ARIZONA MISSING LINKAGES

US-93: Wickenburg to Santa Maria River Linkage Design

Paul Beier, Daniel Majka

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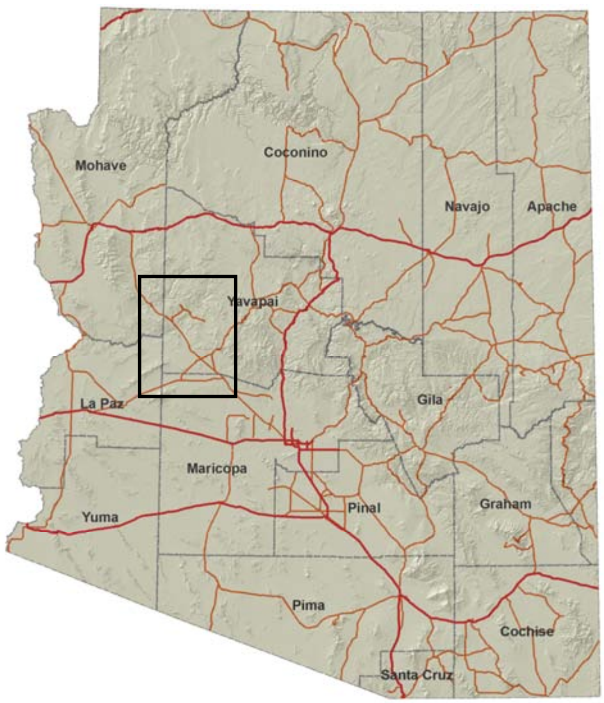

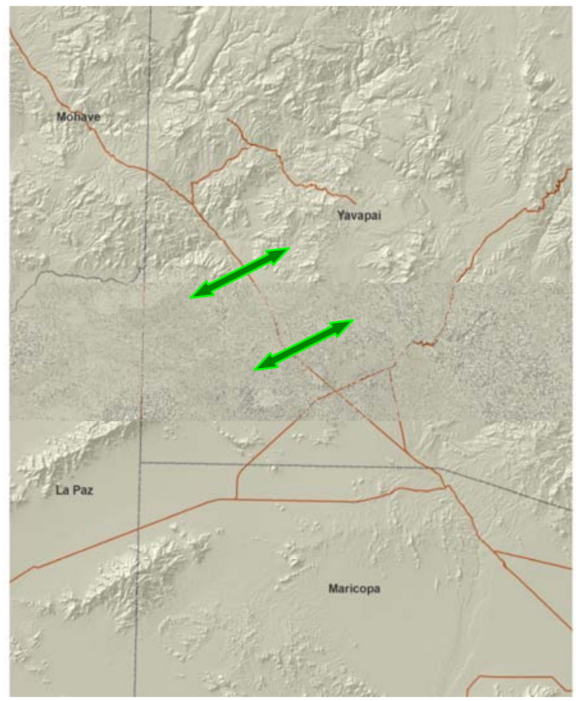

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Terminology

Key terminology used throughout the report includes:

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

Linkage Design: A set of recommendations intended to maintain the ability of wildlife to move across potential barriers to movement.

Linkage Planning Area: The portion of US-93 from Wickenburg to the Santa Maria River, and all land within 3 miles (5 km) of this portion of US-93, where current and future urbanization, roads, and other human activities threaten to prevent wildlife movement between the wildland blocks.

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.

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 provide recommendations that will help conserve and enhance wildlife movement across US-93 between Wickenburg and the Santa Maria River. It is anticipated that this stretch of US-93 will be expanded within the next 5-10 years, and the new lanes of this highway could become a further barrier to wildlife movement. The BLM land west of US-93, as well as the currently undeveloped State Trust lands to the east contiguous with the Prescott National Forest, represents a massive public investment in biological diversity, and a Linkage Design to minimize this impact is a reasonable step to maintain the value of that investment.

To develop our recommendations, we first asked academic scientists, agency biologists, and conservation organizations to identify focal species that are sensitive to habitat loss and fragmentation. The focal species include 1 amphibian, 8 reptiles, 9 birds, and 7 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, mule deer). Some species are habitat specialists (e.g. bighorn sheep), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer, rattlesnakes, desert tortoise). Some species are rare and/or endangered (desert tortoise, bighorn sheep), while others are common but still need gene flow among populations (black-tailed jackrabbits, javelina). All the focal species are part of the natural heritage of this mosaic of Apache Highlands and Sonoran Desert. Together, these 25 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.

We modeled habitat suitability of these focal species, and visited the area to identify and evaluate barriers to wildlife movement. We used these observations to suggest strategies to mitigate those barriers, with special emphasis on opportunities to reduce the adverse effects of current and future alignments of US-93.

The ecological, educational, recreational, and spiritual values of protected wildlands in surrounding US-93 are immense. Our Linkage Design represents an opportunity to protect a truly functional connection across US-93. The cost of implementing this vision will be small compared to the cost of building the new highway or compared to the benefits of the public's existing investment in protected wild habitat. If implemented, our plan would not only permit movement of individuals and genes across this stretch of US-93, 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 the critical role of the linkage 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 years, 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 Linkage Design surrounding US-93 from Wickenburg to the Santa Maria River.

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	Lowland Leopard Frog	Black-throated Sparrow
*Black-tailed Jackrabbit	Arizona Black Rattlesnake	Golden Eagle
*Desert Bighorn Sheep	Black-neck Garter Snake	Peregrine Falcon
*Javelina	Chuckwalla	Gambel's Quail
*Kit Fox	*Desert Tortoise	Loggerhead Shrike
*Mountain Lion	*Gila Monster	Southwestern Willow Flycatcher
*Mule Deer	Rosy Boa	Western Burrowing Owl
	Speckled Rattlesnake	Yellow-billed Cuckoo
	Western Red-tailed Skink	Zone-tailed Hawk

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

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 Noss 1998, Beier and Loe 1992, Noss 1992, Beier 1993, Forman 1995, 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). This Linkage is one of these first 8 linkages.

Ecological Significance of this Linkage

The Linkage Planning area lies within the Sonoran Desert Ecoregion, near its transition to the Apache Highlands Ecoregion. The Sonoran Desert Ecoregion consists of 55 million acres within southern Arizona, southeastern California, northern Baja, California, and northwestern Sonora (Marshall et al.

2000). 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, whose conservation is critical for maintaining the earth's biodiversity.

The Linkage Planning Area includes a large BLM-administered wildland block to the west of US-93 made up of many mountain ranges and adjacent Sonoran desert wildlands (Figure 1). Mountain ranges of this wildland block include the Black Mountains, extending northwest-southeast for 21 km (13 mi) through the Arrastra Mountain and Tres Alamos Wilderness areas; the Poachie Range, extending 22.5 km (14 mi) to the north of the Arrastra Mountain wilderness area, the Rawhide Mountains, extending east-west for 24 km (15 mi); the Buckskin Mountains, extending east-west for 37 km (23 mi) south of the Rawhide Mountains, and the Harcuvar Mountains, which extend northeast-southwest for 48 km (30 mi). The geologic features and topographic diversity of these mountains provide important ecological value for the area's wildlife, and support important drainage systems in the area, including the Santa Maria River, the Big Sandy River, the Bill Williams River, Cottonwood Canyon, Black Canyon Wash, and Date Creek. These watersheds provide important riparian habitat and wildlife corridors.

A large wildland block of currently undeveloped ASLD land east of US-93 encompasses several small mountain ranges and adjacent Sonoran desert wildlands, and is contiguous with the Apache Highlands Ecoregion (Figure 1). Mountain ranges of this wildland block include the Date Creek Mountains, extending eastward for 21 km (13 mi); and the Weaver Mountains, which extend east of the Date Creek Mountains and are dominated by chaparral and pinyon-juniper woodlands. These mountains, together with the complex topography south of SR 97, support important riparian systems such as the Santa Maria River, Placeritas Creek, Date Creek, and Bridle Creek.

The Linkage Planning Area ranges in elevation from 1,100 ft at the Bill Williams River and 1,250 ft at the confluence of the Santa Maria and Big Sandy Rivers to nearly 5,000 ft at the Poachie Mountains, 5,100 ft in the Harcuvar Mountains, 4,900 ft in the Date Creek Mountains, and 6,500 ft in the Weaver Mountains. Paloverde-mixed cacti desert scrub, Sonoran mid-elevation desert scrub, and mesquite upland scrub communities dominate the lower elevations surrounding US-93, rising to areas of chaparral, pinyon-juniper and pine-oak woodlands, and ponderosa pine forest to the east, with creosote flats to the west (Figure 2). Included within the mapped paloverde and Sonoran mid-elevation desert scrub vegetation associations is an extensive Joshua tree forest which dominates the viewshed along the highway.

The varied habitat types in the Linkage Planning Area support a diverse assemblage of species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the desert tortoise and desert bighorn sheep (USFWS 2005). In this report, we provide suggestions to connect habitat needed for these species to achieve viable populations. The Linkage Planning Area is also home to far-ranging mammals such as mule deer, mountain lion, and badger. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from crossing structures that enable them to cross US-93, thereby linking the large areas of habitat adjacent to the highway (Turner et al. 1995). Less-mobile species and habitat specialists such as black-tailed jackrabbits, Gila monster, desert tortoise, and rattlesnakes 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.

Existing Conservation Investments

The wildland block west of US-93 is protected by the Bureau of Land Management. Although our analyses are confined to those BLM lands along US-93 between state roads 71 and 97, the western wildland block is actually much larger if one considers the 4.8 million total acres (1.9 million ha) of contiguous BLM land and the adjacent 665,000-acre (269,000 ha) Kofa National Wildlife Refuge. There are several large designated Wilderness areas within the western wildland block, including the 129,800-acre Arrastra Mountain Wilderness area, the 8,300-acre Tres Alamos Wilderness area, the 38,470-acre Rawhide Mountains Wilderness area, and the 25,050-acre Harcuvar Mountains Wilderness area (Figure 3).

The wildland block east of US-93 is primarily comprised of land administered by the Arizona State Land Department. Although this State land is not permanently protected for conservation, it does not currently appear to be threatened by development. The eastern wildland block also includes 9,560 acres of BLM-administered land near the Santa Maria River, and is adjacent to a much larger block of BLM land that includes the 27,440-acre Upper Burro Creek Wilderness Area. To the east, the State land abuts 616,000 acres (249,000 ha) of the Prescott National Forest.

Threats to Connectivity

Major potential barriers in the linkage planning area include U.S. Highway 93, land alteration due to mining, the Burlington Northern Santa Fe Railroad (about 10 miles east of US-93), and future urban development along the US-93 corridor.

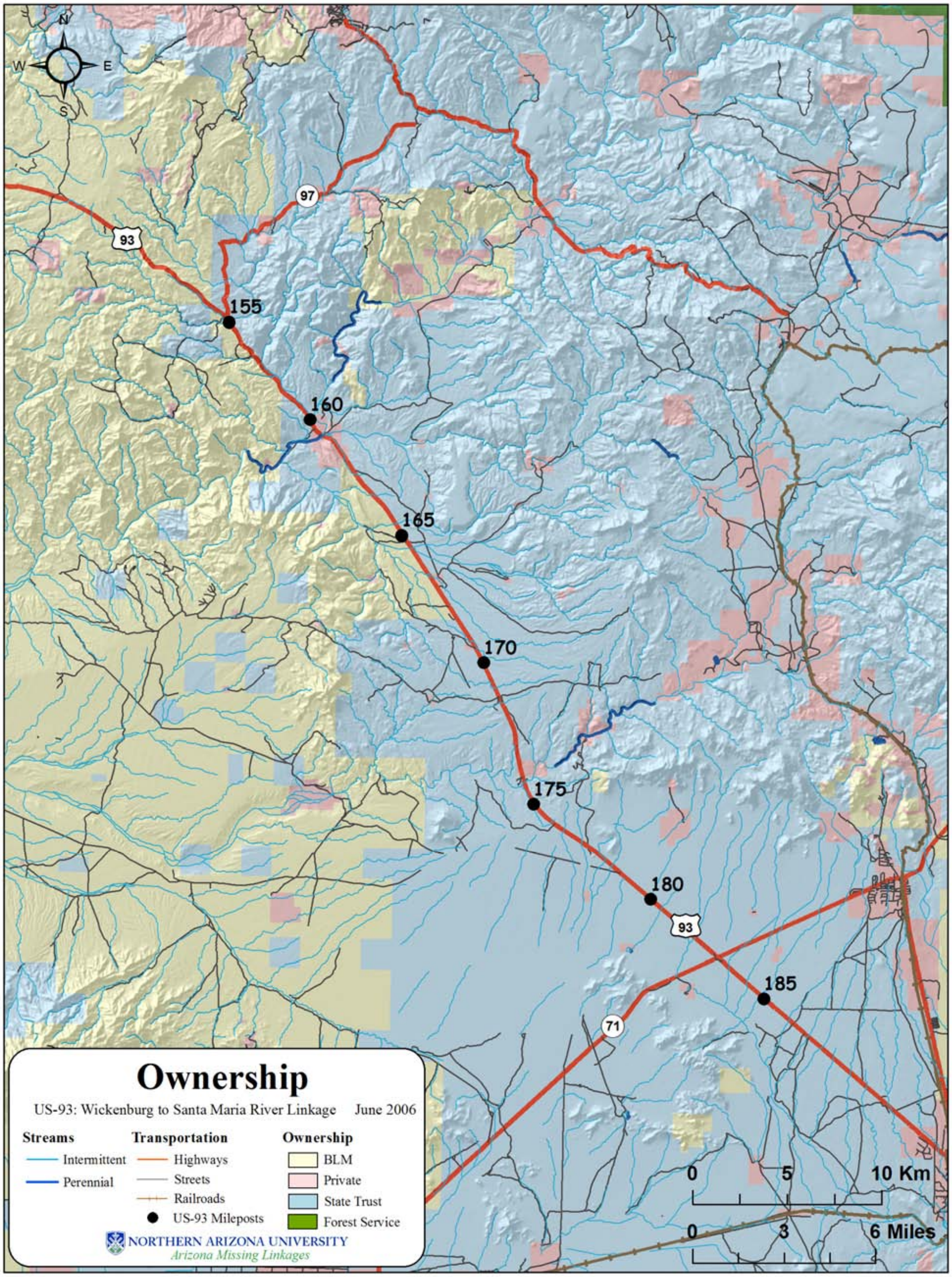

Figure 1: Land ownership within the Linkage Planning Area along US-93. Mileposts on US 93 are indicated.

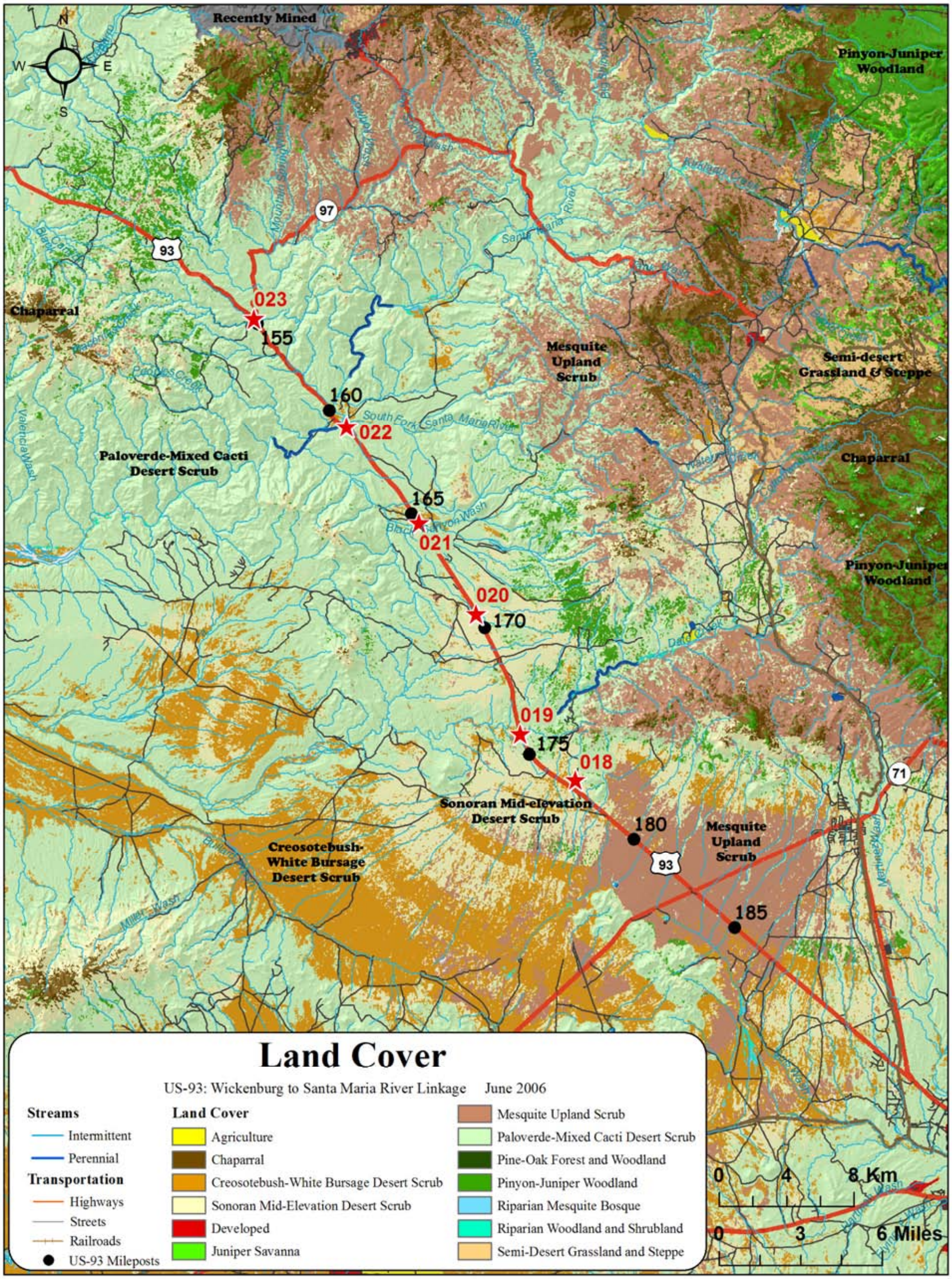

Figure 2: Land cover and field investigation waypoints (Red stars) within the Linkage Planning Area along US-93. The accompanying CD-ROM includes photographs taken at waypoints.

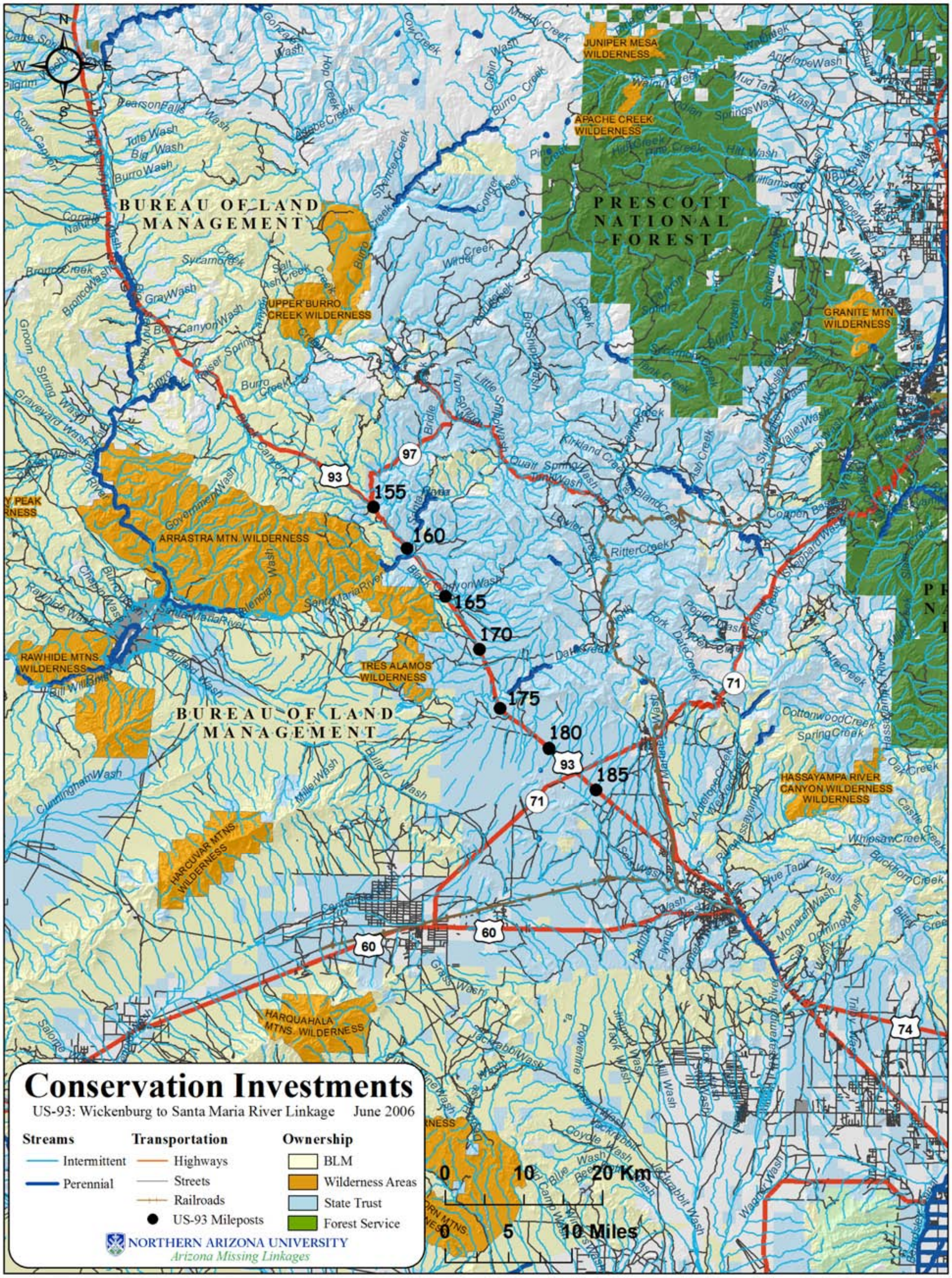

Figure 3: Existing conservation investments within the Linkage Planning Area.

Because there are many realignment options for US-93 between Wickenburg and the Santa Maria River, we cannot make recommendations for specific crossing structures in the linkage area[1]. Instead, this Linkage Design provides maps of potential habitat for focal species, describes barriers to movement, and recommends mitigation measures to reduce the impact of the future and existing US-93 alignments on wildlife movement. To simplify recommendations, we have divided US-93 into six 5-mile milepost increments (MP 155 – 185) between state roads 97 and 71. In this section, we describe the land cover patterns surrounding US-93, and recommend mitigations for barriers to animal movement, starting at the northernmost milepost (MP 155) of concern in the linkage planning area.

The land cover surrounding milepost 155-160 is primarily composed of paloverde-mixed cacti desert scrub, with small amounts of creosotebush-white bursage desert scrub and riparian vegetation (Table 2). Riparian areas within a half mile of the existing US-93 alignment include Placeritas Creek, which crosses US-93 near MP 155, and Bridle Creek, which runs parallel to the east side of US-93 for approximately 3 miles before joining the Santa Maria River near MP 160. The areas surrounding this segment of US-93 linkage provide optimal live-in and pass-through habitat for species dependent on desert vegetation and/or complex topography, such as black-tailed jackrabbit, javelina, desert tortoise, and Gila monster (Table 3).

Table 2: Percentage composition of land cover classes within ½ mile (800 m) of US-93.

LAND COVER	US 93 MILEPOSTS					
	155-160	**160-165**	**165-170**	**170-175**	**175-180**	**180-185**
Pinyon-Juniper Woodland	0%	0%	0%	1%	1%	0%
Creosotebush-White Bursage Desert Scrub	3%	8%	7%	4%	14%	6%
Sonoran Mid-elevation Desert Scrub	0%	3%	39%[a]	54%	42%	1%
Mesquite Upland Scrub	0%	0%	0%	2%	23%	87%
Paloverde-Mixed Cacti Desert Scrub	95%	87%	54%[a]	39%	20%	6%
Riparian Mesquite Bosque	1%	1%	0%	0%	0%	0%
Riparian Woodland and Shrubland	1%	1%	0%	0%	0%	0%

[a] In this area, these 2 vegetation communities contain a substantial Joshua Tree woodland

Table 3. Distribution of optimal and suitable habitat of focal species in 5-mile segments of US-93.

FOCAL SPECIES	AREAS (MILEPOSTS) THAT INTERCEPT LARGE AREAS OF POTENTIAL BREEDING HABITAT OF THE SPECIES	
	SUITABLE HABITAT	OPTIMAL HABITAT
American badger	155-185	175-185
Black-tailed jackrabbit	155-185	155-177
Desert bighorn sheep	155-160	none
Javelina	155-185	155-185
Kit fox	155-185	160-177
Mule deer	155-168, 180-185	180-185
Desert tortoise	155-185	155-162
Gila monster	155-185	155-162

[1] According to the Draft Environmental Assessment for the future US-93 alignment (Available from: http://www.wickenburg.civilnet.sverdrup.com), the current preferred alignment for US-93 between State Roads 71 and 97 will use the existing roadway for one direction of travel, and construct a new two-lane road for the opposite direction of travel. The new roadway would be constructed on the west side of the existing alignment from MP 185 to approximately MP 173, where the road would shift to the east side of the existing alignment to the Santa Maria River (MP 161.5).

The land cover surrounding mileposts 160-165 is similar to that between mileposts 155-160, with increased amounts of creosotebush-white bursage desert scrub and riparian vegetation (Table 2). The Santa Maria River is the major riparian feature of the linkage planning area, crossing this segment of US-93 near MP 161.5 (Figure 4). The Santa Maria River provides important willow and cottonwood habitat for species such as yellow-billed cuckoo and black-neck gartersnake, and was included as a specific river reach where recovery efforts should be focused for the southwestern willow flycatcher (USFWS 2002). Also included along this segment of the highway is Black Canyon Wash, which parallels the highway to the west before crossing US-93 south of MP 165. The Black Mountains within the Arrastra Mountain Wilderness Area lie several miles west of US-93, while Malpais Mesa lies two miles east of US-93. The areas surrounding this segment of US-93 linkage provide potentially optimal live-in and pass-through habitat for species dependent on desert vegetation and/or complex topography, such as black-tailed jackrabbit, javelina, kit fox, desert tortoise, mule deer, and Gila monster (Table 3).

Figure 4: Facing north from waypoint 022, the Santa Maria River provides important willow and cottonwood riparian habitat.

Land cover between mileposts 165 and 170 transitions from paloverde-dominated vegetation associations to Sonoran mid-elevation desert scrub as US-93 rises from 2,250 ft at MP 165 to 2,850 ft at MP 170. Sonoran mid-elevation desert scrub is typically composed of an open shrub layer of species such as creosote bush (*Larrea tridentate*), goldenbush (Ericameria linearifolia), buckwheat (*Eriogonum fasciculatum*), and Ocotillo (*Fouquieria splendens*) on rocky soils. Included within both the mapped paloverde-mixed cacti desert scrub and Sonoran mid-elevation desert scrub vegetation associations is a large Joshua tree forest which is particularly extensive within this stretch of US-93 (Figure 5). Within this span of US-93, Black Canyon Wash[2] crosses at MP 165.5 (Figure 6), and several unnamed washes also parallel or cross the highway. Approximately 1¼ miles west of US-93 from mileposts 165-168 is Arrastra Mountain Wilderness Area, while Tres Alamos Wilderness Area is 4-5 miles west of US-93 along mileposts 168-171. The areas surrounding this segment of US-93 linkage provide potentially optimal live-in and pass-through habitat for species dependent on desert vegetation and/or complex topography, such as badger, black-tailed jackrabbit, javelina, kit fox, desert tortoise, and Gila monster (Table 3).

Figure 5: Northeast (azimuth 64) from waypoint 020, a Joshua tree forest mixed with paloverde and creosotebush vegetation associations dominates the landscape.

Between mileposts 170 and 175, vegetation surrounding US-93 is dominated by Sonoran mid-elevation desert scrub, with large amounts of paloverde-mixed cacti desert scrub, and small patches of scattered pinyon-juniper woodlands east of the highway. Date Creek crosses US-93 near MP 174, and provides a potential dispersal corridor composed of diverse topography and riparian habitat between the Black Mountains to the west of the highway and the Date Creek Mountains to the east (Figure 7). Species such as chuckwalla (Lamb et al. 1992) and mule deer are known to occur in both mountain ranges, and potentially optimal live-in and pass-through habitat for species dependent on desert vegetation such as

[2] The *Draft Environmental Assessment for US-93: Wickenburg to Santa Maria River* refers to this bridge as Big Jim Wash; however, this wash is labeled as Black Canyon Wash on 1:24,000 USGS topo maps, and we could find no other reference to Big Jim Wash.

badger, black-tailed jackrabbit, javelina, kit fox, desert tortoise, and Gila monster surrounds this stretch of US-93 (Table 3).

Figure 6: Southwest (azimuth 240) from waypoint 021, a lower reach of Black Canyon Wash crosses US-93 near MP 165.

The land cover surrounding mileposts 175 to 180 is primarily flat desert scrub associations, including a mix of Sonoran mid-elevation desert scrub, mesquite upland scrub, paloverde-mixed cacti desert scrub, and creosotebush-white bursage desert scrub (Figure 8). No major named riparian systems cross this stretch of US-93, although several unnamed washes cross the highway. The areas surrounding this segment of US-93 linkage provide potentially optimal live-in and pass-through habitat for species dependent on desert vegetation or flatter topography, such as badger, black-tailed jackrabbit, and javelina (Table 3).

The land immediately surrounding mileposts 180 to 185 is heavily dominated by mesquite upland scrub, with small amounts of creosotebush and paloverde vegetation associations. Sols Wash parallels US-93 approximately 1 mile west of the highway from mileposts 183 to 185. The area surrounding this segment of US-93 linkage provides potential optimal live-in and pass-through habitat for species dependent on desert vegetation and/or flatter topography, such as badger, black-tailed jackrabbit, and javelina (Table 3).

Figure 7: Looking eastward from waypoint 019, Date Creek is a sandy xeroriparian wash.

Figure 8: Northeast from waypoint 018, the land surrounding US-93 near milepost 177 is flat and dominated by desert scrub (here: mostly creosotebush associations).

Mitigating Barriers to Movement

Although roads occupy only a small fraction of the Linkage Design, they can have severe impacts on animal movement. In this section, we review the potential impacts of these features on ecological processes, identify specific barriers, and suggest mitigations for these barriers. The complete database of our field investigations, including UTM coordinates and photographs, is provided in Appendix E and the Microsoft Access database on the CD-ROM accompanying this report.

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, habitat 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). Recent research also documents that roadway lighting has important impacts on animals (Rich and Longcore 2006).

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			★

Existing Roads and Crossing Structures in the Linkage Design Area

US-93 is the primary highway connecting Phoenix to northwest Arizona and Las Vegas. In the linkage planning area, it runs northwest-southeast from State Road 97 to State Road 71 for approximately 45 km (28 mi), and is the single most important transportation threat to connectivity. NAFTA and the proposed CANAMEX effort to promote commerce among Canada, the United States, and Mexico will likely cause large increases in traffic on US-93. The currently preferred alignment for US-93 between State Roads 71 and 97 will use the existing roadway for one direction of travel, and construct a new two-lane road for the opposite direction of travel. The new alignment would be constructed on the west side of the existing alignment from MP 185 to approximately MP 173, where the road would shift to the east side of the existing alignment to the Santa Maria River (MP 161.5). Part of US-93 have been designated as "Joshua

Forest Scenic Road" due to prominence of Joshua trees along the highway; this designation includes Mileposts 155-180 in the planning area. The other roads in the linkage are local roads with relatively low traffic and traffic speed.

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 near suitable scrub habitat to cross highways, 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. In the rugged and rocky terrain of this linkage area, many culverts designed to carry water under roads likely have large pour-offs at their downstream ends. Although this works fine for carrying water, these culverts do not promote animal movement.

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 a 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). In bighorn sheep habitat, a road tunnel provides an ideal overpass for bighorn, and a wide overpass or open underpass are likely sufficient also.
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 (~ 1 mile) 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). A 1.1 m (3.5 ft) high concrete wall with a 6-inch lip at the top has been successful at preventing snakes, frogs, and other herpetofauna from crossing US 441 in central Florida, instead diverting the species to a nearby drainage culvert (Figure 10). 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**. As noted above, 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, with native land cover up to both culvert openings, as noted above.

Figure 11: The protruding lip on a concrete wall will stop snakes and other reptiles and amphibians from scaling the wall, and the concrete is less permeable than wire fencing. The Paynes Prairie Ecopassage (Florida) successfully directs animals to the undercrossing (culvert) and has reduced road mortality by over 95%.

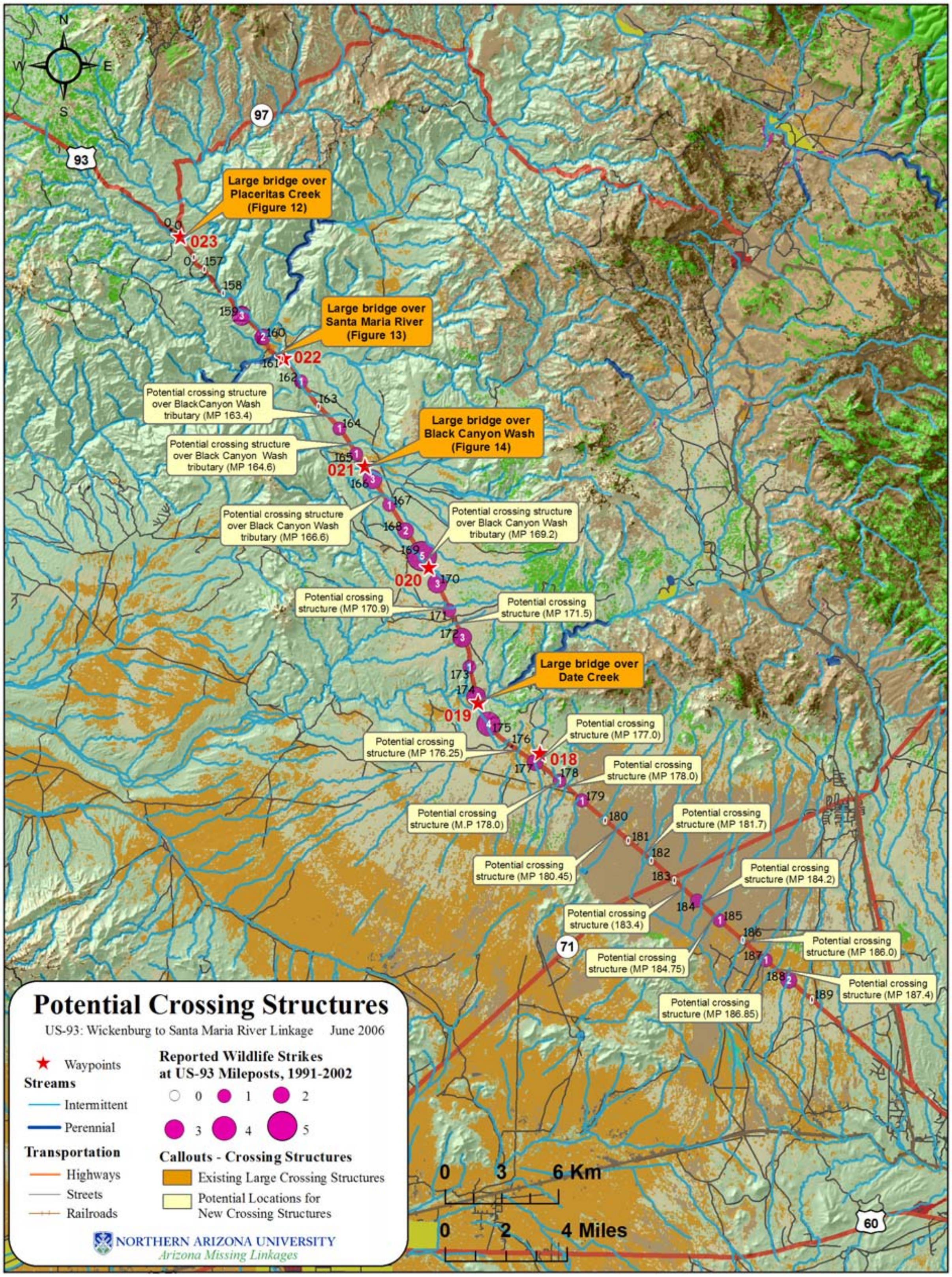

Figure 12: Existing and potential locations of crossing structures along US-93. Also shown are reported wildlife strikes (from draft EIS, reported by AZGFD & ADOT), numbered mileposts, and field investigation waypoints.

Existing Crossing Structures and Recommendations for US-93

Although we could not visit all potential realignments, we did visit and photograph existing major crossing structures in the area (Figure 2, Figure 12). In Figure 12, we point out locations where dry washes cross US-93; these are potential locations for improved crossing structures that can be added when the highway is upgraded. Several crossing structures on the existing US-93 alignment are sufficient for animal movement, including recently constructed bridges over Placeritas Creek (Figure 13), a large open bridge over the Santa Maria River (Figure 14), a bridge over Black Canyon Wash (Figure 15), and a bridge 216' in width over Date Creek (no photograph, but see Figure 12 for location). The remaining crossing structures are not adequate to serve the movement needs of the full suite of wildlife species. In addition to following the above general recommendations throughout US-93, we have several specific recommendations for crossing structures:

- The greatest frequency of reported wildlife-automobile collisions between 1991 and 2002 occurred between the Black Canyon Wash and Date Creek bridges, indicating a need for larger crossing structures between these two locations (Figure 12). Mule deer likely move between the Black Mountains to the west of the highway and the Date Creek Mountains to the east along this portion of US-93. We recommend the creation of at least three new bridges or large, open culverts suitable for ungulates between the existing Black Canyon Wash and Date Creek bridges. Four washes which cross this segment of the highway at approximate mileposts 166.6, 169.2, 170.9, and 171.5 provide potential locations for new bridges. Additionally, wildlife fencing should be installed to direct animals towards these crossing structures.

- Between the Santa Maria River and Black Canyon Wash bridges, at least 3 mid-sized culverts should be created. These culverts should follow the general guidelines suggested above, and provide for small mammals and herpetofauna. Two potential locations for these structures are over tributaries of Black Canyon Wash, labeled on Figure 12.

- Between the Date Creek bridge and SR 71, the topography is relatively flat, and fewer large animals have been struck by vehicles (Figure 12). For this section of US-93, we recommend the creation of at least 6 small or midsized crossing structures to provide connectivity across the highway for species such as javelina and black-tailed jackrabbit. These locations are highlighted on Figure 12. Low wildlife fencing should be suitable for guiding these species towards crossing structures.

- Along all portions of US-93, measures should be taken to ensure amphibians and reptiles can cross the highway. The topography is particularly rugged along most portions of US-93, potentially providing habitat for species such as Arizona black rattlesnake, rosy boa, speckled rattlesnake, chuckwalla, Sonoran desert tortoise, and Gila monster. To ensure these species and other reptiles and amphibians can cross US-93, we recommend installation of impermeable fencing (such as the lipped concrete wall shown in Figure 11) along all portions of US-93 which are adjacent to rock outcrops and steep slopes. This fencing should guide amphibians and reptiles to small crossing structures spaced according to the guidelines above.

Figure 13: Large bridges permit both lanes of traffic to cross over Placeritas Creek at waypoint 023.

Figure 14: Looking north from waypoint 022, a large bridge 616' in width crosses over the Santa Maria River.

Figure 15: South from waypoint 021, a large multiple-span bridge crosses over Black Canyon Wash.

Appendix A: Linkage Design Methods

Our goal was to provide information to help transportation agencies to construct crossing structures along US-93, and its potential expansion along the existing alignment. These structures will conserve and enhance wildlife movement through the existing habitat surrounding the highway.

To create the Linkage Design, we used GIS approaches to estimate potential habitat suitability for focal species representing the ecological community in the area[3]. By carefully selecting a diverse group of focal species, the Linkage Design should ensure the long-term viability of all species in the protected areas. Our approach included four 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) Carry out field visits to identify barriers to movement and suggest locations for underpasses or overpasses within Linkage Design area.

During 2005-2007, we are producing 16 linkage designs under contract to Arizona Game and Fish Department. In most cases, our analyses focus on a "Potential Linkage Area" – a swath of private and state land between publicly-owned wildland blocks. In this study, the closest wildland block east of US-93, the Prescott National Forest, is in the Apache Highlands ecoregion, which supports a different assemblage of species than the Sonoran desert of the BLM block west of US-93. For this report, we therefore used the large areas of ASLD land east of US-93 as a wildland block. Because these lands form a large contiguous block (not checkerboarded with private land as elsewhere) with little development pressure, they form a reasonable wildland block. In this case, the Potential Linkage Area (or Linkage Planning Area) is all land within 3 miles (5 km) of any of the currently proposed alignments for US-93.

Because we defined the Linkage Planning Area differently than in our other reports, we cannot conduct the same wildlife corridor analyses that we use in our other reports. Instead we map the distribution of potential habitat, breeding patches, and population cores for each focal species within the linkage planning area. We use these maps and literature on how wildlife crosses highways to provide general recommendations for accommodating movement by these species in future highway realignments.

Focal Species Selection

To represent the needs of the ecological community within the linkage planning area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 20 species (Table 1) that had one or more of the following characteristics:

- habitat specialists, especially habitats that may be relatively rare in the linkage planning area.
- species sensitive to highways, canals, urbanization, or other potential barriers in the linkage planning area, especially species with limited movement ability.

[3] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute "truth" but rather an estimate or prediction of wildlife habitat. 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 a particular landscape) 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.

- 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 A. 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 (most herpetofauna, which are saxicolous or riparian-dwelling), or if the species probably can fly across unsuitable habitat (all suggested birds).

Habitat Suitability Models

We created habitat suitability models (Appendix A) for each species by estimating how the species responded to four habitat factors that were mapped at a 30x30 m level of resolution (Figure 16):

- *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 B.
- *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[4].

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 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.

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

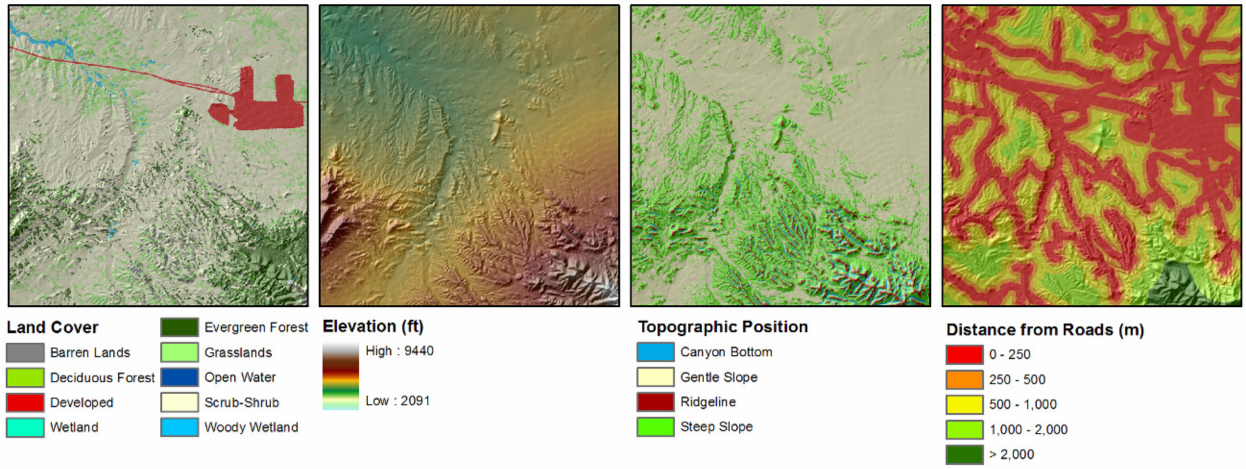

Figure 16: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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 Protected Wildland blocks and in the linkage planning 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 linkage planning 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 17). 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.

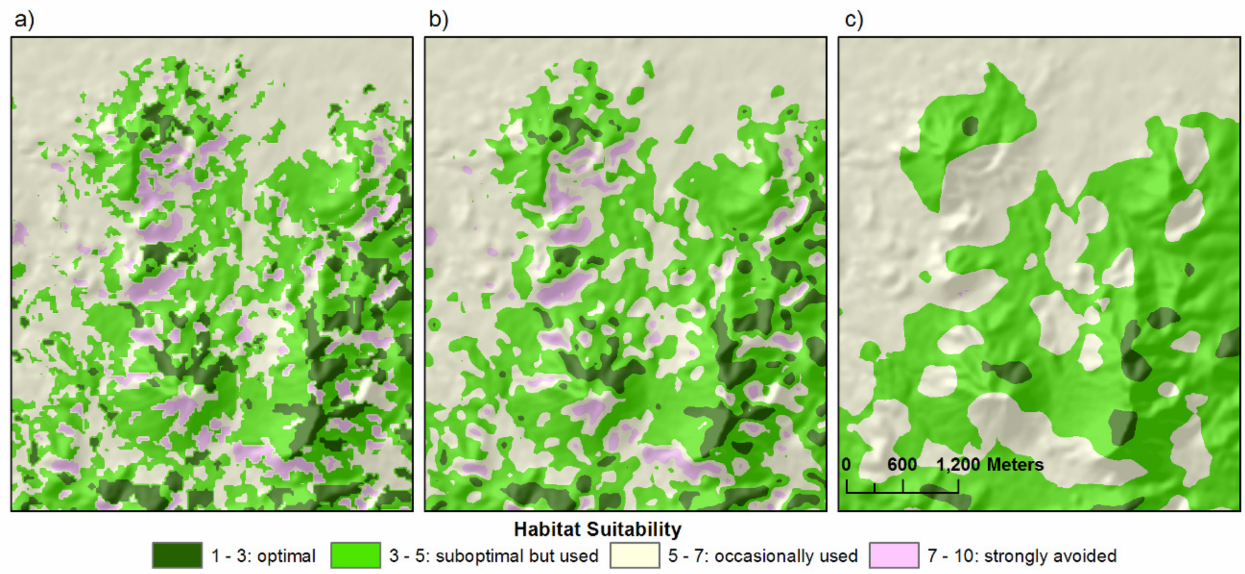

Figure 17: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

Field Investigations

Although our analyses consider human land use and distance from roads, our GIS layers only crudely reflect important barriers that are only a pixel or two in width, such as freeways, canals, and major fences. Therefore we visited each linkage design area to assess such barriers and identify restoration opportunities. We documented areas of interest using GPS, photography, and field notes. We evaluated existing bridges, underpasses, overpasses, and culverts along highways as potential structures for animals to cross the highway, or as locations where improved crossing structures could be built. We noted recent (unmapped) housing & residential developments, major fences, and artificial night lighting that could impede animal movement, and opportunities to restore native vegetation degraded by human disturbance or exotic plant species. A database of field notes, GPS coordinates, and photos of our field investigations can be found in Appendix E, 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	Bighorn Sheep	Black-tailed Jackrabbit	Javelina	Mountain Lion
Factor Weights					
Land Cover	65	30	70	50	70
Elevation	7	10	10	30	0
Topography	15	50	10	20	10
Distance from Roads	13	10	10	0	20
Land Cover					
Pine-Oak Forest and Woodland	5	9	6	7	1
Pinyon-Juniper Woodland	4	9	4	5	1
Juniper Savanna	2	8	3	7	4
Semi-Desert Grassland and Steppe	1	5	4	2	5
Chaparral	5	9	6	3	3
Creosotebush-White Bursage Desert Scrub	2	6	2	4	6
Sonoran Mid-elevation Desert Scrub	3	2	1	2	6
Mesquite Upland Scrub	3	7	4	2	4
Paloverde-Mixed Cacti Desert Scrub	4	3	1	1	7
Riparian Mesquite Bosque	6	9	5	1	4
Riparian Woodland and Shrubland	6	9	4	2	2
Volcanic Rock Land and Cinder Land	10	7	9	9	9
Recently Mined or Quarried	9	10	10	10	8
Agriculture	6	10	6	7	10
Developed, Medium - High Intensity	10	10	9	7	10
Developed, Open Space - Low Intensity	7	10	6	4	8
Open Water	9	10	9	10	9
Elevation (ft)					
Elevation range: score	0-5500: 1 5500-8000: 3 8000-11000: 6	0-2950: 2 2950-3300: 1 3300-7000: 3 7000-11000: 7	0-6000: 1 6000-8000: 4 8000-11000: 8	0-5000: 1 5000-7000: 3 7000-11000: 10	
Topographic Position					
Canyon Bottom	5	8	3	1	1
Flat - Gentle Slopes	1	7	1	1	3
Steep Slope	8	5	4	7	3
Ridgetop	7	1	4	4	4
Distance from Roads (m)					
Distance from roads: score	0-250: 6 250-1500: 1	0-1000: 6 1000-15000: 2	0-250: 9 250-500: 6 500-1000: 3 1000-15000: 1		0-200: 8 200-500: 6 600-1000: 5 1000-1500: 2 1500-15000: 1

	Kit Fox	Mule Deer	Desert Tortoise	Gila Monster
Factor Weights				
Land Cover		80	30	10
Elevation		0	25	35
Topography		15	40	45
Distance from Roads		5	5	10
Land Cover				
Pine-Oak Forest and Woodland		3	10	10
Pinyon-Juniper Woodland		5	10	6
Juniper Savanna		4	10	10
Semi-Desert Grassland and Steppe		2	8	5
Chaparral		4	10	6
Creosotebush-White Bursage Desert Scrub		6	5	7
Sonoran Mid-elevation Desert Scrub		6	4	3
Mesquite Upland Scrub		3	7	4
Paloverde-Mixed Cacti Desert Scrub		3	1	1
Riparian Mesquite Bosque		3	5	5
Riparian Woodland and Shrubland		3	10	5
Volcanic Rock Land and Cinder Land		8	10	1
Recently Mined or Quarried		6	10	10
Agriculture		6	10	10
Developed, Medium - High Intensity		9	10	9
Developed, Open Space - Low Intensity		5	7	1
Open Water		10	10	10
Elevation (ft)				
Elevation range: score			0-5000: 1 5000-7000: 7 7000-11000: 10	0-1700: 4 1700-4000: 1 4000-4800: 4 4800-5700: 7
Topographic Position				
Canyon Bottom		2	8	1
Flat - Gentle Slopes		2	5	5
Steep Slope		4	3	1
Ridgetop		6	7	1
Distance from Roads (m)				
Distance from roads: score		0-250: 7 250-1000: 3 1000-15000: 1	0-250: 5 250-500: 4 500-1000: 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.

Potential Habitat Suitability

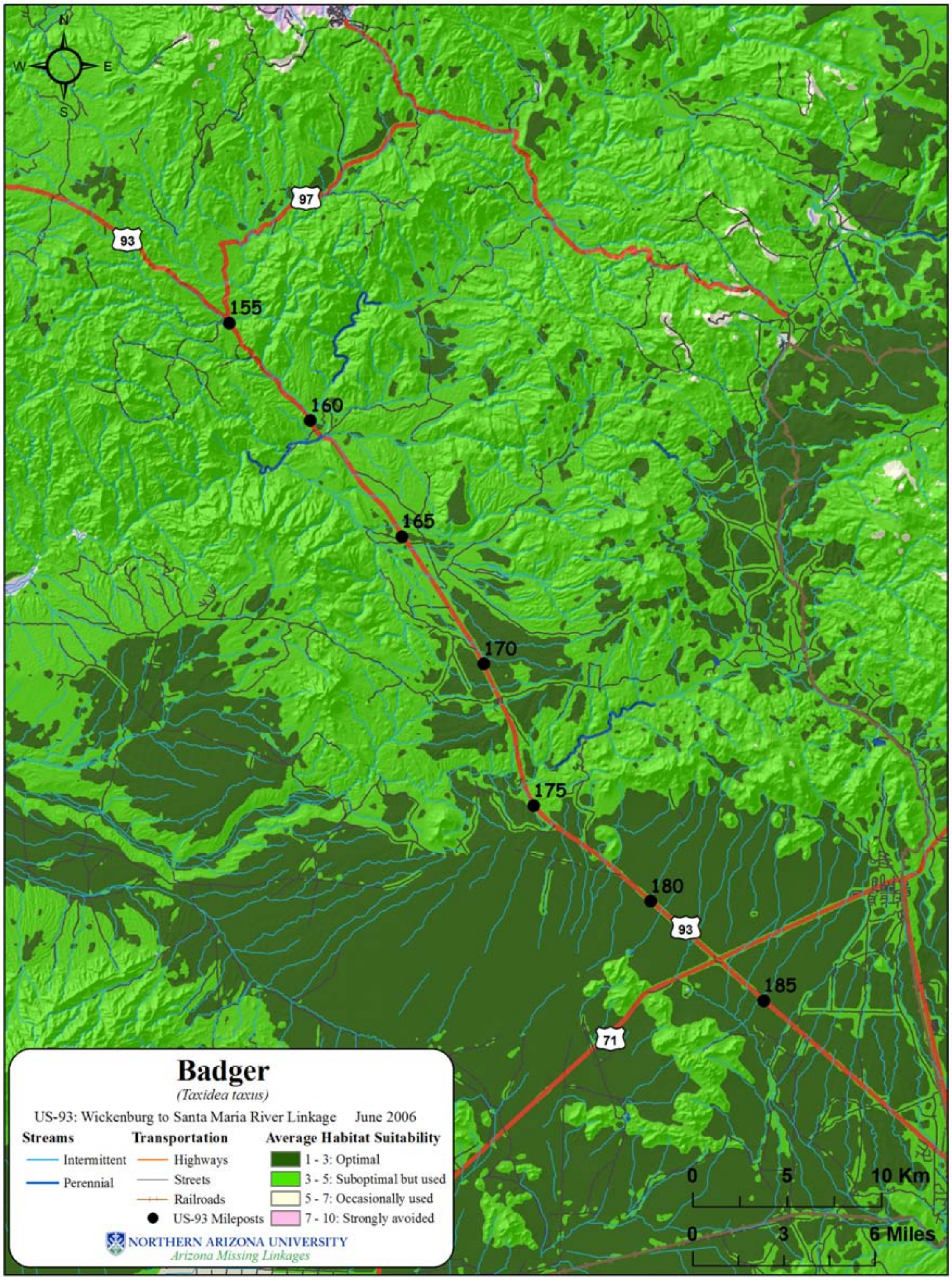

Figure 18: Modeled habitat suitability of badger.

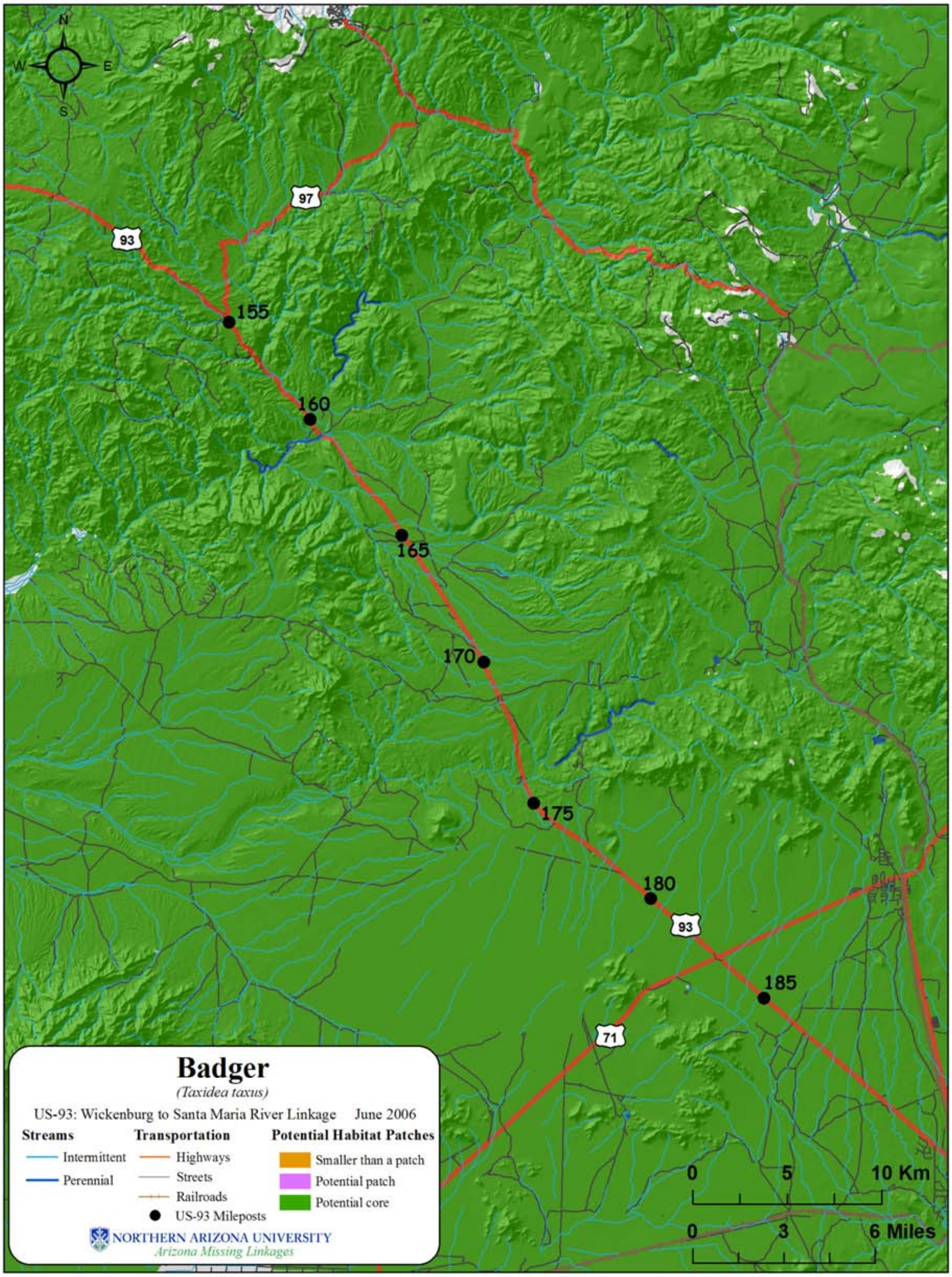

Figure 19: Potential habitat patches and cores for badger.

Black-tailed Jackrabbit (*Lepus californicus*)

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

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

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

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

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

Potential Habitat Suitability

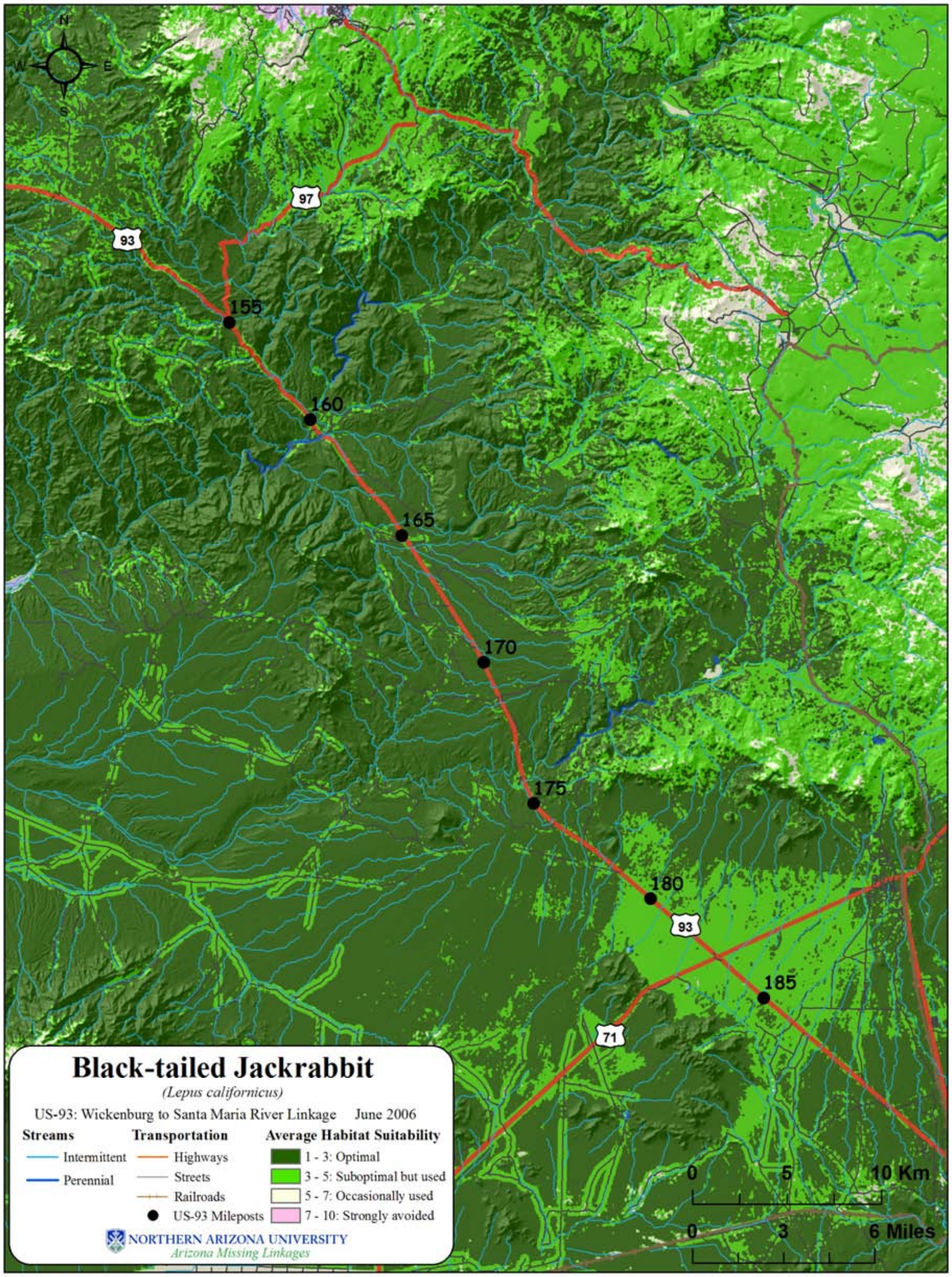

Figure 20: Modeled habitat suitability of black-tailed jackrabbit.

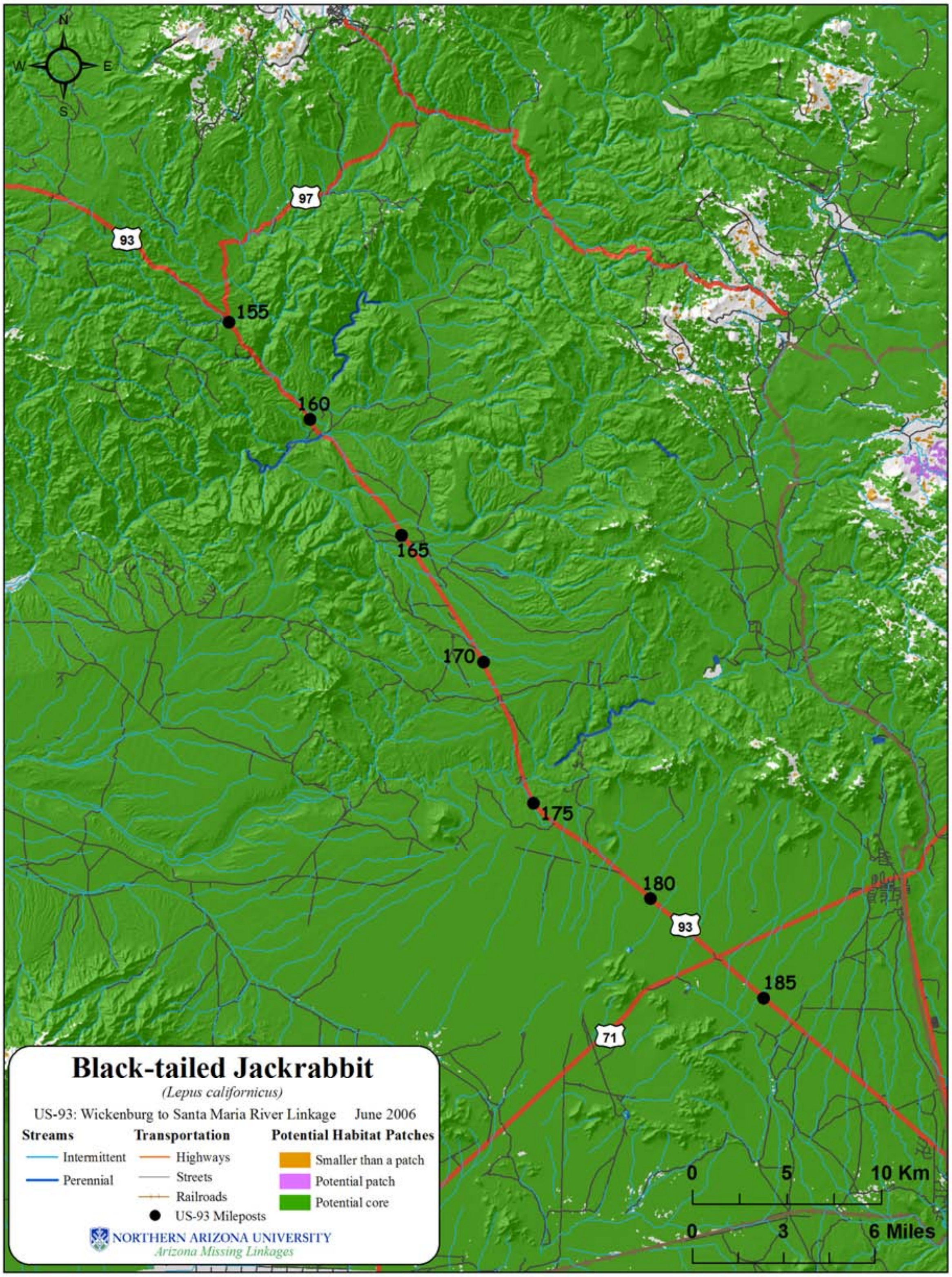

Figure 21: Potential habitat patches and cores for black-tailed jackrabbit.

Desert Bighorn Sheep (*Ovis canadensis nelsoni)*

Justification for Selection

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

Distribution

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

Habitat Associations

Bighorn sheep habitat includes mesic to xeric grasslands found within mountains, foothills, and major river canyons (Shackleton 1985). These grasslands must also include precipitous, rocky slopes with rugged cliffs and crags for use as escape terrain (Shackleton 1985; Alvarez-Cardenas et al. 2001; Rubin et al. 2002; New Mexico Department of Game and Fish 2004). Slopes >80% are preferred by bighorn sheep, and slopes <40% are avoided (Alvarez-Cardenas et al. 2001). Dense forests and chaparral that restrict vision are also avoided (NatureServe 2005). In Arizona, the desert bighorn subspecies (*O. canadensis nelsoni*) is associated with feeding grounds that include mesquite, ironwood, palo verde, catclaw coffeeberry, bush muhly, jojoba, brittlebrush, calliandra, and galleta (Hoffmeister 1986). Water is an important and limiting resource for desert bighorn sheep (Rubin et al. 2002). Where possible, desert bighorn will seek both water and food from such plants as cholla, prickly pear, agave, and especially saguaro fruits (Hoffmeister 1986). Bighorn sheep will also occasionally graze on shrubs such as sagebrush, mountain mahogany, cliffrose, and blackbrush (New Mexico Department of Game and Fish 2004). Elevation range for bighorn sheep varies across their range from 0 – 3,660 m (New Mexico Department of Game and Fish 2004), but in Arizona the desert bighorn subspecies is found from 100 – 1000m elevation, with the best habitat found from 900 – 1,000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong topographic preferences, topographic position received an importance weight of 50%, while vegetation, elevation, and distance from roads received weights of 30%, 10%, and 10%. For specific costs of classes within each of these factors used for the modeling process, see Table 4. Because bighorn sheep actively select slopes greater than 40% for escape terrain, any pixel located further than 300 meters from a slope greater than 40% was reclassified to a suitability score between 5 and 10.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 16.9 km^2 (Shackleton 1985), and minimum potential habitat core size was defined as 84.5 km^2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Potential Habitat Suitability

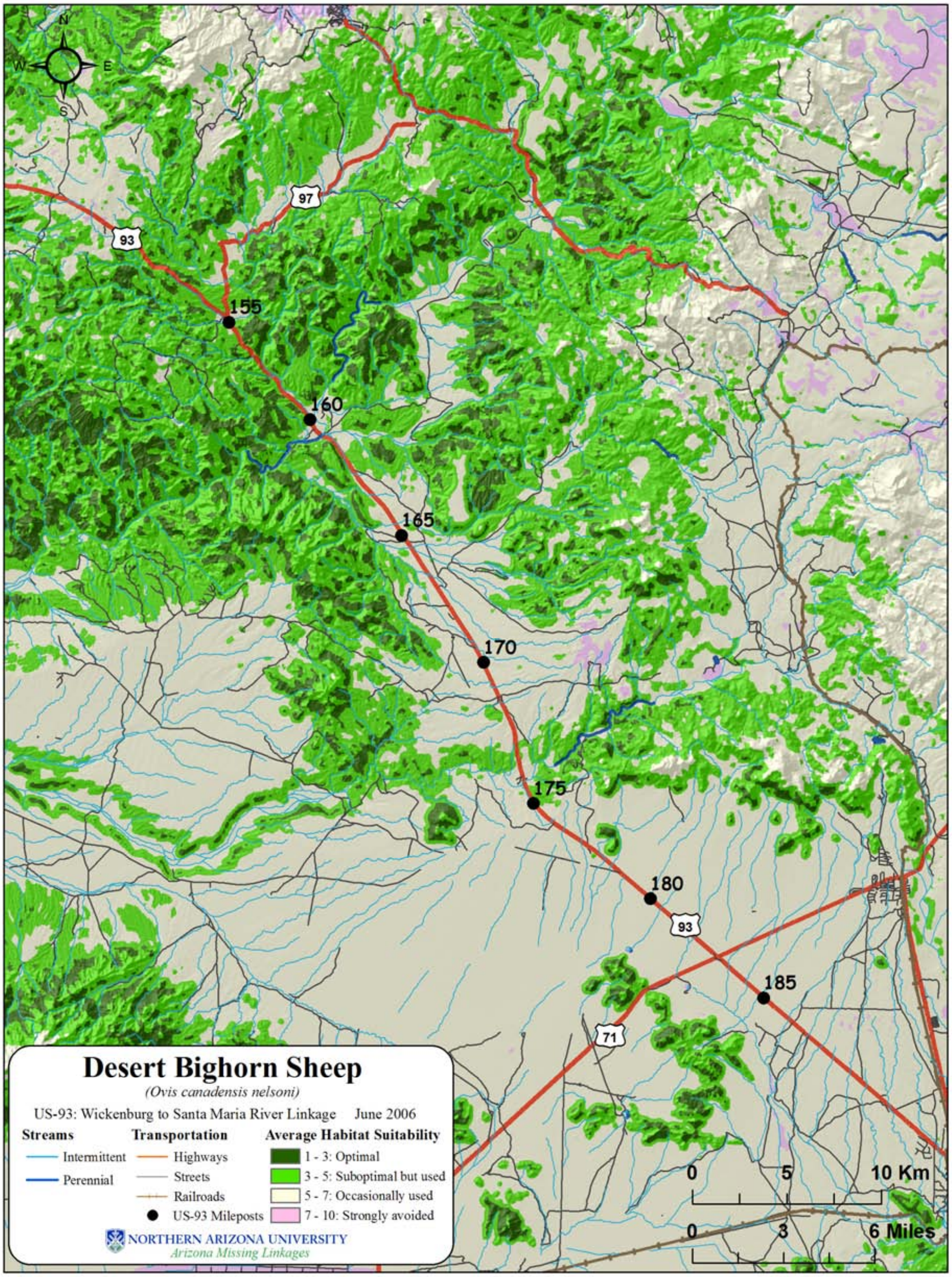

Figure 22: Modeled habitat suitability of desert bighorn sheep.

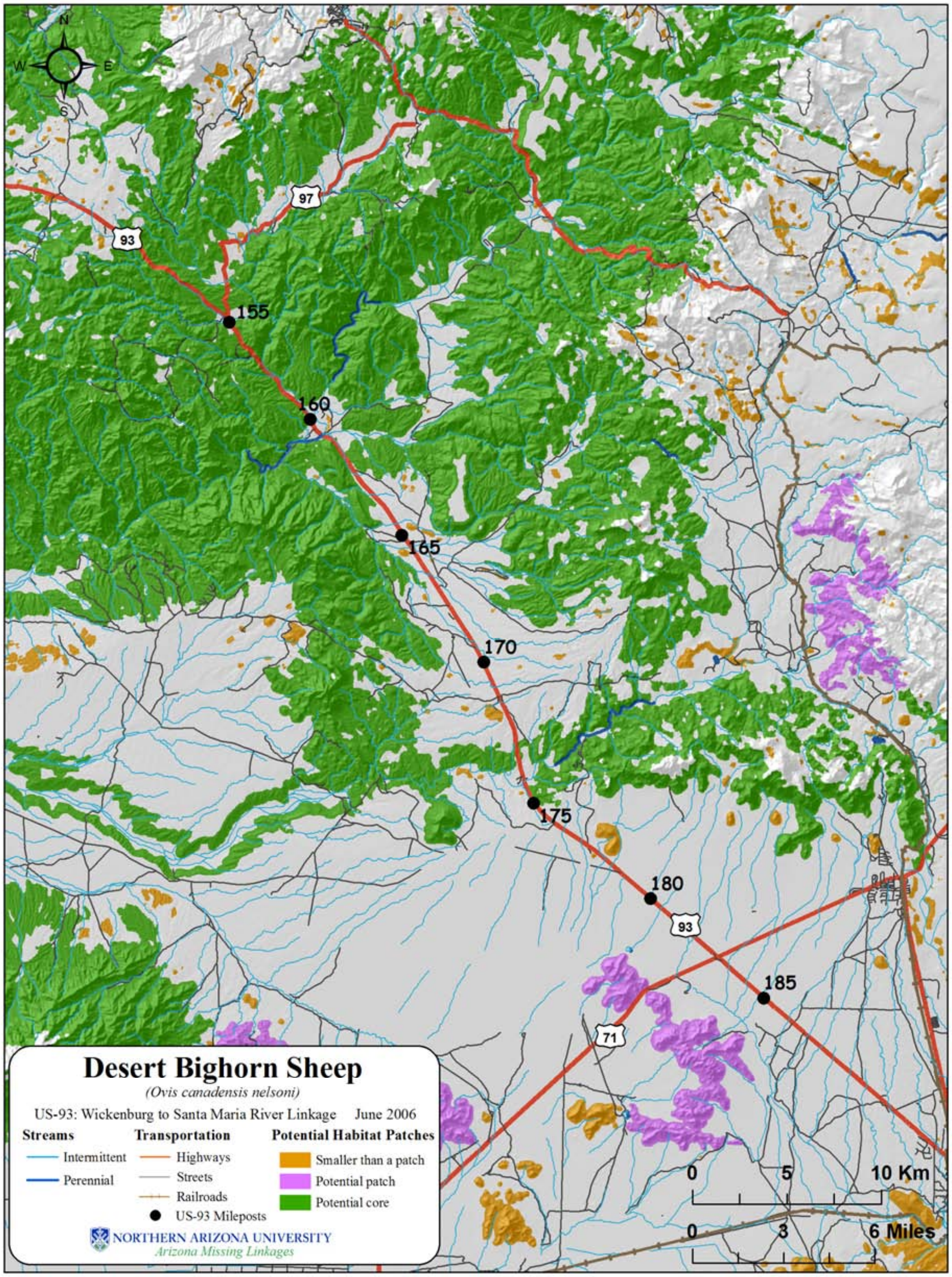

Figure 23: Potential habitat patches and cores for desert bighorn sheep.

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Potential Habitat Suitability

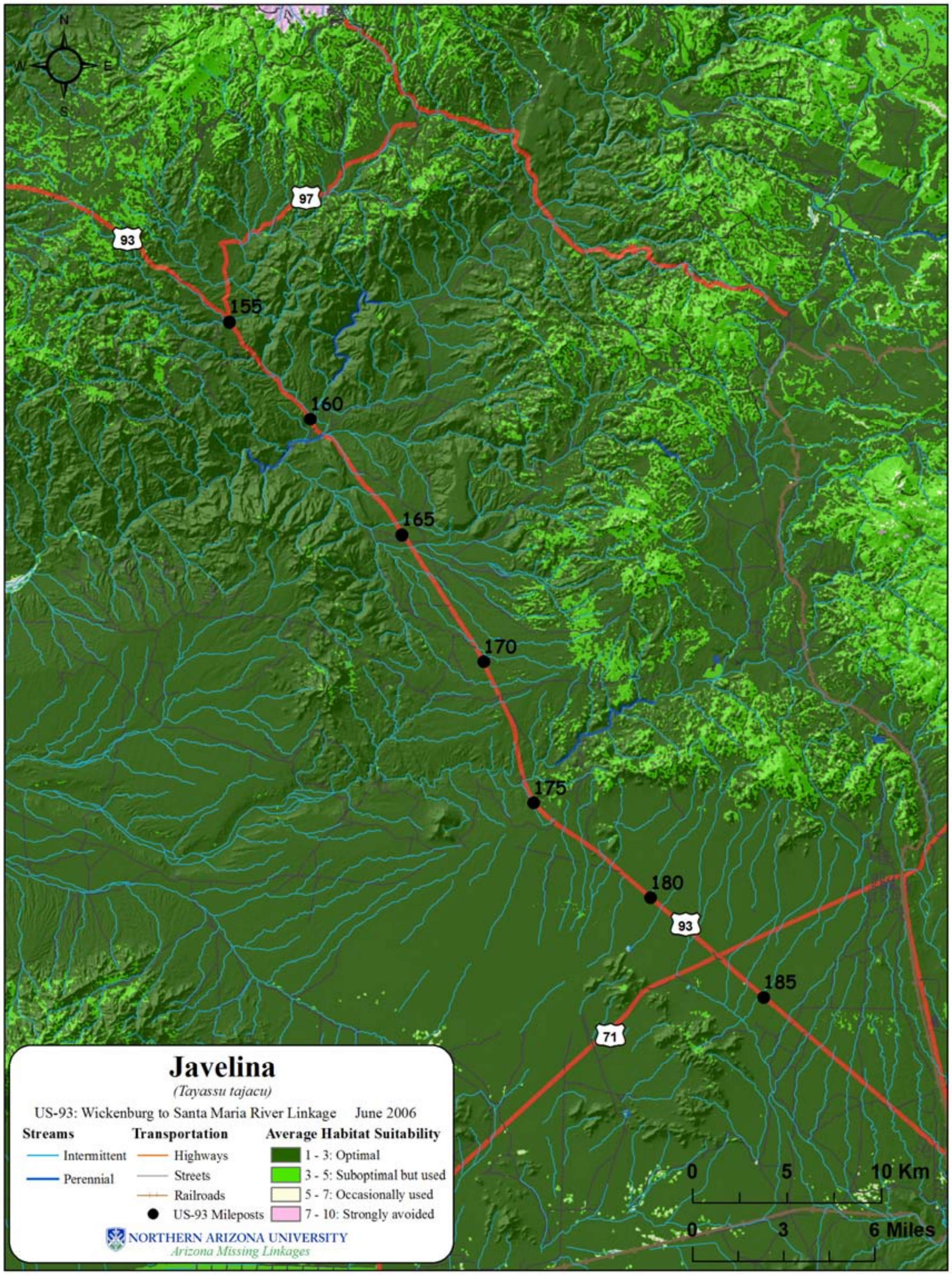

Figure 24: Modeled habitat suitability of javelina.

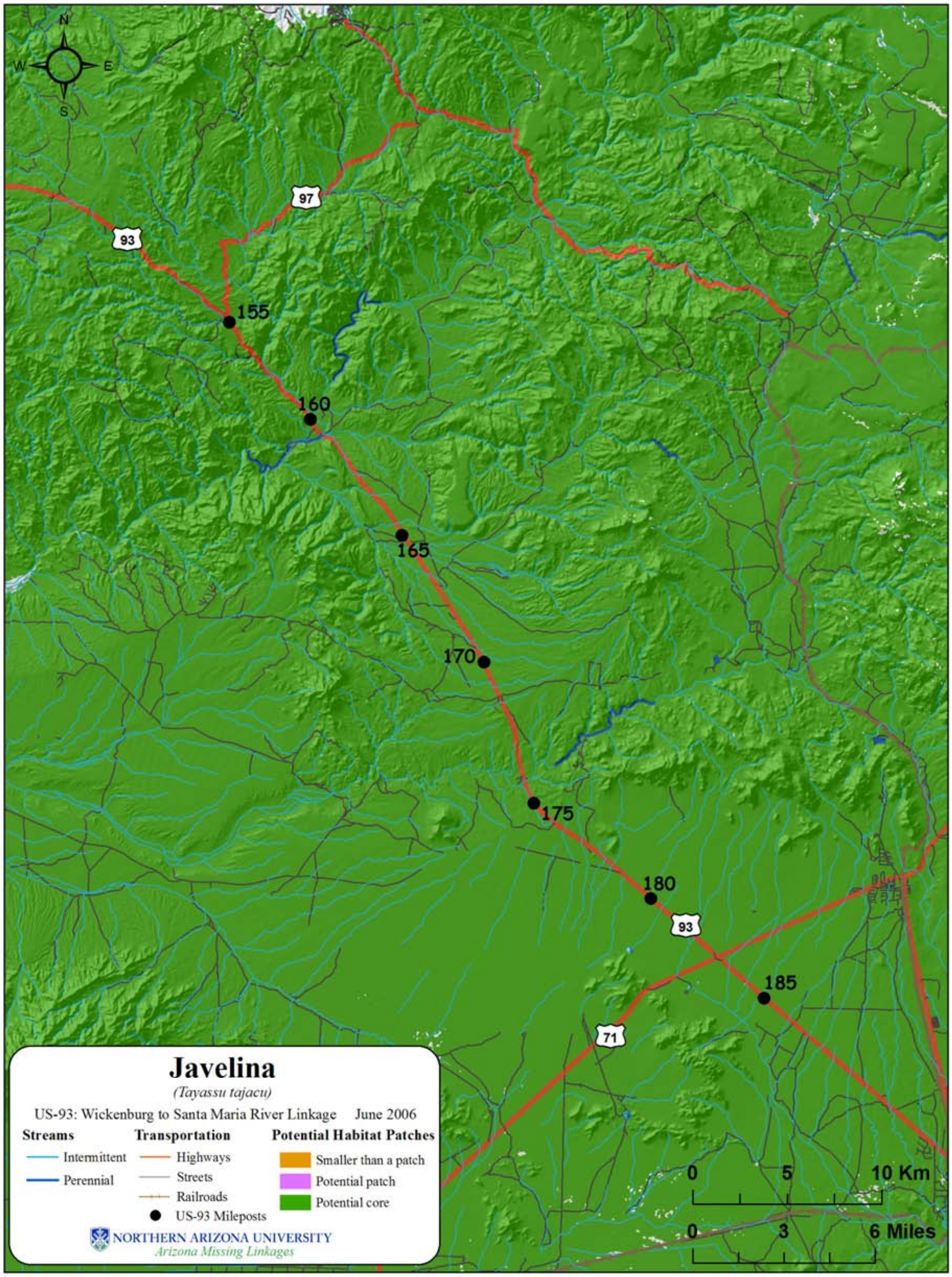

Figure 25: Potential habitat patches and cores for javelina.

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, Chichuahua, 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 1,230 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.

Potential Habitat Suitability

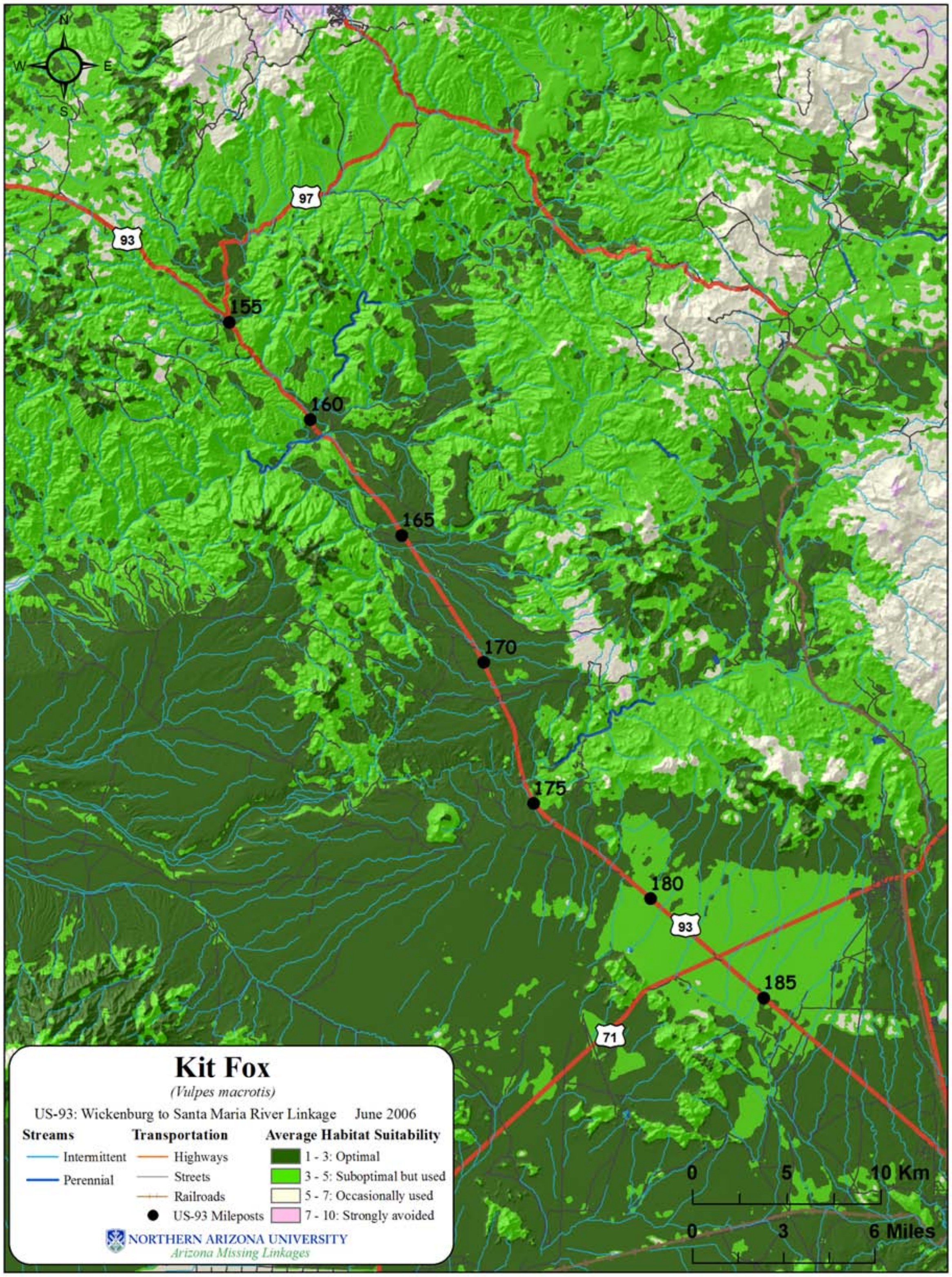

Figure 26: Modeled habitat suitability of kit fox.

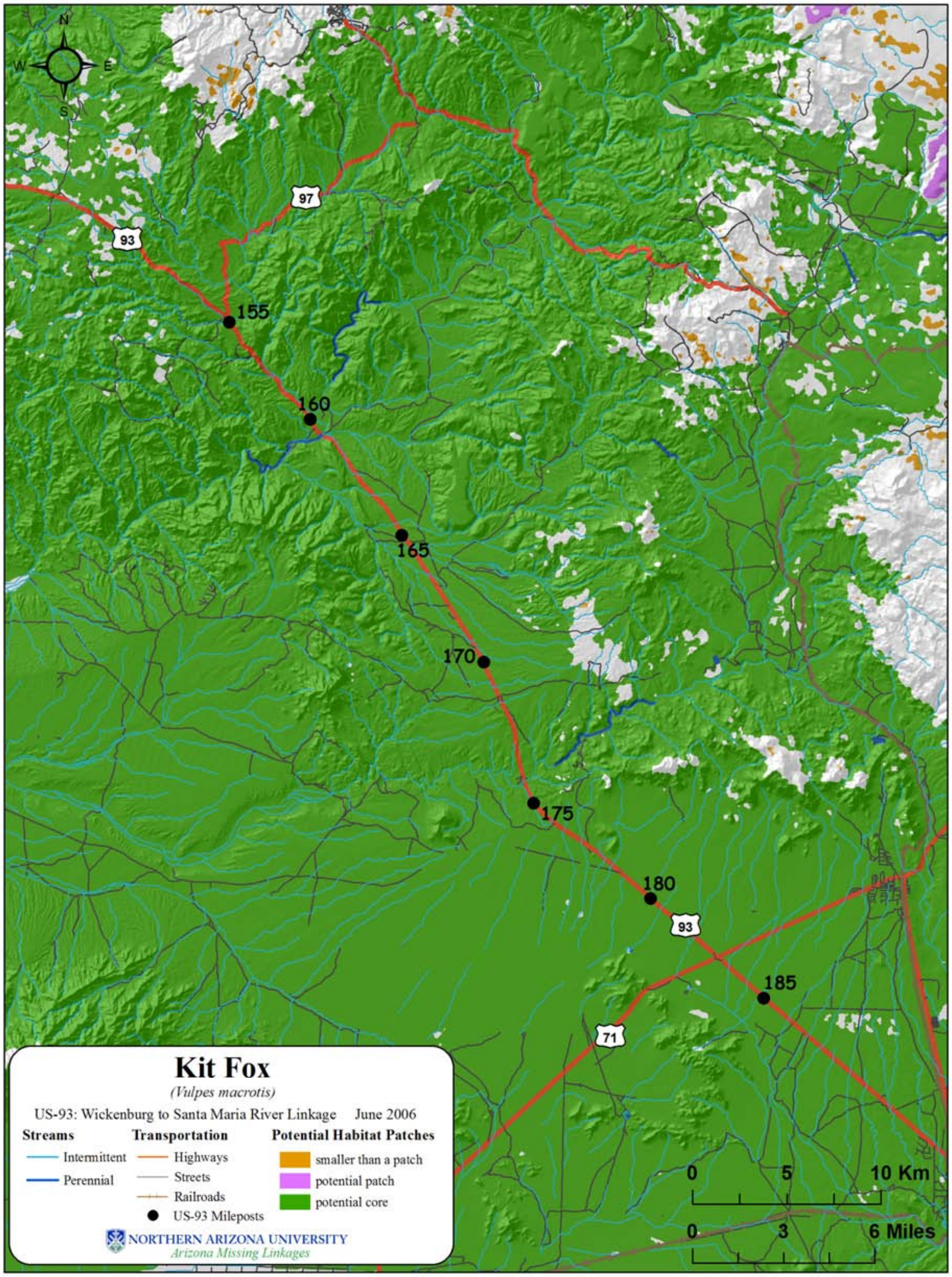

Figure 27: Potential habitat patches and cores for kit fox.

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).

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 4,000 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 km^2 for males and 69.9 km^2 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 km^2 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.

Potential Habitat Suitability

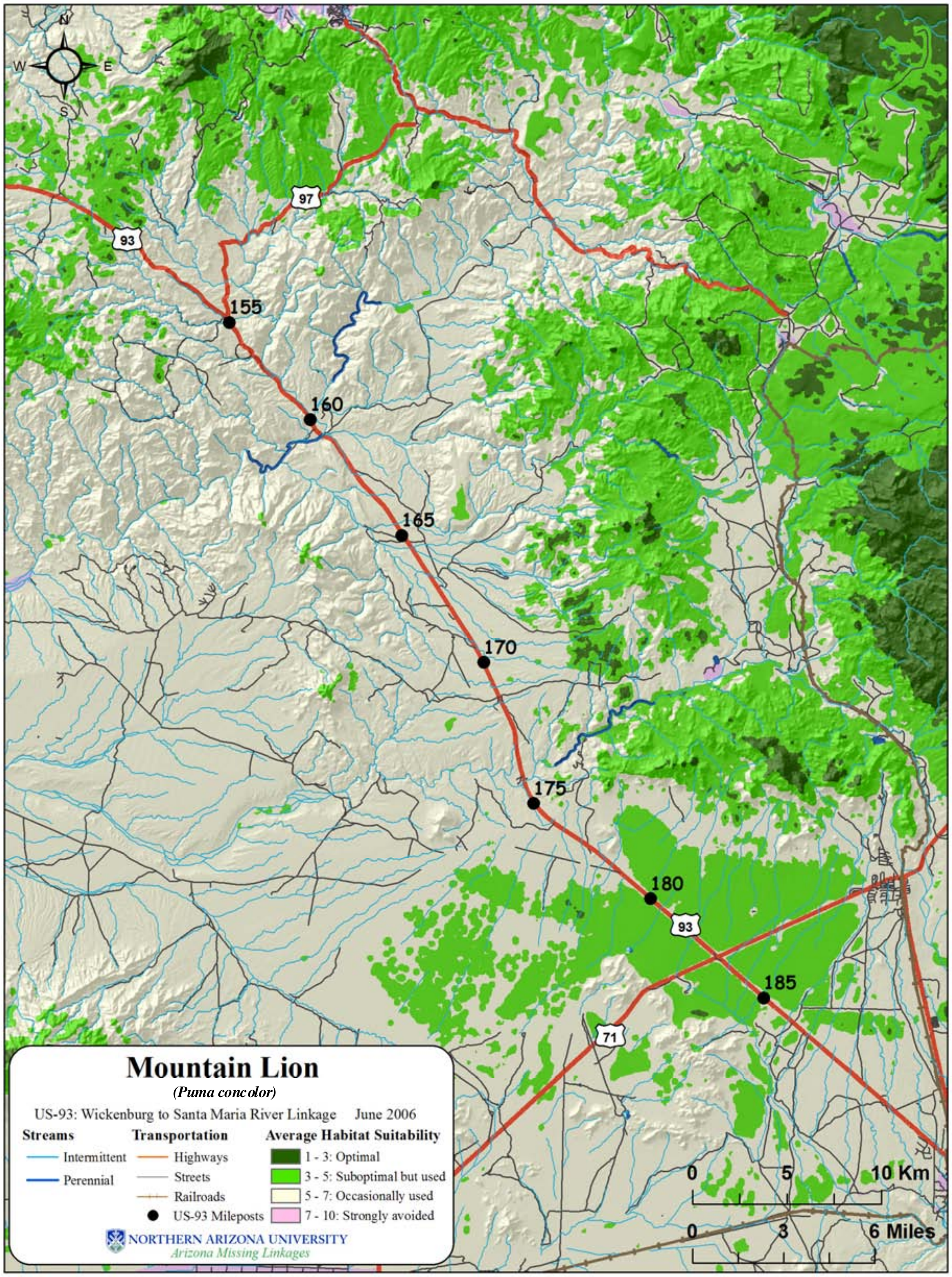

Figure 28: Modeled habitat suitability of mountain lion.

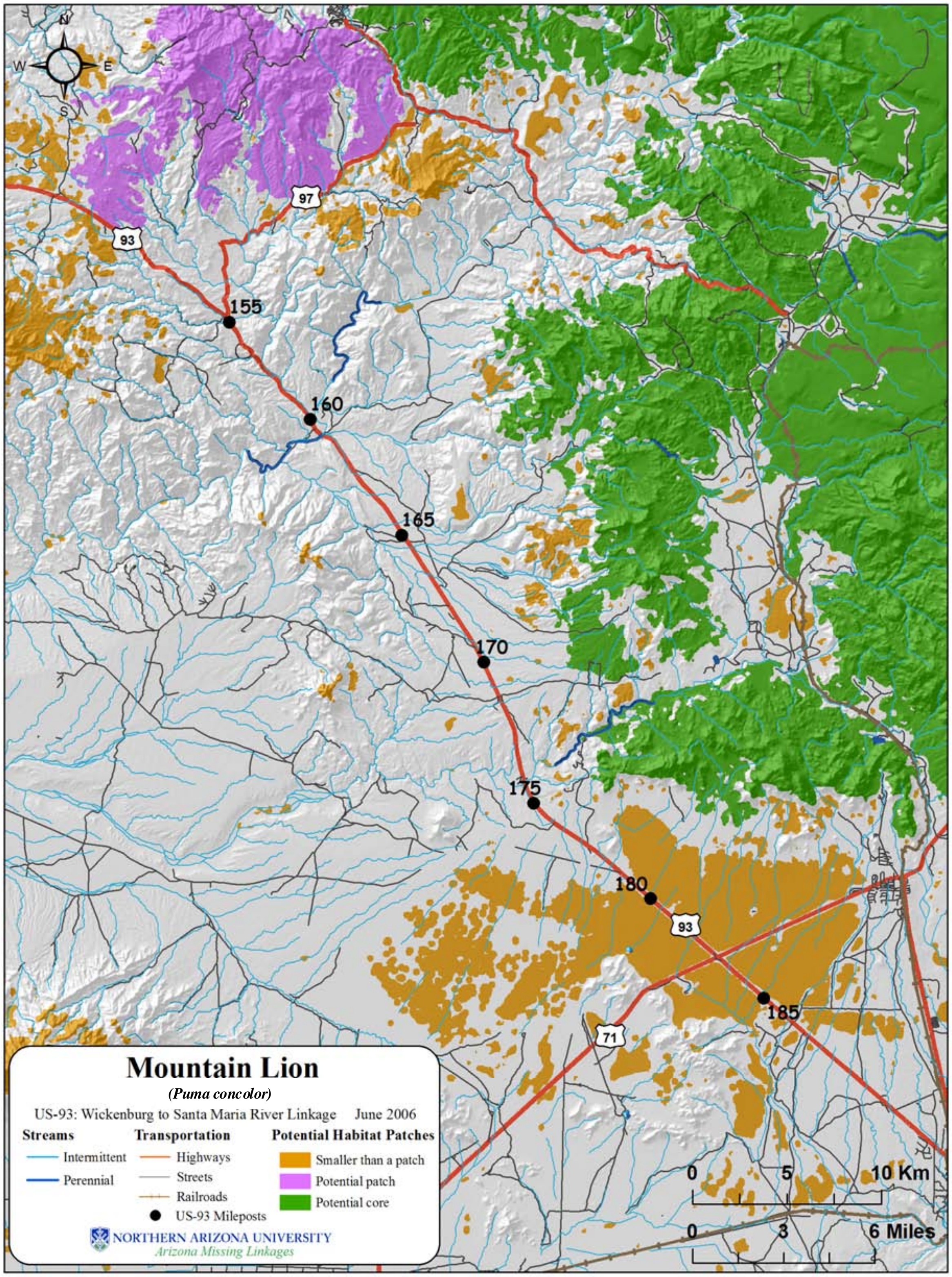

Figure 29: Potential habitat patches and cores for mountain lion.

Mule Deer (*Odocoileus hemionus*)

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

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).

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.

Potential Habitat Suitability

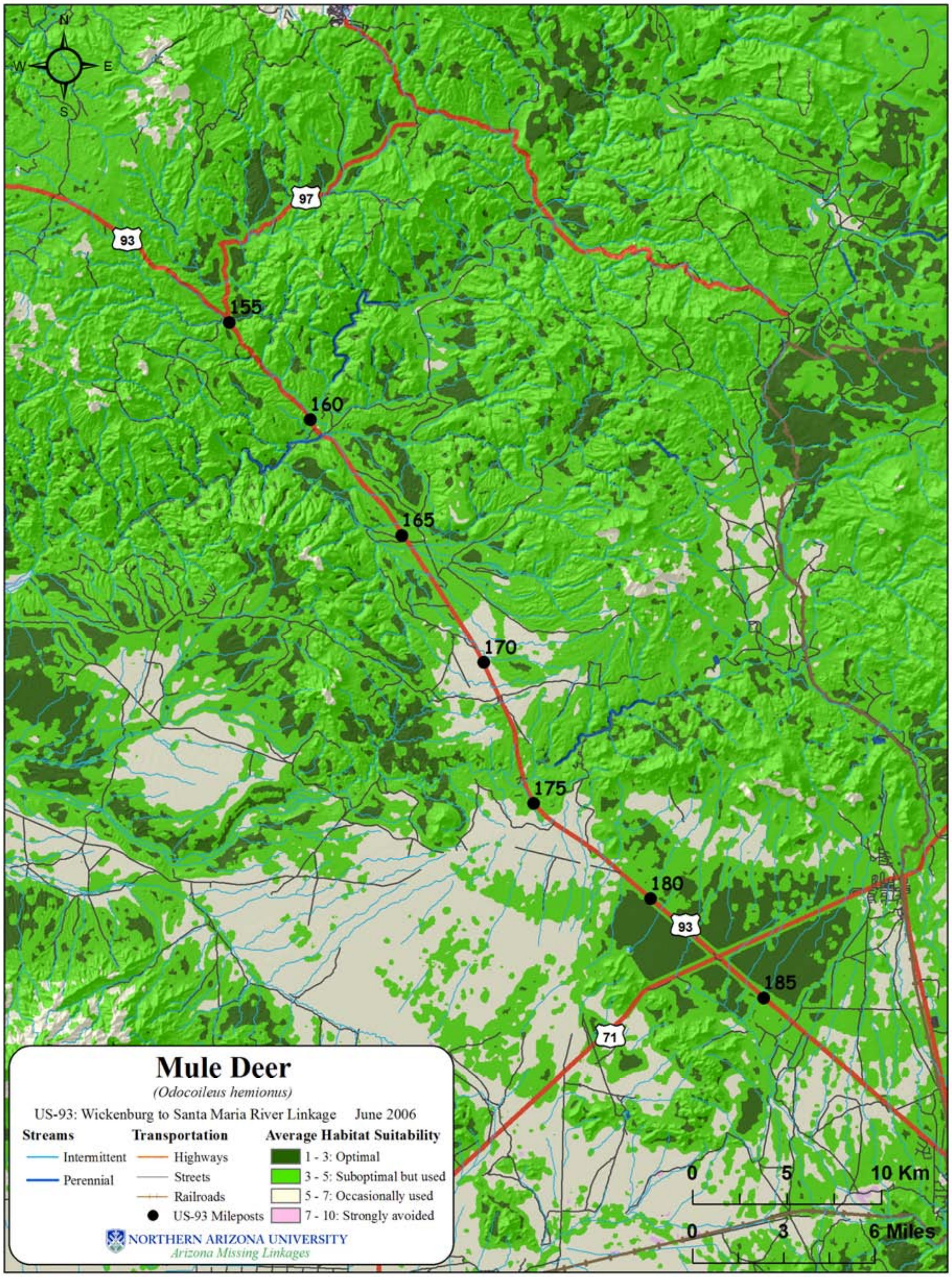

Figure 30: Modeled habitat suitability of mule deer.

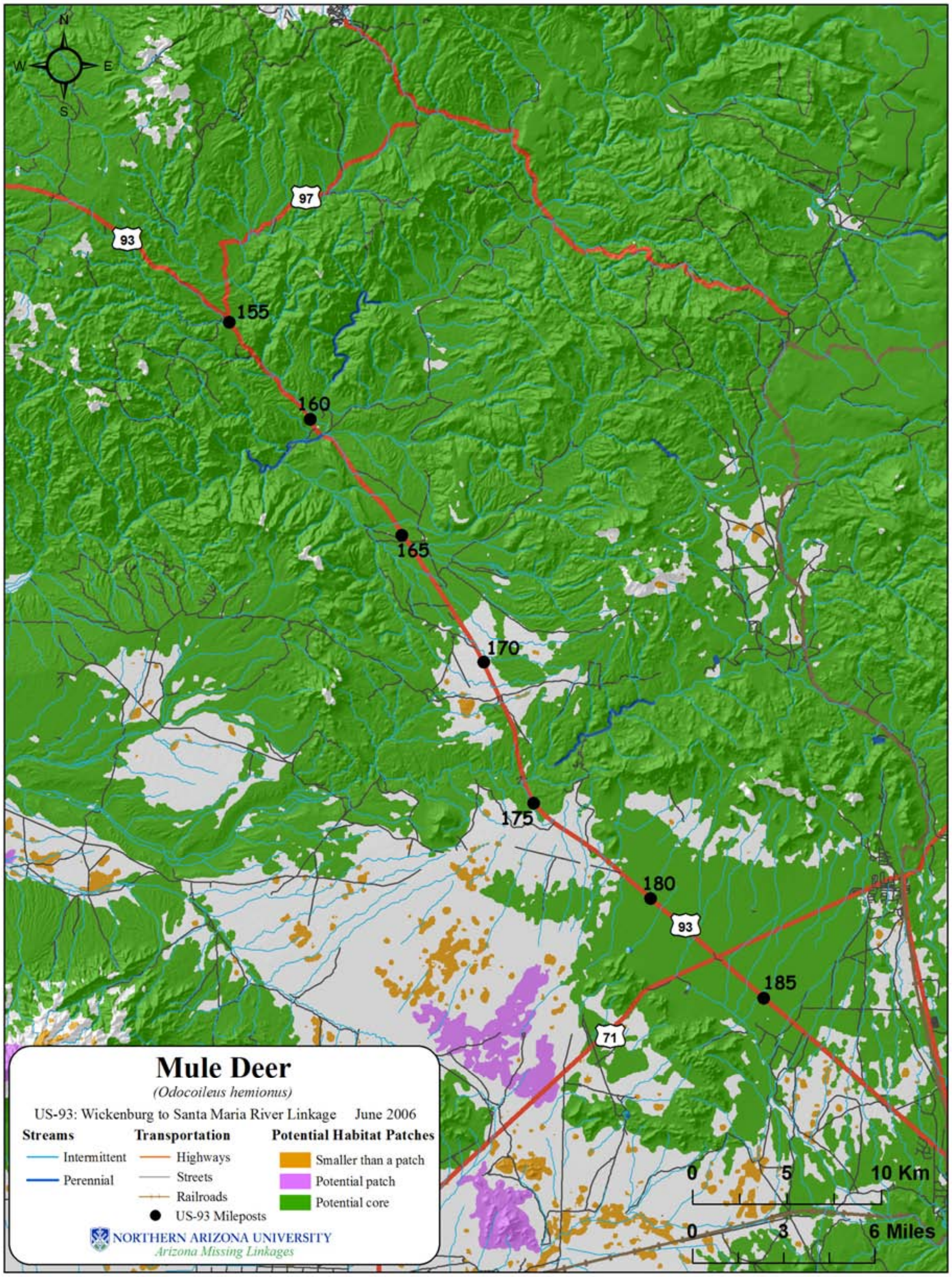

Figure 31: Potential habitat patches and cores for mule deer.

Desert Tortoise (*Gopherus agassizii*)

Justification for Selection

While the Mojave population of desert tortoise is listed as Threatened by the Fish & Wildlife Service, the Sonoran population is not currently listed. However, all desert tortoise populations are susceptible to habitat fragmentation, and need connectivity to maintain genetic diversity. Their ability to survive as an individual or population near roads is limited because of the potential for roadkill (Edwards et al. 2003).

Distribution

Desert tortoises are found deserts throughout California, southeastern Nevada, southwestern Utah, and Arizona. Desert tortoises are divided into two populations: the Mojave Desert population occurs north and west of the Colorado River, while the Sonoran Desert population occurs south and east of the Colorado River. Desert tortoises are found within Ironwood Forest National Monument with greatest frequency in the Sawtooth, West Silverbell, and Silverbell Mountains.

Habitat Associations

Tortoises are dependent on soil type and rock formations for shelter. Typical tortoise habitat in the Sonoran Desert is rocky outcrops (Bailey et al. 1995) where they make their burrows on south facing slopes. Exceptions to this rule usually involve some other topographical feature (such as caliche caves) that act similarly as shelter (Taylor Edwards, personal comm.). Desert Tortoises are obligate herbivores (Oftedal 2002) so vegetation is an important part of their habitat. However, desert tortoises also occur over a wide range of vegetation (Sinaloan thornscrub - Mojave Desert), so vegetation is therefore a variable resource. Desert tortoises eat both annuals and perennials, but not generally the desert plants that characterize a vegetation type (saguaro cactus, palo verde, etc.). Optimal habitat usually lies in Arizona Upland, between 2,200 and 3000 ft, although some low desert populations occur at ~1500 ft (Eagletail Mtns) and others breed at elevations up to ~4500ft (Chiminea Canyon) (Aslan et al. 2003; T. Edwards, personal comm.).

Spatial Patterns

Mean home range estimates (minimum convex polygon) from 5 different studies at 6 different sites accross the Sonoran Desert are between 7 and 23 ha (Averill-Murray et al. 2002). The Sonoran desert tortoise: natural history, biology, and conservation. Density of tortoise populations range from 20 - upwards of 150 individuals per square mile (from 23 Sonoran Desert populations; Averill-Murray et al. 2002). Tortoises have overlapping home ranges, so the estimated space needed for roughly 20 adults is approximately 50 hectares, which is the size of the Tumamoc Hill population near Tucson (Edwards et al. 2003). Desert tortoises are a long-lived species (well exceeding 40 years; Germano 1992) with a long generation time (estimated at 25 years; USFWS 1994). A 5-10 year time frame for a desert tortoise population is relatively insignificant, such that 20 adult individuals might maintain for 30+ years without ever successfully producing viable offspring. Also, tortoises have likely maintained long-term, small effective population sizes throughout their evolutionary history (see Edwards et al. 2004 for more insight into genetic diversity; Germano 1992; USFWS 1994). While long-distance movements of desert tortoises appear uncommon, they do occur and are likely *very* important for the long-term maintenance of populations (Edwards et al. 2004). Desert tortoises may move more than 30 km during long-distance movements (T. Edwards, personal comm.)

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 25%, 40%, and 5%, 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 15 ha, and minimum potential core size was defined as 50 ha (Rosen & Mauz 2001; Phil Rosen, personal comm.). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Potential Habitat Suitability

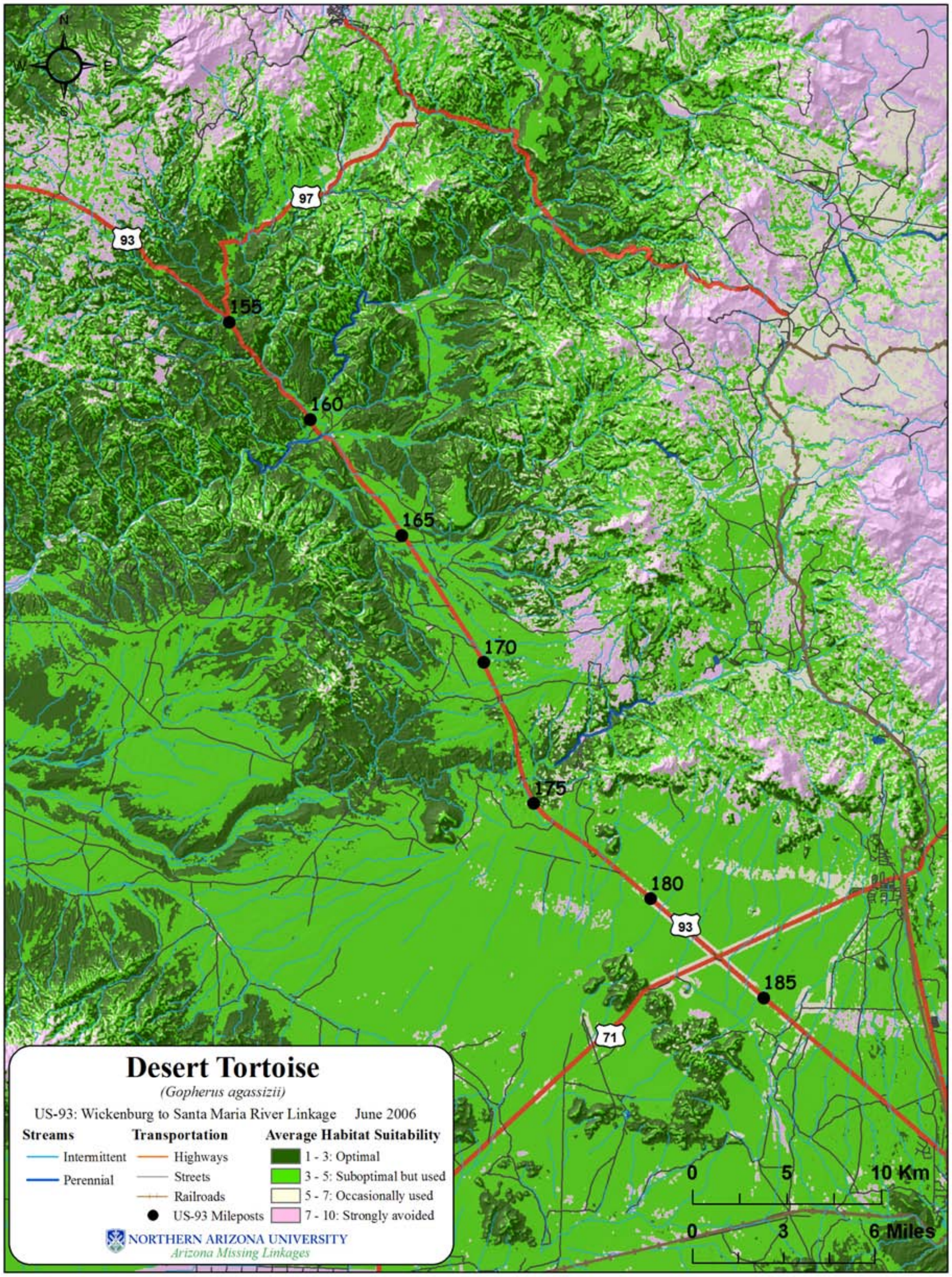

Figure 32: Modeled habitat suitability of desert tortoise.

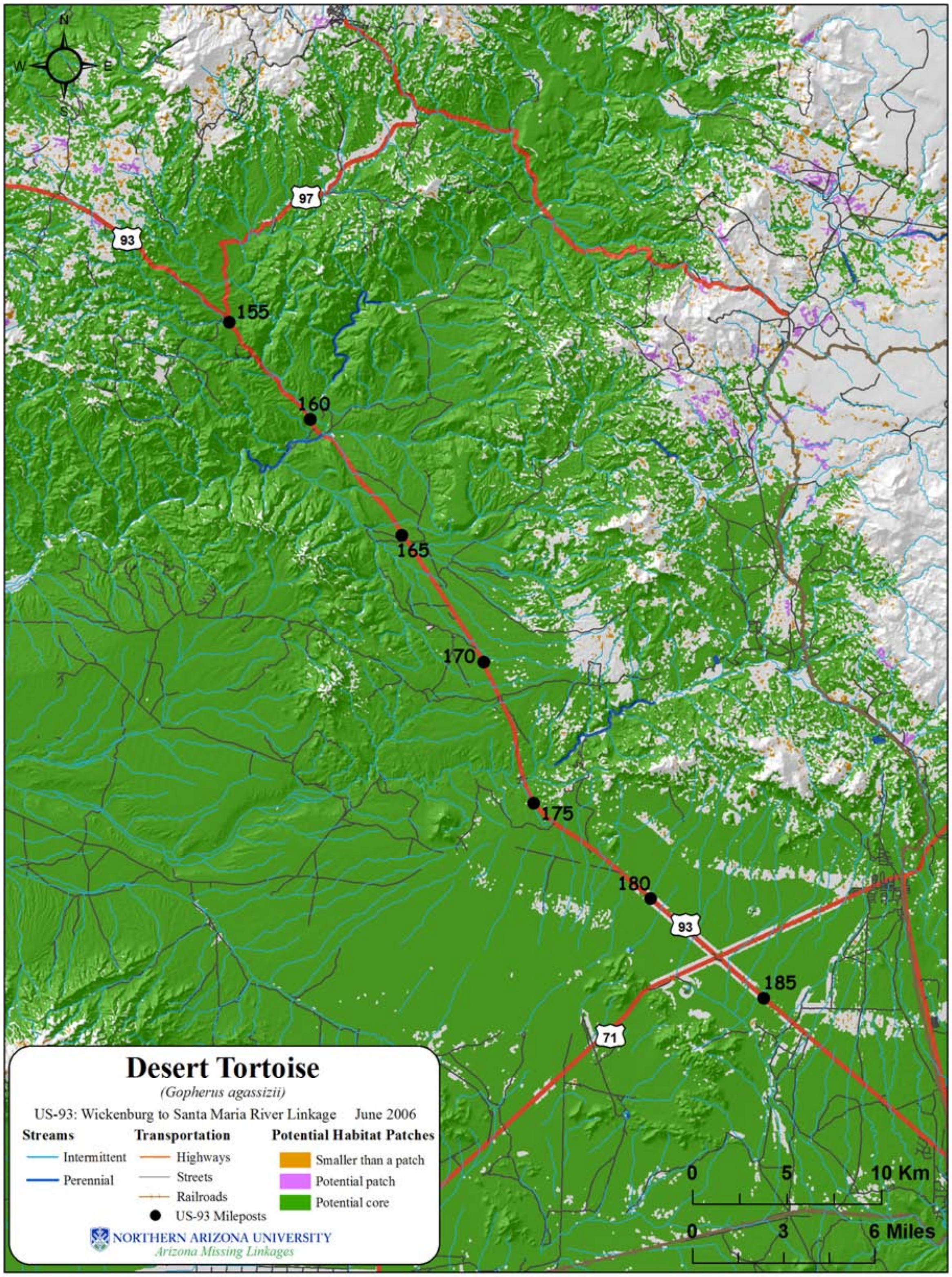

Figure 33: Potential habitat patches and cores for desert tortoise.

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 1,700 and 4,000 ft.

Spatial Patterns
Home ranges from 13 to 70 hectares, and 3 to 4 km in length 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.

Potential Habitat Suitability

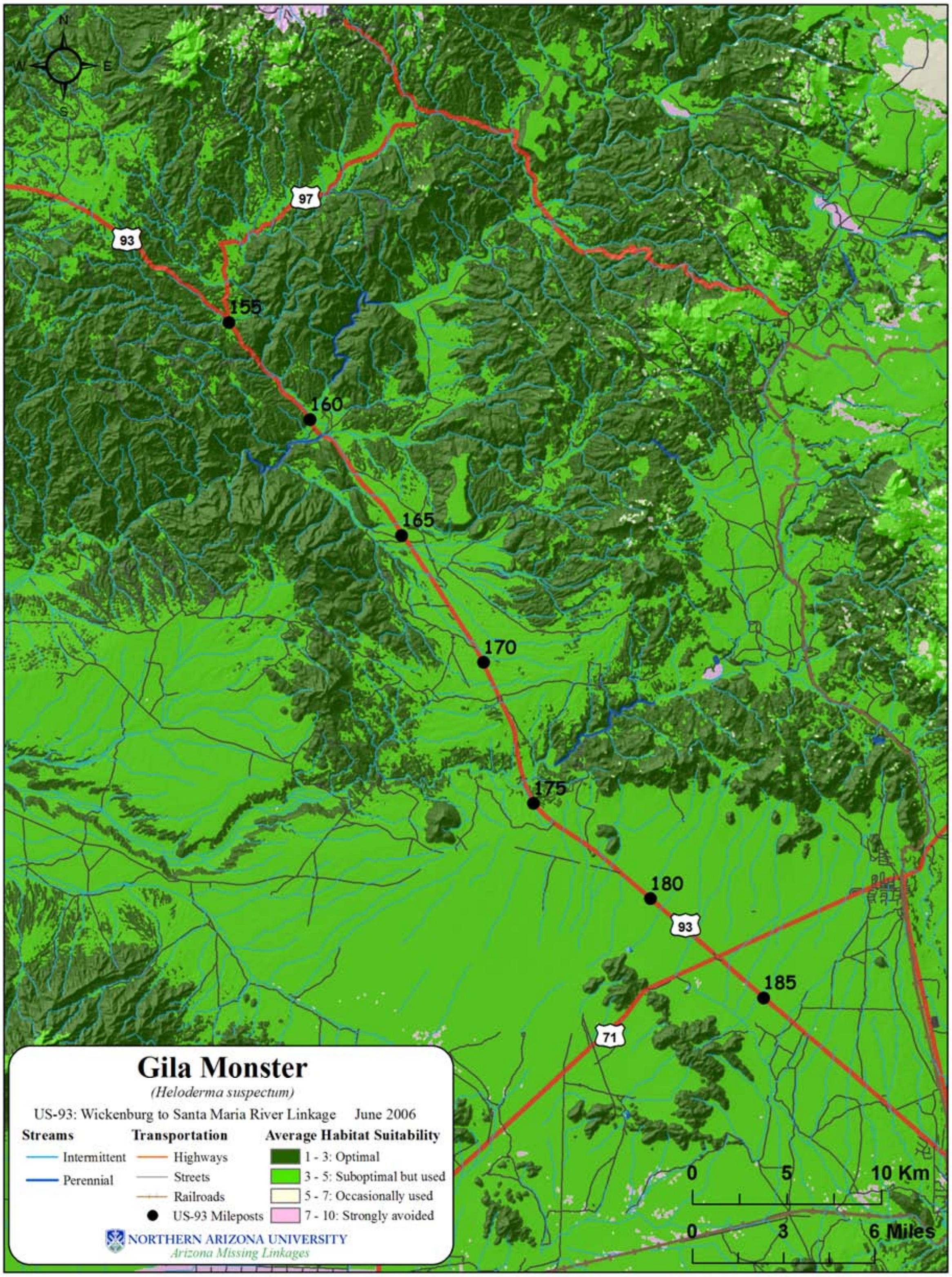

Figure 34: Modeled habitat suitability of Gila monster.

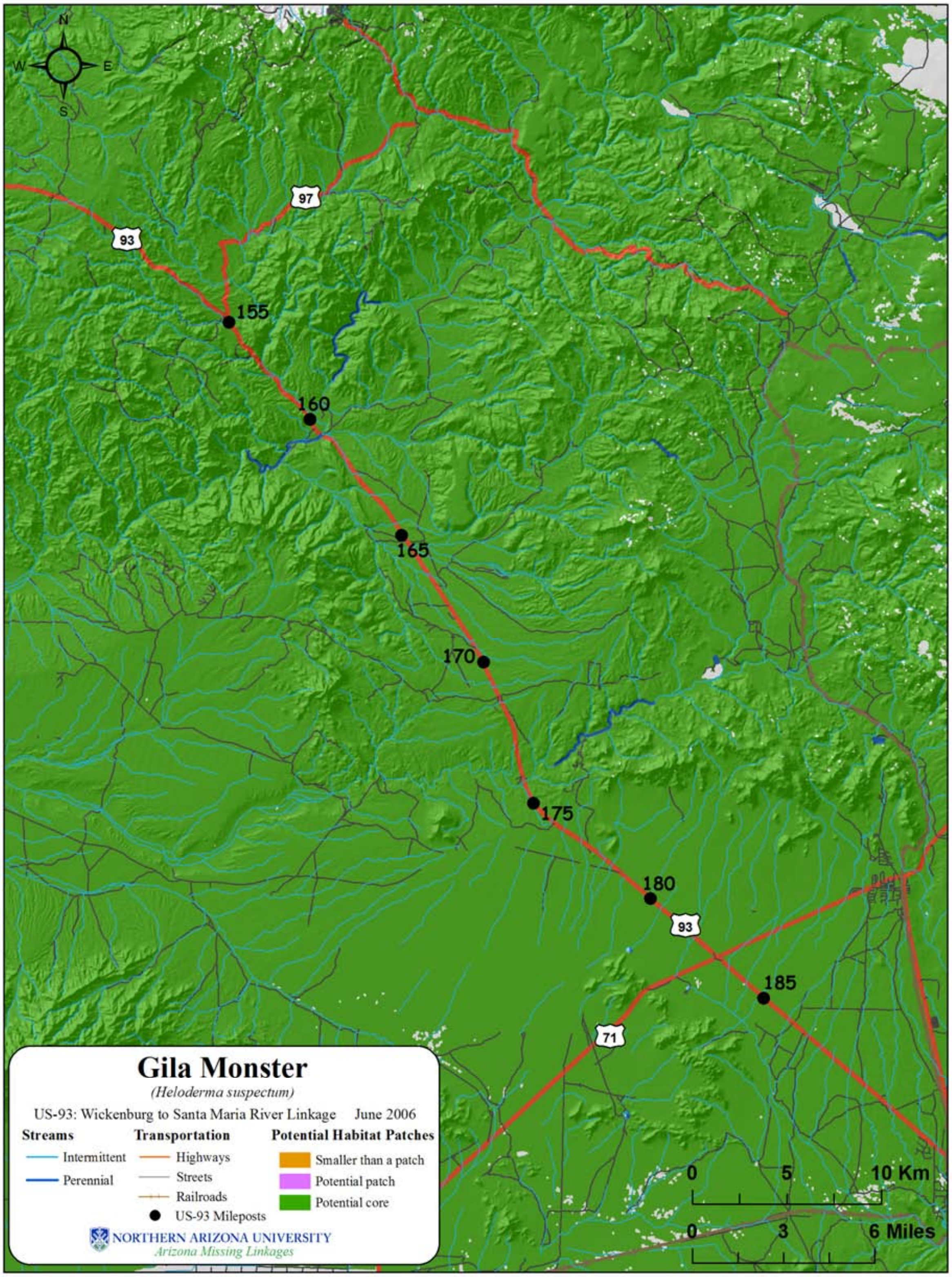

Figure 35: Potential habitat patches and cores for Gila monster.

Suggested Focal Species not Modeled

The habitat requirements and connectivity needs of several other suggested focal species were not modeled in this study. We did not model species for which there were insufficient data to quantify habitat use in terms of available GIS data (most herpetofauna, which are saxicolous or riparian-dwelling), or if the species probably can fly across unsuitable habitat (all suggested birds). A list of these species follows:

Herpetofauana

- Arizona black rattlesnake, chuckwalla, rosy boa, and speckled rattlesnake are all saxicolous species which are primarily dependent on the presence rocks and rock outcrops for suitable habitat. Because rock outcrops are not adequately mapped in the ReGAP land cover layer, and we had no other adequate GIS layers which mapped rocky areas, we could not model habitat suitability for these species.
- Blackneck garter snake, lowland leopard frog, and western red-tailed skink are all dependent on riparian vegetation associations. There is currently adequate crossing structures for US-93 over the major riparian systems in the linkage area, including the Santa Maria River, Date Creek, and Black Canyon Wash.

Birds

According to Troy Corman, Neotropical Migratory Birds Coordinator for AZGFD, “most bird species are not good candidates as focal species” for linkage design studies, because they can simply fly over areas of unsuitable habitat (personal comm.). Suggested birds for this linkage design included:

- Black-throated sparrow
- Gambel’s quail
- Golden eagle
- Loggerhead shrike
- Peregrine falcon
- Southwestern willow flycatcher
- Western burrowing owl
- Yellow-billed Cuckoo
- Zone-tailed hawk

Appendix C: 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 within the Linkage Design 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.

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.

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.

Sonoran Mid-Elevation Desert Scrub. Vegetation is characterized by a typically open to moderately dense shrubland.

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.

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (2 CLASSES) –

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

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

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

Appendix D: Literature Cited

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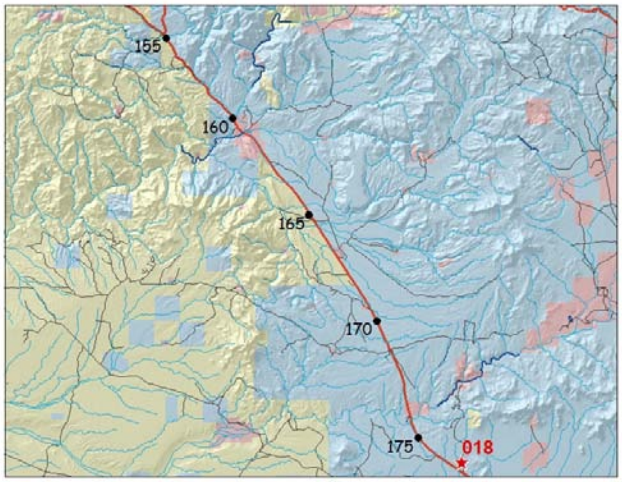
Appendix E: Database of Field Investigations

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 E: Database of Field Investigations

Linkage #:	34	**Waypoint #:**	018		
Linkage Zone:	Highway 93 South	**Latitude:**	34.18186021	**Longitude:**	-113.027810
Observers:	Paul Beier, Dan Majka	**UTM X:**	313121.65	**UTM Y:**	3784178.981
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

State land surrounds this waypoint. Land cover is mostly flat desert, composed of mostly creosote, with some Joshua trees. Photo taken from dirt road N of US93.

Site Photographs

Name: DSCF0046.jpg

Azimuth: 150 **Zoom:** 1x

Name: DSCF0047.jpg

Azimuth: 48 **Zoom:** 1x

Name: DSCF0048.jpg

Azimuth: 300 **Zoom:** 1x

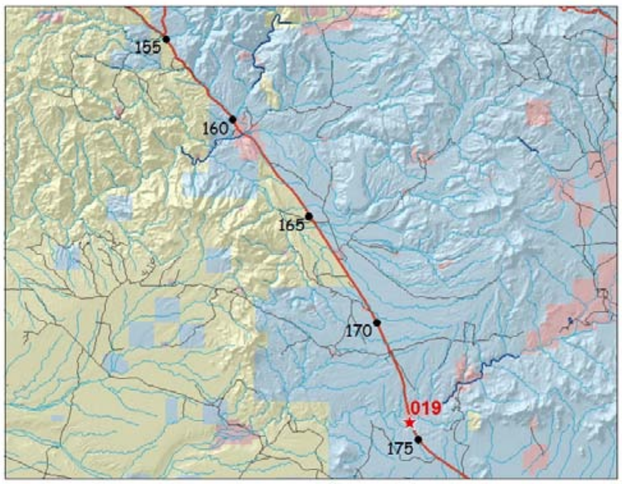
Name: DSCF0049.jpg

Azimuth: 222 **Zoom:** 1x

Appendix E: Database of Field Investigations

Linkage #:	34	**Waypoint #:**	019		
Linkage Zone:	Highway 93 South	**Latitude:**	34.20544378	**Longitude:**	-113.063939
Observers:	Paul Beier, Dan Majka	**UTM X:**	309844.5185	**UTM Y:**	3786861.427
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

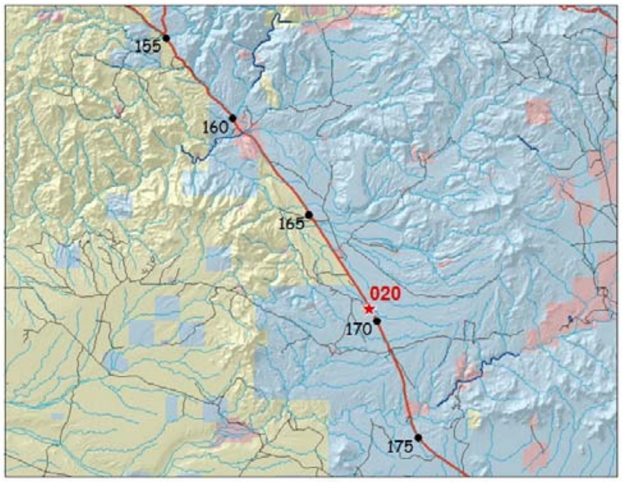
Photo was taken loooking up Date Creek from Date Creek Bridge.

Site Photographs

Azimuth: 74 **Zoom:** 1x

Linkage #:	34	**Waypoint #:**	020		
Linkage Zone:	Highway 93 South	**Latitude:**	34.26942352	**Longitude:**	-113.093897
Observers:	Paul Beier, Dan Majka	**UTM X:**	307229.9334	**UTM Y:**	3794013.734
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

The vegetation surrounding this waypoint is mostly a 'forest' of Joshua trees.

Site Photographs

Name: DSCF0051.jpg

Azimuth: 64 **Zoom:** 3x

Name: DSCF0052.jpg

Azimuth: 350 **Zoom:** 1x

Appendix E: Database of Field Investigations

Linkage #: 34

Linkage Zone: Highway 93 South

Observers: Paul Beier, Dan Majka

Field Study Date: 5/17/2006

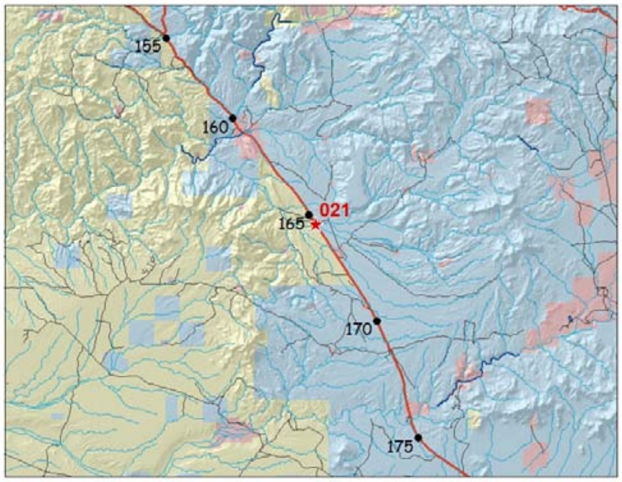
Waypoint #: 021

Latitude: 34.31719651 **Longitude:** -113.131802

UTM X: 303850.8112 **UTM Y:** 3799384.818

Last Printed: 9/21/2006

Waypoint Map



Waypoint Notes

Bridge over wash.

Site Photographs

Name: DSCF0053.jpg

Azimuth: 200 **Zoom:** 1x

Notes: A large bridge approx. 8 ft tall, 4 piers, with natural bottom, covers this wash.

Name: DSCF0054.jpg

Azimuth: 96 **Zoom:** 1x

Notes: Looking up wash

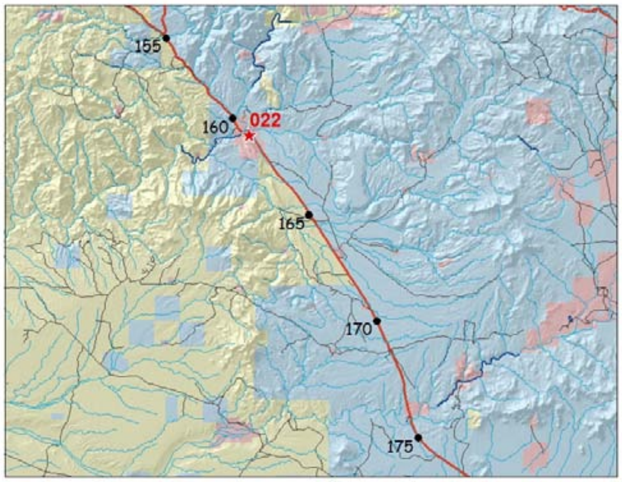
Name: DSCF0055.jpg

Azimuth: 240 **Zoom:** 1x

Notes: Looking down wash.

Linkage #:	34	**Waypoint #:**	022		
Linkage Zone:	Highway 93 South	**Latitude:**	34.36790904	**Longitude:**	-113.179771
Observers:	Paul Beier, Dan Majka	**UTM X:**	299557.1839	**UTM Y:**	3805103.213
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Santa Maria River. Photos taken from US93 & road 1/4 mile south of Santa Maria Bridge.

Site Photographs

Name: DSCF0056.jpg

Azimuth: 270 **Zoom:** 6x

Notes: Bridge over Santa Maria River.

Name: DSCF0057.jpg

Azimuth: 0 **Zoom:** 1x

Notes: Riparian area of Santa Maria River, adjacent to bridge.

Name: DSCF0058.jpg

Azimuth: 70 **Zoom:** 1x

Notes: Looking up River.

Name: DSCF0059.jpg

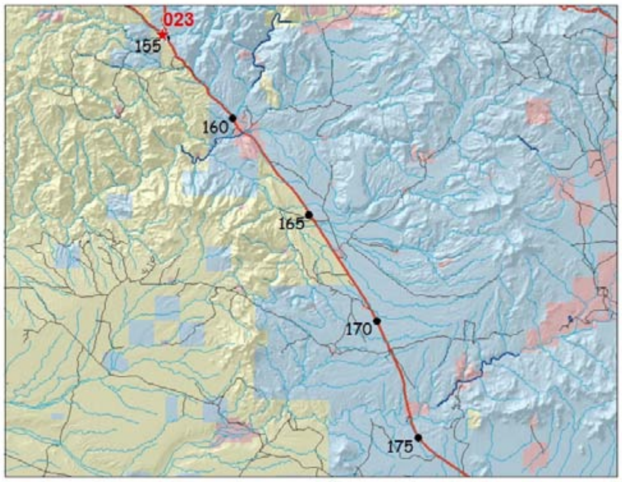
Azimuth: 5 **Zoom:** 3x

Notes: Close up of bridge from closer location

Appendix E: Database of Field Investigations

Linkage #:	34	**Waypoint #:**	023		
Linkage Zone:	Highway 93 South	**Latitude:**	34.42461848	**Longitude:**	-113.241008
Observers:	Paul Beier, Dan Majka	**UTM X:**	294064.0485	**UTM Y:**	3811515.922
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Bridge over wash. Photos taken from US93, 1/4 mile south of Jct with AZ74.

Site Photographs

Name: DSCF0060.jpg

Azimuth: 140 **Zoom:** 1x

Name: DSCF0061.jpg

Zoom: 1x

Notes: Bridges over both roads. Police officer questioning Paul Beier: "You might want to wear orange vests when you do this."