ARIZONA MISSING LINKAGES

Hualapai - Peacock Linkage Design

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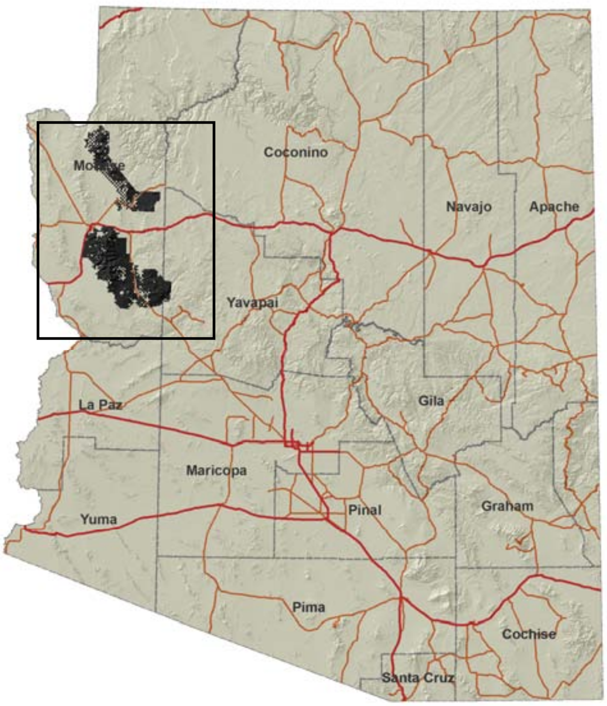
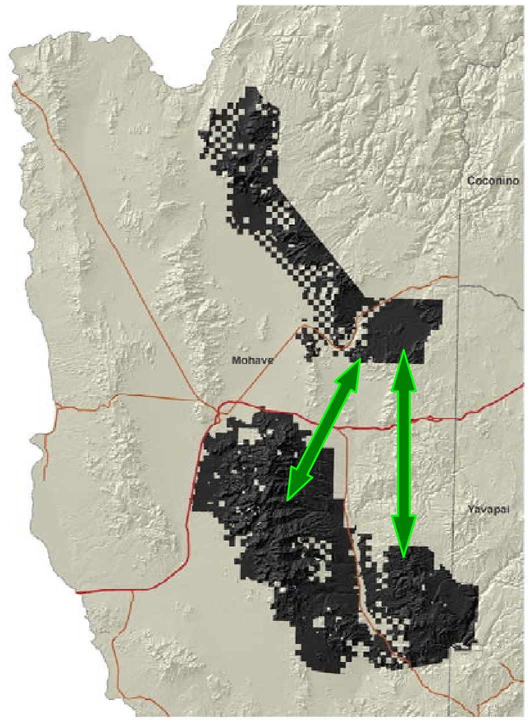
NORTHERN ARIZONA UNIVERSITY

HUALAPAI - KINGMAN LINKAGE DESIGN





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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 protected habitat block to a potential population core in the other protected habitat 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: A continuous corridor of land which encompasses the biologically best corridors of all focal species and thus should – if conserved – maintain or restore the ability of wildlife to move between the *wildland blocks*.

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 Area will 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 model assumes that habitat suitability is the best indicator of the cost of movement through the pixel.

Wildland Blocks: 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. In map legends in this report, the wildland blocks are labeled "Protected Habitat Blocks."

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, 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 corridors that will conserve and enhance wildlife movement between two large areas of BLM-administered wildlands east of Kingman, Arizona. Running east-west through this region, Interstate 40 and future urban development provide an impediment to animal movement between the Hualapai and Aquarius Mountains to the south, and the Peacock and Cottonwood 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 23 focal species that are sensitive to habitat loss and fragmentation, including 2 amphibians, 4 reptiles, 4 birds, 2 fish, and 11 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. pronghorn, 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 scrub deserts and rugged highlands. Together, these 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 (Figure 1) provides live-in or move-through habitat for each focal species. The Linkage Design (Figure 1) is composed of four strands which together provide habitat for movement and reproduction of wildlife between the Hualapai-Aquarius Mountains area on the south and the Peacock-Cottonwood Mountains on 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 ecological, educational, recreational, and spiritual values of protected wildlands surrounding Kingman are immense. 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-Aquarius and Peacock-Cottonwood 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-Peacock Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	Lowland Leopard Frog	Black-throated Sparrow
Bats	Northern Leopard Frog	Gambel's Quail
*Black Bear	Arizona Black Rattlesnake	Western Burrowing Owl
*Black-tailed Jackrabbit	Black-necked Gartersnake	Yellow-billed Cuckoo
*Elk	Chuckwalla	
Hualapai Mexican Vole	*Gila Monster	**FISH**
*Javelina		Desert Sucker
*Kit Fox		Longfin Dace
*Mountain Lion		
*Mule Deer		
*Pronghorn		

* 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), or because the species probably can travel (e.g., by flying) across unsuitable habitat.

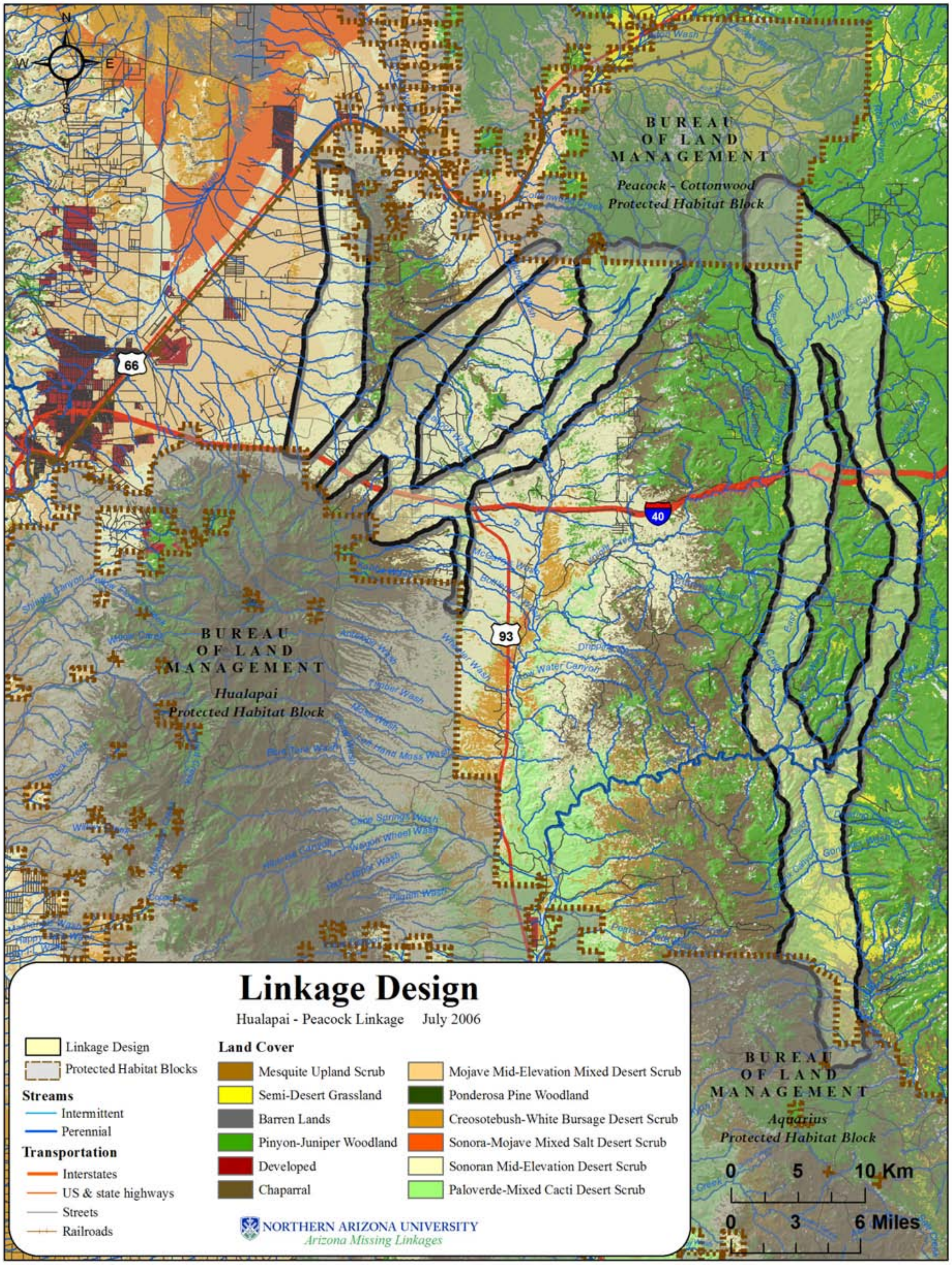

Figure 1: The Linkage Design between the Peacock-Cottonwood, Hualapai, and Aquarius wildland blocks includes four terrestrial strands, each of which is important to different species.

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, 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). The Hualapai-Peacock Linkage is one of these first 8 linkages.

Ecological Significance of the Hualapai-Peacock Linkage

The Hualapai-Peacock Linkage Planning area is the only 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 area are:

- The southern lowlands of the Linkage Planning Area are 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 generally much 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 plant 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, three wildland blocks are separated by Interstate 40 and a matrix of state trust and private land 12 to 32 miles wide (Figure 3). We have named these wildland blocks the Hualapai, the Aquarius, and the Peacock-Cottonwood[1]. All three areas are administered by the Bureau of Land Management.

The northern Peacock-Cottonwood protected block encompasses most of the Peacock Mountains, the Music Mountains, and the Cottonwood Mountains (Figure 4), which together support drainages such as Cottonwood Canyon, Truxton Wash, and Wright Canyon. Most of this protected block is found within the Colorado Plateau Ecoregion, and is dominated by pinyon-juniper woodlands and semi-desert grassland. Elevation within this protected block ranges from 2,500 to 6,750 ft.

[1] All three blocks of BLM land have no formal designation on most maps. We named them after prominent topographic features found in each blocks: the Peacock and Cottonwood Mountains in the northern block, and the Hualapai and Aquarius Mountains in the southern block (Figure 4).

The southern Hualapai and Aquarius wildland blocks join together to form one connected protected block approximately 25 miles south of I-40; however, they provide two distinct northern edges which need connectivity with the Peacock-Cottonwood protected block, so we treat them as two blocks. The Hualapai protected 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 protected block is found within the Apache Highlands Ecoregion, with the western foothills and flats falling within the Mojave Desert Ecoregion. Within this protected 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 protected block ranges from 1,550 to 8,400 ft., providing geologic and topographic variability that contributes to high biological diversity.

The Aquarius protected block encompasses the Aquarius Mountains, which support numerous drainages, such as Big Sandy River, Black Canyon, Box Canyon Wash, Burro Creek, Francis Creek, Kaiser Spring Canyon, and Sycamore Creek. The highlands of this protected block fall within the Apache Highlands Ecoregion, where pinyon-juniper woodlands and chaparral dominate. The western low elevation slopes and flats fall mainly within the Sonoran Desert Ecoregions, where paloverde-mixed cacti desert scrub dominates. Elevation within this protected block ranges from 1,900 to 6,200 ft.

Between the wildland blocks, the lowlands of Linkage Planning Area are dominated by mid-elevation desert scrub, while the Peacock and Aquarius Mountains of the Planning Area are dominated by pinyon-juniper woodland and chaparral (Figure 4). The 18 miles of perennially flowing water in Trout Creek provides the most prominent riparian habitat in the Linkage Planning Area.

The varied habitat types in the Linkage Planning Area support many animal species. The Linkage Planning Area is 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, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

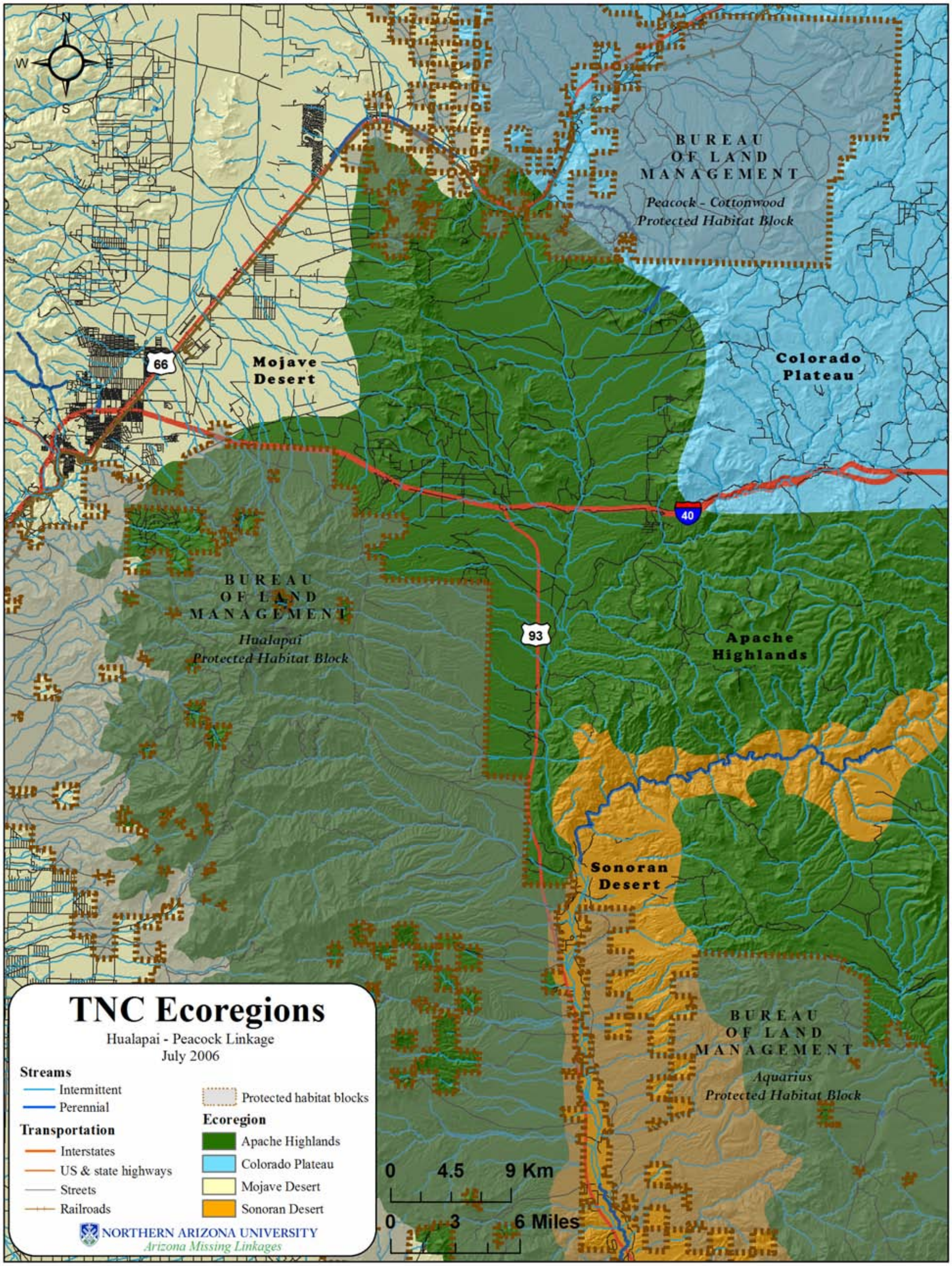

Figure 2: Ecoregions within the Linkage Planning Area. The Linkage Planning Area is the only location in Arizona where four of the state's five ecoregions converge.

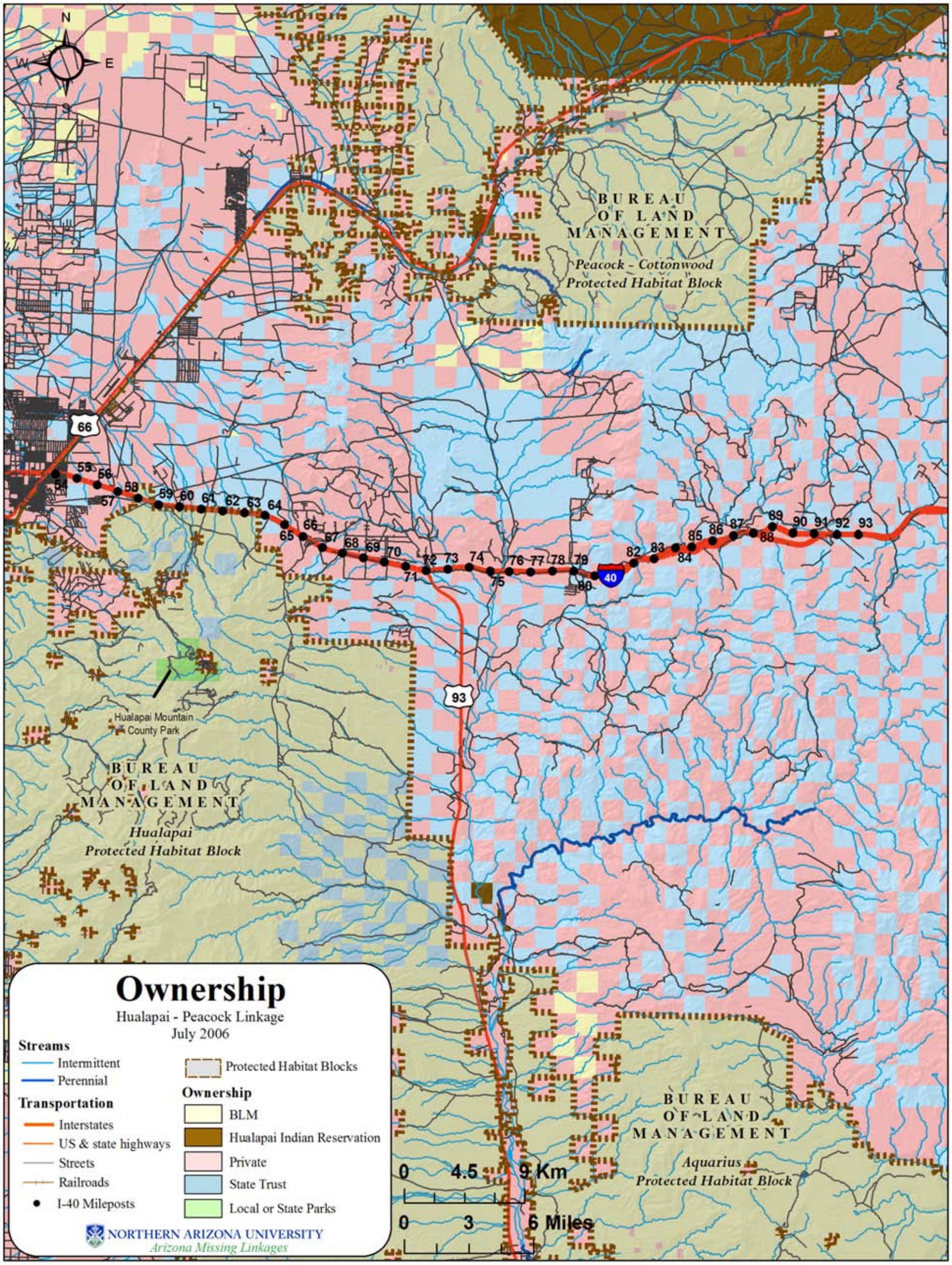

Figure 3: Land ownership within the Linkage Planning Area.

Existing Conservation Investments

The proposed Hualapai-Peacock 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 habitat block, and in the linkage area.

The wildland blocks are comprised of land federally protected by the Bureau of Land Management. The **northern Peacock-Cottonwood** protected habitat block consists of nearly 334,700 acres of vegetation dominated by pinyon-juniper woodlands, mid-elevation desert scrub, and semi-desert grasslands and steppe. At its north end, this block adjoins the 1.1 million acre Grand Canyon National Park, as well as the half-million acre Lake Mead National Recreation Area (Figure 5). Adjacent to the north rim of the Grand Canyon is another 2.7 million acres of BLM-administered land.

The southern wildland blocks are part of one large block of BLM land which encompasses nearly 4.8 million acres in the central and southern areas of western Arizona (Figure 5). This large block of BLM land is also contiguous with the 665,000 acre Kofa National Wildlife Refuge, making it one of the largest continuous blocks of federal land in Arizona. For our analysis, we defined two blocks of habitat which are separated by US-93, each of which has a distinct northern boundary. The **southwestern Hualapai protected block** consists of approximately 510,000 acres of BLM land, whose highlands are dominated by ponderosa pine woodlands and chaparral, and lowlands are comprised mostly of mid-elevation desert scrub and paloverde-mixed cacti desert scrub. The Hualapai protected block contains the 40,000 acre Wabayuma wilderness area, dominated by rugged and diverse topography which supports desert and forest vegetation, and the Hualapai Mountain County Park. The **southeastern Aquarius protected block** consists of nearly 188,000 acres of BLM land with vegetation composition similar to the Hualapai protected block. This block includes the 37,400 acre Upper Burro Creek wilderness area, a rugged and remote wilderness that supports 9 miles of the perennial Burro Creek, providing important riparian resources to wildlife and humans.

About half of the linkage area between these blocks is owned by Arizona State Land Department. The State land is mostly checkerboarded with private land (Figure 5), but some large areas north of I-40 are in unfragmented state ownership.

Connectivity between these wildland blocks would help to 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 and expanding urban development. Until recently, most development has occurred within the city limits of Kingman. However, the proposed Peacock Highlands and Peacock Vistas developments are planned to occupy over 9,000 acres east of Kingman into the foothills of the Peacock Mountains (see Figure 20). If not mitigated, these urban barriers could permanently inhibit wildlife movement between the Peacock-Cottonwood and Hualapai-Aquarius 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.

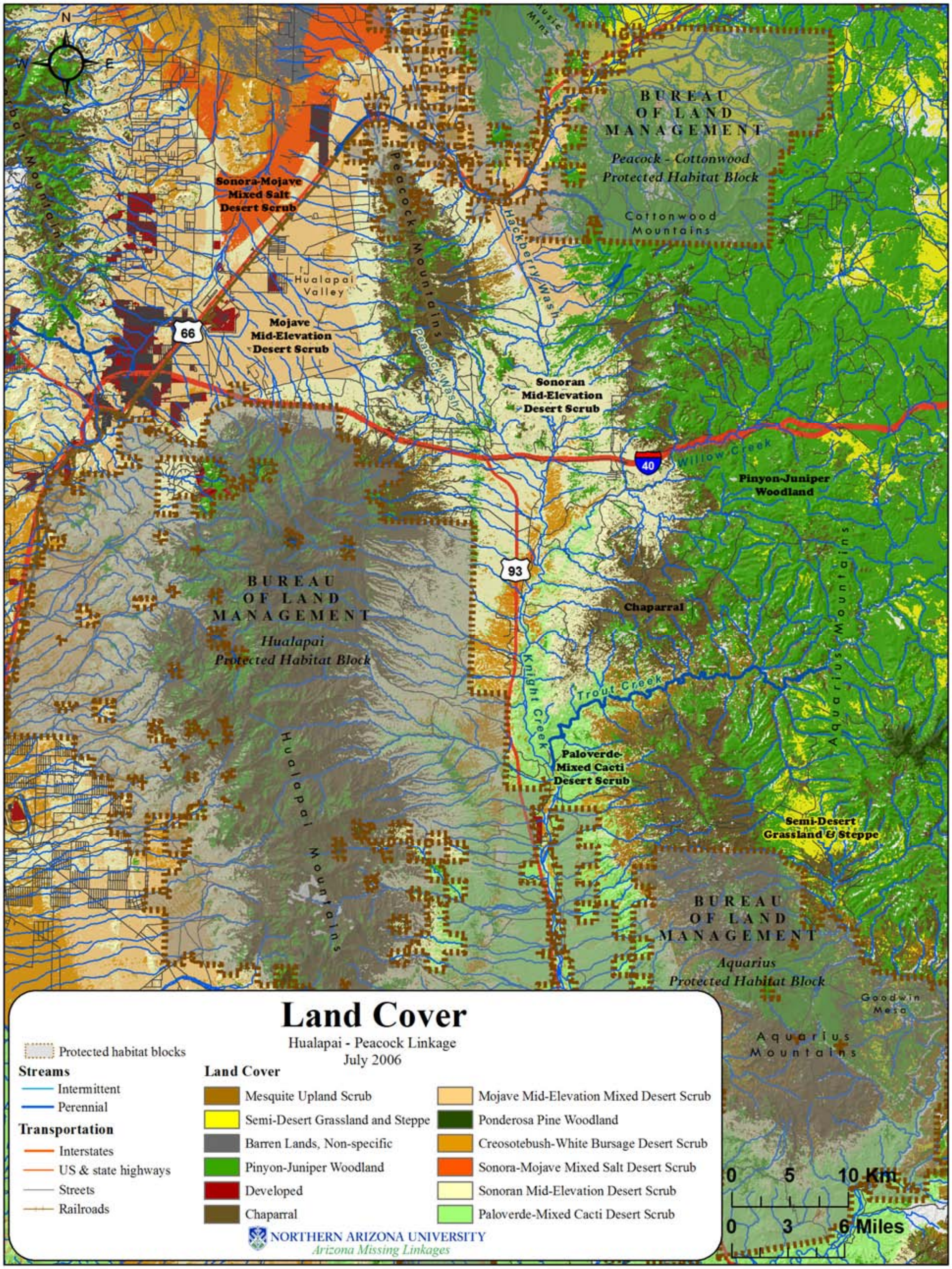

Figure 4: Land cover within the Linkage Planning Area.

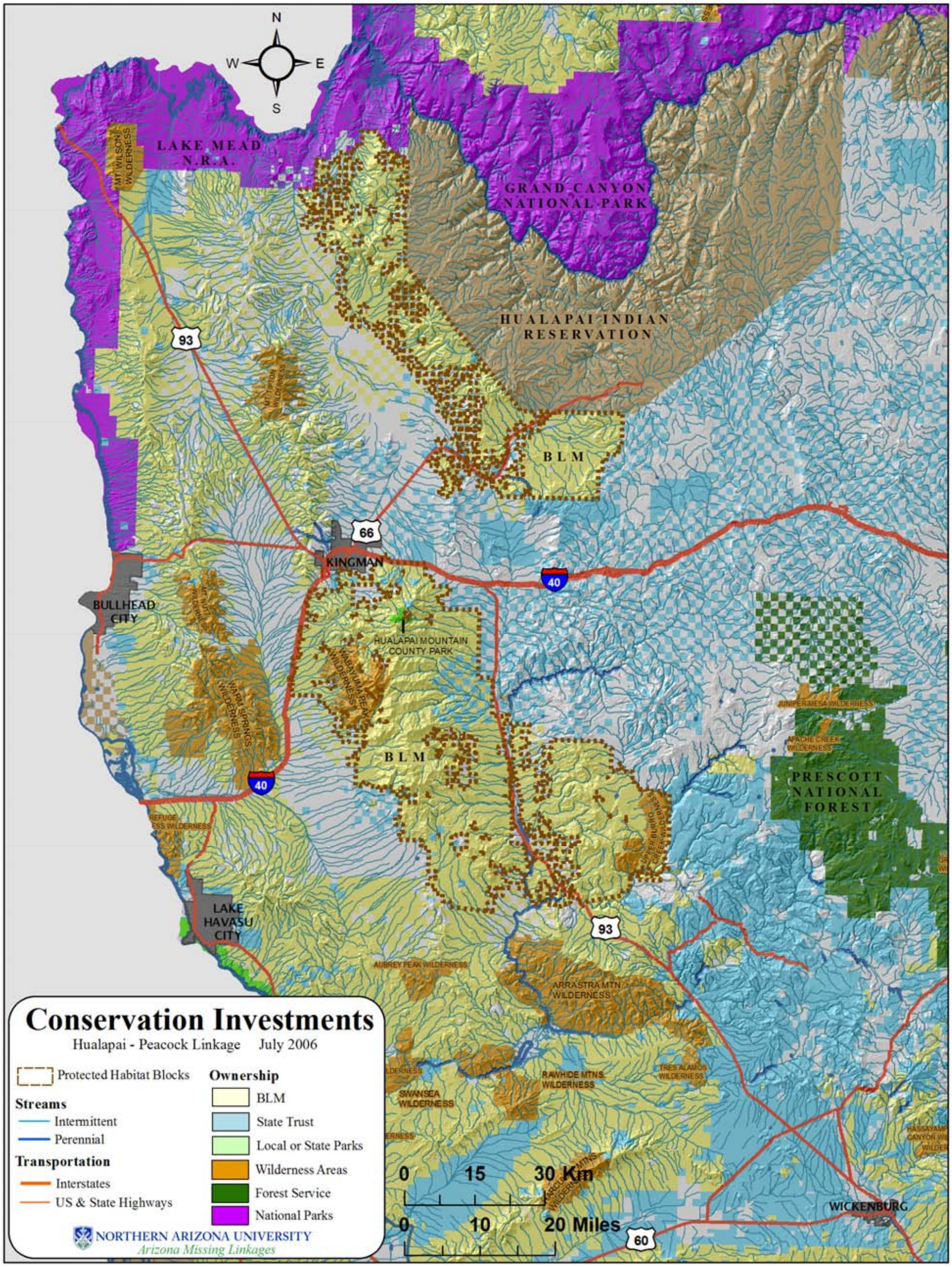

Figure 5: Existing conservation investments within the Linkage Planning Area.

Linkage Design & Recommendations

The final Linkage Design (Figure 1, Figure 6, Figure 7) is composed of four strands which together provide habitat for movement and reproduction of wildlife between the Hualapai-Aquarius habitat block and the Peacock-Music-Aquarius habitat block. 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.

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

Four Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of four distinct strands which connect the Peacock-Cottonwood protected habitat block with the Hualapai and Aquarius wildland blocks. Three of these strands connect the Hualapai and Peacock-Cottonwood wildland blocks, while the fourth strand connects the Aquarius and Peacock-Cottonwood wildland blocks. In Figures 6, 7, and 11, we label these strands A through D from west to east and describe them in that order.

Strand A, the westernmost strand of the linkage design, begins at the Northern foothills of the Hualapai Mountains, captures many unnamed washes and the western foothills of the Peacock Mountains before joining the northern Peacock-Cottonwood protected block near the northern edge of the Peacock Mountains. The strand is about 23 km long, and is composed of Mid-elevation Desert Scrub (82%), Chaparral (13%), and Pinyon-Juniper Woodland (4%). This strand is the flattest strands of the linkage design, with an average slope of 9.9% (Range: 0-78%, SD: 10.6) and 73% of the land having a topographic position classified as flat or gently sloped (< 12% slope). This linkage provides live-in and pass-through habitat for species dependent on desert vegetation or flatter topography, such as badger, black-tailed jackrabbit, javelina, and pronghorn.

Strand B runs through the eastern foothills of the Peacock Mountains, captures 4.6 km of Peacock Wash, 2.5 km of Hackberry Wash, and several unnamed washes, and joins the northern Peacock-Cottonwood protected block in the southern Cottonwood Mountains 4 km southeast of the junction of Hackberry and Truxton Washes. The strand is approximately 25 km in length, and is primarily composed of Mid-elevation Desert Scrub (46%), Chaparral (40%), Mesquite Upland Scrub (6%) and Pinyon-Juniper Woodland (6%). This strand has an average slope of 12% (Range: 0-80%, SD: 11.4), with approximately one-third (32%) classified as steep slopes, 62% as flat-gentle slopes, 2% as canyon bottom, and 4% as ridgetop. This linkage strand provides live-in and pass-through habitat for species dependent on denser vegetation or rugged topography, such as Gila monster, javelina, mountain lion, and mule deer.

Strand C runs from the northeast corner of the Hualapai Mountains through the western foothills of the Cottonwood Mountains, captures 2.5 km of Peacock Wash, 3 km of Hackberry Wash, a portion of Cottonwood Creek, and many unnamed washes, and joins the Peacock-Cottonwood protected block in the southern Cottonwood Mountains. It is distinguished from the middle strand of the linkage design by greater dominance of Pinyon-Juniper Woodland (49%), and decreased amounts of Mid-elevation Desert Scrub (38%) and Chaparral (8%). This strand is topographically similar to strand B between the Hualapai and Peacock-Cottonwood blocks, with an average slope of 13% (Range: 0-95%, SD: 14.0). About one-third (30%) of the land in this strand is classified as steep slopes, 63% as flat-gentle slopes, 3% as canyon bottom, and 4% as ridgetop. This linkage strand provides live-in and pass-through habitat for species dependent on denser vegetation or rugged topography, such as elk, javelina, mountain lion, and mule deer.

Strand D, the westernmost linkage strand, runs between the Aquarius and Peacock-Cottonwood wildland blocks, and provides a unique, topographically diverse connection for wide-ranging species such as elk, mountain lion, mule deer, and pronghorn. The southern end of this strand begins north of Goodwin Mesa and west of Southeast Mesa in the Aquarius Mountains. The central portion has two sub-strands to encompass both the rugged pinyon-juniper woodlands of the Aquarius Mountains and the flatter grasslands east of the Aquarius Mountains. These sub-strands join again to the north and the fourth strand meets the Cottonwood Mountains near Tuckayou Wash. This strand is about 70 km long, and encompasses portions of many riparian or drainage systems, including (South to North) Francis Creek, Skunk Canyon, Simmons Gulch, Gonzales Wash, Dividing Canyon, Trout Creek (perennial), McGee Wash, Ash Creek, Knight Creek, Lookout Wash, Tuckayou Wash, and Hells Canyon. Composition of land cover within this strand is dominated by Pinyon-Juniper Woodland (75%), with smaller amounts of Chaparral (10%) and Semi-Desert Grassland and Steppe (9%). Strand D contains the most topographic complexity in the linkage design, with an average slope of 17% (Range: 0-130%, SD: 14.2). Most of this strand is classified as steep slopes (47%), while 41% is classified as flat-gentle slopes, 6.5% is classified as ridgetop, and 5.5% is classified as canyon bottom.

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

The Linkage Design encompasses 163,470 acres (66,150 ha) of land, and is composed of 35% state trust land, 54% private land, and 11% Bureau of Land Management land (Figure 6). Thirteen natural vegetation communities account for more than 99% of the land cover (Figure 7), barren lands account for 0.2%, developed land accounts for 0.3%, and invasive grassland or forbland accounts for approximately 0.1% of the linkage design (Table 2). Natural vegetation is dominated by evergreen forest associations, and has a similar composition to land cover found in each of the wildland blocks, although the wildland blocks contain less scrub-shrub associations than the linkage design.

The Linkage Design captured 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, 51% of the land is classified as gentle slopes, 39% is classified as steep slopes, 4.3% is classified as canyon bottom, and 5.5% is classified as ridgetop (Figure 8). Aspect categories were represented fairly equally, although slightly more land in the linkage had southern aspects than northern aspects (Figure 8).

Table 2: Approximate land cover found within Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (54.4%)			
Pine-Oak Forest and Woodland	1180	477	0.7%
Pinyon-Juniper Woodland	87287	35234	53.4%
Ponderosa Pine Woodland	521	211	0.3%
Grasslands-Herbaceous (5.8%)			
Juniper Savanna	844	342	0.5%
Semi-Desert Grassland and Steppe	8721	3529	5.3%
Scrub-Shrub (38.9%)			
Big Sagebrush Shrubland	560	226	0.3%
Blackbrush-Mormon-tea Shrubland	270	109	0.2%
Chaparral	22104	8945	13.5%
Creosotebush	89	36	0.1%
Mesquite Upland Scrub	4216	1706	2.6%
Mid-elevation Desert Scrub	36078	14600	22.1%
Paloverde-Mixed Cacti Desert Scrub	209	85	0.1%
Woody Wetland (0.3%)			
Riparian Woodland and Shrubland	413	167	0.3%
Barren Lands (0.2%)			
Mixed Bedrock Canyon and Tableland	339	137	0.2%
Altered or Disturbed (0.1%)			
Invasive Grassland or Forbland	147	59	0.1%
Developed and Agriculture (0.3%)			
Medium-High Intensity Developed	473	191	0.3%

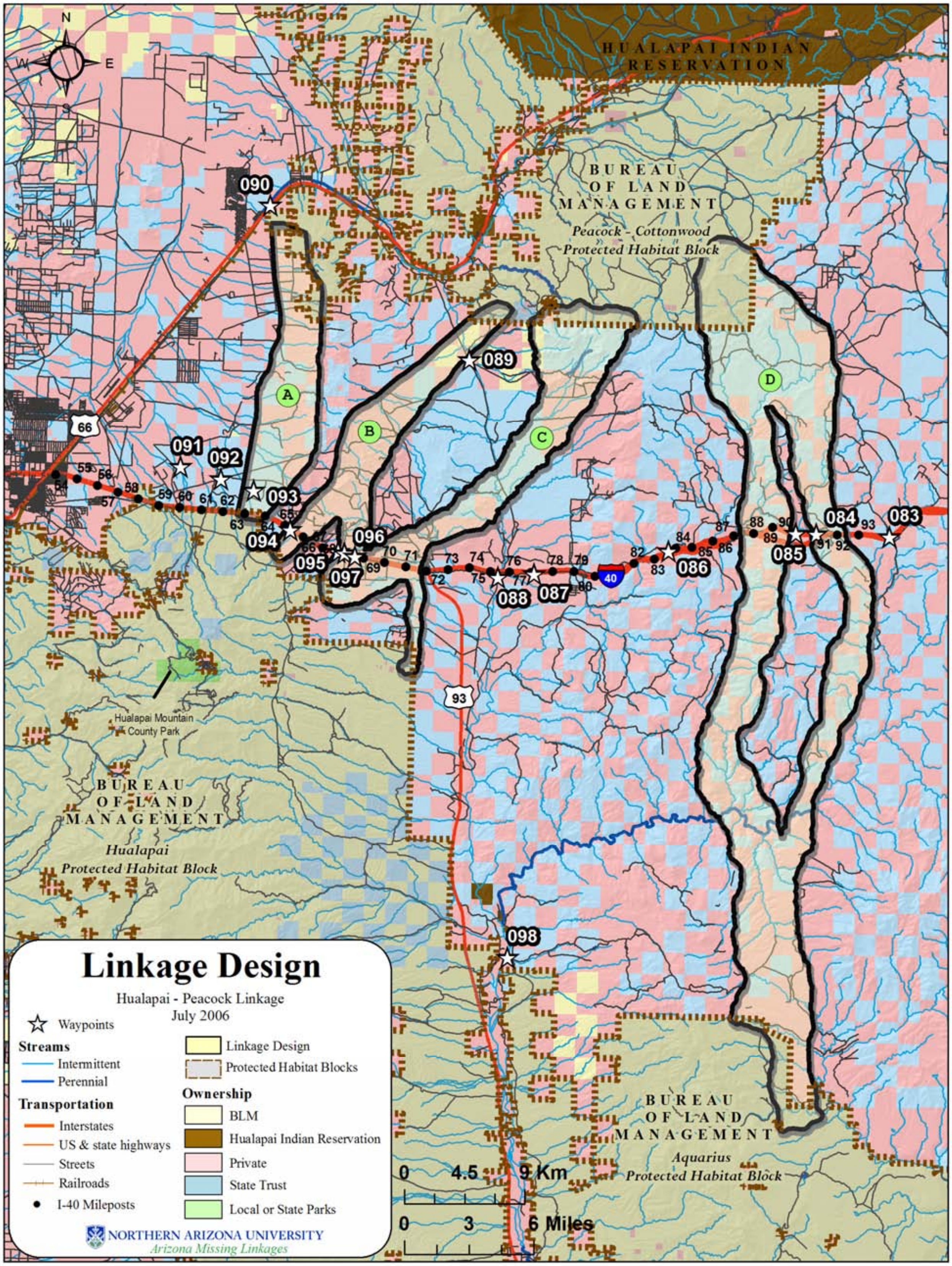

Figure 6: Property ownership, field investigation waypoints (stars), and milepost numbers on I-40 within Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.

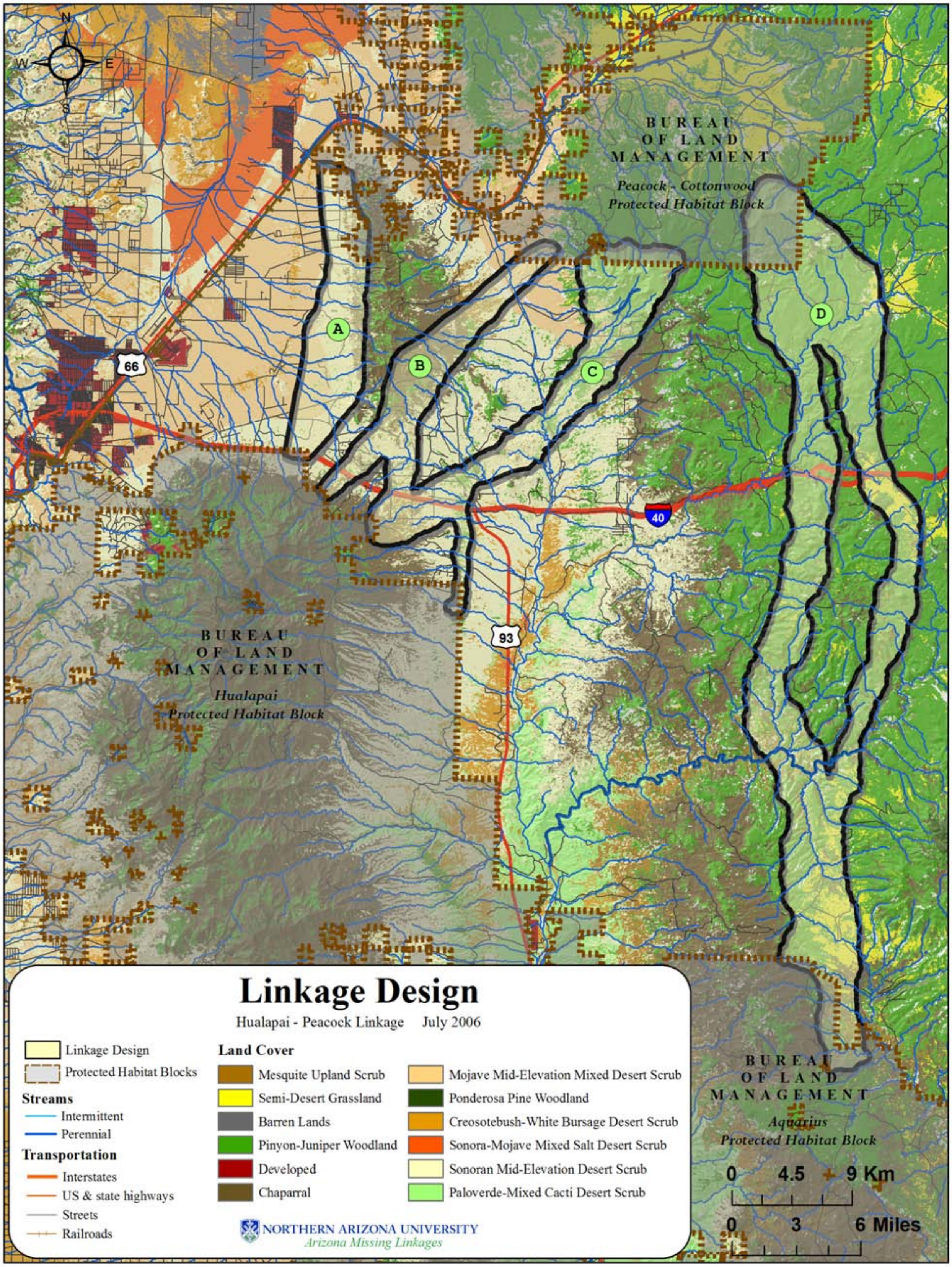

Figure 7: Land cover within Linkage Design.

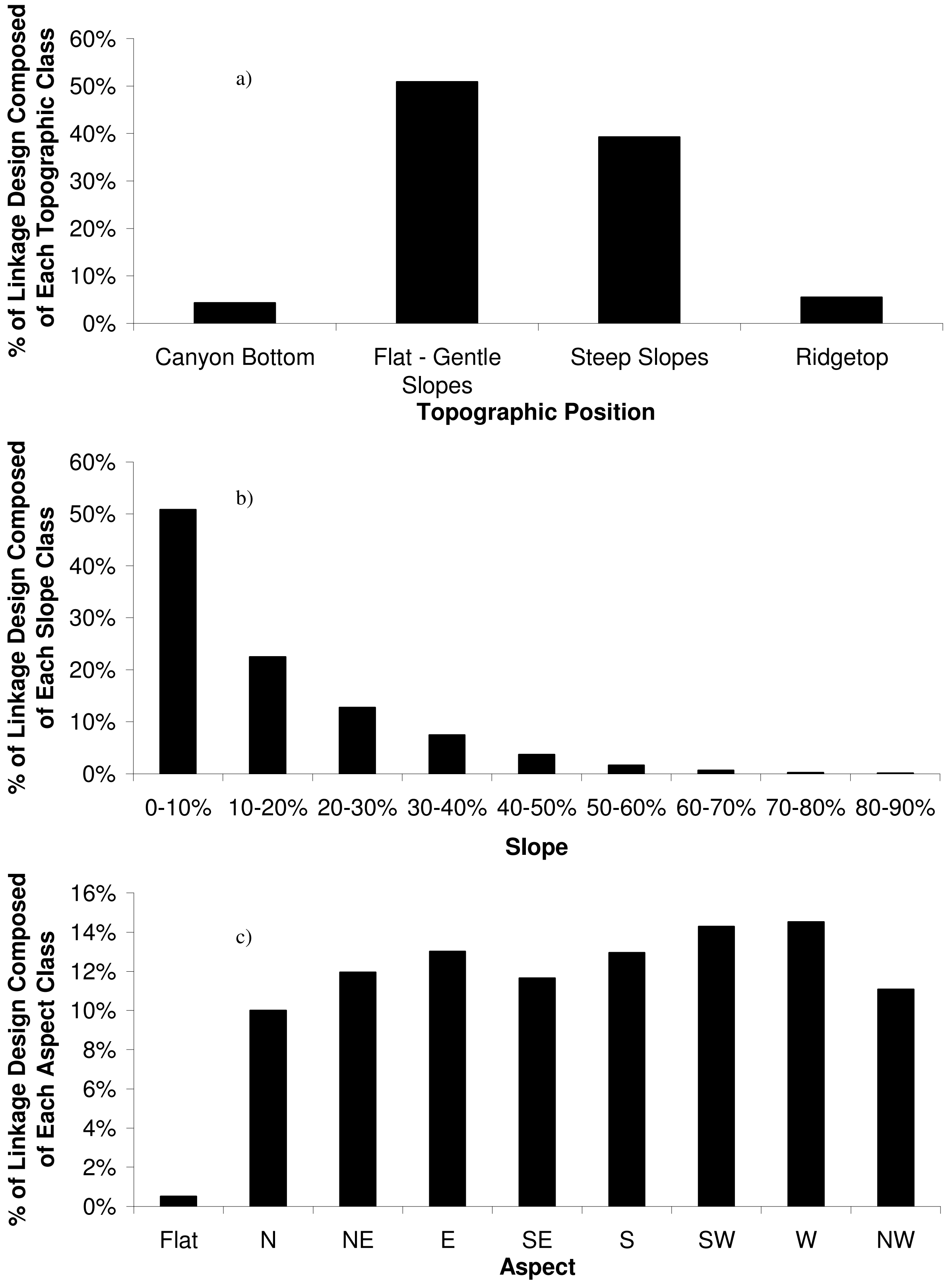

Figure 8: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect. In panel (a), gentle slopes are defined as < 12%.

Removing and Mitigating Barriers to Movement

Although roads 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 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, Aquarius, and Peacock-Cottonwood 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 protected 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. The severity of these effects depends on the ecological characteristics of a given species (Figure 9). 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).

Drainage culverts can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species, including mice, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). 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. 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.

Figure 9: 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. 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.

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.

Existing Roads in the Linkage Design Area

There are approximately 333 km (207 mi) of roads in the Linkage Design, including, 16.7 km (10.4 mi) of highways, and 316 km (190 mi) of local roads (Table 3). We conducted field investigations of many of these roads to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 3: Major transportation routes in the Linkage Design.

ROAD NAME	KILOMETERS	MILES
I-40	16.7	10.4
Trout Creek Rd	6.6	4.1
Dicks Camp Rd	5.2	3.3
Hackberry Rd	4.4	2.8
County Highway 193	3.8	2.4
Corral Rd	3.7	2.3
McCarrell Rd	3.7	2.3
Dubois Rd	3.7	2.3
Jan Rd	3.3	2.1
Lan Dr	3.2	2.0
Windup Trl	3.2	2.0
Tobasa Rd	3.1	2.0
Westwind Rd	3.1	1.9
Watertank Rd	3.0	1.9
Grounds Ranch Rd	2.7	1.7
Lois Ln	2.6	1.6

Rease Rd	2.4	1.5
Ranch Trl	2.4	1.5
Named Roads < 1.5 mile long each	43.4	26.9
Unnamed Roads	213.0	132.4
Total length of roads	**333**	**207**

Existing Crossing Structures on I-40

I-40 runs east-west through all strands of the linkage design, and is the single most significant transportation barrier to animal movement in the linkage area. Because every animal moving between the Hualapai, Aquarius, and Peacock-Cottonwood wildland blocks must traverse this highway, crossing structures along I-40 are crucial to success of the linkage design. Within the linkage design, crossing structures have been built to accommodate intermittent stream flow in several washes. Most structures are small concrete box culverts. Although there are 8 large bridges over riparian features in the planning area, they fall outside of all strands of the linkage design (Figure 11).

Within the western three linkage strands (A, B, and C) which connect the Aquarius and Peacock-Cottonwood wildland blocks, we observed four small crossing structures which are representative of the small crossing structures found in the linkage planning area (Figure 11). We list them from west to east:

- In linkage strand B, there is a multiple span box culvert under I-40. This structure was composed of four 4 x 10 ft box culverts which are heavily silted, providing limited connectivity for species moving between the Hualapai and Peacock Mountains (Figure 12).

- Also in Strand B is a single 10 x 8 ft box culvert under I-40 that was not built for a wash but as a vehicle underpass (Figure 13)

- Two 8 x 12 ft box culverts cross under I-40 near MP 68.1, but are currently unusable as crossing structures by most species. A 3 ft pour-off prevents small mammals and reptiles from entering into the structure, and an angled exit makes the culvert appear closed and dark, discouraging ungulates such as mule deer or elk from using the structure (Figure 14)

- A single 8 x 8 ft box culvert crosses under I-40 near MP 68.6, but access by most wildlife is prevented by a barbwire fence (Figure 15).

- In the pinyon-juniper and chaparral dominated uplands between the Aquarius and Cottonwood Mountains, six large concrete bridges in the eastbound lanes of I-40 cross over Willow Creek; however, these bridges are several miles west of the Aquarius-Cottonwood linkage strand, and do not provide connectivity across the westbound lanes of the highway (Figure 11, Figure 16). We observed one pair of crossing structures over Lookout Wash in the eastern fork of Strand D, where five 8 x8 ft box culverts cross under the westbound lanes of I-40 and six box culverts cross under the eastbound lanes. We observed cattle adjacent to the westbound crossing structure, and found evidence of recent use of the structure by cattle.

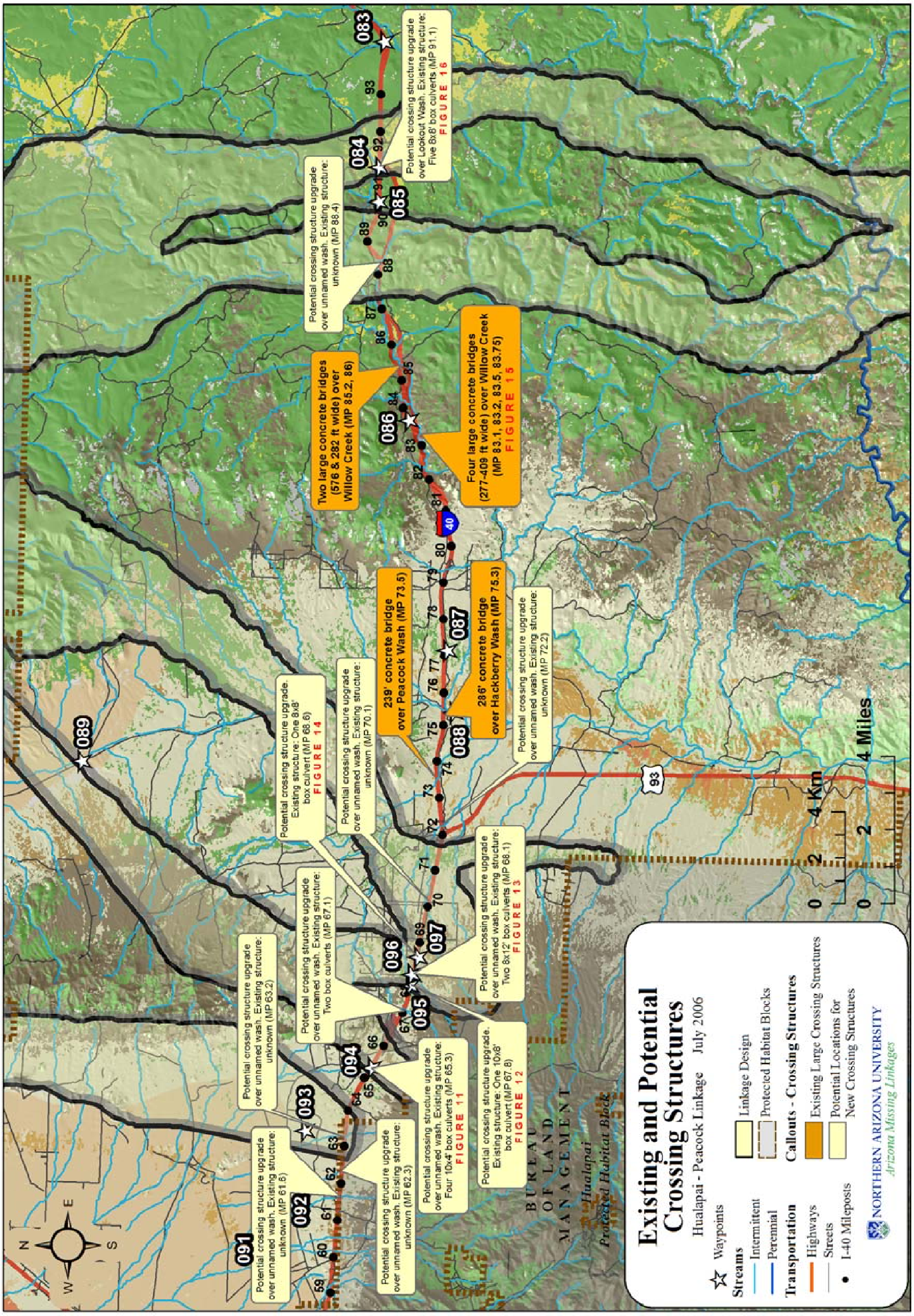

Figure 11: Crossing structures in Linkage Design. Note that the existing bridges (indicated by orange text boxes) occur *outside* of the Linkage Design.

Figure 12: Looking north, four 4x10 ft box culverts provides only limited connectivity due to a heavily silted-in bottom (waypoint 094).

Figure 13: Looking southwest from waypoint 095, a single 10x8' box culvert runs under I-40. A dirt road runs through the culvert.

Figure 14: Looking south-southeast from waypoint 096, two 8x12 ft culverts under I-40 are unusable to most species due to a 3 ft pour-off (top) and an angled exit (bottom).

Figure 15: Looking northeast from waypoint 097, a single 8x8 ft culvert crosses under I-40.

Figure 16: Large bridges in the eastbound lanes of I-40 cross Willow Creek in 6 locations between milepoints 83.1-86. This photo taken from waypoint 086 shows bridge at MP 83.75.

Figure 17: Looking southeast from waypoint 084, five 8x8 box culverts cross over Lookout Wash.

Figure 18: Six culverts cross under the westbound lanes of I-40 for the wash (bottom).

Recommendations for Highway Crossing Structures

The existing crossing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between the Hualapai/Aquarius and Peacock-Cottonwood wildland blocks must traverse I-40, crossing structures along this highway are crucial to success of the corridor. We recommend upgrading the crossing structures described above as follows:

- In strand A, there should be two large crossing structures (bridge or large box culvert) for mid-sized animals, and one pipe culvert every 300m for passage by small animals. Because we did not attempt to locate small pipe culverts, we do not know how many new ones will be needed. Only one intermittent wash crosses I-40 in this linkage strand, at MP 63.2; this wash is a good location for a larger, more open culvert usable by mid-size animals.

- Build at least 3 new bridges in Strands B and C. These strands provide connectivity for large mammals such as mule deer, elk, and mountain lion; however, existing crossing structures are not large or open enough to meet the needs of these species. One bridge should be created between MP 65 and MP 66.3, replacing the inadequate existing structure over an intermittent wash here (Figure 11). Two additional bridges should be constructed between MP 67.7 and 71.7. Three existing crossing structures described above (Figure 13, Figure 14, Figure 15) provide locations where an existing culvert could be upgraded to a bridge. Another location where a bridge could be installed in the linkage strand is over the unnamed wash at MP 70 (Figure 11)

- Within the eastern fork of Strand D, at least two new bridges should be created. Because large mammals such as pronghorn, elk, mule deer, and mountain lion may pass through this portion of the linkage design, these bridges should be tall and wide enough to provide open, unobstructed views through the bridge. In the western fork of this linkage strand, the existing culvert at MP 88.4 could be upgraded to a bridge. The existing culverts over Lookout Wash (Figure 18) in the eastern fork of this linkage strand could be upgraded to bridges to provide connectivity for pronghorn across I-40. Because the eastbound and westbound lanes of I-40 diverge in this portion of the linkage design, fencing should be installed to guide species to crossing structures.

Urban Development as Barriers to Movement

Urban and industrial development, unlike roads, creates barriers to movement which cannot easily be removed, restored, or otherwise mitigated (Figure 19). Most large carnivores, small mammals, and reptiles cannot occupy these areas for a significant period of time, although several species of lizards or small mammals may occasionally occupy residential areas. While mapped urban areas only accounted for 0.3% of the land cover, residential development appears to be increasing rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

Most of the linkage design is currently free of urban barriers; however, two planned residential developments between the Kingman Airport and Peacock Mountains threaten connectivity in Strand A (Figure 20). The Peacock Highlands Development has been planned as a self-contained community occupying 7,176 acres of land that is now covered with native vegetation. Of these 7,176 acres, 4,450 acres are planned for residential use, 2,726 acres are planned for non-residential use; 615 acres will be for three golf courses, 433 acres will be for parks, and 62 acres will be for clubhouse and recreation (Rhodes Homes Arizona 2005). As of February 2005, 46,026 dwelling units are planned for the Peacock Highlands Development, composed of 22% low density (4 units per acre), 43% medium density (6 units per acre), and 35% high density housing settlements (12 units per acre). The location where the Peacock Highlands Development is mostly composed of mid-elevation desert scrub, providing potential habitat for species such as badger, black-tailed jackrabbit, Gila monster, javelina, and kit fox (Figure 21).

Figure 19: This photo taken northwest of the westernmost strand of the linkage design (waypoint 090) illustrates a linear strip of urban development that likely impedes animal movement. A more compact urban development would not present such a large barrier.

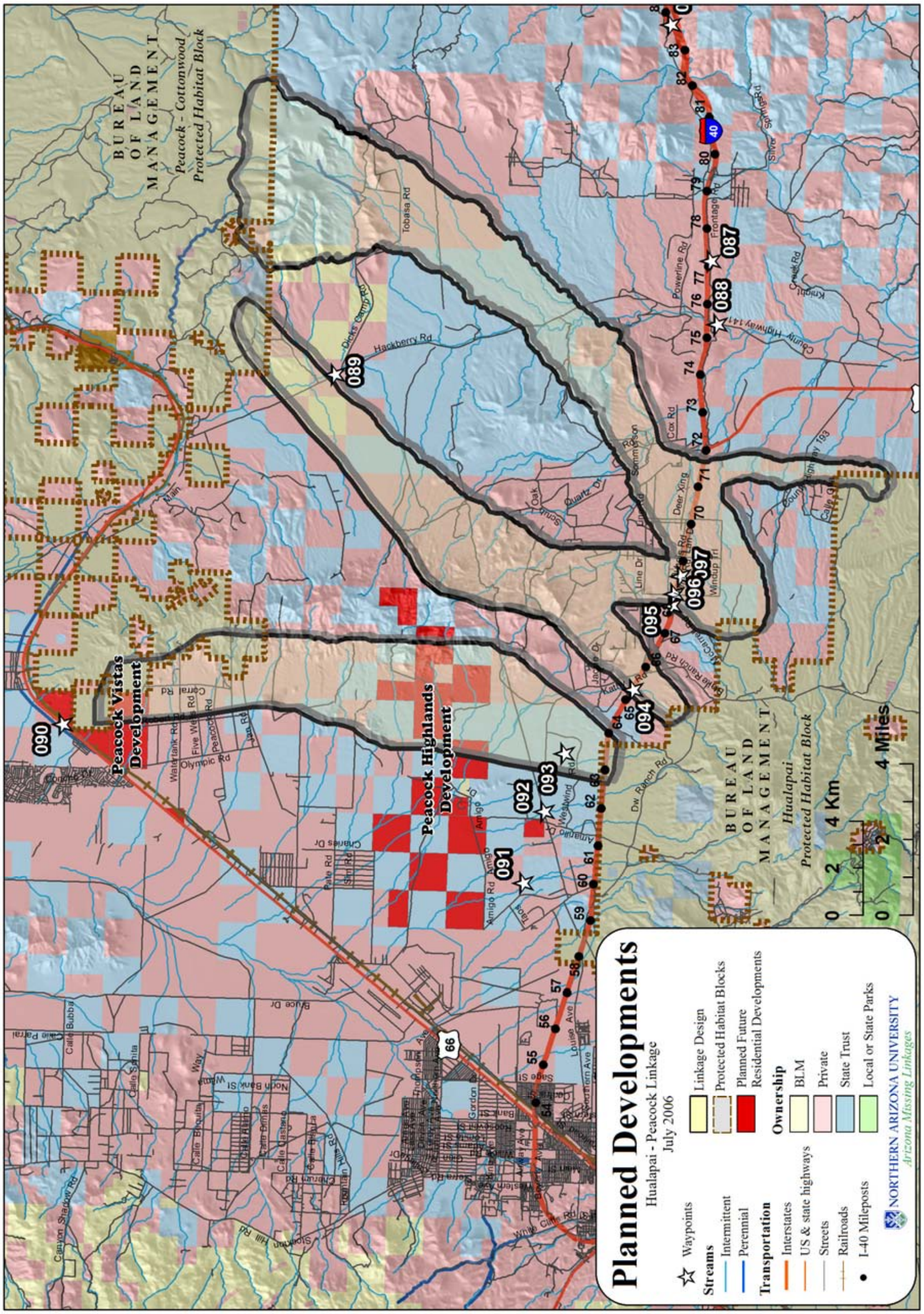

Figure 20: The planned Peacock Highlands and Peacock Vistas residential developments may negatively affect connectivity if precautions are not taken.

Figure 21: The land on which Peacock Highlands would be developed is now covered with mid-elevation desert scrub. Both photos taken from waypoint 093. Top photo looks north, bottom photo looks northeast towards Peacock Mountains.

Rhodes Homes is also planning the Peacock Vistas Development, which would build 9,490 dwelling units (3,419 units at low density, 1,784 units at medium density, and 4,287 units at high density) on 2,087 acres, and would affect the northern connection of the linkage design with the Peacock Mountains (Figure 20). In addition to the 1,510 acres planned for residential uses, 338 acres are planned for commercial development.

Scaling back both of these developments to avoid building in Strand A of the Linkage Design (Figure 19) would mitigate their impact on wildlife connectivity. In general, planning for compact growth near existing urban areas will have much less impact on wildland connectivity than "leapfrog" developments, especially developments that are highly linear (Figure 18) or involve every other section of a checkerboard (Figure 19).

Mitigation for Urban Barriers

To conserve connectivity, we have the following recommendations for all existing and future urban, residential, and industrial developments in this linkage zone:

1) Encourage conservation easements and land acquisition with willing land owners in the Linkage Design to protect important habitat.
2) Develop a public education campaign to inform those living and working within the linkage area about the local wildlife and the importance of maintaining ecological connectivity.
3) Encourage homeowners to focus outside lighting on their houses only, and never out into the linkage area.
4) Ensure that all domestic pets are kept indoors or in fenced areas.
5) Reduce vehicle traffic speeds in sensitive locations and create adequate crossing structures over washes throughout developed areas.
6) Discourage the conversion of natural areas within the Linkage Design into residential areas. Where development is permitted, encourage small building footprints on large (> 10-acre) parcels.
7) Encourage the use of wildlife-friendly fencing.
8) Discourage the killing of 'threat' species such as rattlesnakes.

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[2]. 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

[2] 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.

focal species to 8 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.

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 22):

- *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[3].

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[4] 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.

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

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

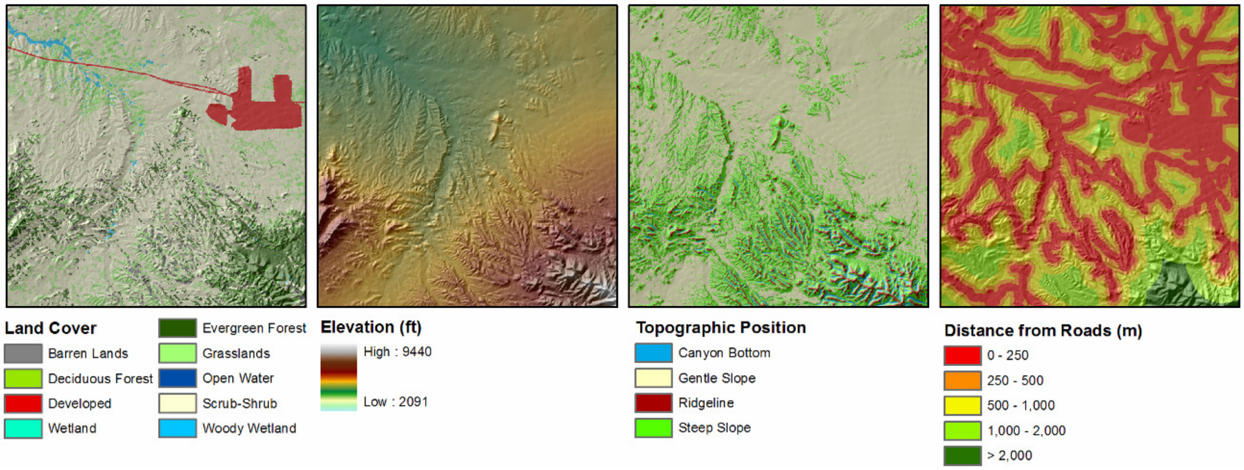

Figure 22: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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 23). We averaged habitat suitability within a 3x3-pixel neighborhood (0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[5]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 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.

[5] An animal that moves over large areas for daily foraging perceives the landscape as composed of relatively large patches, because the animal readily moves through small swaths of unsuitable habitat in an otherwise favorable landscape (Vos et al. 2001). In contrast, a less-mobile 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.

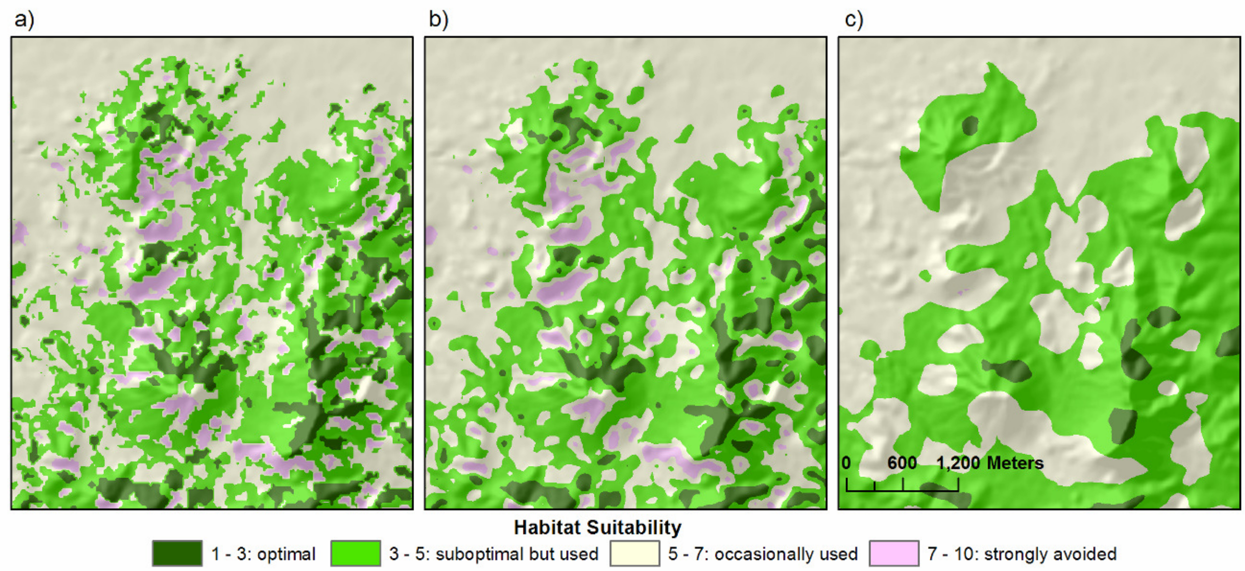

Figure 23: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

Identifying Biologically Best Corridors

The *biologically best corridor*[6] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one protected habitat block to a potential population core in the other protected habitat 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).

We then identified potential population cores and habitat patches that fell completely within each protected habitat 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 protected habitat block or (for a wide-ranging species with no potential habitat patch entirely within a habitat block) any suitable habitat within the protected block.

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[7]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected habitat block. We similarly calculated the lowest cumulative travel cost from the 2nd protected habitat block, and added these 2 travel costs to calculate the *total travel cost* for

[6] 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.
[7] Levey et al. (2005) provide evidence that animals make movement decisions based on habitat suitability.

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 24). 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.

After developing a biologically best corridor for each species, we combined biologically best corridors to form a union of biologically best corridors (UBBC).

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[8] 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 habitat block, we added these polygons to the UBBC to create a *preliminary linkage design*.

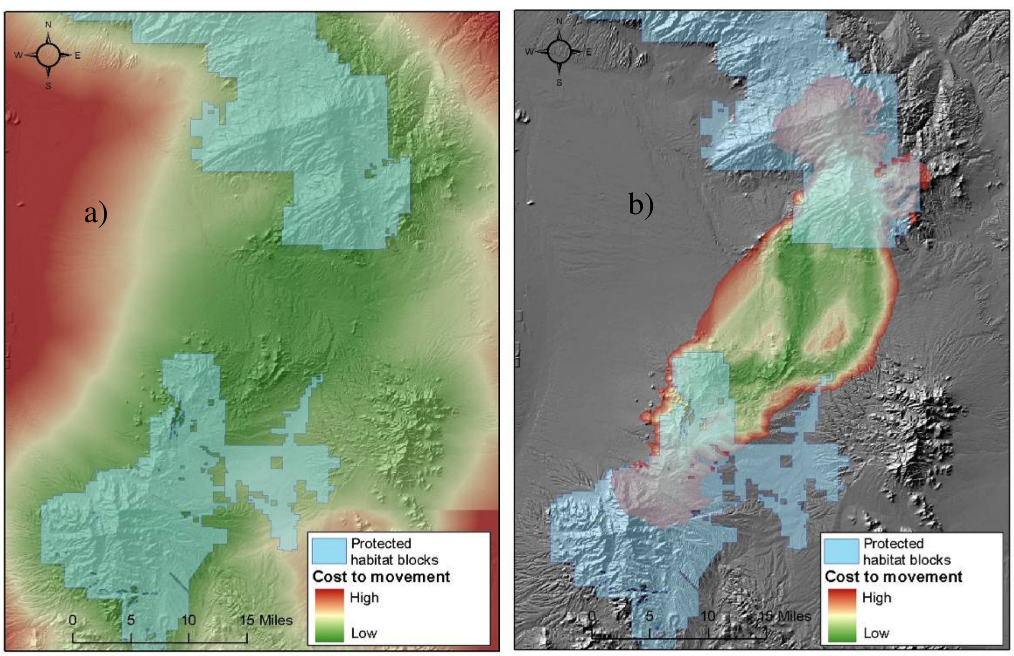

Figure 24: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

[8] 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.

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, 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.

Appendix B: Individual Species Analyses

Table 4: 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	Black Bear	Black-tailed Jackrabbit	Elk	Javelina
Factor Weights					
Land Cover	65	75	70	75	50
Elevation	7	10	10	0	30
Topography	15	10	10	0	20
Distance from Roads	13	5	10	25	0
Land Cover					
Pine-Oak Forest and Woodland	5	1	6	1	7
Pinyon-Juniper Woodland	4	6	4	1	5
Ponderosa Pine Woodland	5	4	6	1	6
Juniper Savanna	2	7	3	1	7
Semi-Desert Grassland and Steppe	1	5	4	7	2
Big Sagebrush Shrubland	3	7	2	6	9
Chaparral	5	3	6	4	3
Creosotebush-White Bursage Desert Scrub	2	9	2	9	4
Mesquite Upland Scrub	3	6	4	7	2
Mid-Elevation Desert Scrub	3	5	1	8	2
Paloverde-Mixed Cacti Desert Scrub	4	5	1	8	1
Riparian Mesquite Bosque	6	5	5	3	1
Riparian Woodland and Shrubland	6	5	4	2	2
Barren Lands, Non-specific	7	10	8	10	9
Invasive Grassland or Forbland	4	10	5	4	5
Invasive Riparian Woodland and Shrubland	8	10	5	2	5
Agriculture	6	6	6	7	7
Developed, Medium - High Intensity	10	10	9	10	7
Developed, Open Space - Low Intensity	7	10	6	7	4
Elevation (ft)					
Elevation range: cost	0-5500: 1 5500-8000: 3 8000-11000: 6	0-2500: 8 2500-4000: 6 4000-6500: 2 6500-8500: 3 8500-11000: 4	0-6000: 1 6000-8000: 4 8000-11000: 8		0-5000: 1 5000-7000: 3 7000-11000: 10
Topographic Position					
Canyon Bottom	5	3	3		1
Flat - Gentle Slopes	1	6	1		1
Steep Slope	8	3	4		7
Ridgetop	7	4	4		4
Distance from Roads (m)					
Distance from roads range: cost	0-250: 6 250-1500: 1	0-100: 10 100-500: 4 500-15000: 1	0-250: 9 250-500: 6 500-1000: 3 1000-15000: 1	0-100: 9 100-200: 8 200-400: 6 400-1000: 5 1000-2000: 2 2000-15000: 1	

	Kit Fox	Mountain Lion	Mule Deer	Pronghorn	Gila Monster
Factor Weights					
Land Cover	75	70	80	45	10
Elevation	0	0	0	0	35
Topography	15	10	15	37	45
Distance from Roads	10	20	5	18	10
Land Cover					
Pine-Oak Forest and Woodland	8	1	3	8	10
Pinyon-Juniper Woodland	8	1	5	6	6
Ponderosa Pine Woodland	8	4	5	7	10
Juniper Savanna	3	4	4	4	10
Semi-Desert Grassland and Steppe	1	5	2	1	5
Big Sagebrush Shrubland	4	6	3	4	10
Chaparral	6	3	4	8	6
Creosotebush-White Bursage Desert Scrub	1	6	6	2	7
Mesquite Upland Scrub	5	4	3	7	4
Mid-Elevation Desert Scrub	1	6	6	3	3
Paloverde-Mixed Cacti Desert Scrub	3	7	3	3	1
Riparian Mesquite Bosque	4	4	3	8	5
Riparian Woodland and Shrubland	5	2	3	8	5
Barren Lands, Non-specific	9	8	10	7	10
Invasive Grassland or Forbland	4	7	5	3	10
Invasive Riparian Woodland and Shrubland	6	5	3	8	4
Agriculture	7	10	6	8	10
Developed, Medium - High Intensity	9	10	9	10	9
Developed, Open Space - Low Intensity	7	8	5	8	1
Elevation (ft)					
Elevation range: cost					0-1700: 4 1700-4000: 1 4000-4800: 4 4800-5700: 7 5700-11000: 10
Topographic Position					
Canyon Bottom	7	1	2	7	1
Flat - Gentle Slopes	1	3	2	1	5
Steep Slope	5	3	4	8	1
Ridgetop	4	4	6	6	1
Distance from Roads (m)					
Distance from roads range: cost	0-50: 7 50-250: 3 250-500: 2 500-15000: 1	0-200: 8 200-500: 6 600-1000: 5 1000-1500: 2 1500-15000: 1	0-250: 7 250-1000: 3 1000-15000: 1	0-100: 10 100-250: 6 250-1000: 3 1000-15000: 1	0-1000: 5 1000-3000: 3 3000-15000: 1

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 4.

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 – Nearly all habitat within the linkage zone was calculated as suitable (cost <5), so the standard geometric habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area, although optimal habitat is located between wildland blocks (Figure 25). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.7 to 10.0, with an average suitability cost of 2.9 (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 26).

Union of biologically best corridors – The two additional strands of the UBBC between the Hualapai and Peacock-Cottonwood wildland blocks also provide potential habitat for badger in the linkage design. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threats to its connectivity and persistence are likely high-traffic roads such as I-40 and habitat fragmentation.

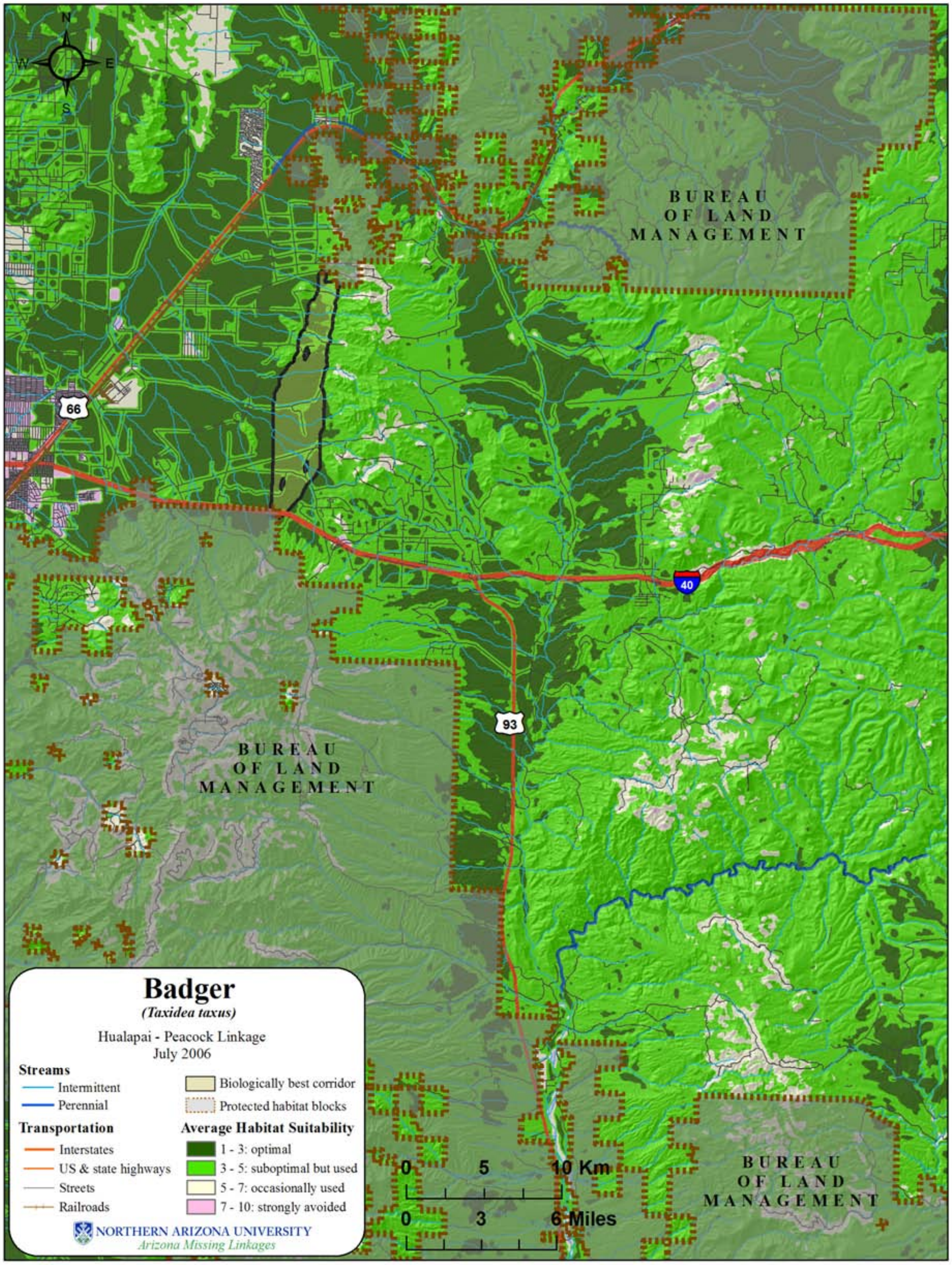

Figure 25: Modeled habitat suitability of badger.

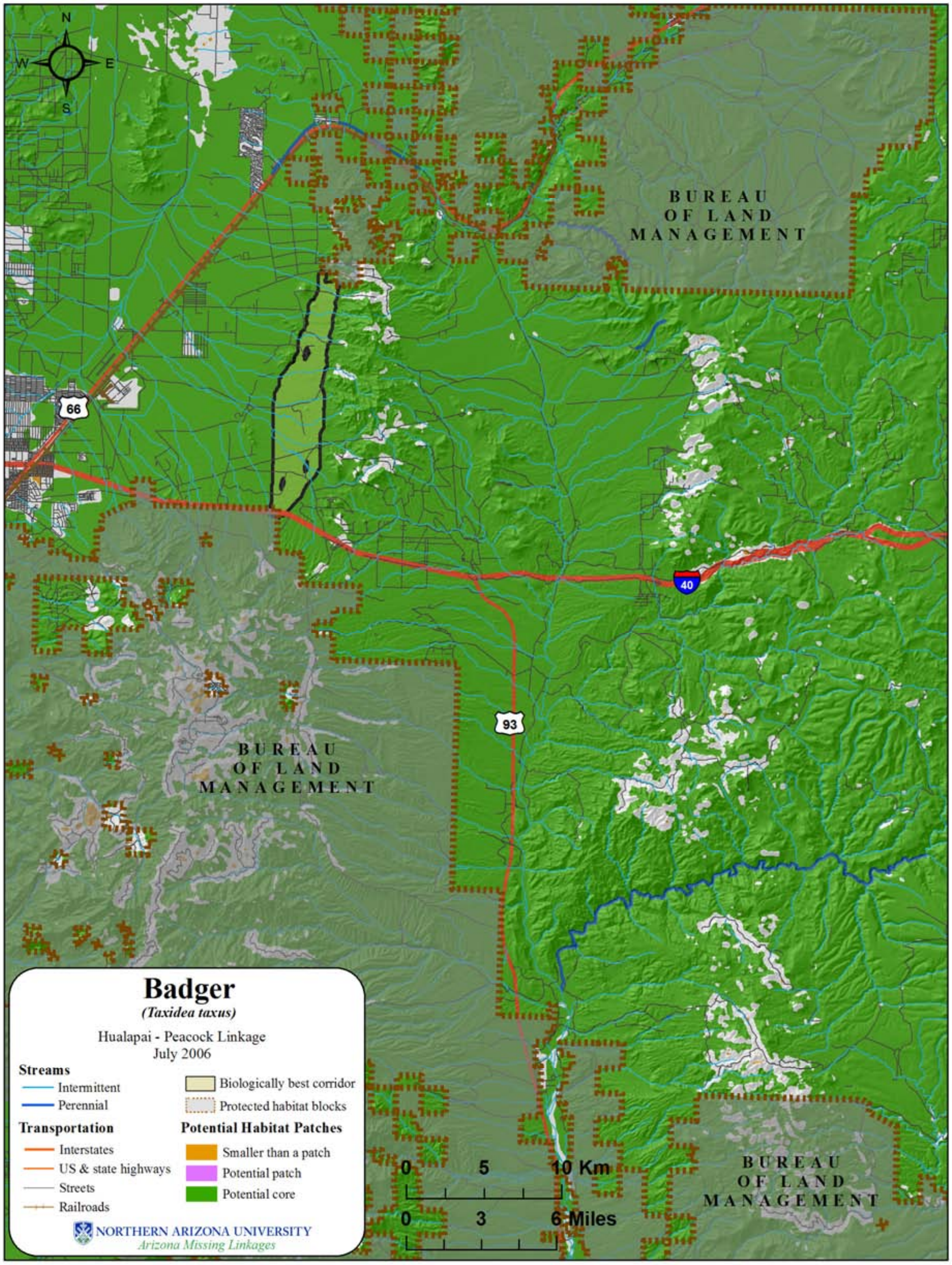

Figure 26: Potential habitat patches and cores for badger.

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). Within the linkage planning area, black bear have seen by Willow Ranch near Knight Creek and the edge of Truxton flat along Wright Creek (AZGFD 2006).

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 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 10 km2, 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 50km2, 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 (Hoffmeister 1986), have some habitat along Trout and Knight Creeks within the Aquarius protected block, and are occasionally are found near Truxton flat in the Peacock-Cottonwood protected block (AZGFD Hunting Unit Reports). Because black bear habitat is limited in the linkage area, and no potential habitat cores are within the Peacock-Cottonwood block, we did not create a biologically best corridor for this species. Instead, we used the standard habitat suitability model to assess potential habitat for this species within the union of biologically best corridors.

Results & Discussion

Union of biologically best corridors – The union of biologically best corridors encompasses only marginal bear habitat. Two strands of the linkage design capture potential habitat in the foothills of the Peacock Mountains, and the easternmost corridor of the UBBC, composed primarily of pinyon-juniper woodlands, provides an important seasonally-used food item, but does not provide for all needs of black bears (S. Cunningham, personal comm.).

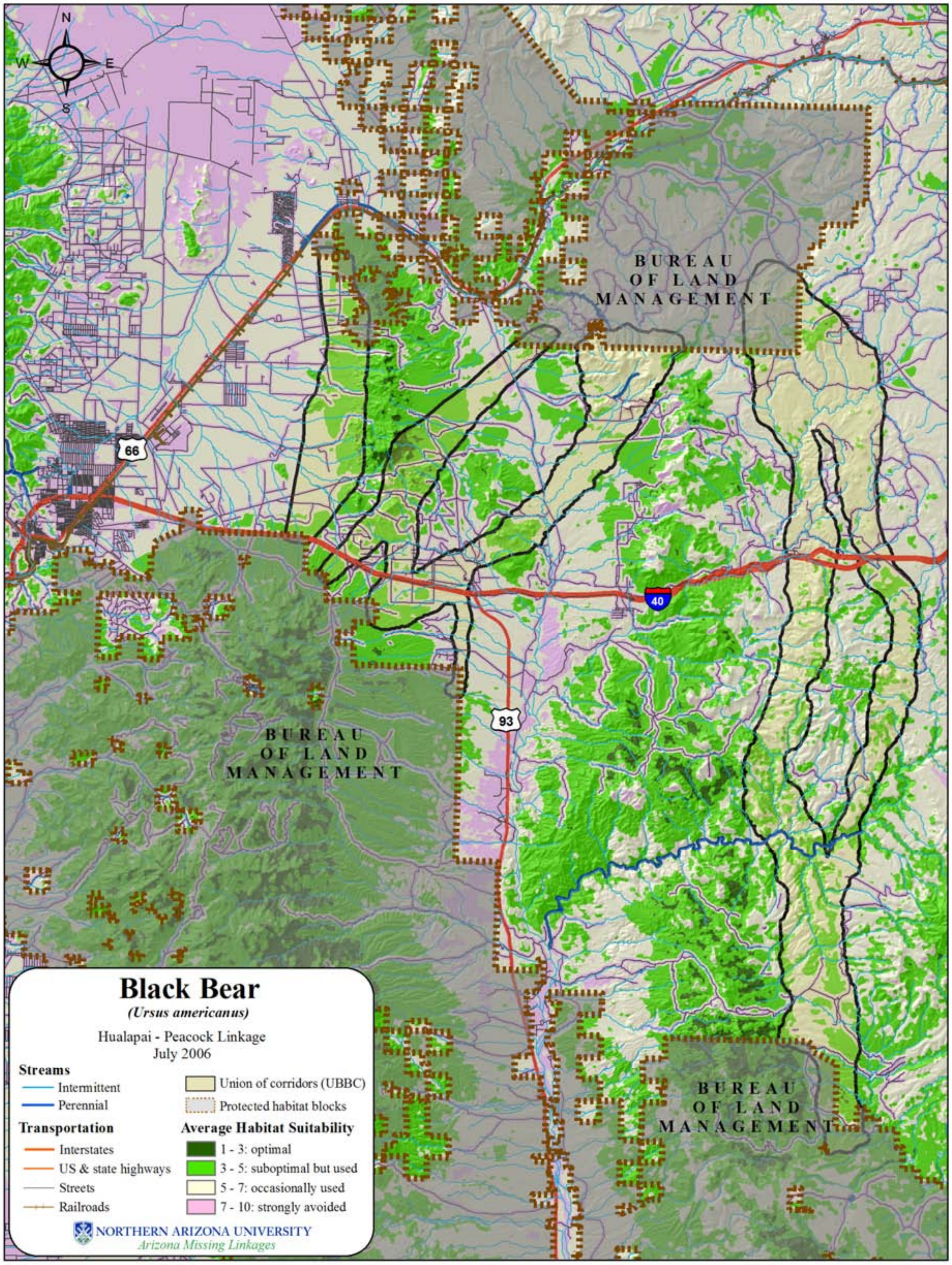

Figure 27: Modeled habitat suitability of black bear.

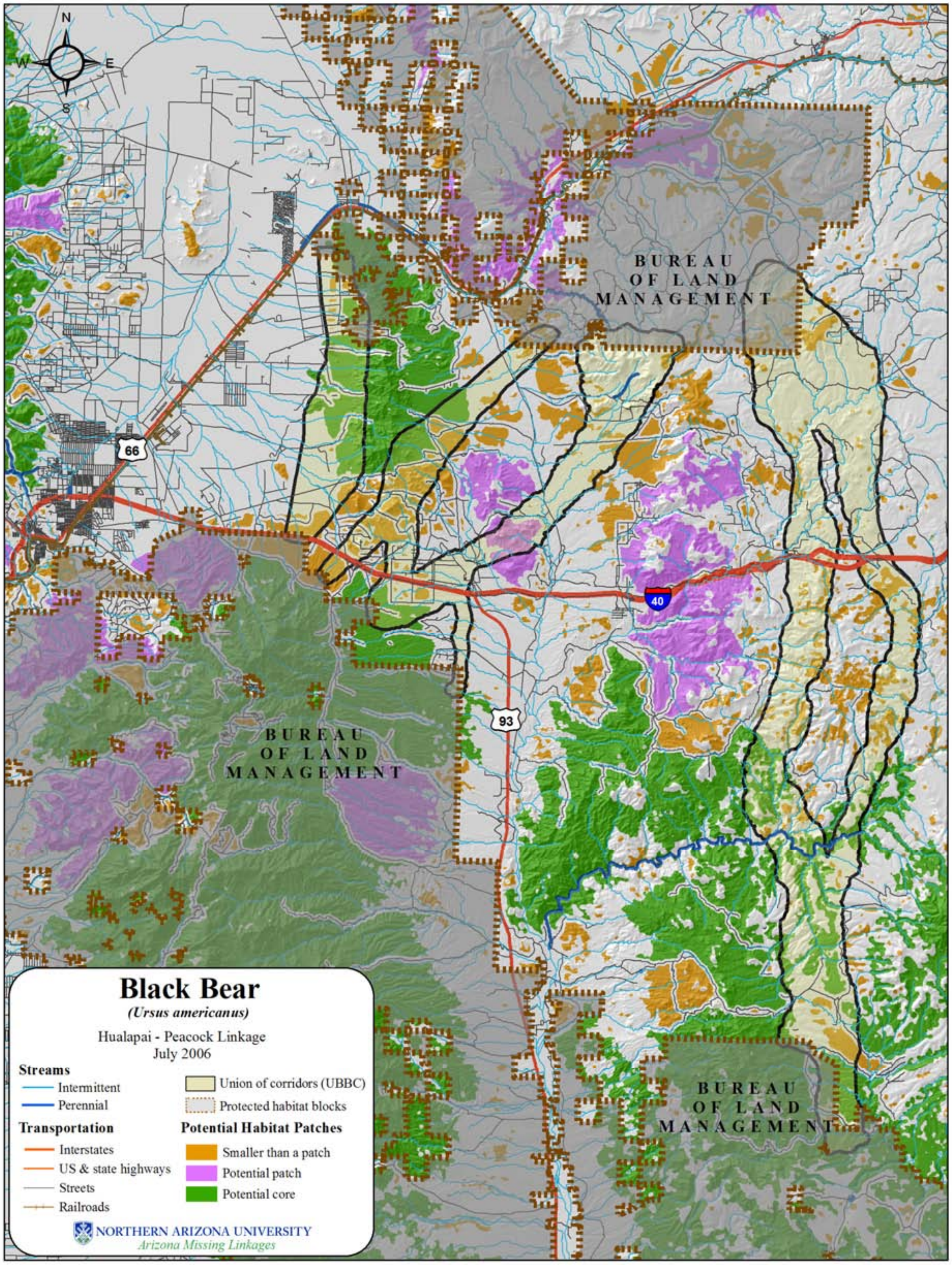

Figure 28: Potential habitat patches and cores for black bear.

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 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 100 hectares (Best 1993), and minimum potential habitat core size was defined as 500 ha, 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 3x3 neighborhood moving window analysis.

Biologically best corridor analysis –Nearly all habitat within the linkage zone was calculated as suitable, so the standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area, with optimal habitat located between wildland blocks (Figure 29). The biologically best corridor for this species consisted of two nearly distinct strands, which are comparable in habitat quality. 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 the entirety of the corridor is a potential habitat core (Figure 30).

Union of biologically best corridors – Because both strands of the biologically best corridor for this species were similar in habitat quality, we felt removing the westernmost strand for the UBBC was justified. Nearly the entire UBBC is a potential core for this species, although the easternmost strand of the linkage design is composed of less suitable habitat. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threats to its connectivity and persistence are likely high-traffic roads such as I-40 and habitat fragmentation.

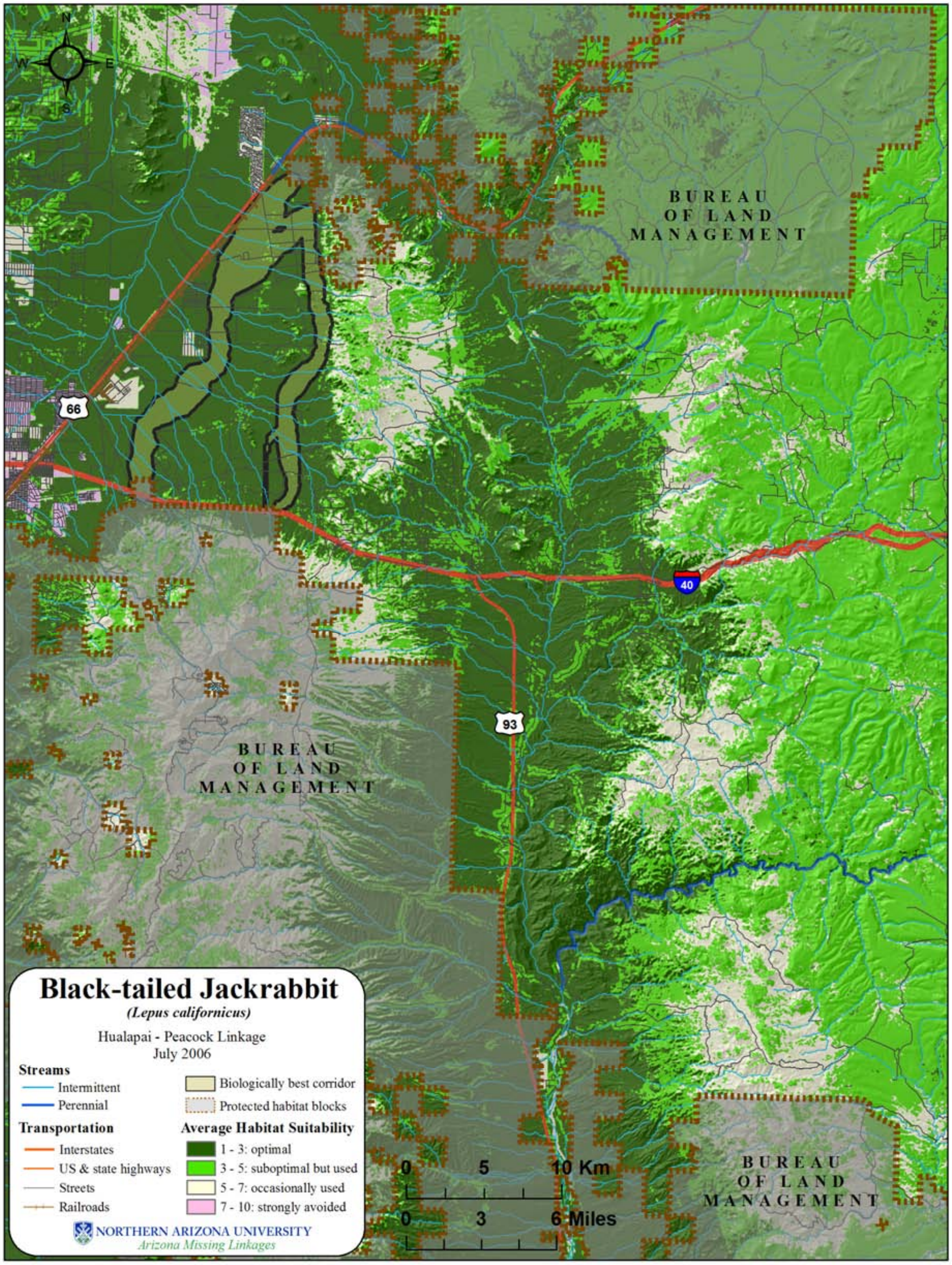

Figure 29: Modeled habitat suitability of black-tailed jackrabbit.

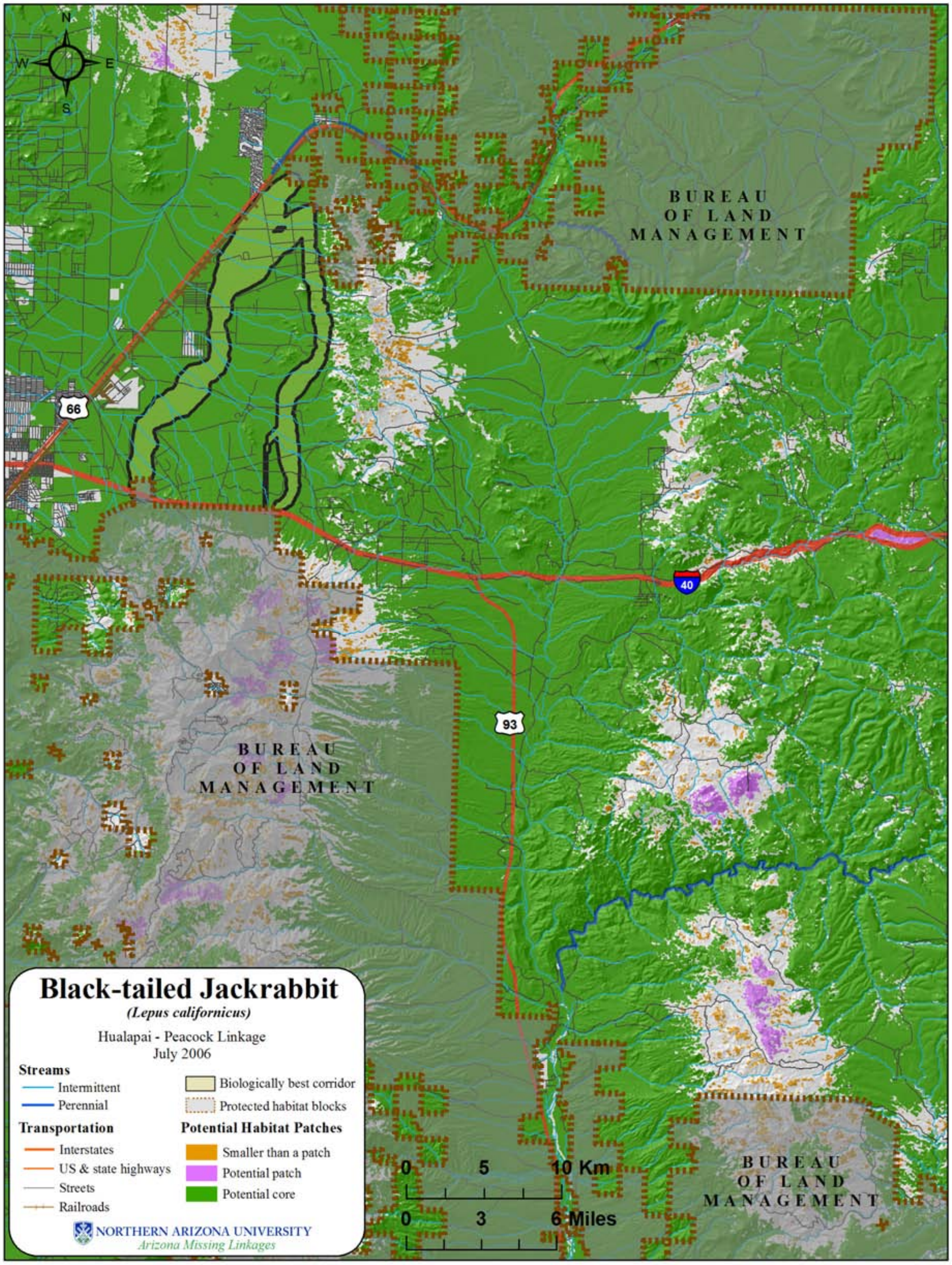

Figure 30: Potential habitat patches and cores for black-tailed jackrabbit.

Elk (*Cervus elaphus*)

Justification for Selection
Elk are seasonal migrants which require large tracts of land to support viable populations. They are prey for large carnivores such as mountain lion, and 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 Game and Fish Department 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 (7,000 to 10,000 ft) and lower elevation winter range (5,500 to 6,500 ft) (Arizona Game and Fish Department 2006.) Elk may move as far as 100 km to locations 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 4.

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 –The standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for this species within the potential linkage area (Figure 31). Between the Hualapai and Peacock-Cottonwood blocks, the average habitat suitability ranged from 1.0 to 9.0, with an average suitability of 4.4 (S.D: 2.8). Between the Aquarius and Peacock-Cottonwood blocks, the average habitat suitability ranged from 1.0 to 10.0, with an average suitability of 2.3 (S.D: 1.6). The entire corridor between the Aquarius and Cottonwood Mountains is a potential habitat core for elk; however, the corridor between the Hualapai and Cottonwood Mountains is composed of less suitable habitat.

Union of biologically best corridors – The union of biologically best corridors provides an expanded amount of suitable habitat for elk, although optimal habitat is concentrated within the linkage strand between the Aquarius and Cottonwood Mountains (Figure 32). The farthest distance between a core or patch and another core or patch in any of the strands of the UBBC is approximately 17 km in Linkage Strand 3 between the Hualapai and Peacock-Cottonwood blocks. This species appears to be well-served by the linkage design.

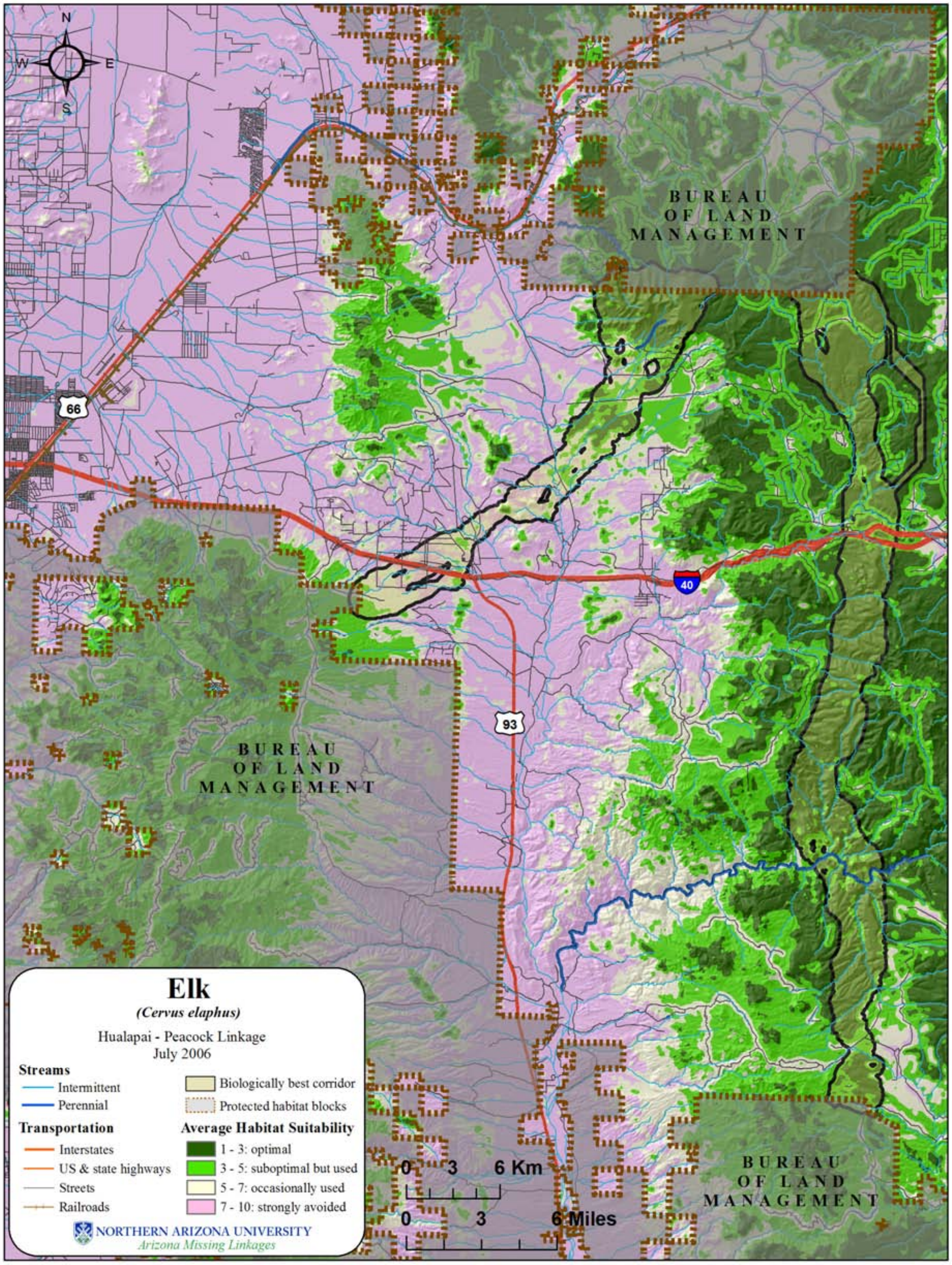

Figure 31: Modeled habitat suitability of elk.

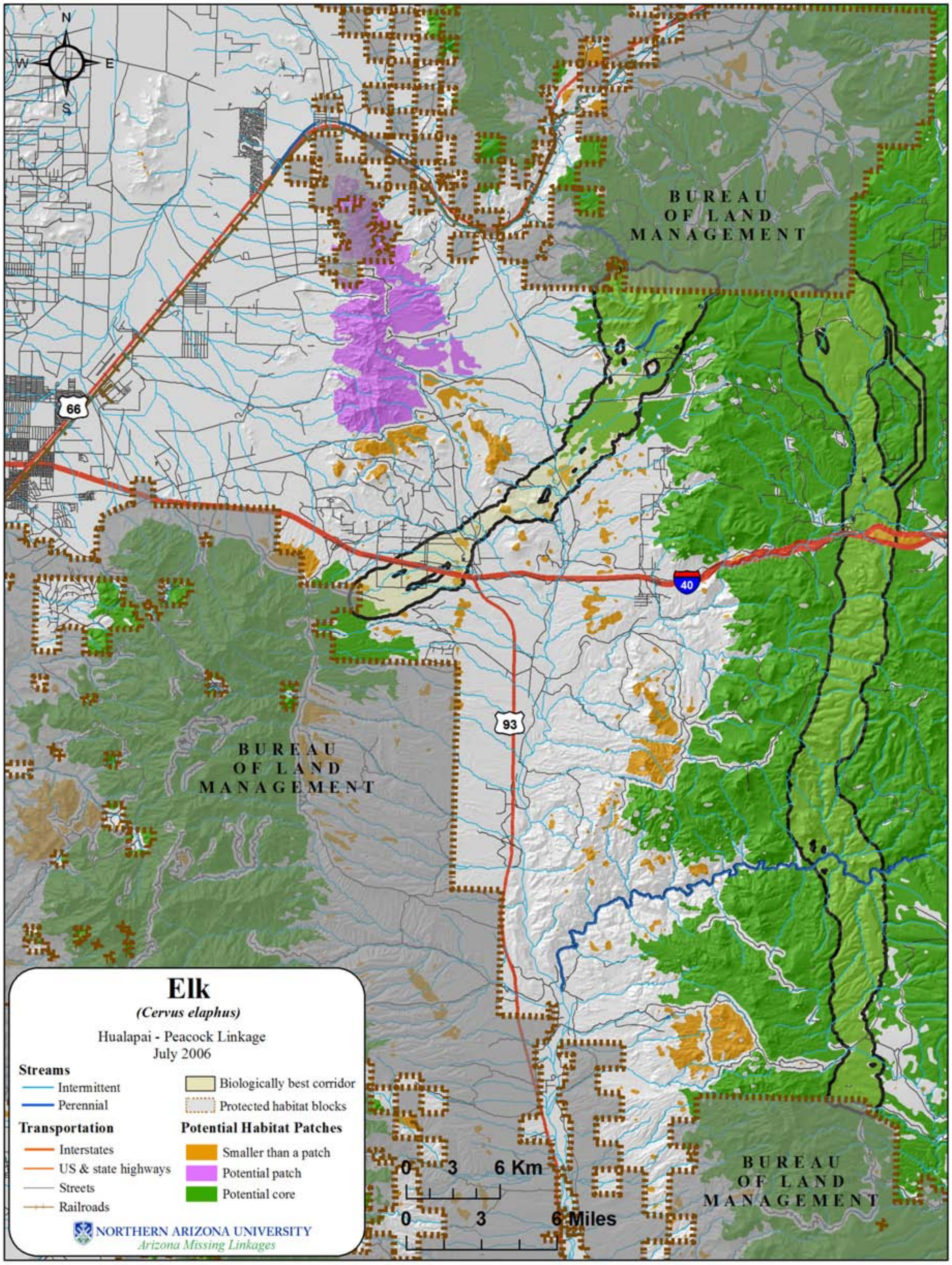

Figure 32: Potential habitat patches and cores for elk.

Javelina (*Tayassu tajacu*)

Justification for Selection

Young javelina are 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 also 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). In Arizona, they occur mostly south of the Mogollon Rim and west to Organ Pipe National Monument (Hoffmeister 1986). Javelina are found in most places throughout the linkage planning area, including near Knight Creek, Trout Creek, Big Sandy River, Wright Creek, Cottonwood Cliffs, Cross Mountain, Juniper Mountains, the Black Mountains, Bozarth Mesa, Goodwin Mesa, and in the chaparral vegetation in the foothills of the Hualapai Mountains (AZGFD 2006).

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 are rarely 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 4.

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, 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 – Nearly all habitat within the linkage zone was calculated as suitable (cost < 5), so the standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant suitable habitat for this species within the potential linkage area (Figure 33). Within the biologically best corridor for this species, habitat suitability ranged from 1.5 to 4.8, with an average suitability cost of 1.6 (S.D: 0.4). 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 34).

Union of biologically best corridors – The two additional strands of the UBBC between the Hualapai and Peacock-Cottonwood wildland blocks are largely composed of potentially optimal habitat for javelina in the linkage design, while the linkage strand between the Aquarius and Cottonwood Mountains is composed of lesser-quality habitat that is still potentially usable. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threats to its connectivity and persistence are likely high-traffic roads such as I-40 and habitat fragmentation.

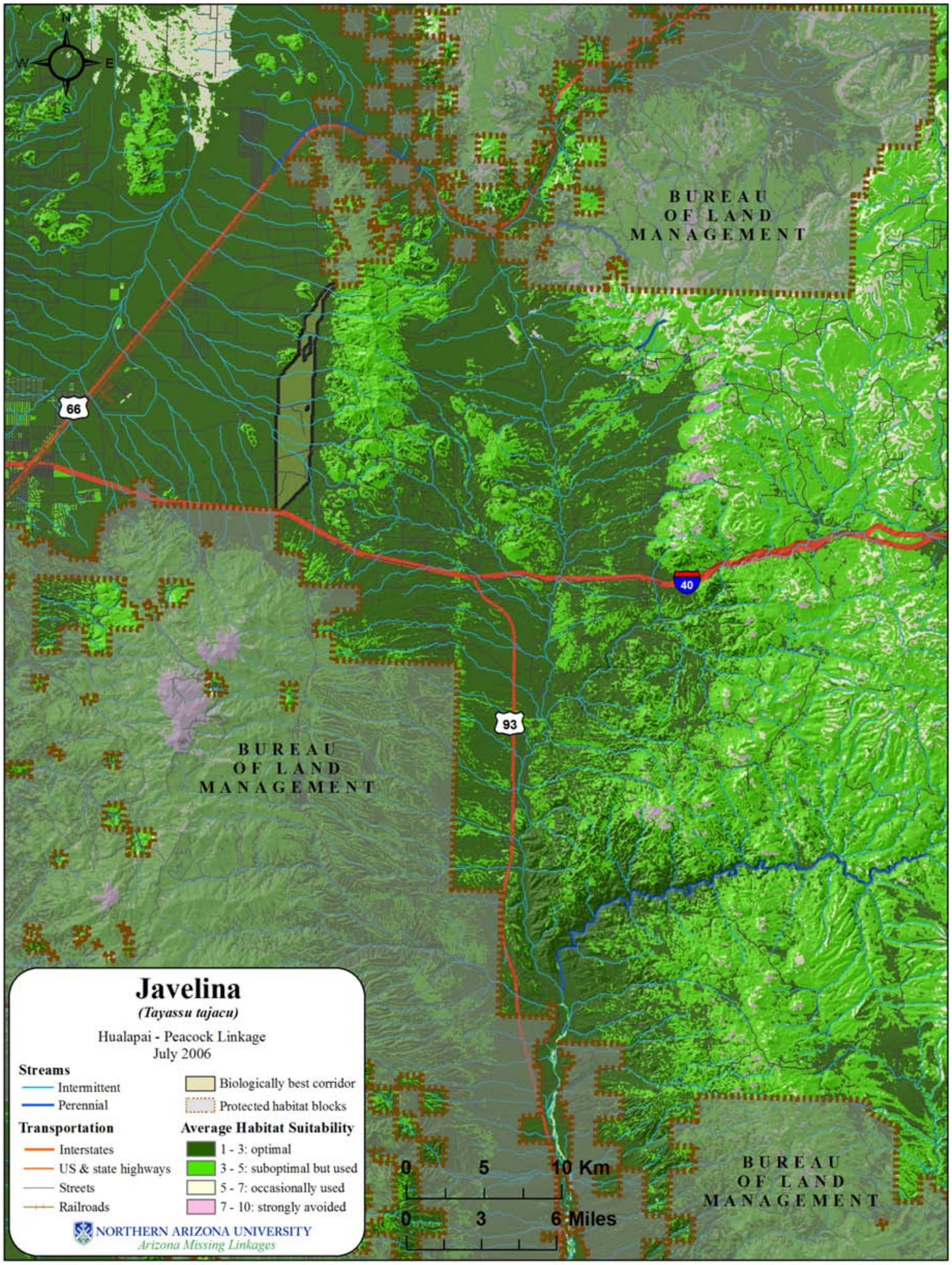

Figure 33: Modeled habitat suitability of javelina.

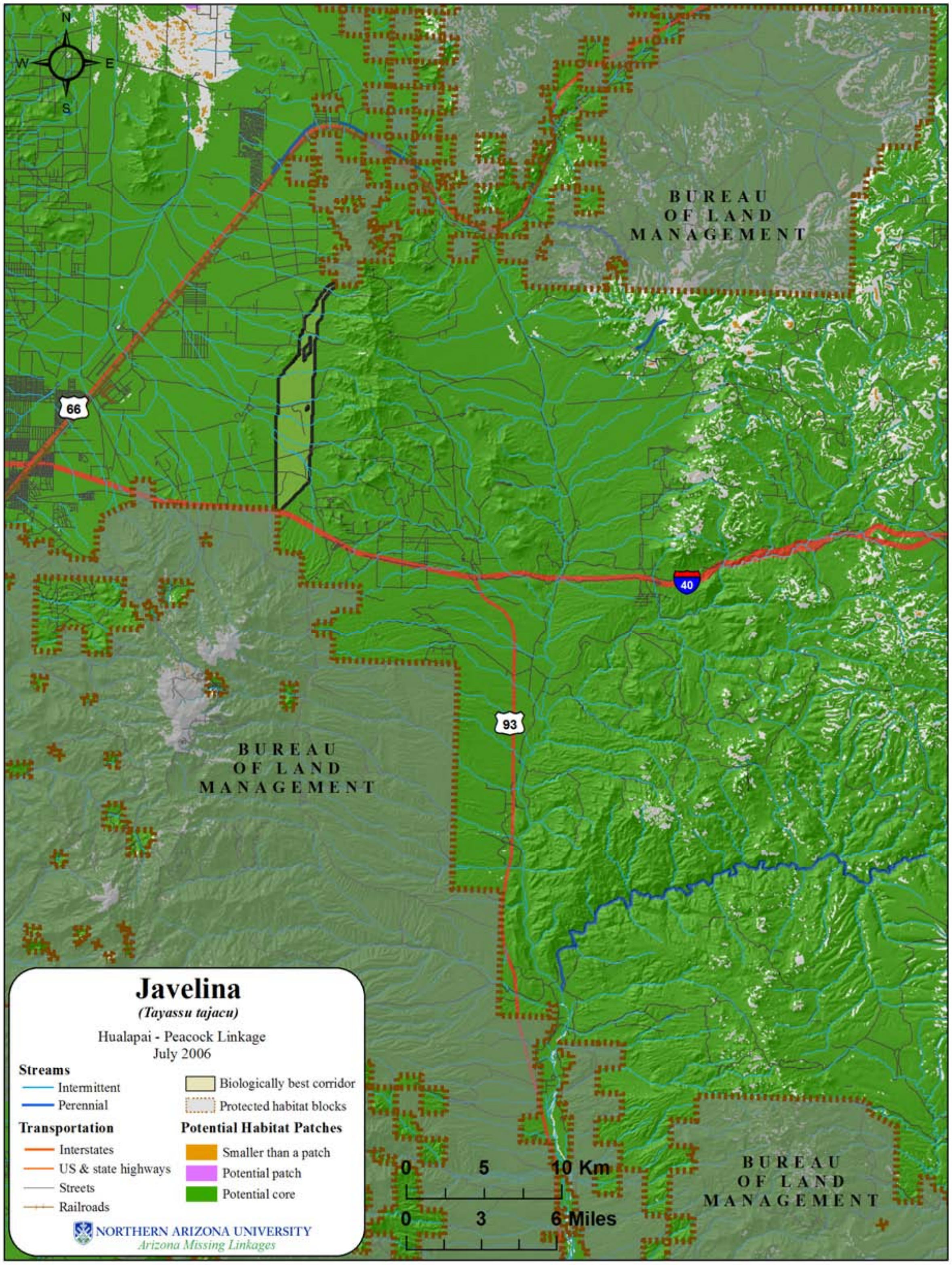

Figure 34: Potential habitat patches and cores for javelina.

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 in 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 1adult per 471 ha to 1 adult per 1,036 ha (McGrew 1979). Arjo et al. (2003) reported home range size from 1,151-4,308 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 4.

Patch size & configuration analysis – In our analyses, we defined minimum patch size for kit fox as 259 ha and minimum core size as 1,295 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 – Because there is little suitable habitat for kit fox in the forested mountains of the Peacock-Cottonwood, Hualapai, and Aquarius wildland blocks, we did not create a biologically best corridor for the species. Instead, we used the standard habitat suitability model to assess potential habitat for this species within the union of biologically best corridors.

Results & Discussion

Union of biologically best corridors – Optimal habitat for kit fox is found in the desert scrub vegetation associations between the wildland blocks (Figure 35). The three linkage strands between the Hualapai and Peacock-Cottonwood wildland blocks, particularly the westernmost strand, all contain large amounts of potential habitat cores for this species (Figure 36). This species appears to be well-served by the linkage design.

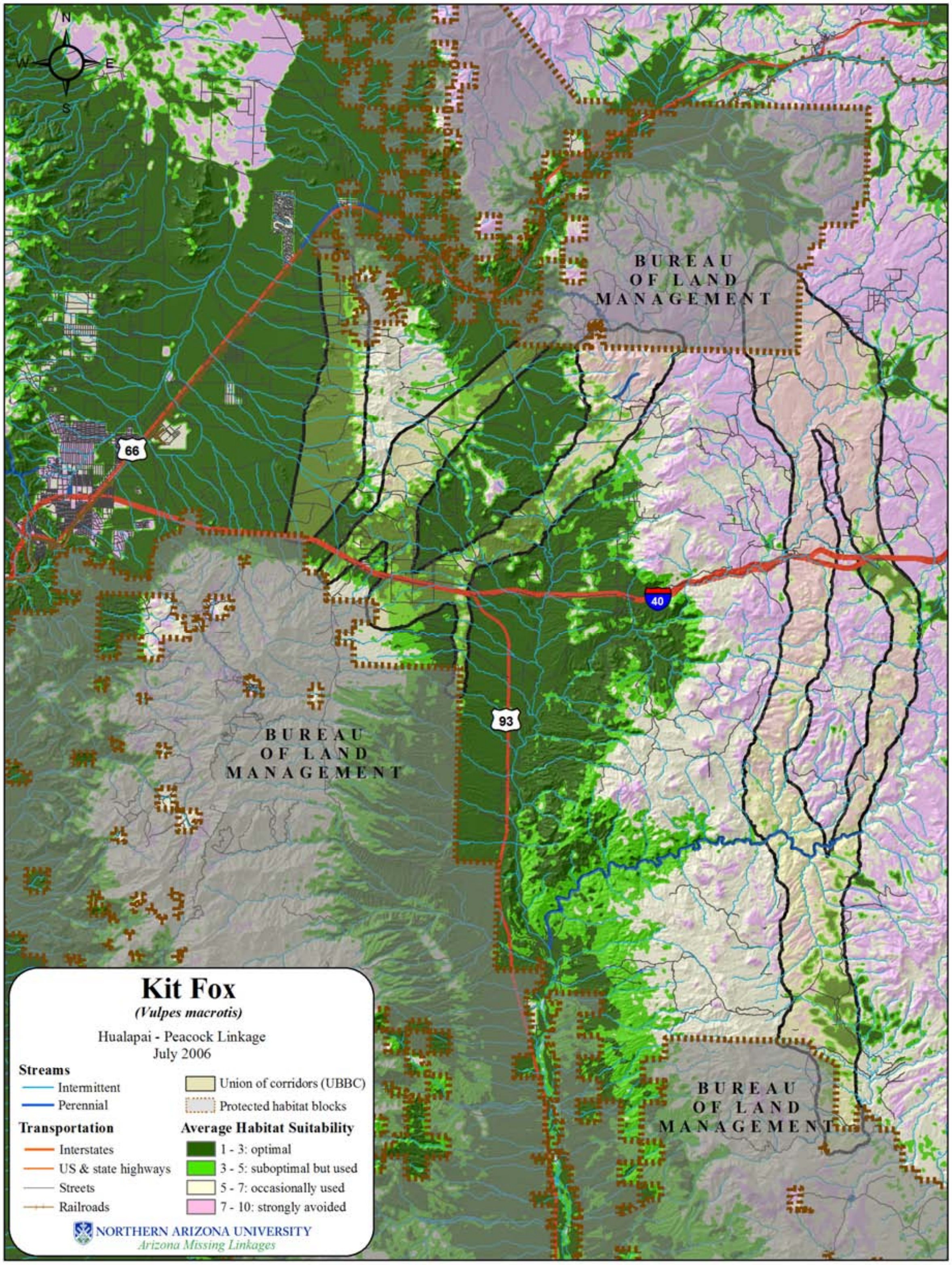

Figure 35: Modeled habitat suitability of kit fox.

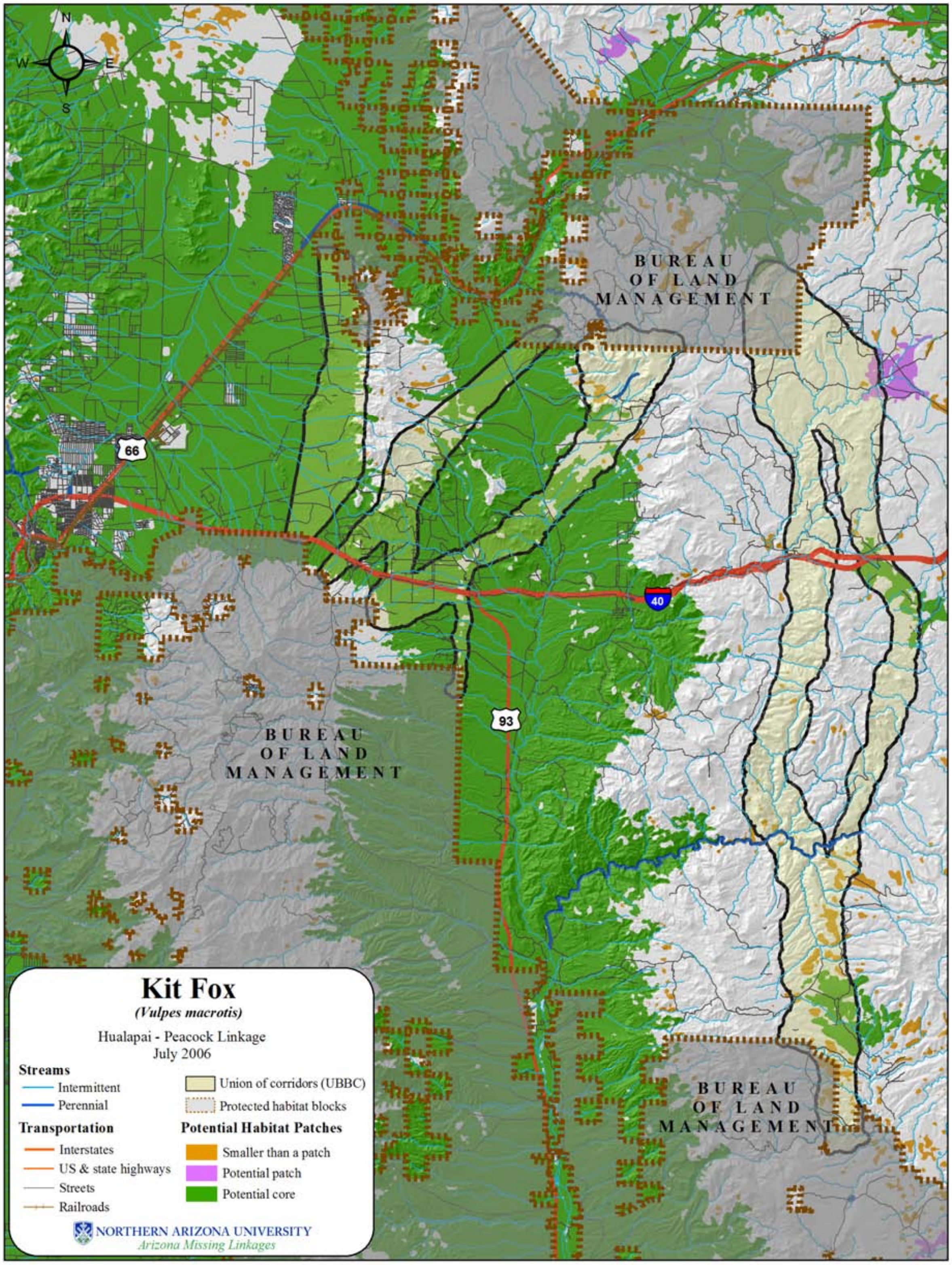

Figure 36: Potential habitat patches and cores for kit fox.

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, Aquarius, Peacock, Music, 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, mixed forests, 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 4.

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* – Most of the habitat within the linkage zone was calculated as suitable (cost <5), so the standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for this species within the potential linkage area (Figure 37). Between the Hualapai and Peacock-Cottonwood blocks, the average habitat suitability ranged from 1.0 to 10.0, with an average suitability of 3.8 (S.D: 1.9). Between the Aquarius and Peacock-Cottonwood blocks, the average habitat suitability ranged from 1.0 to 10.0, with an average suitability of 2.1 (S.D: 1.1). The entire corridor between the Aquarius and Cottonwood Mountains is a potential habitat core for mountain lions, and nearly the entire corridor between the Hualapai and Cottonwood Mountains is composed of suitable habitat.

Union of biologically best corridors – The union of biologically best corridors provides an expanded amount of suitable habitat for mountain lion, although optimal habitat is concentrated within the linkage strand between the Aquarius and Cottonwood Mountains (Figure 38). The farthest distance between a core or patch and another core or patch in any of the strands of the UBBC is approximately 11.2 km in Linkage Strand 3 between the Hualapai and Peacock-Cottonwood blocks, although many stepping-stone patches of habitat provide cover for mountain lions moving between cores. This species appears to be well-served by the linkage design.

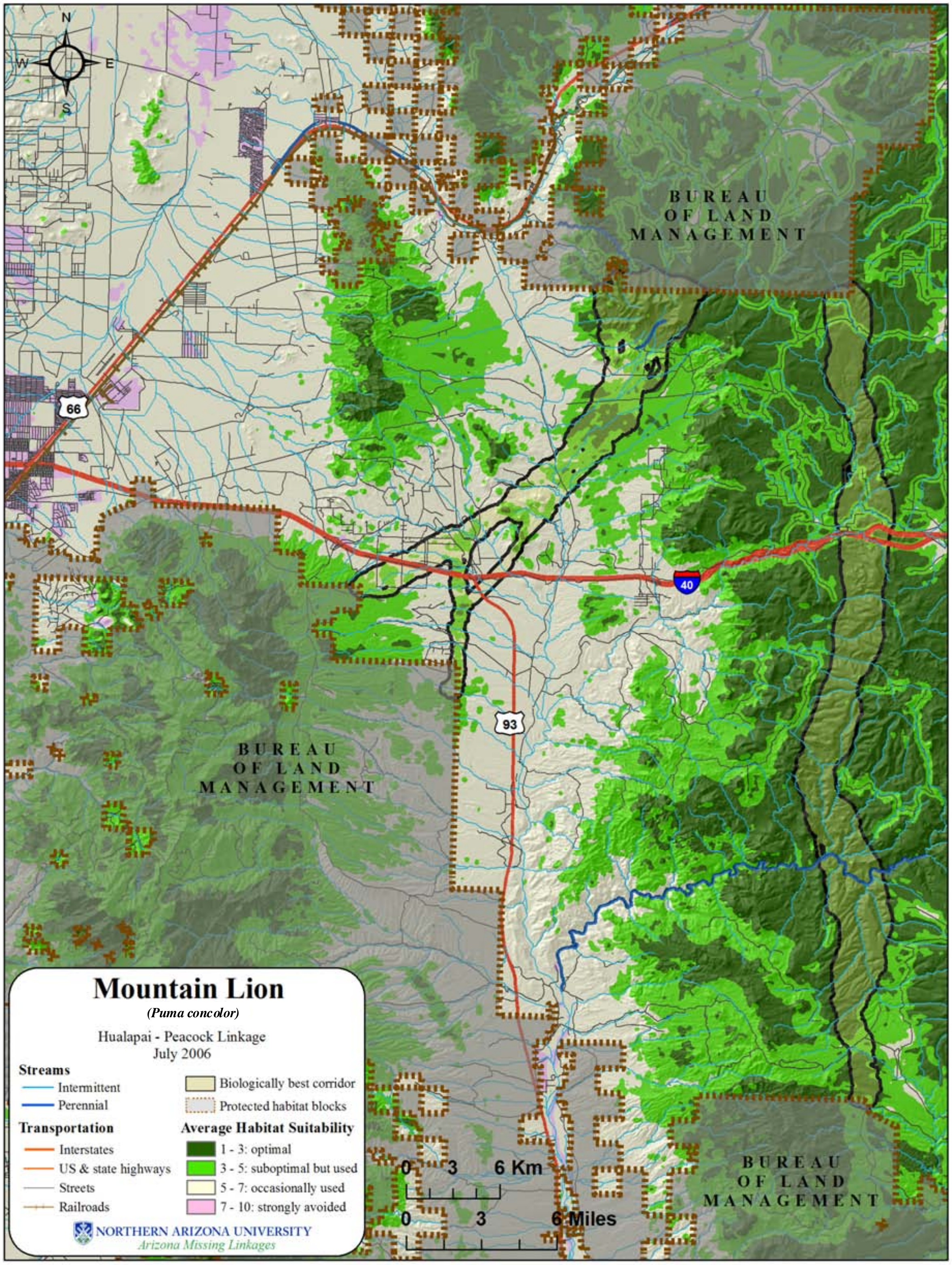

Figure 37: Modeled habitat suitability of mountain lion.

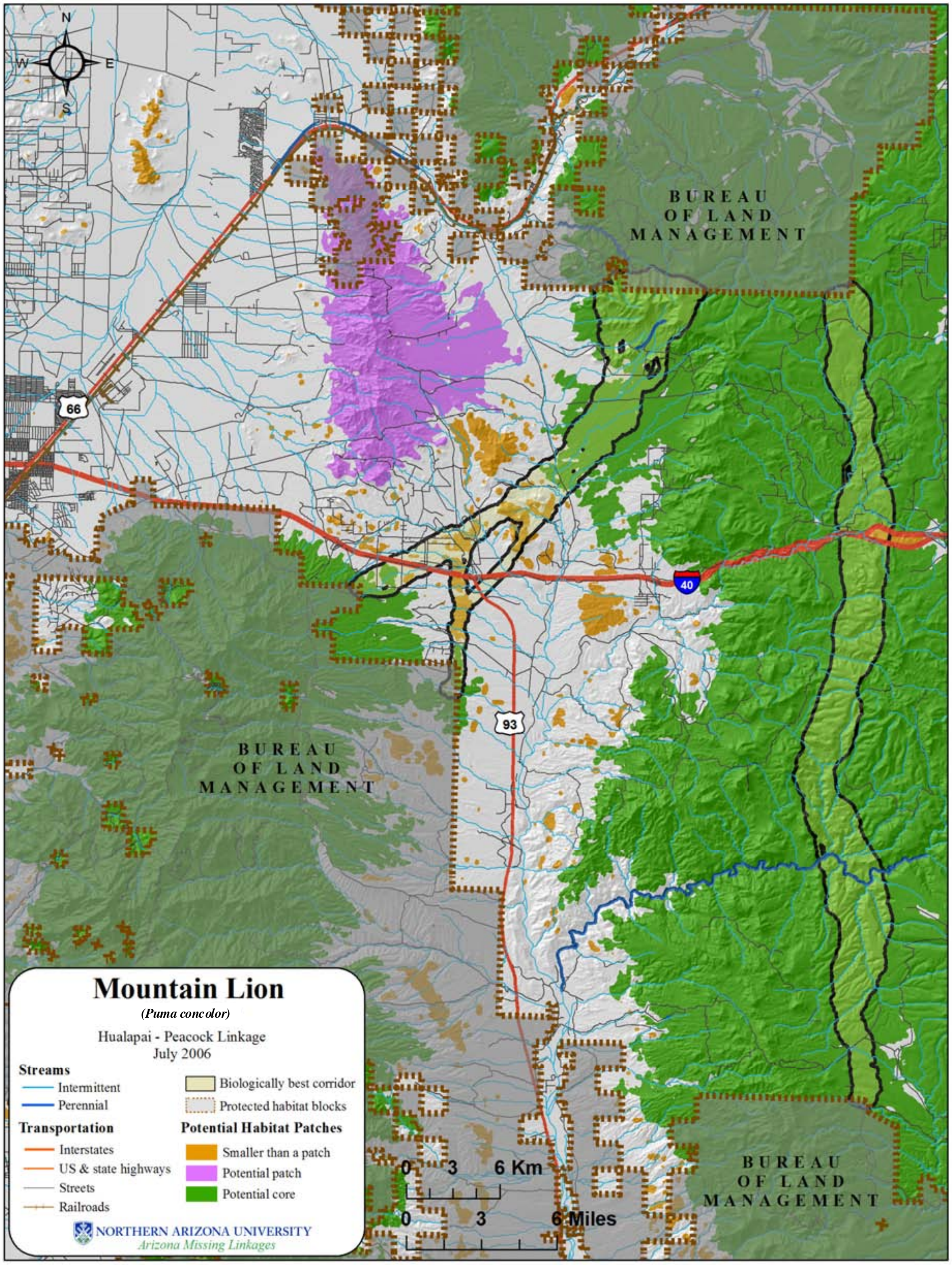

Figure 38: Potential habitat patches and cores for mountain lion.

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

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). The mule deer found in the yellow pine and spruce-fir live there from April to the beginning of winter, when they move down to the pinyon-juniper zone (Hoffmeister 1986). Elsewhere in the state, mule deer live in desert shrub, chaparral or even more xeric habitats, which include scrub oak, mountain mahogany, sumac, skunk bush, buckthorn, and manzanita (Wallmo 1981; Hoffmeister 1986). Mule deer occur in all mountains areas of the linkage planning area, and have high densities in the Peacock Hualapai, and Music Mountains (AZGFD 2006).

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

Conceptual Basis for Model Development
Habitat suitability model – Vegetation has the greatest role in determining deer distributions in desert systems, followed by topography (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 4.

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 due to the species' large spatial requirements.

Biologically best corridor analysis – The standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a fair amount of suitable habitat for this species within the potential linkage area, although nearly all suitable habitat is classified as 'suboptimal but usable' (Figure 39). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 2.4 to 8.6, with an average suitability cost of 4.7 (S.D: 1.0). Within the BBC for this species, potential suitable habitat appears to be abundant. The farthest distance between a core or patch and another core or patch in the biologically best corridor for mule deer is approximately 4.5 km, between the Hualapai protected habitat block and the Peacock Mountains (Figure 40).

Union of biologically best corridors – The strand of the UBBC between the Aquarius and Peacock-Cottonwood protected block significantly increases potential habitat for mule deer, while the westernmost strand of desertscrub plains offers only negligible amounts of suitable habitat. Strand 3 of the UBBC also provides habitat for mule deer; however, the distance between cores within this strand is approximately 14 km, significantly higher than other strands of the linkage design.

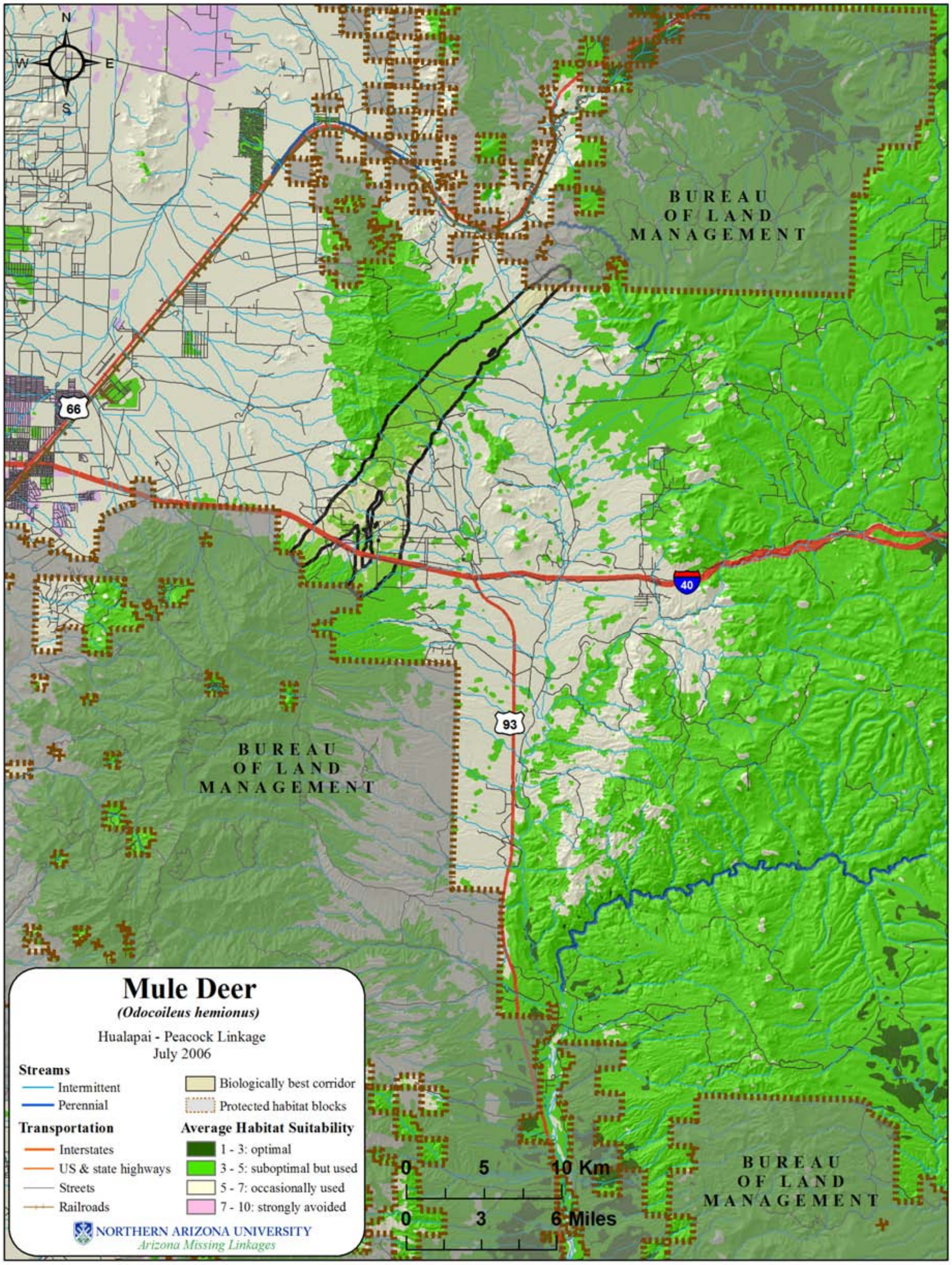

Figure 39: Modeled habitat suitability of mule deer.

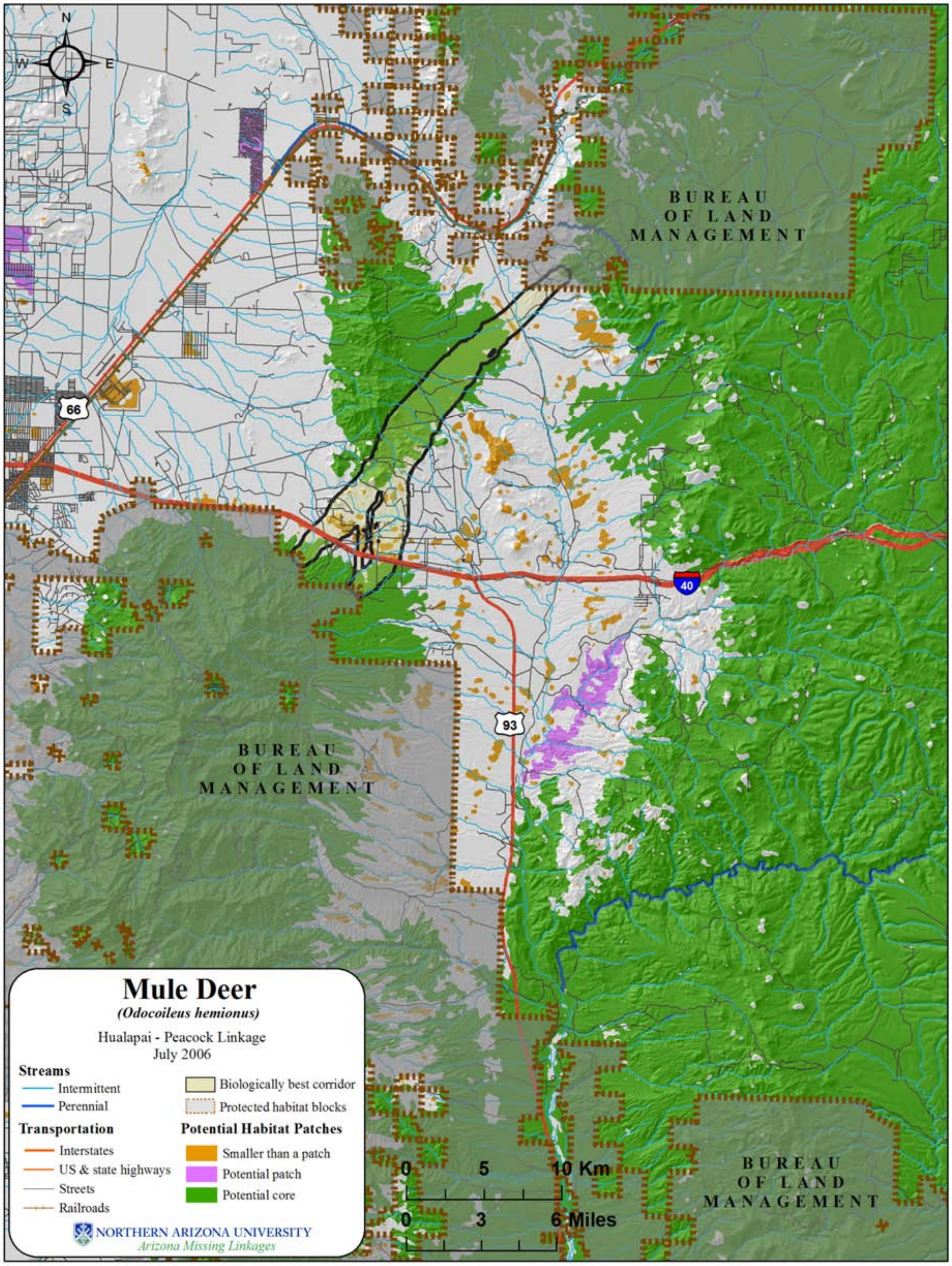

Figure 40: Potential habitat patches and cores for mule deer.

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 protected 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 4.

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 – The standard geometric habitat suitability model was used in the corridor analysis. Unlike other corridor analyses in this study, the corridor analysis for pronghorn was performed with designated starting habitat patches where pronghorn are known to occur: Truxton Flat in the northern Peacock-Cottonwood protected block and Goodwin Mesa in the southern Aquarius protected block.

Results & Discussion

Initial biologically best corridor – Modeling results indicate only small amounts of suitable habitat within the biologically best corridor for this species (Figure 41). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.9 to 10.0, with an average suitability cost of 5.5 (S.D: 1.6). Within the corridor, there are no large patches or cores. The greatest distance between two significantly-sized pieces of habitat within the corridor is approximately 16 km (Figure 42).

Union of biologically best corridors – A fair amount of potential habitat between the Hualapai and Peacock-Cottonwood wildland blocks was encompassed by the union of biologically best corridors. This habitat is concentrated in linkage strand west of the Peacock Mountains, and the third linkage strand between the Hualapai and Peacock-Cottonwood wildland blocks which runs through Badger Flat (Figure 42).

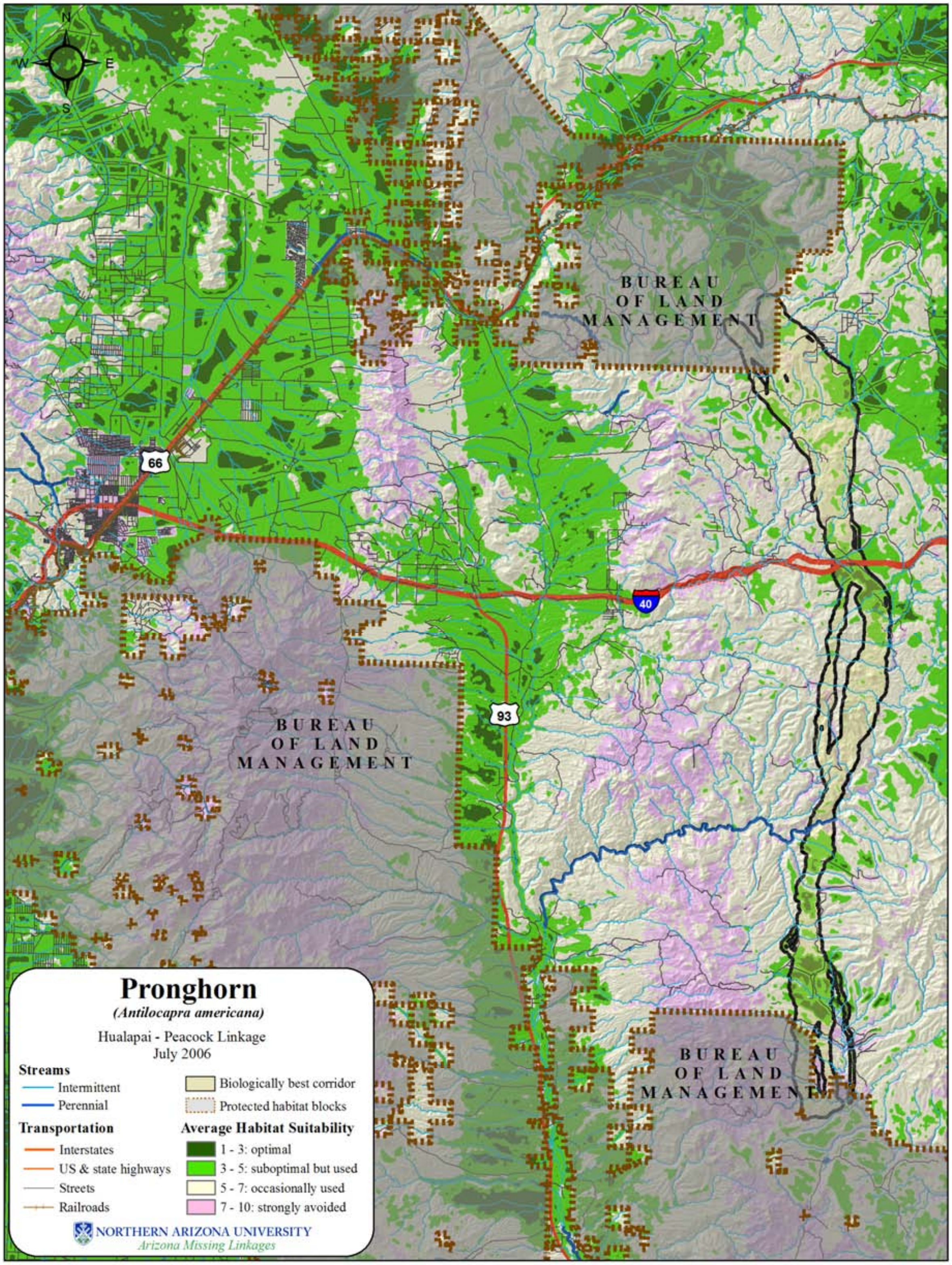

Figure 41: Modeled habitat suitability for pronghorn.

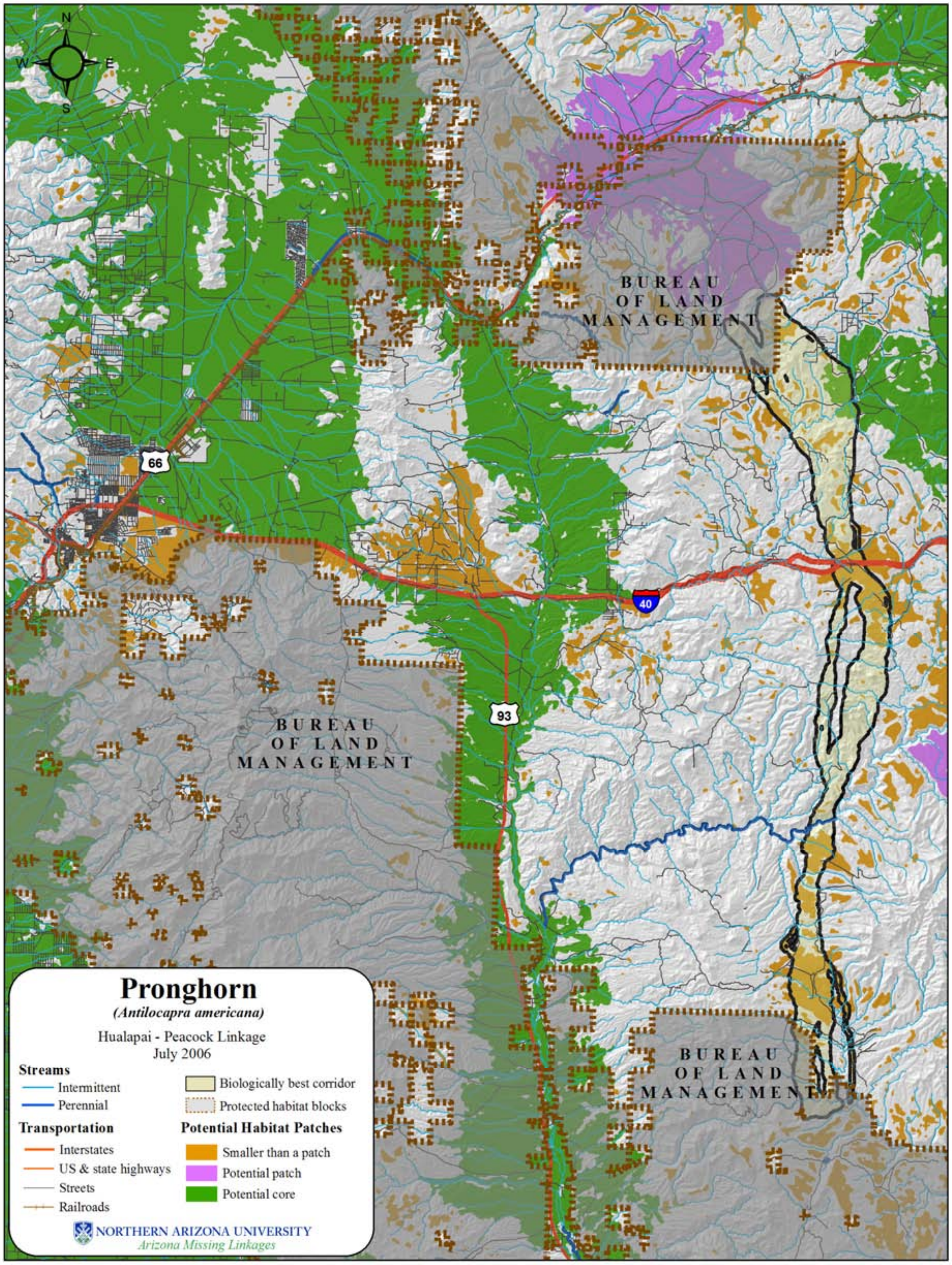

Figure 42: Potential habitat patches and cores for pronghorn.

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 4.

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 – The standard geometric habitat suitability model was used in the corridor analysis.

Results & Discussion
Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area (Figure 43); however, potential habitat may be over-predicted, due to our inability of incorporating rocky outcrops into the habitat modeling procedure. Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.7 to 5.9, with an average suitability cost of 3.6 (S.D: 0.8). 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 44).

Union of biologically best corridors – The additional strands of the UBBC between the Hualapai and Peacock-Cottonwood wildland blocks significantly increase potential suitable habitat for Gila Monster, while the easternmost strand of the UBBC is mostly composed of pinyon-juniper woodlands which are likely not suitable for the species.

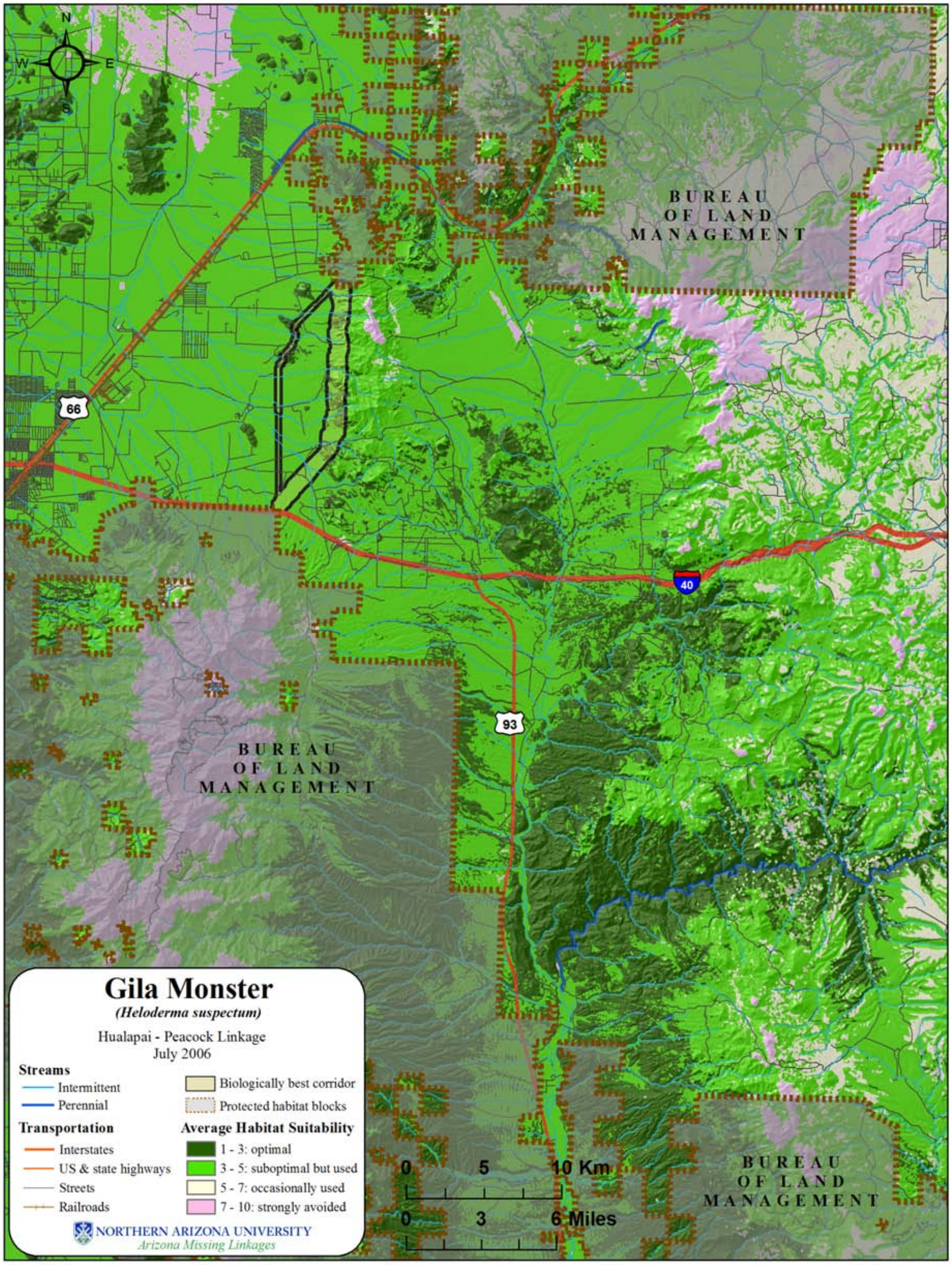

Figure 43: Modeled habitat suitability of Gila monster.

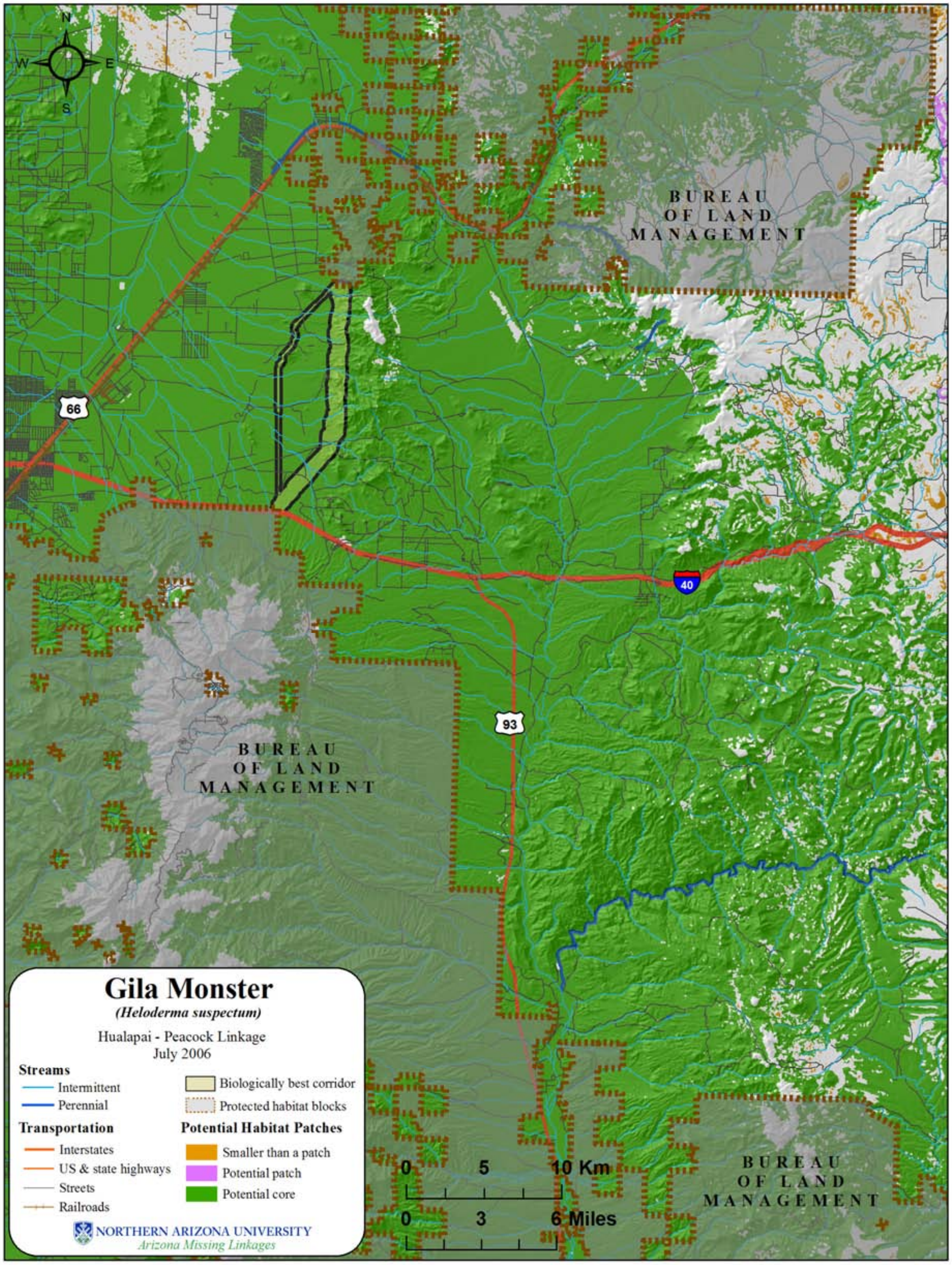

Figure 44: Potential habitat patches and cores for Gila monster.

Appendix C: Suggested Focal Species Not Modeled

The habitat requirements and connectivity needs of several 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.
- Desert Bighorn Sheep (*Ovis canadensis*) –While bighorn sheep occur along the Grand Canyon, and there may be limited potential habitat in the Aquarius Mountains east of Wickieup, and limited habitat in the Hualapai Mountains (Rebecca Peck,BLM, personal comm.), no known populations of bighorn sheep occur in any of the wildland blocks.
- 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.
- 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 (often 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 tortoise 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 where lowland leopard frogs may occur which connect wildland blocks.
- Northern Leopard Frog (*Rana pipiens*) – There are no riparian systems in the linkage planning area where northern leopard frogs may occur which connect wildland blocks.

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 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). This species was seen north of I-40 within the 2nd and 3rd strands of the linkage design strand between the Hualapai and Peacock-Cottonwood wildland blocks during field investigations on July 18, 2006. 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. They occur in riparian cottonwood-willow forests such.

Fish

- Desert Sucker (*Catostomus clarki*) – There are no riparian systems in the linkage planning area where desert suckers may occur which connect wildland blocks.
- 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. (Arizona Game and Fish Department 2002).

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor edits to the union of biologically best corridors (Figure 45):

- We filled-in small holes that were created as an artifact of the modeling process if they were composed of natural vegetation and not developed land.
- We removed the westernmost strand between the Hualapai and Peacock-Cottonwood wildland blocks. This strand was one of two corridors that were created by the black-tailed jackrabbit model (Figure 29). These corridors were equal in habitat quality, and black-tailed jackrabbits were seen in both black-tailed jackrabbit corridors upon field investigation.
- We removed several small 'slivers' in the easternmost strand between the Peacock-Cottonwood and Aquarius wildland blocks. These slivers provided no additional high-quality habitat beyond the main, large corridor.
- We widened small sections of all corridors to increase high-quality habitat. The middle corridor between the Peacock-Cottonwood and Hualapai wildland blocks was widened into the Peacock Mountains to encompass chaparral habitat in the Peacocks, which is preferred habitat by black bear.

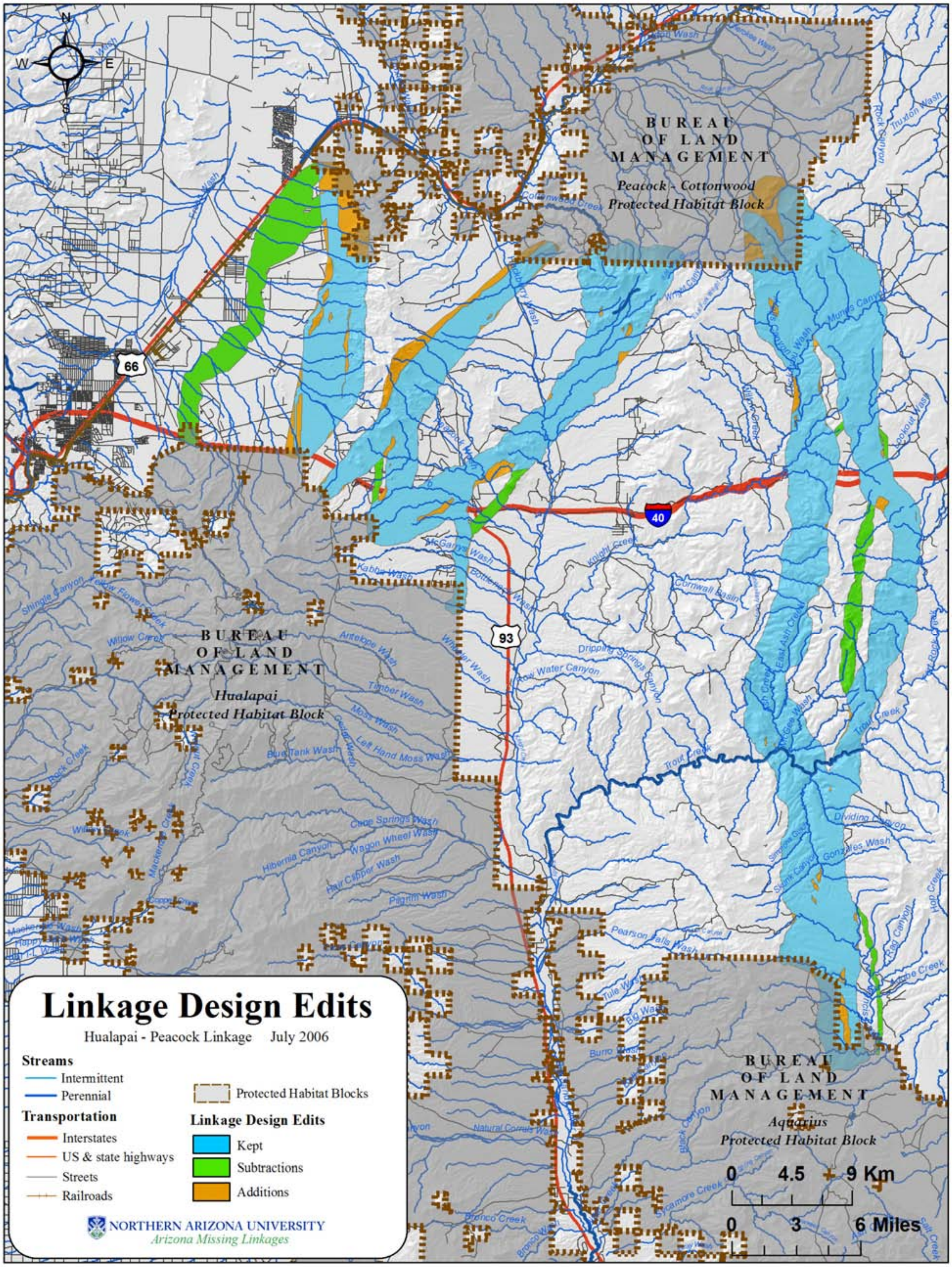

Figure 45: Edits made to union of biologically best corridors to create final Linkage Design.

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 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.

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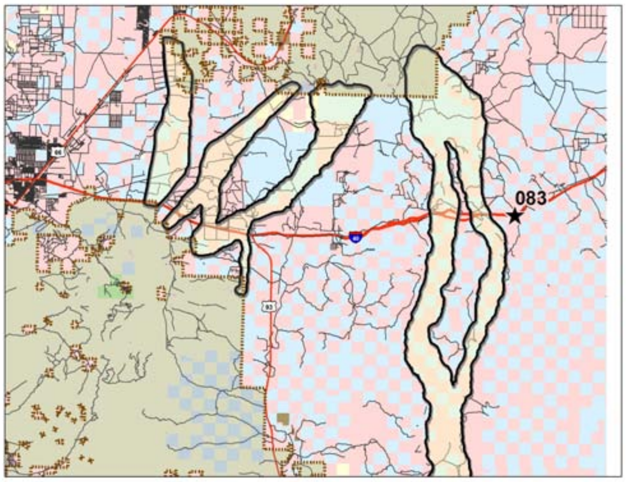
Appendix G: Database of Field Investigations

Attached is a database of field notes, GPS coordinates, and photos collected as part of our field investigations of this linkage zone. 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.

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	083		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.19029268	**Longitude:**	-113.316774
Observers:	Paul Beier, Dan Majka	**UTM X:**	289061.6386	**UTM Y:**	3896604.631
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Bridge at MP 94.5 over Eastbound lanes of I40

Site Photographs

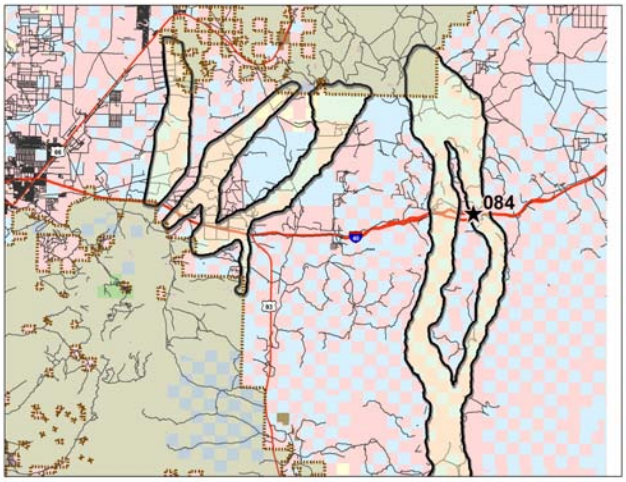
Name: DSCF0004.jpg

Azimuth: 160 **Zoom:** 1x

Notes: Photo taken from bridge on west-bound lanes

Linkage #:	21	**Waypoint #:**	084		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.19106289	**Longitude:**	-113.377015
Observers:	Paul Beier, Dan Majka	**UTM X:**	283577.8143	**UTM Y:**	3896819.642
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

MP 91.1 - Lookout Wash Culverts. Cattle were adjacent to structure, and appear to use culverts.

Site Photographs

Name: DSCF0005.jpg

Azimuth: 140 **Zoom:** 1x

Notes: Five 8 x 8 ft box culverts under west bound lanes

Name: DSCF0006.jpg

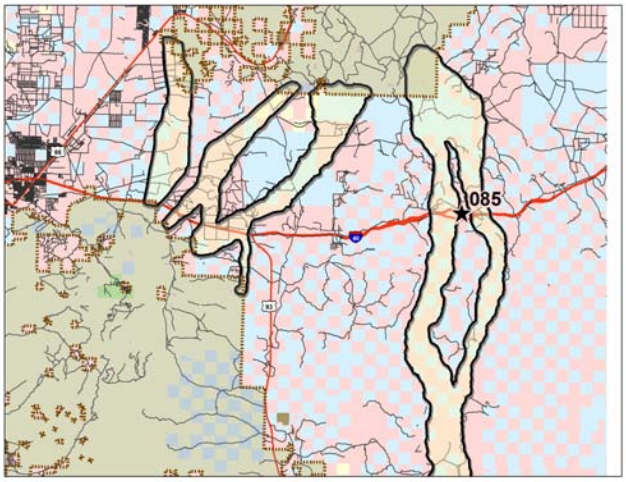
Azimuth: 140 **Zoom:** 3x

Notes: Six box culverts under east-bound lanes of I40

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	085		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.19096608	**Longitude:**	-113.393542
Observers:	Paul Beier, Dan Majka	**UTM X:**	282072.4802	**UTM Y:**	3896845.034
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Rocky outcrops and boulders are adjacent to the road from approx. MP 90.4 to 89.3. Photos taken standing on rocks on north side of west bound lanes of I40, near MP 90.1. Additional Note: Wash at MP 88.4 has no major crossing structure.

Site Photographs

Name: DSCF0007.jpg

Azimuth: 300 **Zoom:** 1x

Name: DSCF0008.jpg

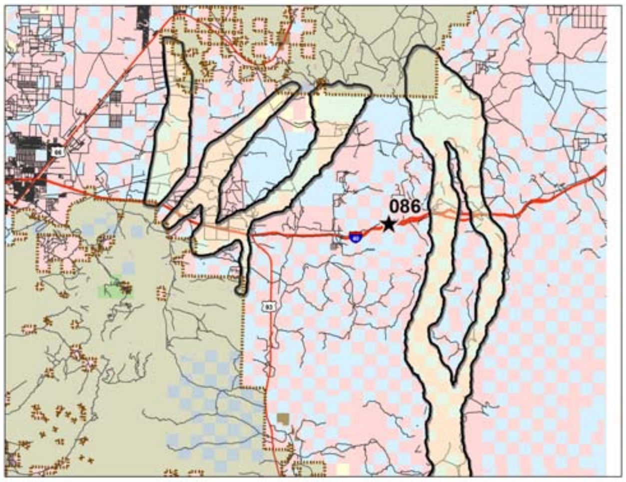
Azimuth: 48 **Zoom:** 1x

Name: DSCF0009.jpg

Azimuth: 130 **Zoom:** 1x

Linkage #:	21	**Waypoint #:**	086		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.17698985	**Longitude:**	-113.497949
Observers:	Paul Beier, Dan Majka	**UTM X:**	272525.4888	**UTM Y:**	3895528.620
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

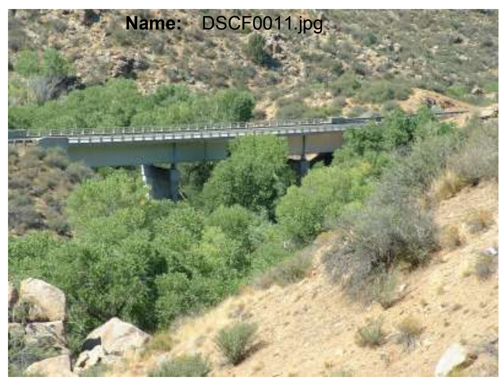
Large bridges in the eastbound lanes of I40 cross Wiillow Creek in 6 locations.

Site Photographs

Name: DSCF0010.jpg

Azimuth: 167 **Zoom:** 1x

Name: DSCF0011.jpg

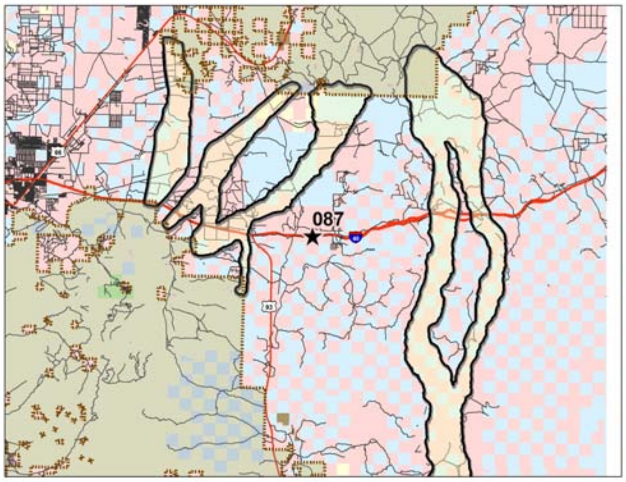


Azimuth: 220 **Zoom:** 6x

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	087		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.15942775	**Longitude:**	-113.607930
Observers:	Paul Beier, Dan Majka	**UTM X:**	262456.6881	**UTM Y:**	3893837.633
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos taken from dirt frontage road (Austin Mtn Rd?)

Site Photographs

Name: DSCF0012.jpg

Azimuth: 256 **Zoom:** 1x

Name: DSCF0013.jpg

Azimuth: 356 **Zoom:** 1x

Name: DSCF0014.jpg

Azimuth: 102 **Zoom:** 1x

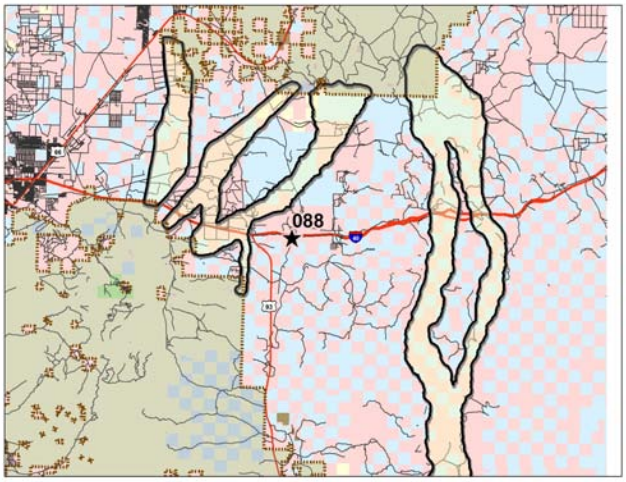
Name: DSCF0015.jpg

Azimuth: 230 **Zoom:** 1x

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	088		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.15630146	**Longitude:**	-113.637367
Observers:	Paul Beier, Dan Majka	**UTM X:**	259765.5887	**UTM Y:**	3893561.548
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos taken from County Road 141

Site Photographs

Name: DSCF0016.jpg

Azimuth: 16 **Zoom:** 1x

Notes: Bridges over Big Sandy River (left) and Hackberry Rd (right)

Name: DSCF0017.jpg

Azimuth: 16 **Zoom:** 4x

Notes: Bridge over Big Sandy River (also possibly known as Hackberry Wash on maps?)

Name: DSCF0018.jpg

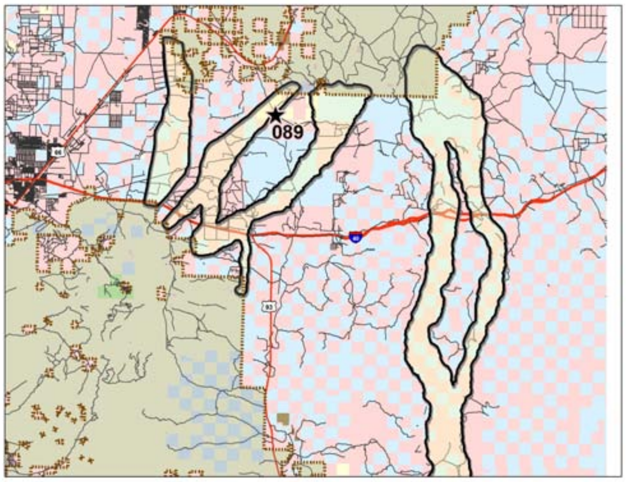
Azimuth: 20 **Zoom:** 6x

Notes: I40 bridge over Hackberry Rd

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	089		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.30262745	**Longitude:**	-113.665428
Observers:	Paul Beier, Dan Majka	**UTM X:**	257644.8897	**UTM Y:**	3909863.254
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos taken from east edge of mule deer BBC.

Site Photographs

Name: DSCF0019.jpg

Azimuth: 270 **Zoom:** 1x

Notes: Peacock Mtns & mule deer corridor

Name: DSCF0020.jpg

Azimuth: 350 **Zoom:** 1x

Name: DSCF0021.jpg

Azimuth: 214 **Zoom:** 3x

Notes: Hualapai Mtns

Name: DSCF0022.jpg

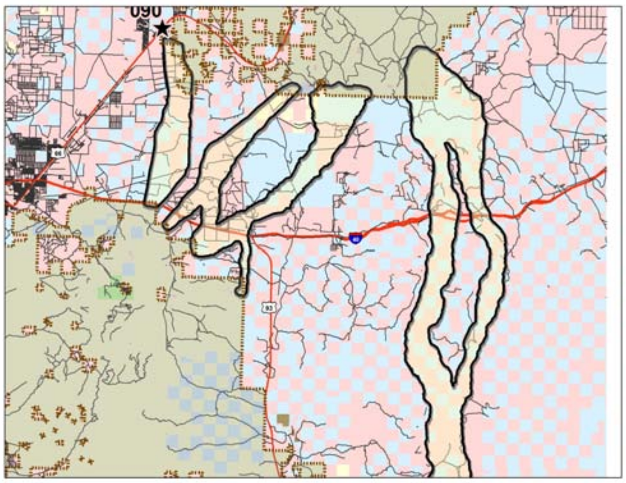
Azimuth: 20 **Zoom:** 1x

Notes: Cottonwood Mtns?

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	090		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.40320073	**Longitude:**	-113.832790
Observers:	Paul Beier, Dan Majka	**UTM X:**	242742.8628	**UTM Y:**	3921444.029
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

These photos illustrate a linear strip of development within flat desert scrub that could block animal movement. This development is not is not within the linkage design.

Site Photographs

Name: DSCF0023.jpg

Azimuth: 284 **Zoom:** 3x

Name: DSCF0024.jpg

Azimuth: 270 **Zoom:** 1x

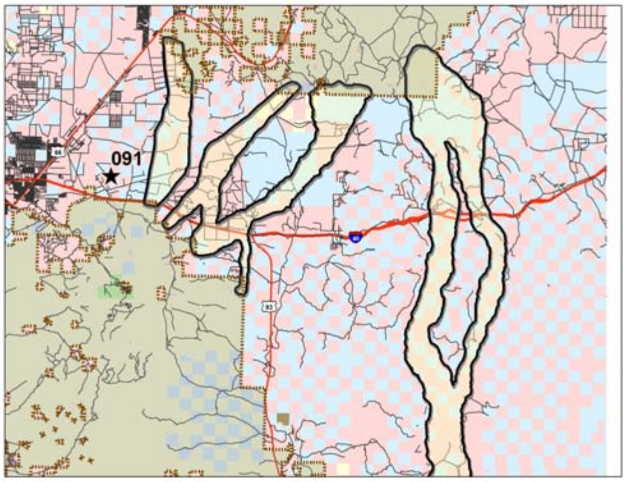
Name: DSCF0025.jpg

Azimuth: 256 **Zoom:** 4x

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	091		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.22487205	**Longitude:**	-113.900603
Observers:	Paul Beier, Dan Majka	**UTM X:**	236003.2741	**UTM Y:**	3901837.261
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos show flat desert scrub lands; taken from El Paso Rd near Amarillo Rd.

Site Photographs

Name: DSCF0026.jpg

Azimuth: 0 **Zoom:** 1x

Notes: Black-tailed jackrabbit corridor passes across field of view

Name: DSCF0027.jpg

Azimuth: 60 **Zoom:** 1x

Notes: Towards Peacock Mtns

Name: DSCF0028.jpg

Azimuth: 160 **Zoom:** 1x

Notes: Towards Hualapai Mtns

Name: DSCF0029.jpg

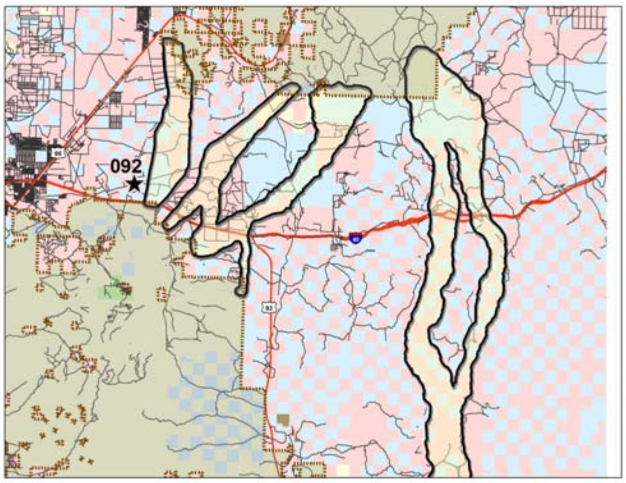
Azimuth: 310 **Zoom:** 1x

Notes: Rural home

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	092		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.21760805	**Longitude:**	-113.866887
Observers:	Paul Beier, Dan Majka	**UTM X:**	239049.5346	**UTM Y:**	3900942.156
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Proposed housing development (Peacock Vistas) is in this area. Photos taken from Powerline Rd.

Site Photographs

Name: DSCF0030.jpg

Azimuth: 0 **Zoom:** 1x
Notes: Peacock Mtns

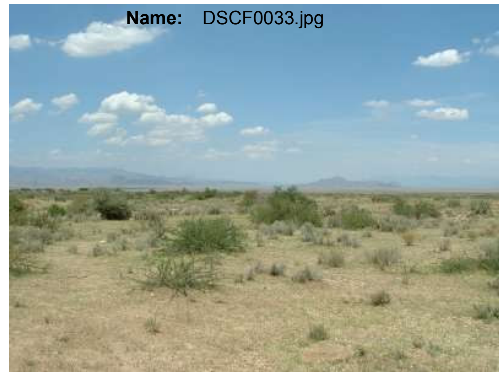
Name: DSCF0031.jpg

Azimuth: 40 **Zoom:** 1x
Notes: Peacock Mtns

Name: DSCF0032.jpg

Azimuth: 180 **Zoom:** 1x
Notes: Hualapai Mtns

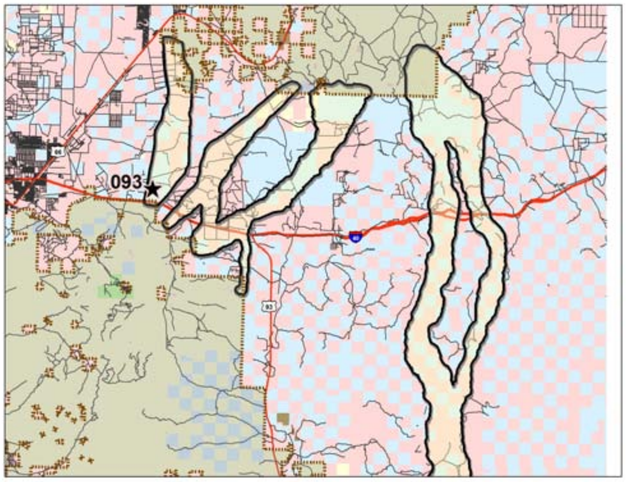
Name: DSCF0033.jpg



Azimuth: 326 **Zoom:** 1x

Linkage #:	21	**Waypoint #:**	093		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.21047739	**Longitude:**	-113.839853
Observers:	Paul Beier, Dan Majka	**UTM X:**	241488.2744	**UTM Y:**	3900080.289
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos taken near main western linkage strand

Site Photographs

Name: DSCF0034.jpg

Azimuth: 10 **Zoom:** 1x

Notes: Towards Peacock Mtns

Name: DSCF0035.jpg

Azimuth: 212 **Zoom:** 1x

Notes: Towards Hualapai Mtns

Name: DSCF0036.jpg

Azimuth: 40 **Zoom:** 1x

Notes: Looking towards southern part of Peacock Mtns

Name: DSCF0037.jpg

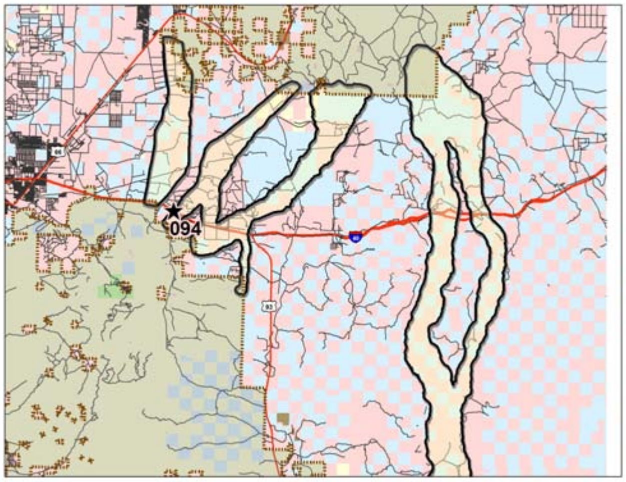
Azimuth: 350 **Zoom:** 1x

Notes: Desert scrub plains where future development is planned.

Appendix G: Database of Field Investigations

Linkage #:	21	**Waypoint #:**	094		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.18472408	**Longitude:**	-113.808925
Observers:	Paul Beier, Dan Majka	**UTM X:**	244223.6158	**UTM Y:**	3897142.983
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Photos of eastbound lanes. Four box culverts, each 8-10 ft wide and 4 ft in height. All are heavily silted-in.

Site Photographs

Name: DSCF0038.jpg

Azimuth: 0 **Zoom:** 1x

Name: DSCF0039.jpg

Azimuth: 0 **Zoom:** 1x

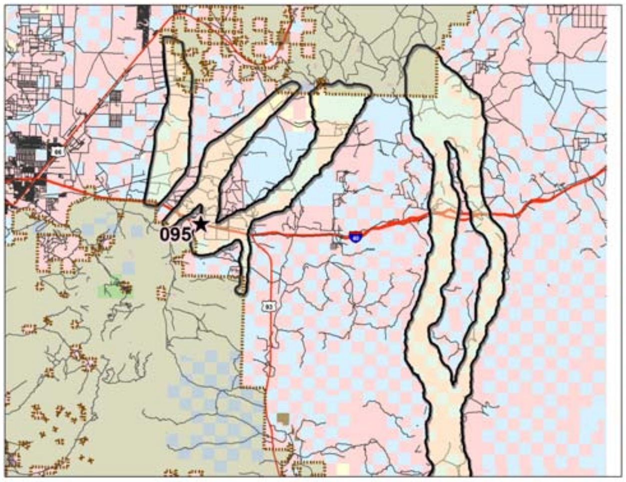
Name: DSCF0040.jpg

Azimuth: 202 **Zoom:** 1x

Notes: Looking up wash towards Hualapai Mtns

Linkage #:	21	**Waypoint #:**	095		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.17076855	**Longitude:**	-113.769002
Observers:	Paul Beier, Dan Majka	**UTM X:**	247816.7668	**UTM Y:**	3895492.637
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Site Photographs

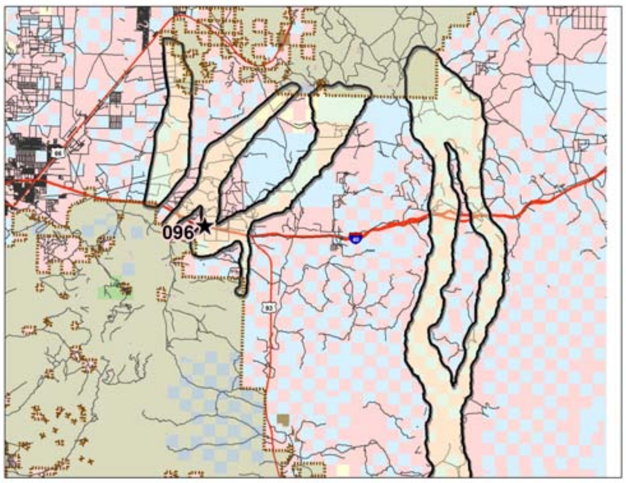
Name: DSCF0041.jpg

Azimuth: 208 **Zoom:** 1x

Notes: 10x8' box culvert under I-40 in mule deer BBC. Might be used as a vehicle underpass?

Linkage #:	21	**Waypoint #:**	096		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.16998442	**Longitude:**	-113.763626
Observers:	Paul Beier, Dan Majka	**UTM X:**	248304.1254	**UTM Y:**	3895392.012
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Two 8x12 ft culverts. Both culverts unusable by most species because a) 3 ft pour-off, and b) an angled exit on one side of the culvert, which would discourage species which need open crossing structures.

Site Photographs

Name: DSCF0042.jpg

Azimuth: 150 **Zoom:** 1x

Name: DSCF0043.jpg

Azimuth: 150 **Zoom:** 1x

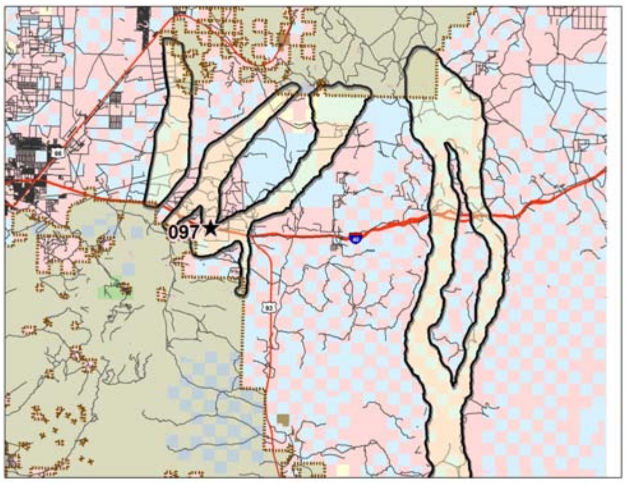
Name: DSCF0044.jpg

Azimuth: Inside Culvert **Zoom:** 0x

Notes: Photo taken inside culvert, showing angled entrance.

Linkage #:	21	**Waypoint #:**	097		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	35.16771066	**Longitude:**	-113.755252
Observers:	Paul Beier, Dan Majka	**UTM X:**	249059.924	**UTM Y:**	3895118.577
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Single 8x8 ft box culvert under I40 in mule deer BBC.

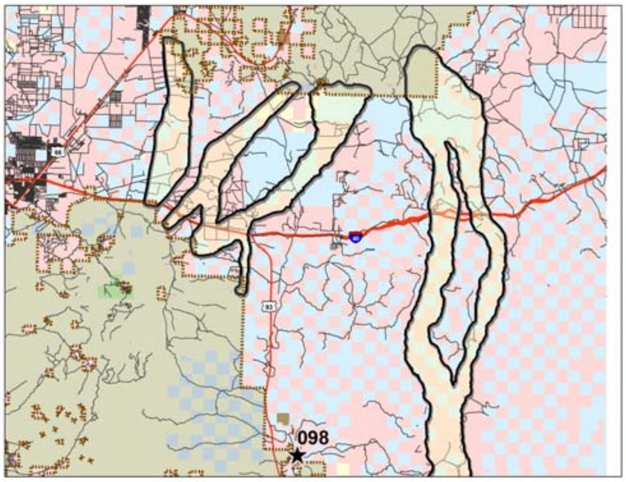
Site Photographs

Name: DSCF0045.jpg

Azimuth: 50 **Zoom:** 1x

Linkage #:	21	**Waypoint #:**	098		
Linkage Zone:	Hualapai - Peacock	**Latitude:**	34.90013039	**Longitude:**	-113.621384
Observers:	Paul Beier, Dan Majka	**UTM X:**	260475.0508	**UTM Y:**	3865104.286
Field Study Date:	7/18/2006	**Last Printed:**	8/3/2006		

Waypoint Map



Waypoint Notes

Looking up Big Sandy River, near junction with Trout Creek

Site Photographs

Name: DSCF0046.jpg

Azimuth: 60 **Zoom:** 1x