Pollock. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.
NatureServe. 2005. NatureServe Explorer: An online encyclopedia of life [web application]. Version 4.6. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: November 29, 2005).
New Mexico Department of Game & Fish. 2002. Biota Information System of New Mexico. New Mexico Department of Game & Fish electronic database, BISON, Version 1/2004, Santa Fe, New Mexico. http://nmnhp.unm.edu/bisonm/bisonquery.php. Accessed 9 September 2005.
Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115: 499-507.
Ockenfels, R.A., and G.I. Day. 1990. Determinants of collared peccary home-range size in central Arizona. In Managing wildlife in the southwest (Krausman, P.R. and N.S. Smith, eds), Arizona chapter of the Wildlife Society, Phoenix, Arizona. Pps 76-81.
Odell, E.A., and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.
O'Gara, B.W., and R.G. Dundes 2002. Distribution: past and present, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 67-119.
Olsen, D.M., and E. Dinnerstein. 1998. The Global 200: A Representation approach to Conserving the Earth's Most Biologically Valuable Ecoregions. Conservation Biology 12:502-515.
Oregon Department of Forestry. 2006. The Oregon Forestland-Urban Interface Fire Protection Act; Property Evaluation and Self-Certification Guide. 32pp. Oregon Department of Forestry, Salem, OR.
Peris, S., and J. Morales. 2004. Use of passages across a canal by wild mammals and related mortality. European Journal of Wildlife Research. 50: 67-72.
Perry, G., R.N. Fisher. 2006. Night Lights and Reptiles: Observed and Potential Effects. Pp 169-191 In C. Rich and T. Longcore, editors, Ecological consequences of artificial night lighting. Island Press, Covelo, California.

Reed, D. H., and R. Frankham. 2003. Correlation between fitness and genetic diversity. Conservation Biology 17:230-237.

Rhodes Homes Arizona. 2005. Peacock Highlands Area Plan, prepared for Mohave County, Arizona.

Rosen, P.C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation 68: 143-148.

Rottenborn, S.C. 1999. Predicting impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.

Rowland, M.M., M.J. Wisdom, B.K. Johnson, and M.A. Penninger. 2004. Effects of roads on elk: implications for management in forested ecosystems. Transactions of the North American Wildlife and Natural Resource Conference 69.

Ruediger, B. 2001. High, wide, and handsome: designing more effective wildlife and fish crossings for roads and highways. ICOET 2001.

Sauvajot et al. (2006) reported that two mountain lions in southern California died from anticoagulant poisoning apparently acquired by preying on coyotes that had eaten poisoned rodents.

Scarbrough, D.L., and P.R. Krausman. 1988. Sexual selection by desert mule deer. Southwestern Naturalist 33: 157-165.

Schwartz, C.C. and A.W. Franzmann. 1992. Dispersal and survival of subadult black bears from the Kenai Peninsula, Alaska. Journal of Wildlife Management 56: 426-431.

Severson, K.E., and A.L. Medina. 1983. Deer and elk habitat management in the Southwest. Journal of Range Management Monograph No. 2. Society for Range Management, Denver, CO. 64 p.

Singer, F.J. 1978. Behavior of mountain goats in relation to US Highway 2, Glacier Park, Montana. Journal of Wildlife Management 42:591-597.

Smith, W.P. 1991. Odocoileus virginianus. Mammalian Species 388: 1-13.

Sowls, L. K. 1997. Javelinas and other peccaries: their biology, management, and use. Second edition. Texas A & M University, College Station, Texas, USA.

Stralberg, D., and B. Williams. 2002. Effects of residential development and landscape composition on the breeding birds of Placer County's foothill oak woodlands. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

Sullivan T.L., and T.A. Messmer. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. Wildlife Society Bulletin 31:163-173.

Thomas, J.W., D.A. Leckenby, H. Henjum, R.J. Pedersen, and L.D. Bryant. 1988. Habitat-effectiveness index for elk on Blue Mountain winter ranges. USDA Forest Service Pacific Northwest Research Station, General Technical Report PNW-GTR-218. 28 p.

Ticer, C.L., R.A. Ockenfels, J.C. DeVos Jr., and T.E. Morrell. 1998. Habitat use and activity patterns of urban-dwelling javelina. Urban Ecosystems 2:141-151.

Ticer, C.L., T.E. Morrell, and J.C. DeVos Jr. 2001. Diurnal bed-site selection of urban-dwelling javelina in Prescott, Arizona. Journal of Wildlife Management 65:136-140.

Turner et al. 1995. Preserve Design for maintaining biodiversity in the Sky Island region. *In*: De Bano, Leonard F., Peter F. Ffolliott, Alfredo Ortega-Rubio, Gerald J. Gottfried, Robert H. Hamre, and Carleton B. Edminster (tech. cords.). 1995. Biodiversity and Management of the Madrean Archipelago: the sky islands of southwestern United States and northwestern Mexico. Gen. Tech. Report RM-GTR-264. Ft. Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountatin Forest and Range Experiment Station. pp. 524-530.

U.S. Fish and Wildlife Service. 1981. Standards for the development of Suitability Index Models. Division of Ecological Services. Government Printing Office, Washington D.C., USA.

Van der Zee, F.F., J. Wiertz, C.J.F. Ter Braak, and R.C. van Apeldoorn. 1992. Landscape change as a possible cause of the badger (Meles meles) decline in the Netherlands. Biological Conservation 61:17-22

Van Wieren, S.E., and P.B. Worm. 2001. The use of a motorway wildlife overpass by large mammals. Netherlands Journal of Zoology 51: 97-105.

Viegas, D.X., B. Allgöwer, N. Koutsias, G. Eftichidis. 2003. Fire Spread and the Wildland Urban Interface Problem. Ch. 12 In Proceedings of the International Scientific Workshop on "Forest Fires in the Wildland-Urban Interface and Rural Areas in Europe: an integral planning and management challenge."

Vohies, C.T., and W.P. Taylor. 1933. The life histories and ecology of jack rabbits, Lepus alleni and Lepus californicus spp., in relation to grazing in Arizona. University of Arizona College Agricultural Technical Bulletin 49: 471-587.

Vos, C.C., J. Verboom, P.F.M. Opdam, and C.J.F. Ter Braak. 2001. Toward ecologically scaled landscape indices. The American Naturalist 183: 24-41.

Wallmo, O.C. 1981. Mule and Black-tailed deer of North America. University of Nebraska Press. Lincoln and London. 605 pp.
Ward, A.L., N.E. Fornwalt, S.E. Henry, and R.A. Hodorff. 1980. Effects of highway operation practices and facilities on elk, mule deer, and pronghorn antelope. Rocky Mountain forest and Range Experiment Station, Ft., Collins, CO Report FHWA-RD-79-143.//Lyons, L.J. 1979, Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry October 1979: 658-660.
Webb, R.H. and H.G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. New York : Springer-Verlag.
Wenger, S.J., and L. Fowler. 2000. Protecting stream and river corridors. Policy Notes, Public Policy Research Series vol 1, no. 1. Carl Vinson Institute of Government, University of Georgia, Athens, GA. Available online: http://www.cviog.uga.edu/publications/pprs/96.pdf.
Wilcove, D.S., J. Lee. 2004. Using economic and regulatory incentives to restore endangered species: Lessons learned from three new programs. Conservation Biology 18: 639-645
Woodroffe, R., L.G. Frank. 2005. Lethal control of African lions (Panthera leo): local and regional population impacts. Animal Conservation 8:91-98.
Yanes, M., J.M. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71: 217-222.
Zoellick, B.W., and N.S. Smith. 1992. Size and spatial organization of home ranges of kit foxes in Arizona. Journal of Mammalogy 73: 83-88.

Appendix G: Database of Field Investigations

Attached is a database of field notes, GPS coordinates, and photos collected as part of our field investigations of this linkage area. The database is found as an MS Access database on the CD-ROM accompanying this report. This database is also an ArcGIS 9.1 Geodatabase which contains all Waypoints within it as a feature class. Additionally, all Waypoints can be found as a shapefile in the /gis directory, and all photographs within the database are available in high resolution in the /FieldDatabase/high-res_photos/ directory.

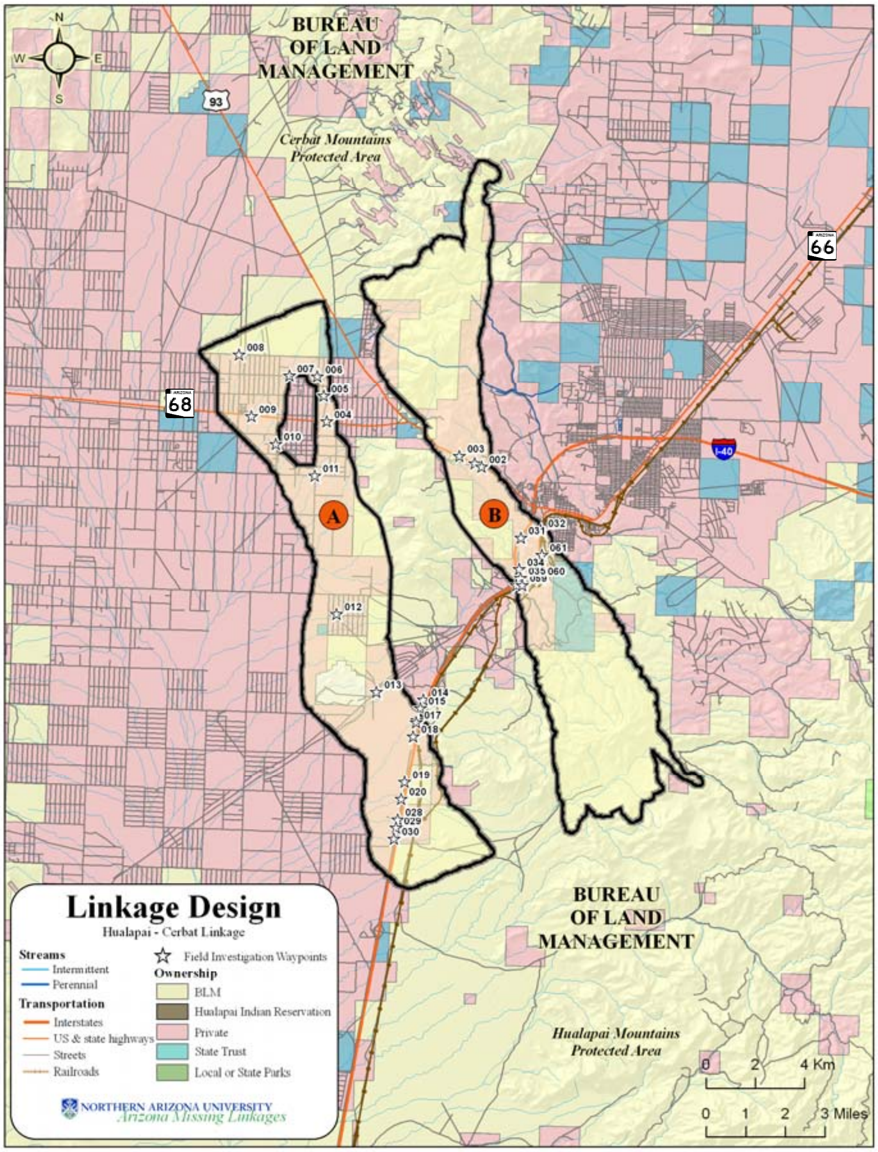
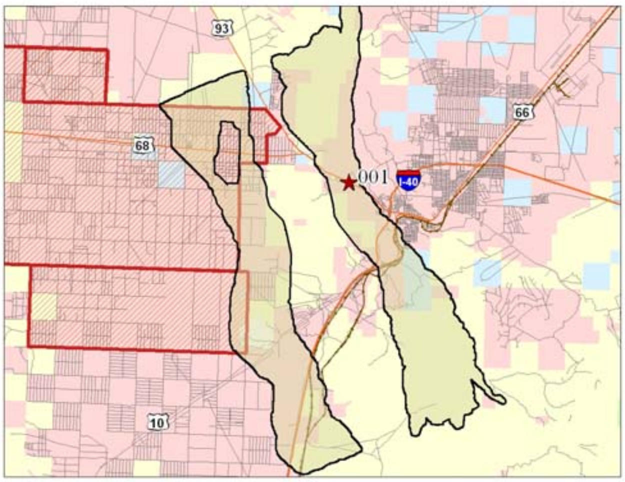


Figure 56: Field Investigation Waypoints within the Linkage Design.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	001		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.20603373	**Longitude:**	-114.094024
Observers:	Emily Garding, Paul Beier	**UTM X:**	218328.4592	**UTM Y:**	3900278.894
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

An existing bridge under US- 93, inside Strand B of the Linkage Design. Note that there is a concrete "jersey" barrier serving as a traffic divider between opposing lanes of traffic on US-93. This barrier could further hinder wildlife movement in this area.

Site Photographs

Name: DCP_5213.jpg

Azimuth: 120 **Zoom:** 3X

Notes: US-93. The nothern entrance of the underpass is located to the left of the billboard.

Name: DCP_5214.jpg

Azimuth: 120 **Zoom:** 1X

Notes: US-93.

Name: DCP_5215.jpg

Azimuth: 285 **Zoom:** 1X

Notes: US-93.

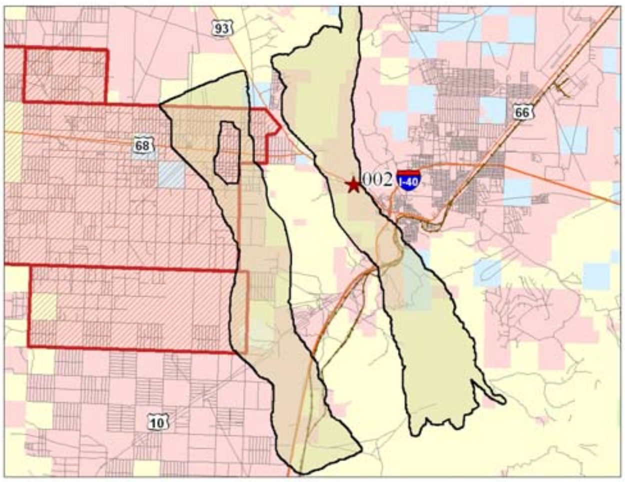
Name: DCP_5216.jpg

Azimuth: 230 **Zoom:** 1X

Notes: Along Strand B of the Linkage Area.

Linkage #:	20	**Waypoint #:**	002		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.20494743	**Longitude:**	-114.091043
Observers:	Emily Garding, Paul Beier	**UTM X:**	218596.1797	**UTM Y:**	3900149.909
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

A closeup of the bridge under US-93, placed approximately 20 feet above the steepsided wash. Note there is no upland habitat in this drainage.

Site Photographs

Name: DCP_5217.jpg

Zoom: 1X

Notes: Under the bridge.

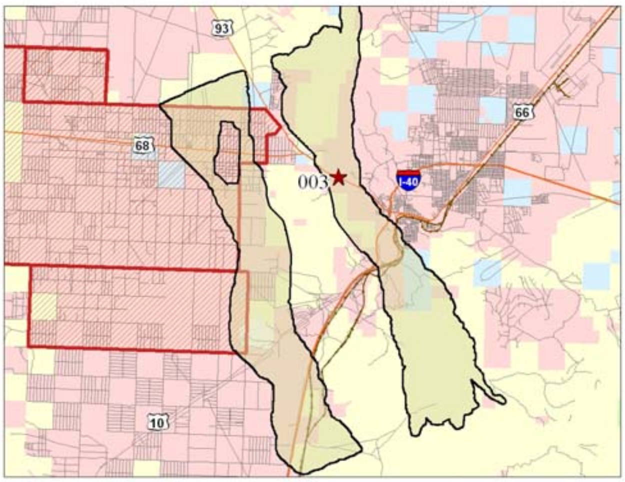
Name: DCP_5218.jpg

Zoom: 1X

Notes: Under the bridge.

Linkage #:	20	**Waypoint #:**	003		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.20855509	**Longitude:**	-114.101062
Observers:	Emily Garding, Paul Beier	**UTM X:**	217696.225	**UTM Y:**	3900578.649
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Existing culvert under US-93 in Strand B of the Linkage Design.

Site Photographs

Name: DCP_5219.jpg

Zoom: 1X

Notes: 3x3' box culverts under US-93.

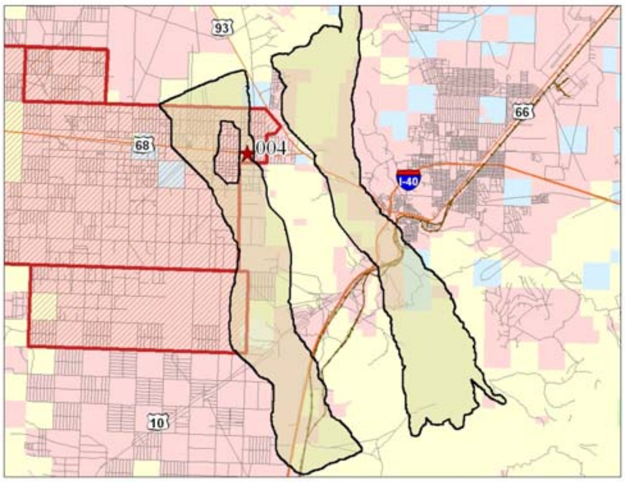
Name: DCP_5220.jpg

Zoom: 1X

Notes: These culverts are not straight, resulting in a completely dark tunnel.

Linkage #:	20	**Waypoint #:**	004		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.21966597	**Longitude:**	-114.160814
Observers:	Emily Garding, Paul Beier	**UTM X:**	212294.1425	**UTM Y:**	3901983.087
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Strand A of the Linkage Area, in the Golden Valley Planning Area.

Site Photographs

Name: DCP_5221.jpg

Zoom: 1X

Notes: Five 8 x 3 foot box culverts under SR-68.

Name: DCP_5222.jpg

Azimuth: 330 **Zoom:** 3X

Notes: Upstream in Linkage Area.

Name: DCP_5223.jpg

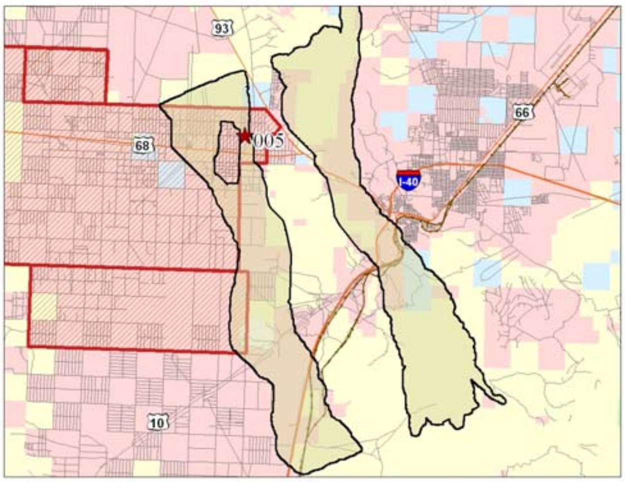
Azimuth: 190 **Zoom:** 3X

Notes: Downstream in Linkage Area.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	005		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.22899654	**Longitude:**	-114.162507
Observers:	Emily Garding, Paul Beier	**UTM X:**	212173.0446	**UTM Y:**	3903023.290
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Unnamed wash in Linkage Area, Strand A, the Golden Valley Planning Area.

Site Photographs

Name: DCP_5224.jpg

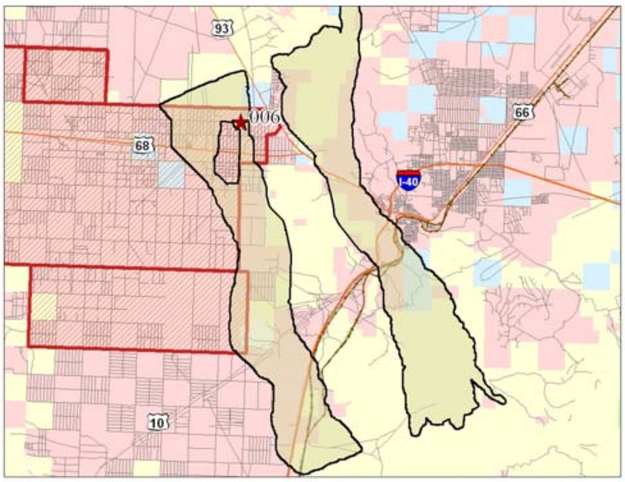
Azimuth: 15 **Zoom:** 3X

Notes: Upstream in linkage area.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	006		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.23613364	**Longitude:**	-114.165565
Observers:	Emily Garding, Paul Beier	**UTM X:**	211919.8732	**UTM Y:**	3903824.084
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Intersection of Burro Drive and Bacobi Road, Golden Valley Planing Area inside Strand A. Jackrabbits and several coveys of Quail were documented in the area during field investigation.

Site Photographs

Name: DCP_5225.jpg

Azimuth: 115 **Zoom:** 1X

Notes: A ranchette typical of the low density housing in this area.

Name: DCP_5226.jpg

Azimuth: 330 **Zoom:** 1X

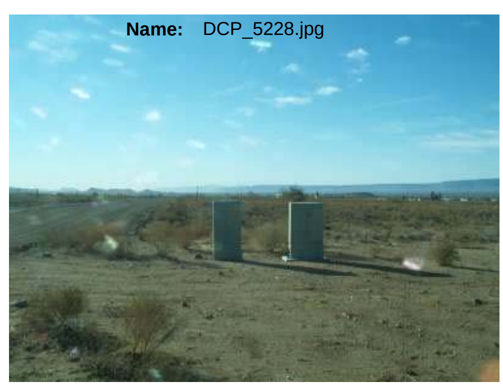
Notes: BLM managed land in the Linkage Area.

Name: DCP_5227.jpg

Azimuth: 265 **Zoom:** 3X

Notes: Burro Drive, one of the large network of rural roads in the area.

Name: DCP_5228.jpg

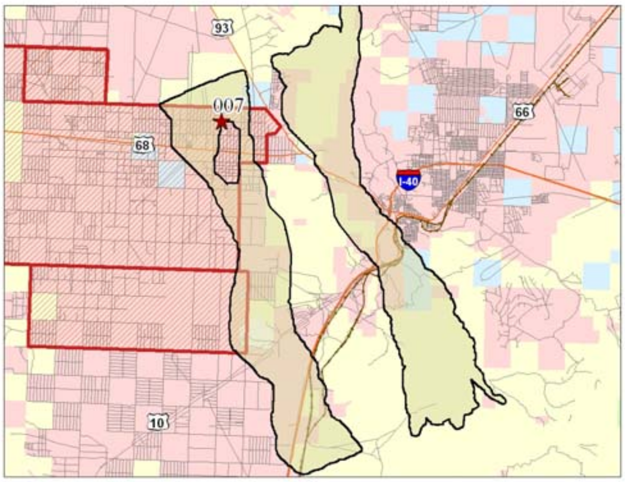


Azimuth: 18 **Zoom:** 1X

Notes: On Bacobi Road. Utility boxes are ubiquitous in anticipation of further development of Golden Valley.

Linkage #:	20	**Waypoint #:**	007		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.23611671	**Longitude:**	-114.178083
Observers:	Emily Garding, Paul Beier	**UTM X:**	210780.2173	**UTM Y:**	3903858.640
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

In Golden Valley Planning Area.

Site Photographs

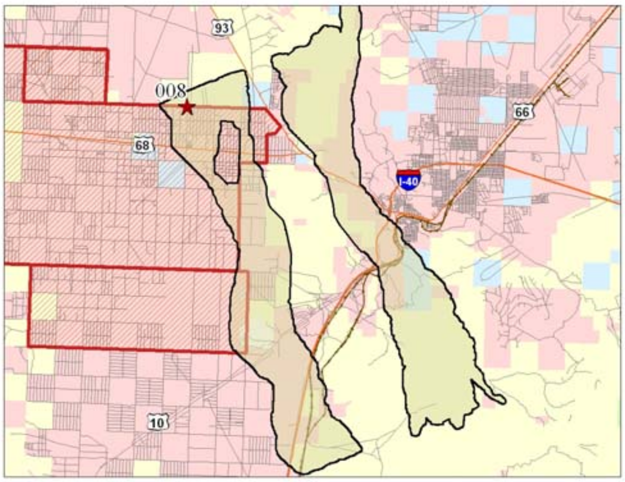
Name: DCP_5229.jpg

Zoom: 1X

Notes: Utility boxes and zoning notices in the Linkage Area, Golden Valley area.

Linkage #:	20	**Waypoint #:**	008		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.24335264	**Longitude:**	-114.200781
Observers:	Emily Garding, Paul Beier	**UTM X:**	208739.7586	**UTM Y:**	3904727.964
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Intersection of Adobe Road and Agua Fria Drive, where the Golden Valley planning area and the BLM parcel inside the Cerbat Mountain Protected Block converge.

Site Photographs

Name: DCP_5230.jpg

Azimuth: 215 **Zoom:** 1X

Notes: Trash, including abandoned vehicles, is accumulating on private lands throughout the Golden Valley Area.

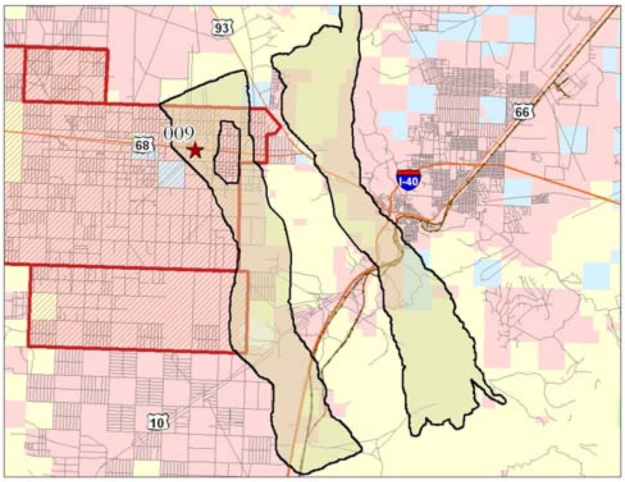
Name: DCP_5231.jpg

Azimuth: 340 **Zoom:** 1X

Notes: Upstream toward BLM land in the Linkage Area, Cerbat Mountains in the background.

Linkage #:	20	**Waypoint #:**	009		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.2206288	**Longitude:**	-114.194474
Observers:	Emily Garding, Paul Beier	**UTM X:**	209232.726	**UTM Y:**	3902188.051
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

SR-68 in 13 Mile Wash, Strand A.

Site Photographs

Name: DCP_5232.jpg

Azimuth: 20 **Zoom:** 1X

Notes: Upstream under the bridge. Note that the entrance is blocked by a fence.

Name: DCP_5233.jpg

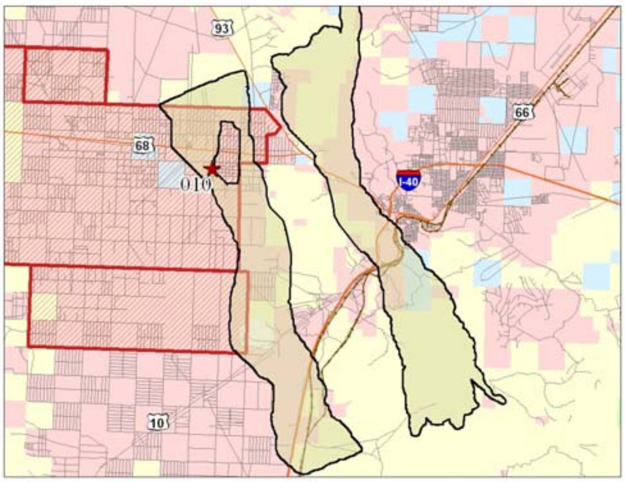
Azimuth: 345 **Zoom:** 3X

Notes: Golden Valley from the highway, with the Cerbat Mountains in the background.

Appendix G: Database of Field Investigations

Linkage #: 20
Waypoint #: 010
Linkage Zone: Cerbat-Hualapai
Latitude: 35.2108006 **Longitude:** -114.183055
Observers: Emily Garding, Paul Beier
UTM X: 210237.4492 **UTM Y:** 3901064.128
Field Study Date: 12/21/2006
Last Printed: 12/11/2007

Waypoint Map



Waypoint Notes

Intersection of Aztec and Adobe Drive south of Sr-68 within Strand A.

Site Photographs

Name: DCP_5235.jpg

Azimuth: 315 **Zoom:** 1X
Notes: Looking toward SR-68.

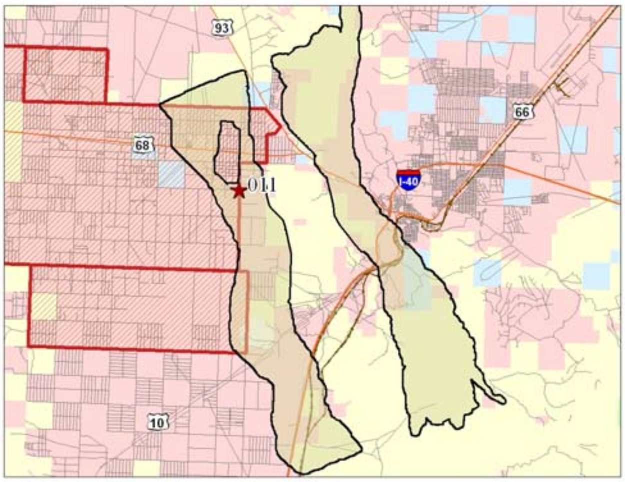
Name: DCP_5236.jpg

Azimuth: 135 **Zoom:** 1X
Notes: Golden Valley South Area.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	011		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.19967857	**Longitude:**	-114.165338
Observers:	Emily Garding, Paul Beier	**UTM X:**	211811.5185	**UTM Y:**	3899778.469
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Intersection of Bacobi and Redwall Roads, on the boundary of the Golden Valley Planning Area within Strand A.

Site Photographs

Name: DCP_5237.jpg

Azimuth: 280 **Zoom:** 1X
Notes: Linkage Area.

Name: DCP_5238.jpg

Azimuth: 180 **Zoom:** 1X
Notes: Bacobi Road.

Name: DCP_5239.jpg

Azimuth: 100 **Zoom:** 1X
Notes: The Cerbat Mountains from Bacobi Road.

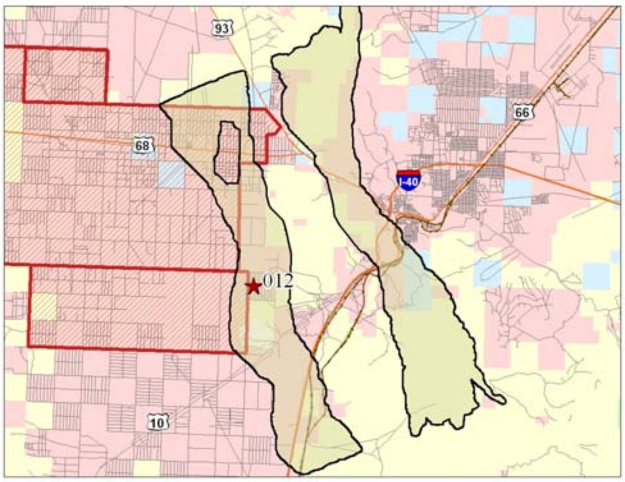
Name: DCP_5240.jpg

Azimuth: 340 **Zoom:** 1X
Notes: Up Bacobi Road.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	012		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.14914961	**Longitude:**	-114.153603
Observers:	Emily Garding, Paul Beier	**UTM X:**	212702.3271	**UTM Y:**	3894137.955
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map

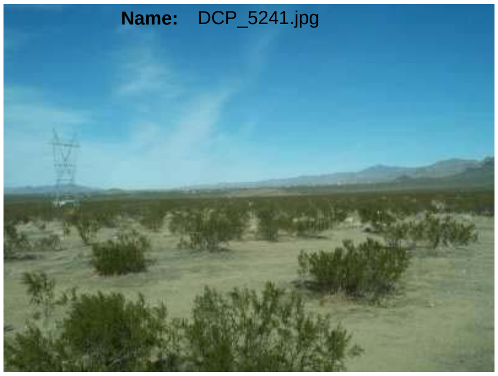


Waypoint Notes

From the northeastern portion of the proposed Golden Valley South Planning Area, on Moenkopi Drive.

Site Photographs

Name: DCP_5241.jpg



Azimuth: 0 **Zoom:** 1X

Notes: Utility corridor near Shinarump Drive in the Linkage Area .

Name: DCP_5242.jpg

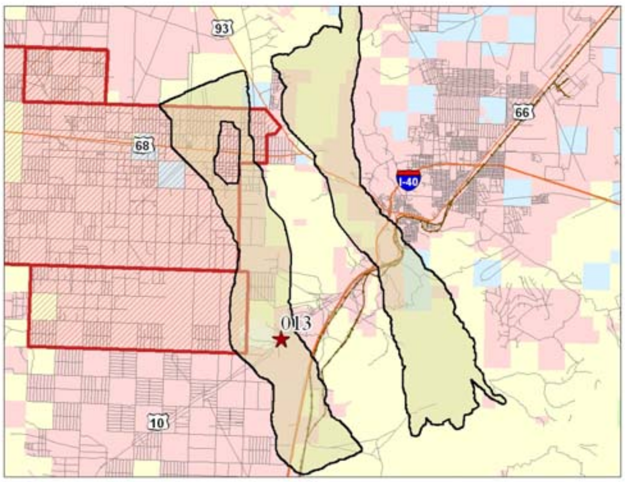
Azimuth: 180 **Zoom:** 1X

Notes: Linkage Area.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	013		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.12117039	**Longitude:**	-114.134749
Observers:	Emily Garding, Paul Beier	**UTM X:**	214322.7652	**UTM Y:**	3890979.177
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Photos of the Linkage Area taken from a vantage point above County Highway 10, formerly Route 66.

Site Photographs

Name: DCP_5243.jpg

Azimuth: 340 **Zoom:** 1X

Notes: Sacramento Valley in the Linkage Area.

Name: DCP_5244.jpg

Azimuth: 340 **Zoom:** 3X

Name: DCP_5245.jpg

Azimuth: 55 **Zoom:** 1X

Notes: Linkage Area .

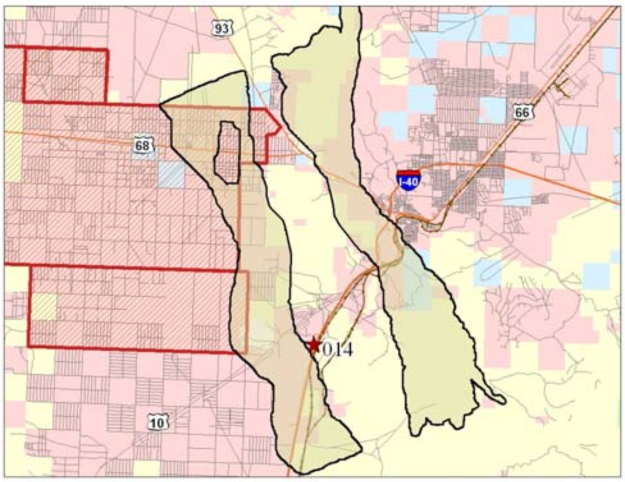
Name: DCP_5246.jpg

Azimuth: 230 **Zoom:** 1X

Notes: Linkage Area.

Linkage #:	20	**Waypoint #:**	014		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.11889362	**Longitude:**	-114.113716
Observers:	Emily Garding, Paul Beier	**UTM X:**	216232.2278	**UTM Y:**	3890666.350
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Both lanes of traffic I-40 in the Linkage Area.

Site Photographs

Name: DCP_5250.jpg

Azimuth: 205 **Zoom:** 3X

Notes: I-40.

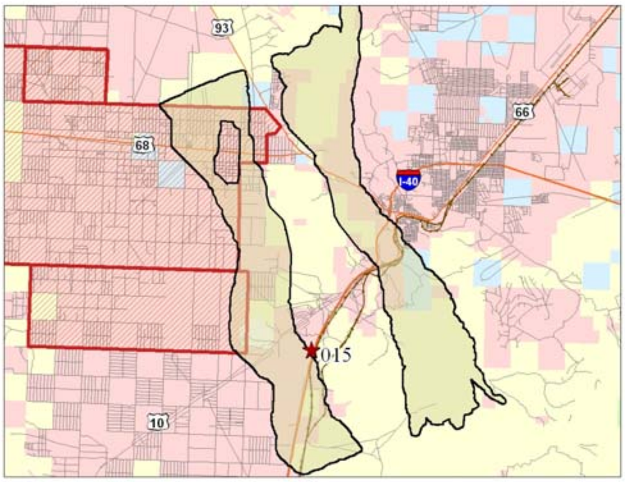
Name: DCP_5251.jpg

Azimuth: 100 **Zoom:** 3X

Notes: Tractor-trailer traffic on I-40, with 2 sets of Railroad Tracks in the background.

Linkage #:	20	**Waypoint #:**	015		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.11568293	**Longitude:**	-114.114808
Observers:	Emily Garding, Paul Beier	**UTM X:**	216121.5318	**UTM Y:**	3890313.227
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Several medium sized box culverts cross underneath I-40.

Site Photographs

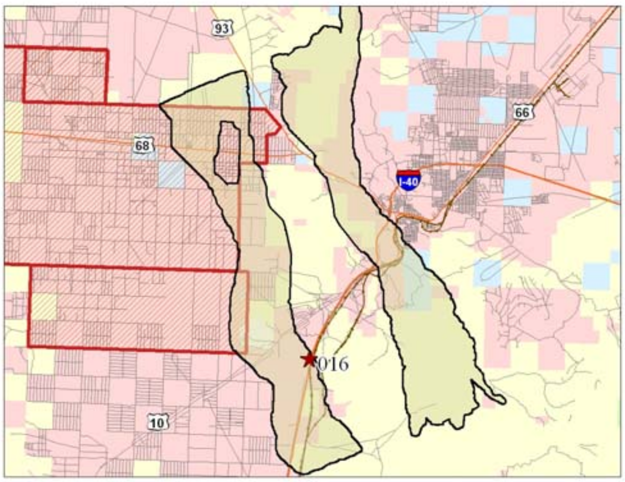
Name: DCP_5252.jpg

Zoom: 1X

Notes: Typical 3' culvert crossing under I-40. The entrance to the culvert is blocked by fencing, and is not flush with the ground.

Linkage #:	20	**Waypoint #:**	016		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.11120783	**Longitude:**	-114.116333
Observers:	Emily Garding, Paul Beier	**UTM X:**	215966.9642	**UTM Y:**	3889821.048
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Four boxes under I-40.

Site Photographs

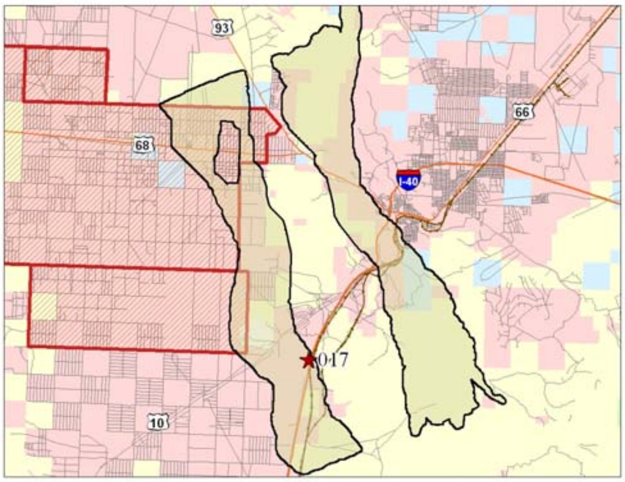
Name: DCP_5253.jpg

Zoom: 1X

Notes: The bottom of the drainage appears to have been built up by sediment since construction.

Linkage #:	20	**Waypoint #:**	017		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.11045547	**Longitude:**	-114.11655
Observers:	Emily Garding, Paul Beier	**UTM X:**	215944.588	**UTM Y:**	3889738.19
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Site Photographs

Name: DCP_5254.jpg

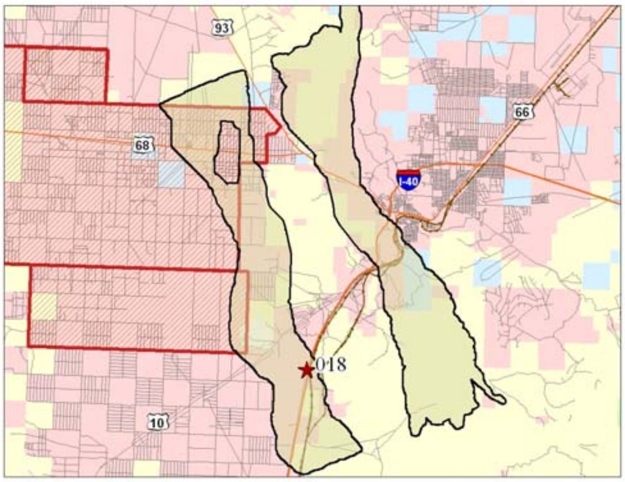
Zoom: 1X

Notes: A four box culvert under I-40.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	018		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.10530664	**Longitude:**	-114.117718
Observers:	Emily Garding, Paul Beier	**UTM X:**	215820.2207	**UTM Y:**	3889170.240
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



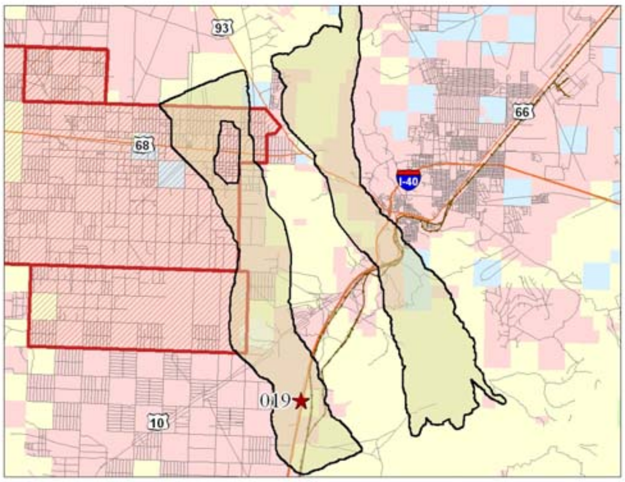
Waypoint Notes

A medium sized culvert pipe.

Site Photographs

Linkage #:	20	**Waypoint #:**	019		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.08843194	**Longitude:**	-114.120884
Observers:	Emily Garding, Paul Beier	**UTM X:**	215472.7777	**UTM Y:**	3887306.972
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

A 2 box culvert under 1-40.

Site Photographs

Name: DCP_5255.jpg

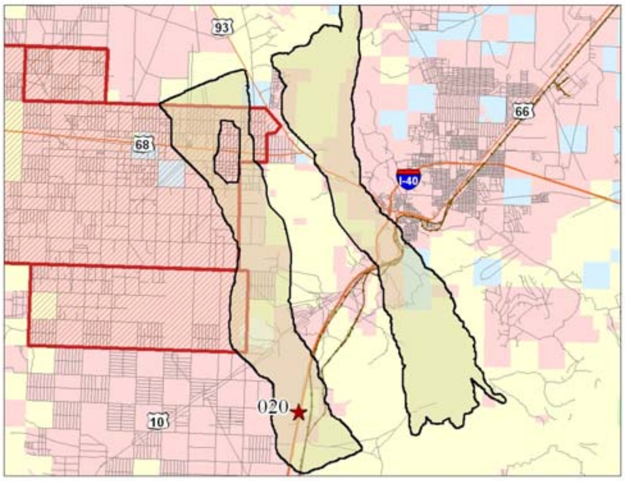
Zoom: 1X

Notes: Traffic on I-40 seen above a potential underpass that is almost completely blocked by sediment, as well as by a fence. Hualapai

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	020		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.08211399	**Longitude:**	-114.122212
Observers:	Emily Garding, Paul Beier	**UTM X:**	215329.7058	**UTM Y:**	3886609.766
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Griffith Wash.

Site Photographs

Name: DCP_5256.jpg

Azimuth: 90 **Zoom:** 1X

Notes: Under I-40. The entrance is blocked by a fence.

Name: DCP_5257.jpg

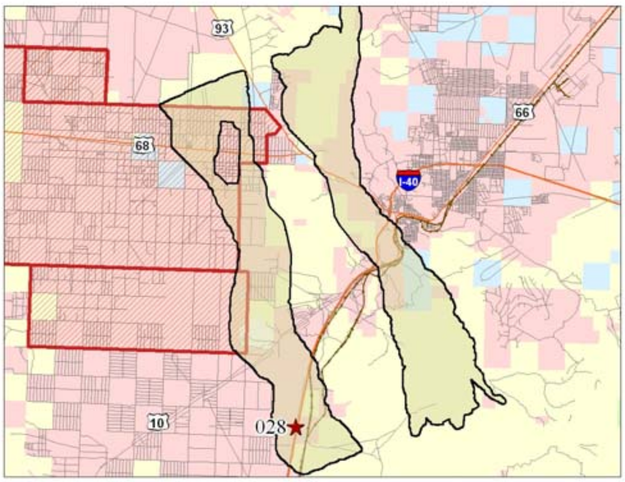
Azimuth: 250 **Zoom:** 1X

Notes: Upstream.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	028		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.07453441	**Longitude:**	-114.123506
Observers:	Emily Garding, Paul Beier	**UTM X:**	215185.3329	**UTM Y:**	3885772.481
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Shingle Canyon.

Site Photographs

Name: DCP_5258.jpg

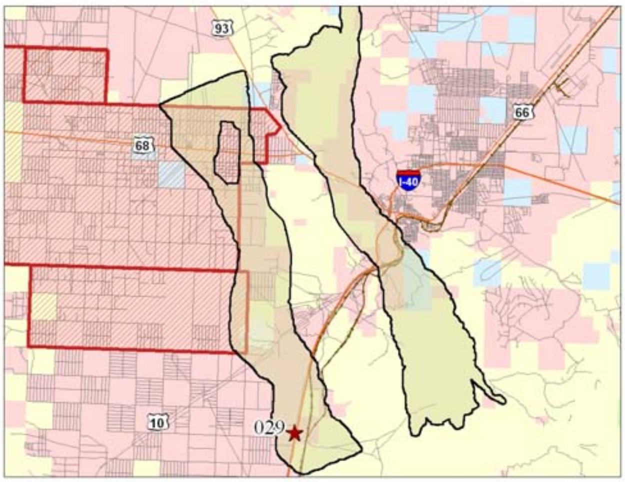
Zoom: 1X

Notes: A 3-box culvert under I-40. The bottom appears to have been built up by sediment.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	029		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.07143134	**Longitude:**	-114.124102
Observers:	Emily Garding, Paul Beier	**UTM X:**	215120.1139	**UTM Y:**	3885429.890
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Four box culvert in unnamed wash.

Site Photographs

Name: DCP_5259.jpg

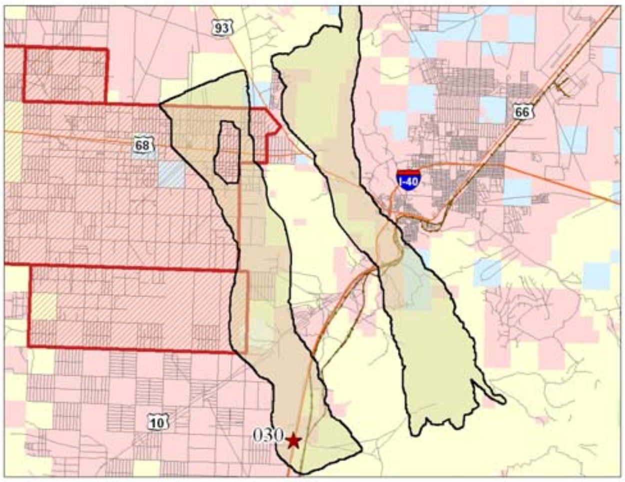
Zoom: 1X

Notes: This underpass is blocked by a fence and the bottom has been built up by sediment.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	030		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.06739562	**Longitude:**	-114.124857
Observers:	Emily Garding, Paul Beier	**UTM X:**	215037.2627	**UTM Y:**	3884984.269
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Site Photographs

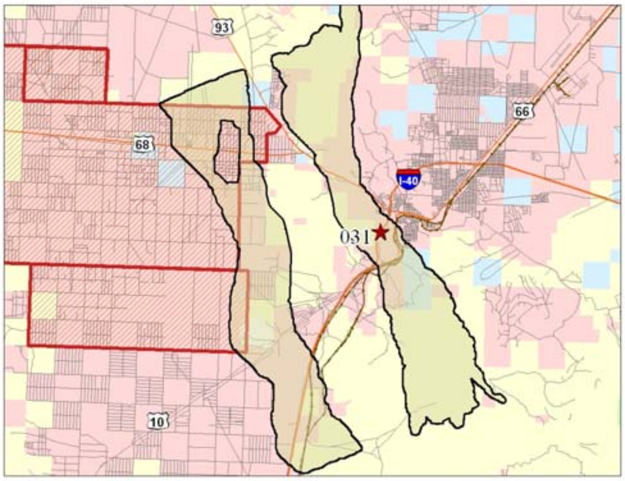
Name: DCP_5260.jpg

Zoom: 1X

Notes: Small box culverts visible under both lanes of I-40, note the fence.

Linkage #:	20	**Waypoint #:**	031		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.17934801	**Longitude:**	-114.072506
Observers:	Emily Garding, Paul Beier	**UTM X:**	220196.4717	**UTM Y:**	3897257.161
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

I-40 and Cook Canyon in Strand B of the Linkage Area.

Site Photographs

Name: DCP_5261.jpg

Azimuth: 205 **Zoom:** 1X

Notes: Cook Canyon provides a good opportunity for a large bridge to facilitate wildlife crossings. Currently there is small box culvert underneath

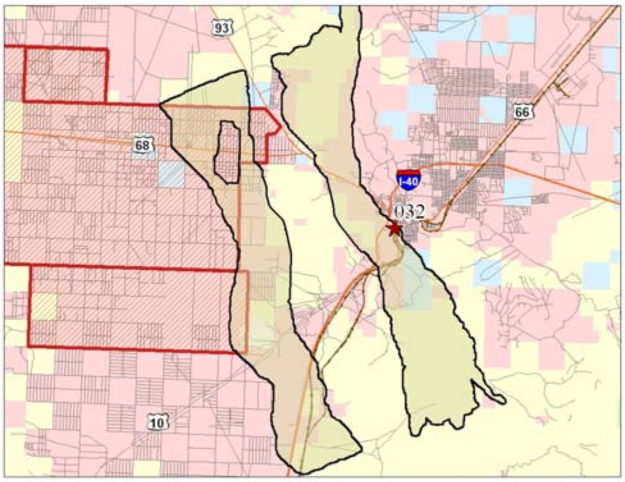
Name: DCP_5262.jpg

Azimuth: 190 **Zoom:** 3X

Notes: I-40 in Cook Canyon.

Linkage #:	20	**Waypoint #:**	032		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.18230892	**Longitude:**	-114.063842
Observers:	Emily Garding, Paul Beier	**UTM X:**	220995.8116	**UTM Y:**	3897561.311
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

The southern edge of the Cerbat Mountains. Photos taken from Route 66 in Strand B of the Linkage Area. This is an area where wildlife movements may be impeded by two sets of railroad tracks, and industrial development.

Site Photographs

Name: DCP_5263.jpg

Azimuth: 229 **Zoom:** 1X

Notes: A tractor-trailer on I-40, rom Route 66.

Name: DCP_5264.jpg

Azimuth: 229 **Zoom:** 2X

Notes: Traffic on I-40 above Route 66.

Name: DCP_5265.jpg

Azimuth: 175 **Zoom:** 1X

Notes: Traffic on Route 66.

Name: DCP_5266.jpg

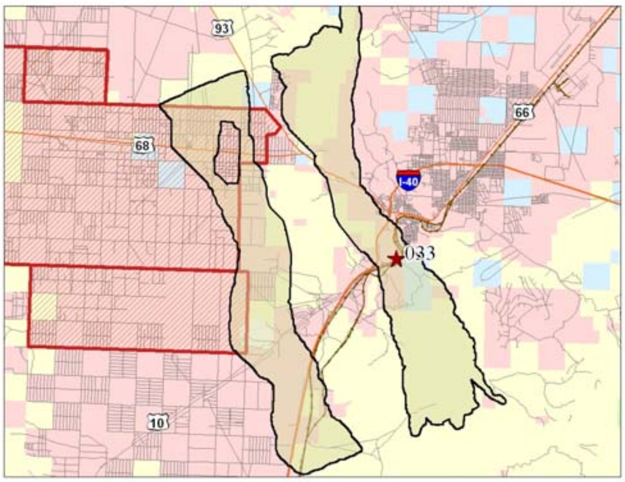
Azimuth: 100 **Zoom:** 1X

Notes: Two sets of Railroad tracks adjacent to Route 66.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	033		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16590847	**Longitude:**	-114.062065
Observers:	Emily Garding, Paul Beier	**UTM X:**	221101.6198	**UTM Y:**	3895736.640
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Sawmill Canyon

Site Photographs

Name: DCP_5268.jpg

Azimuth: 125 **Zoom:** 1X

Notes: One set set of tracks is raised on a bridge while the other is not.

Name: DCP_5269.jpg

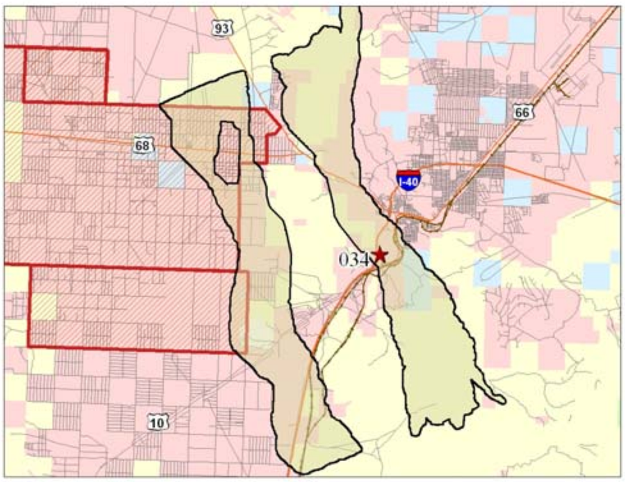
Azimuth: 310 **Zoom:** 1X

Notes: Route 66. Cook Canyon and I-40 are on the far side of this hill.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	034		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16781082	**Longitude:**	-114.072724
Observers:	Emily Garding, Paul Beier	**UTM X:**	220136.9425	**UTM Y:**	3895977.687
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Route 66 approaching I-40.

Site Photographs

Name: DCP_5270.jpg

Azimuth: 340 **Zoom:** 3X
Notes: Cook Canyon, between Route 66 and I-40.

Name: DCP_5271.jpg

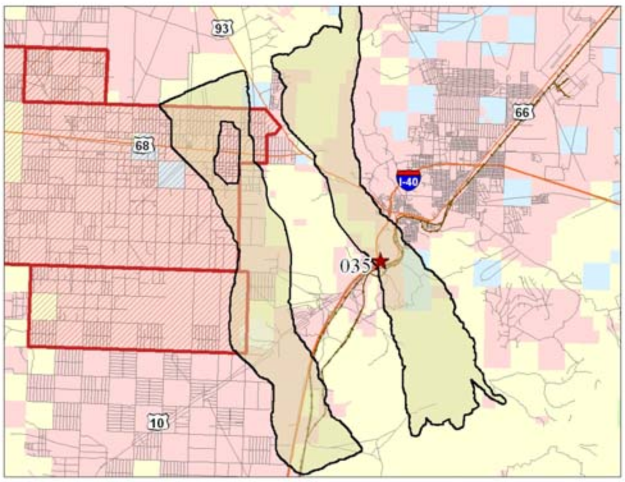
Azimuth: 265 **Zoom:** 1X
Notes: A small culvert under I-40.

Name: DCP_5272.jpg

Azimuth: 190 **Zoom:** 1X
Notes: Route 66. An RV park in the background, and a tractor trailer on I-40 on the right.

Linkage #:	20	**Waypoint #:**	035		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16465101	**Longitude:**	-114.072087
Observers:	Emily Garding, Paul Beier	**UTM X:**	220184.1747	**UTM Y:**	3895625.300
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Near the convergence of Route 66 and I-40.

Site Photographs

Name: DCP_5273.jpg

Azimuth: 165 **Zoom:** 3X

Notes: Railway traffic in the Linkage Area.

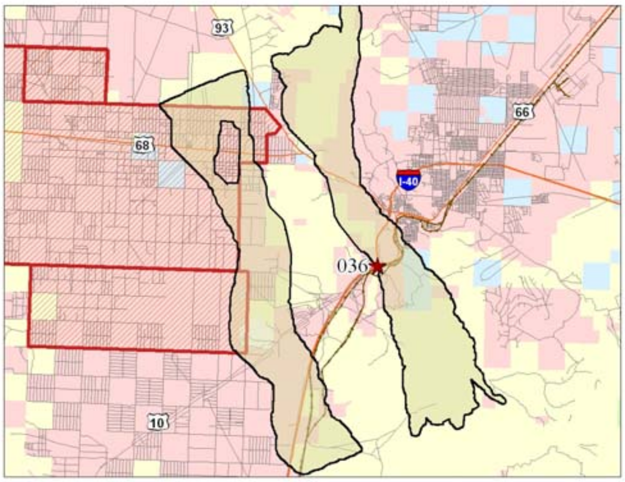
Name: DCP_5274.jpg

Azimuth: 95 **Zoom:** 2X

Notes: A trailer park in the foreground and trains in the background.

Linkage #:	20	**Waypoint #:**	036		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16170033	**Longitude:**	-114.073911
Observers:	Emily Garding, Paul Beier	**UTM X:**	220007.8304	**UTM Y:**	3895303.052
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Near the merging of Route 66 and I-40.

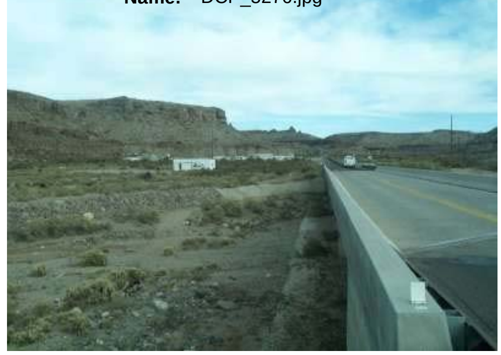
Site Photographs

Name: DCP_5275.jpg

Azimuth: 280 **Zoom:** 1X

Notes: Bridge under I-40 at Holy Moses Wash, Cerbat Mountains in the background.

Name: DCP_5276.jpg

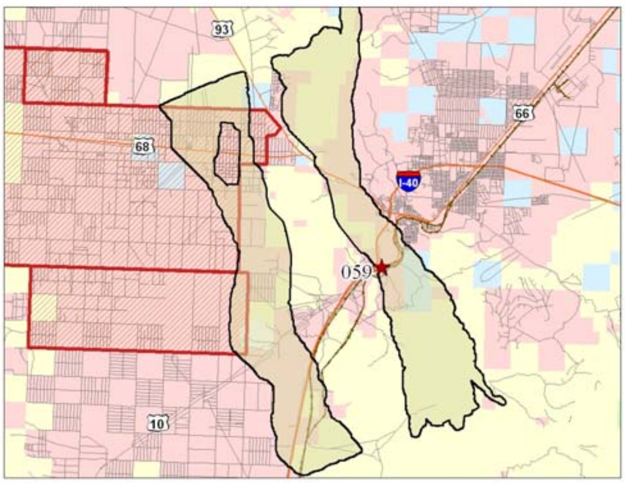


Azimuth: 55 **Zoom:** 1X

Notes: Bridge under Route 66 and Trailer Park in the background.

Linkage #:	20	**Waypoint #:**	059		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16184098	**Longitude:**	-114.071276
Observers:	Emily Garding, Paul Beier	**UTM X:**	220248.4822	**UTM Y:**	3895311.233
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Holy Moses Wash Area.

Site Photographs

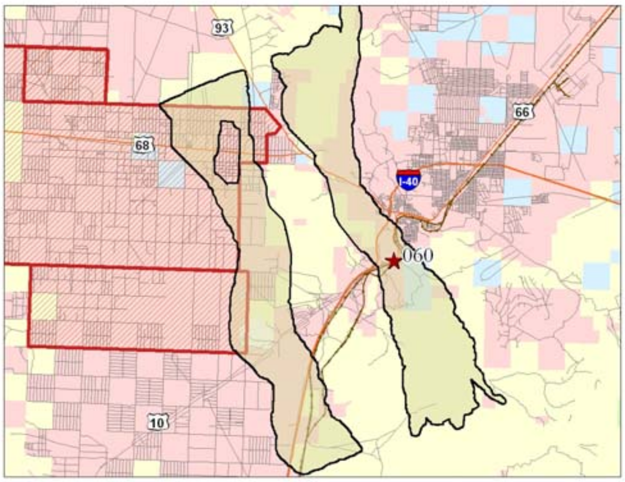
Name: DCP_5277.jpg

Azimuth: 270 **Zoom:** 3X

Notes: Bridge under Route 66 and I-40 at Holy Moses Wash, Cerbat Mountains in the background.

Linkage #:	20	**Waypoint #:**	060		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.16468236	**Longitude:**	-114.063394
Observers:	Emily Garding, Paul Beier	**UTM X:**	220976.3444	**UTM Y:**	3895604.331
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Holy Moses Wash.

Site Photographs

Name: DCP_5278.jpg

Azimuth: 260 **Zoom:** 3X

Notes: Route 66 nears I-40. Holy Moses Wash is on the left and trailer parkson both sides of the highway.

Name: DCP_5279.jpg

Azimuth: 260 **Zoom:** 3X

Notes: A tractor trailer passing over the bridge over Holy Moses Wash in the background..

Name: DCP_5280.jpg

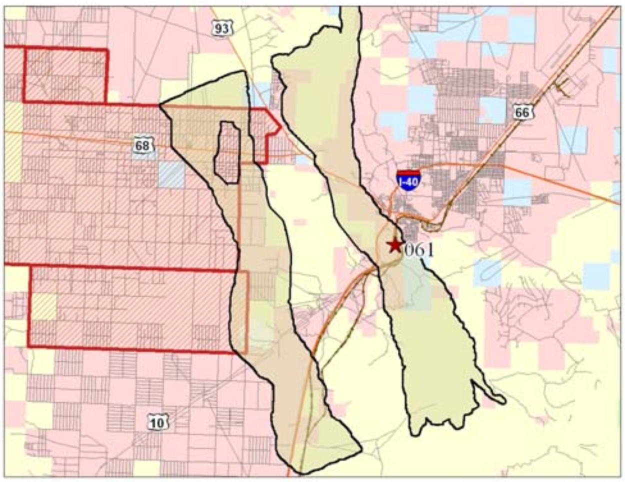
Azimuth: 90 **Zoom:** 1X

Notes: Holy Moses Wash.

Appendix G: Database of Field Investigations

Linkage #:	20	**Waypoint #:**	061		
Linkage Zone:	Cerbat-Hualapai	**Latitude:**	35.17335654	**Longitude:**	-114.062790
Observers:	Emily Garding, Paul Beier	**UTM X:**	221060.9925	**UTM Y:**	3896565.063
Field Study Date:	12/21/2006	**Last Printed:**	12/11/2007		

Waypoint Map



Waypoint Notes

Along Route 66.

Site Photographs

Name: DCP_5281.jpg

Azimuth: 350 **Zoom:** 1X

Notes: Treatment ponds located in between sets of railroad tracks adjacent to Route 66.

Name: DCP_5282.jpg

Azimuth: 115 **Zoom:** 1X

Notes: Downstream.