ARIZONA MISSING LINKAGES

US-60 Superior to Globe
Linkage Design

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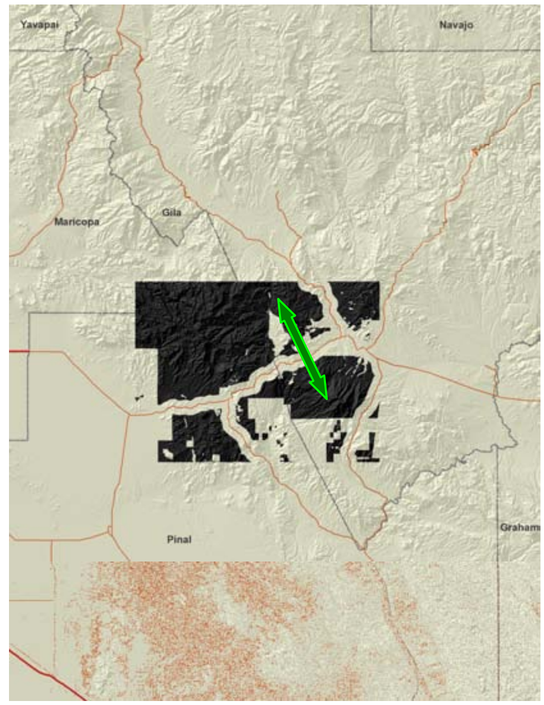

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Terminology

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 southern part of Tonto National Forest, and all land within 3 miles (5 km) of any of the proposed realignments of US-60, where current and future urbanization, roads, and other human activities threaten to prevent wildlife movement between the parts of Tonto NF north and south of the highway.

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

Potential Linkage Area: The area of private and ASLD land between the wildland blocks, where current and future urbanization, roads, and other human activities threaten to prevent wildlife movement between the wildland blocks. The *Linkage Design* would conserve a fraction of this area.

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-60 between Superior and Globe in the Tonto National Forest. It is anticipated that this stretch of US-60 will be re-routed within the next 5-10 years, and the new road could become a barrier to wildlife movement. The Tonto National Forest and adjacent BLM land 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. These species include 1 amphibian, 5 reptiles, 1 bird, 1 plant, and 6 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, black bear). 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, cactus ferruginous pygmy-owl), while others are common but still need gene flow among populations (black-tailed jackrabbits). All the focal species are part of the natural heritage of this mosaic of Apache Highlands and Sonoran Desert. Together, these 12 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 future alignments of US-60.

For purposes of understanding and mitigating impacts, it is convenient to divide US-60 and the proposed realignments into western (town of Superior), central (highland), and eastern (Miami-Globe area) sections. The proposed alternative alignments have massively greater potential impact on wildlife habitat and movement than the current US-60 in the eastern section. The proposed alternatives also have substantially greater impact than the current US-60 in the western section. Significant mitigation measures will be needed if these alternative alignments are selected in the western and eastern sections. Potential impact of wildlife does not differ among alternative alignments in the central section.

In the Miami-Globe area, the increased potential impact of the proposed alternatives are due to the fact that the current US-60 passes through or alongside urban areas and mining areas that are already impermeable to wildlife. In contrast, the proposed alternatives are entirely in natural habitat, and if unmitigated, would isolate 14,000-19,000 acres of natural habitat. We provide detailed recommendations in the section titled *Linkage Design and Recommendations*.

The ecological, educational, recreational, and spiritual values of protected wildlands in the Tonto National Forest are immense. Our Linkage Design represents an opportunity to protect a truly functional landscape-level connection. The cost of implementing this vision will be small compared to the cost of building the new highway or compared to the benefits to 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-60, but should also conserve large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the US Forest Service, Arizona State Parks, Bureau of Land Management, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and other conservancy lands.

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

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

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

Table 1: Focal species[1] selected for Linkage Design on US-60 from Superior to Globe.

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	*Sonoran Desert Toad	Cactus Ferruginous Pygmy-Owl
*Black Bear	*Black-tailed Rattlesnake	
*Black-tailed Jackrabbit	*Desert Tortoise	
*Desert Bighorn Sheep	*Gila Monster	**PLANTS**
*Mountain Lion	*Lyre Snake	Arizona Hedgehog Cactus
*Mule Deer	*Tiger Rattlesnake	

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

[1] Although the Kit Fox was not suggested as a focal species in this linkage area, during field investigations we photographed the fresh carcass of a road-killed Kit Fox on US-60 just east of the linkage area, on the eastern outskirts of Apache Junction.

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). Eight potential linkages emerged as priorities for more detailed planning. This Linkage is one of these first 8 linkages.

Ecological Significance of this Linkage

The Linkage Planning area lies within two ecoregions of southeastern Arizona and southwestern New Mexico: the Sonoran Desert Ecoregion and the Apache Highlands Ecoregion. The Apache Highlands

Ecoregion encompasses 30 million acres of central and southeastern Arizona, northern Sonora, northwestern Chihuahua, and southwestern New Mexico (Marshall et al 2004). This ecoregion spans 7,000 feet in elevation, providing varied ecosystems including sky island forests, grasslands, and riparian corridors (The Nature Conservancy 2006). This variation supports a high level of biological diversity, including 110 mammals, 265 birds, 75 reptiles, and 2000 plant species (The Nature Conservancy 2006).

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.

Within these ecoregions, the Linkage Planning Area includes a large habitat block made up of several small mountain ranges and adjacent Sonoran desert wildlands. Mountain ranges of this habitat block include: the Pinal Mountains, extending 14.5 km (9 mi); the Dripping Springs Mountains, extending 32 km (20 mi); and the Superstition Mountains, which extend for 24 km (15 mi). These mountains' geologic features provide important ecological value for the area's wildlife, and support important drainage systems in the area including Arnett Creek, Pinto Creek, Queen Creek, and Devil's Canyon. These watersheds are important for providing riparian habitat and wildlife corridors. Protected areas of Sonoran desert land extend this habitat block southwestward, with diverse natural features and wildlife habitats.

The Linkage Planning Area ranges from 2,300 feet in elevation on parts of U.S. Highway 60, to 7,850 feet at Pinal Peak in the Pinal Mountains. Paloverde-mixed cacti desert scrub and mesquite upland scrub communities dominate the lower elevations, rising to areas of chaparral, pinyon-juniper and pine-oak woodlands, and ponderosa pine forest (Figure 2). Riparian areas in the Linkage Planning Area include the Pinto Creek, Arnett Creek, and Queen Creek.

The varied habitat types in the Linkage Planning Area support a diverse assemblage of animal species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the desert tortoise, bighorn sheep, and the cactus ferruginous pygmy-owl (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 black bear, 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 corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as black-tailed jackrabbits and tiger 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

Land owned by the Tonto National Forest comprises the majority of this habitat block. The Tonto National Forest extends northward from the Linkage Planning Area to the Mogollon Rim, occupying nearly three million acres of wildlands (USFS 2006). The Tonto National Forest is the fifth largest forest in the United States, attracting 5.8 million visitors annually, making it one of the most visited forests in the U.S. (USFS 2006). This national forest boasts a diverse assemblage of animal and plant species, of which 87 are considered federally endangered, threatened, or sensitive, including 13 birds, 9 mammals, 4 amphibians, 6 reptiles, 18 fish, 24 plants, and 15 invertebrates (USFS 2006). Within the Tonto National Forest, the Superstition Wilderness Area includes 160,200 protected acres of rugged wilderness (USFS 2006). Large protected areas of Sonoran desert habitat owned by the Bureau of Land Management extend southward.

Another existing conservation investment is Boyce Thompson Arboretum State Park, which encompasses 323 acres along U.S. Highway 60 three miles west of Superior (Arizona State Parks 2006). The Boyce Thompson Arboretum State Park is Arizona's oldest and largest botanical garden, and is a major center for desert plant research (Arizona State Parks 2006).

Connectivity will provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in these publicly-owned wildands.

Threats to Connectivity

Major potential barriers in the Linkage Planning Area include U.S. Highway 60, land alteration due to mining, and urban development along the U.S. 60 corridor. The Magma Arizona Railroad operated between Superior and Florence from 1920-1997. Although now dormant, the recent discovery of large new copper deposits could induce the line to reopen in 2009 or thereafter.

Almost all of the private land in the area is recently or actively mined land. Most other private lands are the city of Miami-Globe or the town of Superior. There are also a few small areas of rural and suburban development along and south of the existing US-60 alignment (Figures 1 and 2).

The recently mined areas (Figure 2) include massive mine tailings piles lacking plant or animal life. For purposes of this report, we assume these areas will not be restored to native vegetation in the foreseeable future. US-60 between Superior and Globe is expected to be re-routed within the next 5-10 years. Because the new alignment of US-60 is the greatest potential barrier that can be mitigated, in this report we focus on the potential to mitigate potential impacts of new alignments of this highway.

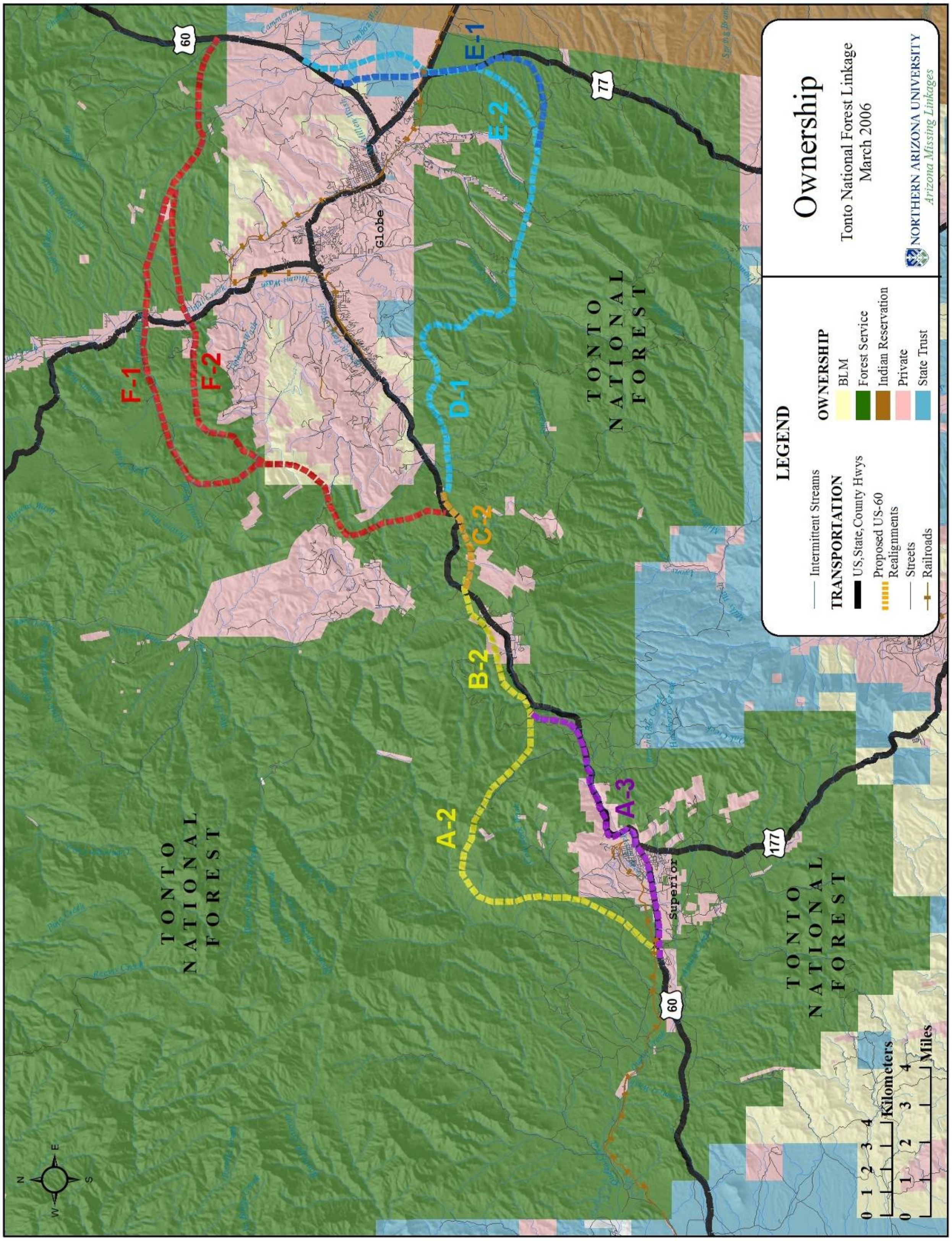

Figure 1: Land ownership within the Linkage Planning Area, and potential realignments of US-60.

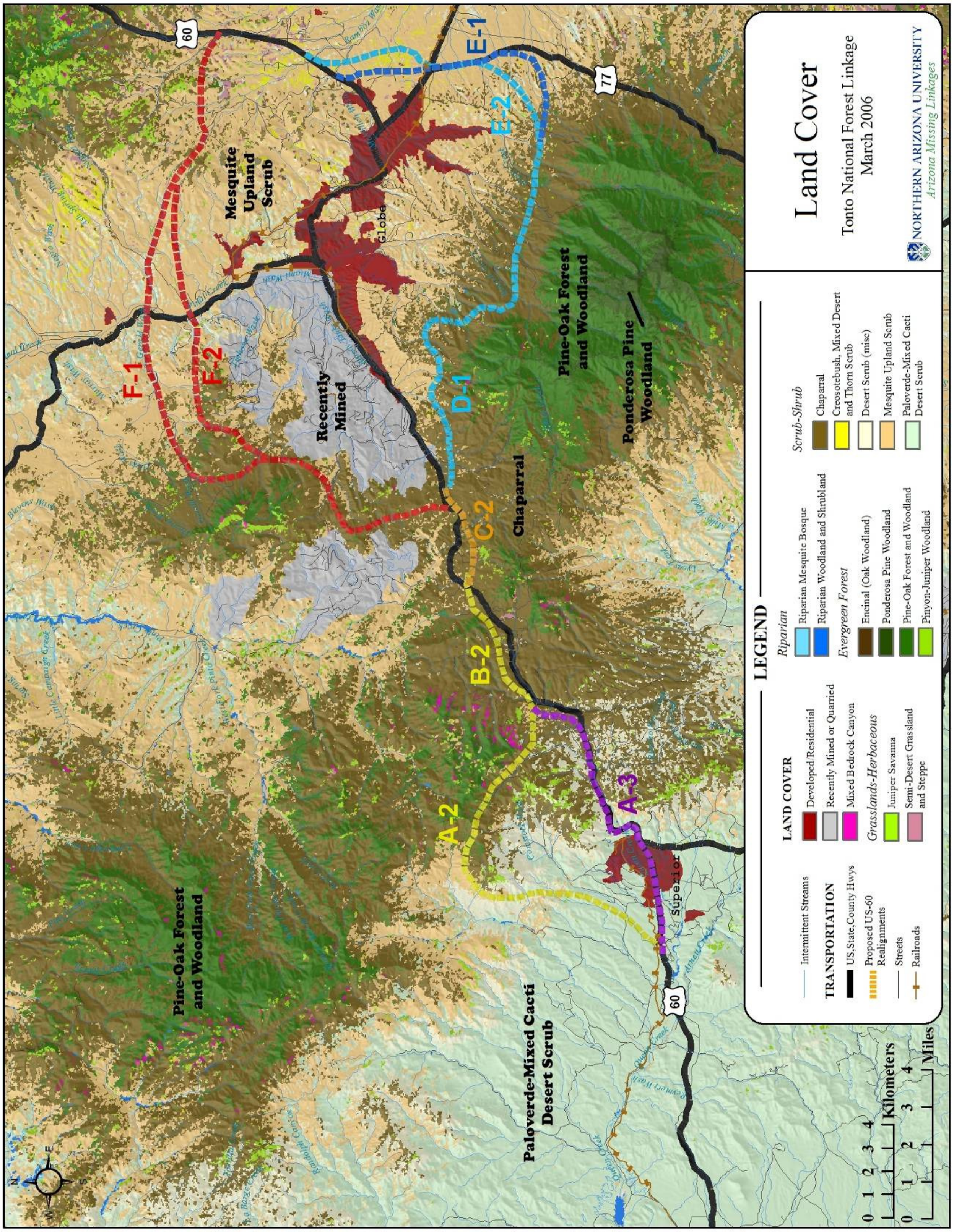

Figure 2: Land cover within the Linkage Planning Area, and potential realignments of US-60.

Linkage Design & Recommendations

Because there are numerous realignment options for US-60 between Superior and Globe, we cannot make recommendations for specific crossing structures in the linkage area. 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 any future US-60 realignment on wildlife movement. The methods used to model focal species are described in Appendixes A and B.

As indicated in Table 2, every potential alignment of US-60 would cross through or near large areas of potential habitat of several focal species (See Appendix B for maps of each species' potential habitat). Thus crossing structures would be needed along all alignments.

Table 2. Distribution of optimal and suitable habitat of focal species in sections of potential alignments of US-60. Appendix B presents maps of modeled habitat for individual species; the alignments are depicted in Figure 4.

FOCAL SPECIES	ALIGNMENTS THAT INTERCEPT LARGE AREAS OF POTENTIAL OPTIMAL AND SUITABLE BREEDING HABITAT OF THE SPECIES
American badger	all
Black bear	A, B, C, E
Black-tailed jackrabbit	A
Bighorn sheep	A, D
Mountain lion	B, C, D
Mule deer	A, B, C
Black-tailed rattlesnake	all
Desert tortoise	A, F
Gila monster	all
Lyre snake	all
Sonoran desert toad	A, E, F
Tiger rattlesnake	A, F

For purposes of understanding and mitigating impacts, it is convenient to divide US-60 and the proposed realignments into western (town of Superior), central (highland), and eastern (Miami-Globe area) sections (Table 3).

Western Subsection (Superior area):

- The proposed A2 alignment bypassing Superior affects 50% more natural habitat than the proposed A-3 alignment, or the current alignment (Table 3). The increased impact of A2 is partly because it is longer than the current road, and partly because part of the current road lies in the town of Superior, while A2 runs entirely through natural land.
- The current US-60 has two bridges (Figure 5, Figure 6) and one tunnel (Figure 7) that provide excellent opportunities for wildlife crossings. Any new alignment should provide structures at least this good.

Central Subsection (B and C alignments):

- The alternatives do not substantially differ from the current US-60 in terms of area of natural land affected (Table 3).
- The bridge over Pinto Creek (Figure 8) provides a superb wildlife crossing opportunity in this area.

Eastern Subsection (Miami-Globe area):

- Most (64%) of the current US-60 passes through urban areas, mine tailings, and active mining areas that are not suitable habitat for any of the focal species (Figure 3), and less than 10% of the current alignment has natural habitat on both sides of the road (Figure 4). Because the mine tailings and urban area effectively block animal movement in this area, the current US-60 has no net impact on wildlife movement. The D, E, and F alignments are all significantly worse because 97% to 100% of each proposed alignment passes through natural habitat (Table 3).

- The D-E alignments could potentially isolate large areas of natural habitat between the alignment and the mined-urban area of Miami-Globe. About 15,000 acres of natural vegetation lie north of D1-E2 and south of the mined-urban area of Miami Globe, mostly mesquite upland scrub and chaparral. These acres could be isolated unless crossing structures are provided. Zero acres are potentially isolated by the current US-60.
- The F1 alignment could isolate about 19,000 acres of natural vegetation south of the alignment and north of the mined-urban area of Miami-Globe, compared to about 14,000 acres for the F2 alignment, and zero acres for the current alignment.
- In this eastern section, the current US-60 has almost no impact on wildlife movement. If the highway is upgraded along the current alignment, no crossing structures for wildlife would be needed in this area. All of the proposed alternative alignments would have severe potential impacts on animal movement. These impacts would have to be mitigated by constructing a diversity of wildlife crossing structures (details below) and by integrating those structures with fencing to guide animals toward the crossing structures.

Thus the proposed alternative alignments have massively greater potential impact on wildlife habitat and movement than the current US-60 in the eastern section. The proposed alternatives also have substantially greater impact than the current US-60 in the western section. Significant mitigation measures will be needed if these alternative alignments are selected in the western and eastern sections. Potential impact of wildlife does not differ among alternative alignments in the central section.

Table 3: Acres (all values in hundreds of acres) of each land cover type within ½ mile (800 m) of US-60 alignments western, central, and eastern subsections. The alternative alignments in the Central subsection affect about the same amount of natural habitat

LAND COVER	WEST (SUPERIOR)		CENTRAL-B		CENTRAL-C		EAST (MIAMI-GLOBE)			
	A3[1]	A2	B1[1]	B2	C1[1]	C2	60[1]	F1	F2	D-E[2]
Developed/residential	9.8	0	0	0	0	0	35.1	0	0	0.3
Recently mined	0	0	0	0	0	0	20.1	3.2	0	0.3
Pine-oak forest & woodland	0	4.6	0.6	0.9	0.3	0.4	0.2	2.3	0.9	4.1
Pinyon-Juniper woodland	0.8	1.6	0.5	0.5	0.1	0.6	0.1	1.2	0.5	0.7
Chaparral	16.6	23.0	33.0	28.7	20.8	20.1	12.2	54.5	16.3	65.4
Mesquite upland scrub	2.7	9.5	2.2	2.6	3.4	1.9	15.8	67.8	38.4	51.2
Paloverde-mixed cacti desert scrub	18.8	25.0	0	0	0.2	0.1	0.5	3.8	1.6	0.6
Desert Scrub	9.9	10.4	2.2	0	0	0	1.6	3.4	2.3	2.1
Creosotebush	0.1	0.2	0.0	0	0.1	0.1	0.6	0.7	0.2	3.8
Other	0.4	0.7	0.3	0.1	0.1	0.1	0.2	1.2	0.2	0.4
Total Area affected	59.2	74.9	38.9	32.9	24.9	23.3	86.2	138.1	60.6	129.1
Total Natural Land affected	49.4	74.9	38.9	32.9	24.9	23.3	31.1	134.3	60.6	128.8

[1] The current alignment of US-60 in this section of the road, or an alignment that closely follows the current alignment.
[2] The statistics are for the combination of D1 and E2. The statistics for the combination of D1 and E1 are substantially the same.

Mitigating Barriers to Movement

Although roads, rail lines, and development 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 and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Figure 3). Direct **roadkill** affects most species, with severe documented impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the Iberian lynx (Forman et al. 2003). In a 4-year study of 15,000 km of road observations in Organ Pipe Cactus National Monument, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km per year killed due to vehicle collisions. Although we may not often think of roads as causing **habitat loss**, a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. Roads cause **habitat fragmentation** because they break large habitat areas into small, isolated habit patches which support few individuals; these small populations lose genetic diversity and are at risk of local extinction.

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

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

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

Existing Roads and Rail Lines in the Linkage Design Area

US-60 runs west-east from Superior to Globe for approximately 45 km (28 mi), and is the single most important transportation threat to connectivity within this portion of the Tonto National Forest. At the present time, a number of realignments have been proposed for US-60 in a Final Feasibility Study released by ADOT in October 2004, but no realignments have been carried forth for further study. The other roads in the linkage are local roads with relatively low traffic and traffic speed.

Although we could not visit all potential realignments, we photographed existing crossing structures in the area (Figure 4). Several crossing structures on the existing US-60 alignment are sufficient for animal movement, including large bridges over Queen Creek (Figure 5 & Figure 6) and a large open bridge over Pinto Creek (Figure 8). A 375 meter portion of US-60 which runs through a tunnel (Figure 7) effectively provides a wildlife overpass through rocky terrain ideal for species such as bighorn sheep.

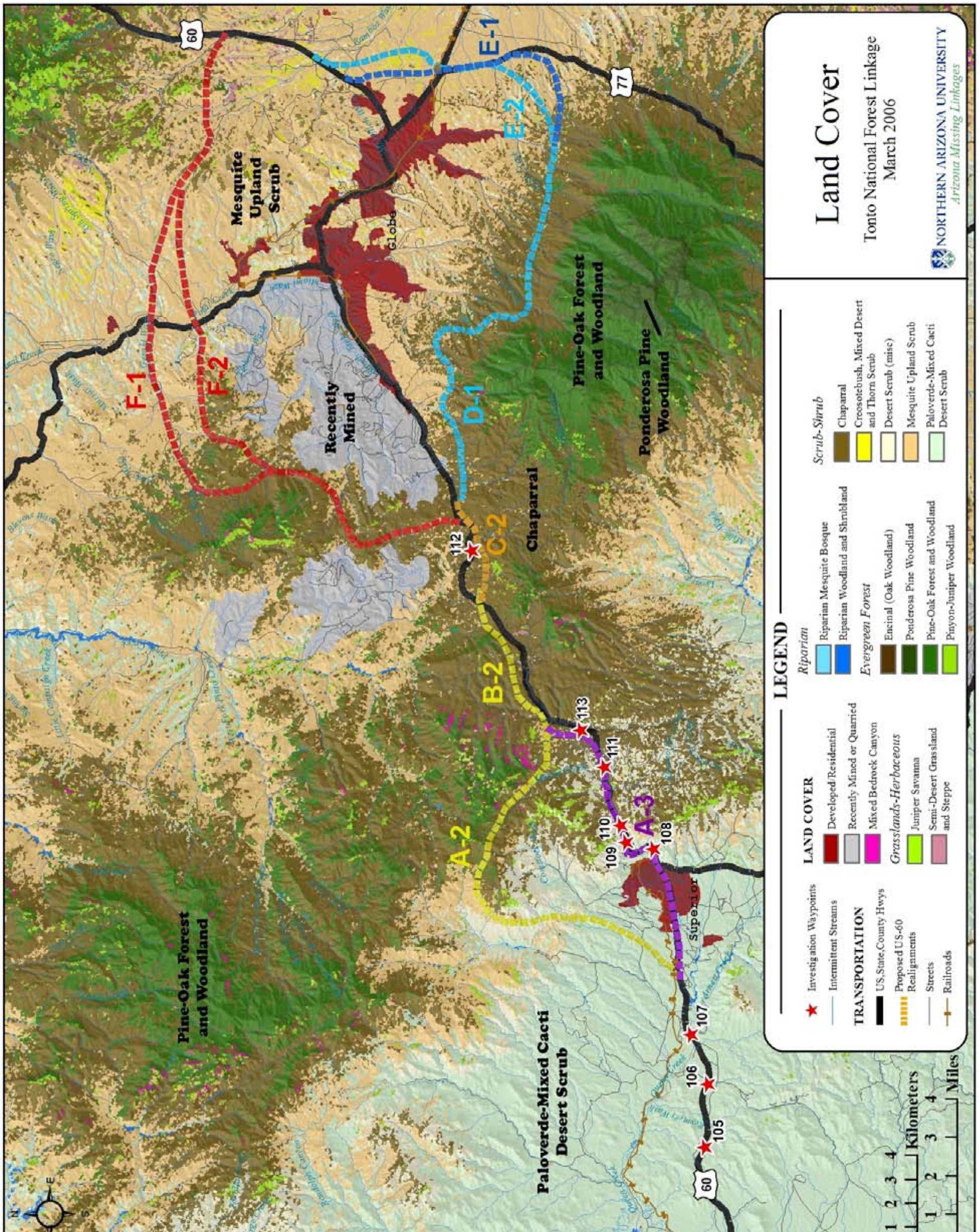

Figure 4: Land cover and field investigation waypoints along US-60. The accompanying CD-ROM includes photographs taken at most waypoints.

Figure 5: West from waypoint 107, Queen Creek crosses US-60 under a large bridge. See Figure 4 to locate this scene within the linkage design.

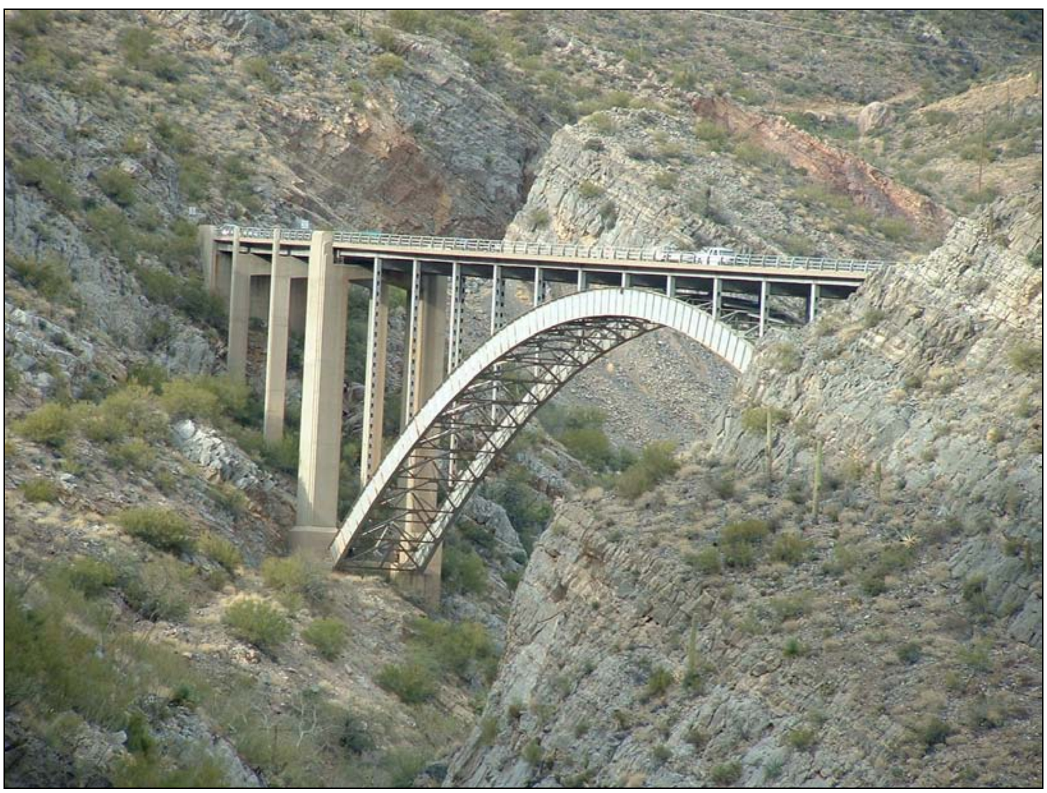

Figure 6: Northwest (azimuth: 328) from waypoint 108, Queen Creek crosses US-60 under a large bridge.

Figure 7: East (azimuth 68) from waypoint 109, US-60 runs through a tunnel for about 375 meters. The rocky "wildlife bridge" above the tunnel is an ideal crossing structure for bighorn sheep.

Figure 8: West from waypoint 112, Pinto Creek crosses US-60 under a large bridge.

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 9). 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). In the rugged terrain of this area, a road tunnel (such as currently exists on US-60 – Figure 7) effectively creates a wildlife overpass ideal for bighorn sheep and some reptiles.

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate drainage beneath highways. For ungulates such as deer that prefer open crossing structures, tall, wide bridges are best. Mule deer in southern California only used underpasses below large spanning bridges (Ng et al. 2004), and the average size of underpasses used by white-tailed deer in Pennsylvania was 15 ft wide by 8 ft high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures have increased connectivity for smaller species crossing bridges on floodplains (Forman et al. 2003).

Drainage culverts can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species, including mice, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). In south Texas, bobcats most often used 1.85 m x 1.85 m box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert. In the rugged and rocky terrain of this linkage area, many culverts designed to carry water under roads have large pour-offs at their downstream ends. Although this works fine for carrying water, these culverts do not promote animal movement.

Figure 9: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

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

1) **Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area** (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald & St Clair 2004; Clevenger & Waltho 2005; Mata et al. 2005). For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and mountain lions, large box culverts with natural earthen substrate flooring are optimal (Evink 2002). For small mammals, pipe culverts from 0.3m – 1 m in diameter are preferable (Clevenger et al. 2001; McDonald & St Clair 2004). In bighorn sheep habitat, a road tunnel (Figure 9) would provide an ideal overpass for bighorn.

2) **At least one crossing structure should be located within an individual's home range**. Because most reptiles, small mammals, and amphibians have small home ranges, metal or cement box culverts should be installed at intervals of 150-300 m (Clevenger et al. 2001). For ungulates (deer, pronghorn, bighorn) and large carnivores, larger crossing structures such as bridges, viaducts, or overpasses should be located no more than 1.5 km (0.94 miles) apart (Mata et al. 2005; Clevenger and Wierzchowski 2006). Inadequate size and insufficient number of crossings are two primary causes of poor use by wildlife (Ruediger 2001).

3) **Suitable habitat for species should occur on both sides of the crossing structure** (Ruediger 2001; Barnum 2003; Cain et al. 2003; Ng et al. 2004). This applies to both *local* and *landscape* scales. On a local scale, vegetative cover should be present near entrances to give animals security, and reduce negative effects such as lighting and noise associated with the road (Clevenger et al. 2001; McDonald & St Clair 2004). A lack of suitable habitat adjacent to culverts originally built for hydrologic function may prevent their use as potential wildlife crossing structures (Cain et al. 2003). On the landscape scale, "Crossing structures will only be as effective as the land and resource management strategies around them" (Clevenger et al. 2005). Suitable habitat must be present throughout the linkage for animals to use a crossing structure.

4) **Whenever possible, suitable habitat should occur *within* the crossing structure.** This can best be achieved by having a bridge high enough to allow enough light for vegetation to grow under the bridge, and by making sure that the bridge spans upland habitat that is not regularly scoured by floods. Where this is not possible, rows of stumps or branches under large span bridges can provide cover for smaller animals such as reptiles, amphibians, rodents, and invertebrates; regular visits are needed to replace artificial cover removed by flood. Within culverts, earthen floors are preferred by mammals and reptiles.

5) **Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement.** Small mammals, carnivores, and reptiles avoid crossing structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004). In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches,

Russian thistle, sand, or garbage that impede animal movement (Beier, personal observation). Bridged undercrossings rarely have similar problems.

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

7) **Raised sections of road discourage animals from crossing roads, and should be used when possible to encourage animals to use crossing structures**. Clevenger et al. (2003) found that vertebrates were 93% less susceptible to road-kills on sections of road raised on embankments, compared to road segments at the natural grade of the surrounding terrain.

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

9) **Design culverts specifically to provide for animal movement**. 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.

Mitigation for Railroads

Although operation of the Magma Arizona Railroad has been suspended, the railroad and railroad embankment are steep, dry, rocky, impediments to movement of many animals. This impact now affects only the westernmost 2 or 3 miles of the Linkage Planning Area, and with no traffic there is no source of funds to mitigate the physical impact of this railroad. If the railroad resumes operation, rail traffic will increase the impact on wildlife movement, and a small portion of mining revenues should be used to mitigate impacts of the railroad operation, including construction of metal or cement box culverts at intervals of 150-300 m and larger crossing structures such as bridges, viaducts, or overpasses at intervals of no more than 1.5 km (0.94 miles), as recommended for roads, above.

Appendix A: Linkage Design Methods

Our goal was to provide information to help transportation agencies to construct crossing structures along US-60 or its potential realignments. These structures will conserve and enhance wildlife movement through the southern part of Tonto National Forest.

To create the Linkage Design, we used GIS approaches to estimate potential habitat suitability for focal species representing the ecological community in the area[1]. 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 focused on a "Potential Linkage Area" – a swath of private and state land between publicly-owned wildland blocks. This case is different because almost all land is within Tonto National Forest and because we cannot predict the location of a realigned US-60, which will be the major potential barrier to wildlife movement. The potential alignments shown in Figures 1 and 2 may not include the alignment ultimately selected – these were simply the routes under consideration in Spring 2006.

For this report, we define the Potential Linkage Area (and the Linkage Planning Area) as all land within 3 miles (5 km) of any of the currently proposed alignments for US-60. The western terminus is just west of Superior, and the eastern terminus is about 5 miles northeast of Globe (Figures 1 and 2).

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 cross highways, to provide 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.

[1] 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 B. As indicated in Table 1, we constructed models for most, 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 (Arizona Hedgehog Cactus, Ferruginous Pygmy-Owl).

Habitat Suitability Models

We created habitat suitability models (Appendix B) for each species by estimating how the species responded to four habitat factors that were mapped at a 30x30 m level of resolution (Figure 10):

- *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 C.
- *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[2].

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%, and added the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10. We used these habitat suitability scores to create a habitat suitability map that formed the foundation for the later steps.

[2] 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.

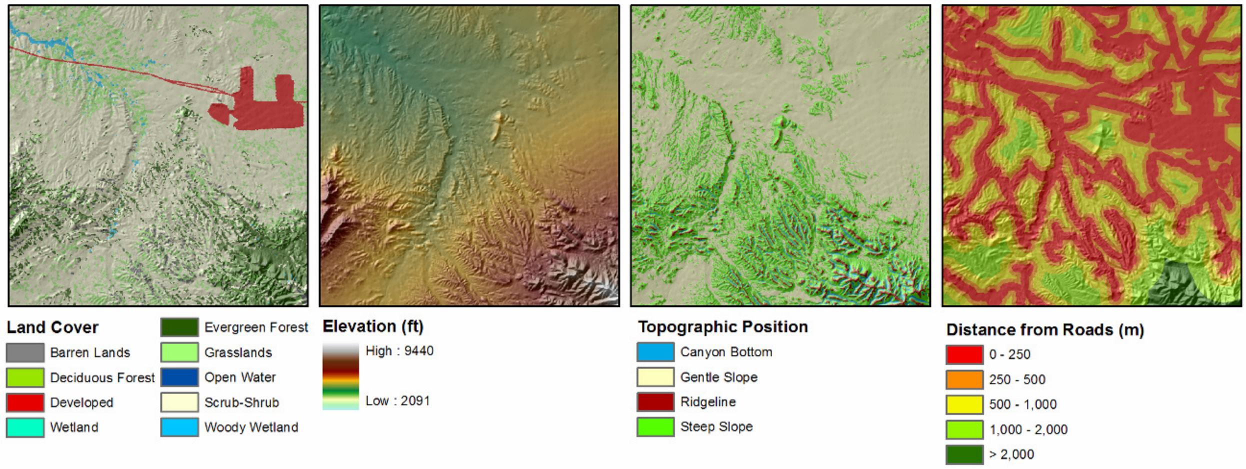

Figure 10: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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

New habitat score for pixel beyond threshold distance = (½ of original habitat score) + 5

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

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 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 11). 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[3]. 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

[3] 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.

breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

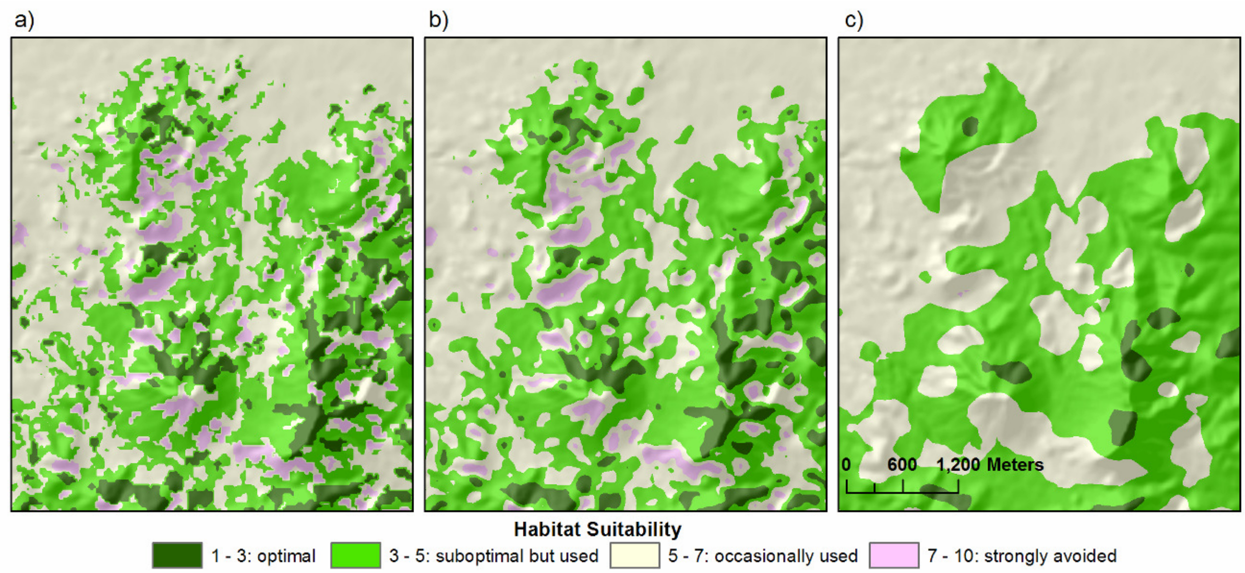

Figure 11: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

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	Black Bear	Black-tailed Jackrabbit	Desert Bighorn Sheep	Mountain Lion
Factor Weights					
Land Cover	65	75	70	30	70
Elevation	7	10	10	10	0
Topography	15	10	10	50	10
Distance from Roads	13	5	10	10	20
Land Cover					
Encinal	6	1	6	9	1
Pine-Oak Forest and Woodland	5	1	6	9	1
Pinyon-Juniper Woodland	4	6	4	9	1
Ponderosa Pine Woodland	5	4	6	9	4
Juniper Savanna	2	7	3	8	4
Semi-Desert Grassland and Steppe	1	5	4	5	5
Chaparral	5	3	6	9	3
Creosotebush, Mixed Des.& Thorn Scrub	2	6	2	6	6
Creosotebush-White Bursage Des. Scrub	2	9	2	6	6
Desert Scrub (misc)	3	5	1	2	6
Mesquite Upland Scrub	3	6	4	7	4
Paloverde-Mixed Cacti Desert Scrub	4	5	1	3	7
Riparian Mesquite Bosque	6	5	5	9	4
Riparian Woodland and Shrubland	6	5	4	9	2
Mixed Bedrock Canyon and Tableland	9	10	8	2	6
Volcanic Rock Land and Cinder Land	10	10	9	7	9
Recently Mined or Quarried	9	10	10	10	8
Developed, Medium - High Intensity	10	10	9	10	10
Developed, Open Space - Low Intensity	7	10	6	10	8
Elevation (ft)					
Elevation range: cost	0-5500: 1 5500-8000: 3 8000-11000: 6	0-2500: 8 2500-4000: 6 4000-6500: 2 6500-8500: 3 8500-11000: 4	0-6000: 1 6000-8000: 4 8000-11000: 8	0-2950: 2 2950-3300: 1 3300-7000: 3 7000-11000: 7	
Topographic Position					
Canyon Bottom	5	3	3	8	1
Flat - Gentle Slopes	1	6	1	7	3
Steep Slope	8	3	4	1	3
Ridgetop	7	4	4	5	4
Distance from Roads (m)					
Distance from Roads range: cost	0-250: 6 250-1500: 1	0-100: 10 100-500: 4 500-15000: 1	0-250: 9 250-500: 6 500-1000: 3 1000-15000: 1		0-200: 8 200-500: 6 600-1000: 5 1000-1500: 2 1500-15000: 1

	Mule Deer	Black-tailed Rattlesnake	Desert Tortoise	Gila Monster	Lyre Snake
Factor Weights					
Land Cover	80	0	30	10	0
Elevation	0	0	25	35	10
Topography	15	90	40	45	80
Distance from Roads	5	10	5	10	10
Land Cover					
Encinal	3		7	5	
Pine-Oak Forest and Woodland	3		10	10	
Pinyon-Juniper Woodland	5		10	6	
Ponderosa Pine Woodland	5		10	10	
Juniper Savanna	4		10	10	
Semi-Desert Grassland and Steppe	2		8	5	
Chaparral	4		10	6	
Creosotebush, Mixed Desert and Thorn Scrub	6		6	3	
Creosotebush-White Bursage Desert Scrub	6		5	7	
Desert Scrub (misc)	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	
Mixed Bedrock Canyon and Tableland	7		10	2	
Volcanic Rock Land and Cinder Land	8		10	1	
Recently Mined or Quarried	6		10	10	
Developed, Medium - High Intensity	9		10	9	
Developed, Open Space - Low Intensity	5		7	1	
Elevation (ft)					
Elevation range: cost			0-2000: 3 2000-3000: 1 3000-5000: 3 5000-7000: 7 7000-11000: 10	0-1700: 4 2700-4000: 1 4000-4800: 4 4800-5700: 7 5700-11000: 10	0-1000: 5 1000-7400: 1 74000-11000: 9
Topographic Position					
Canyon Bottom	2	1	8	1	1
Flat - Gentle Slopes	2	9	5	5	6
Steep Slope	4	1	1	1	1
Ridgetop	6	1	7	1	1
Distance from Roads (m)					
Distance from Roads range: cost	0-250: 7 250-1000: 3 1000-15000: 1	0-35: 10 35-500: 5 500-15000: 1	0-250: 5 250-500: 4 500-1000: 3 1000-15000: 1	0-1000: 5 1000-3000: 3 3000-15000: 1	0-35: 10 35-500: 5 500-15000: 1

	Sonoran Desert Toad	Tiger Rattlesnake
Factor Weights		
Land Cover	5	20
Elevation	50	30
Topography	25	40
Distance from Roads	20	10
Land Cover		
Encinal	7	5
Pine-Oak Forest and Woodland	10	10
Pinyon-Juniper Woodland	10	6
Ponderosa Pine Woodland	10	10
Juniper Savanna	4	10
Semi-Desert Grassland and Steppe	2	5
Chaparral	4	6
Creosotebush, Mixed Desert and Thorn Scrub	2	3
Creosotebush-White Bursage Desert Scrub	4	7
Desert Scrub (misc)	2	3
Mesquite Upland Scrub	1	4
Paloverde-Mixed Cacti Desert Scrub	1	1
Riparian Mesquite Bosque	1	5
Riparian Woodland and Shrubland	2	5
Mixed Bedrock Canyon and Tableland	5	2
Volcanic Rock Land and Cinder Land	10	1
Recently Mined or Quarried	4	10
Developed, Medium - High Intensity	6	9
Developed, Open Space - Low Intensity	4	1
Elevation (ft)		
Elevation range: cost	0-4600: 1	0-4000: 1
	4600-5250: 4	4000-5100: 5
	5250-5800: 5	5100-11000: 10
	5800-11000: 7	
Topographic Position		
Canyon Bottom		1
Flat - Gentle Slopes		6
Steep Slope		1
Ridgetop		3
Distance from Roads (m)		
Distance from Roads range: cost	0-200: 5	0-35: 10
	200-1000: 4	35-1000: 5
	1000-3000: 2	1000-15000: 1
	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

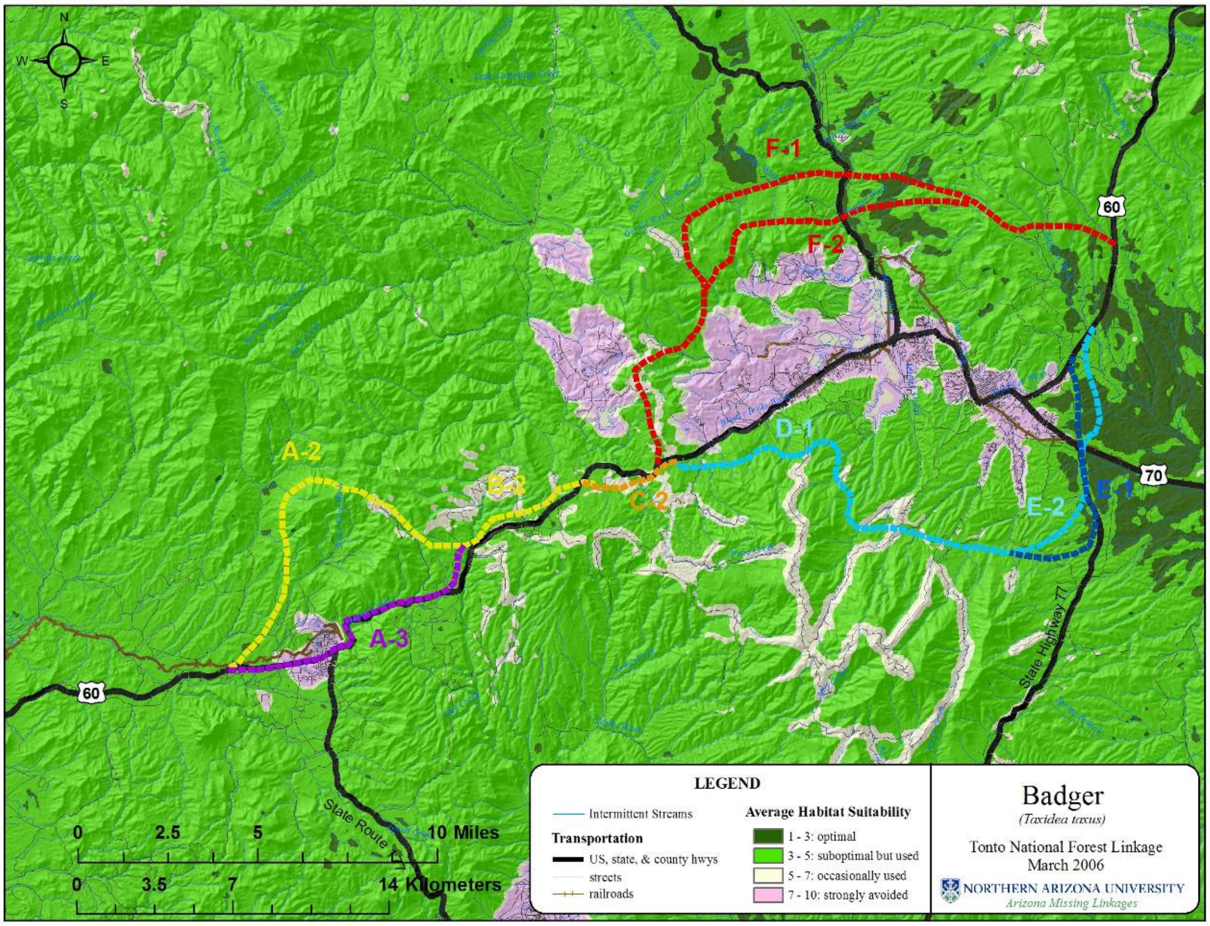

Figure 12: Modeled habitat suitability of badger.

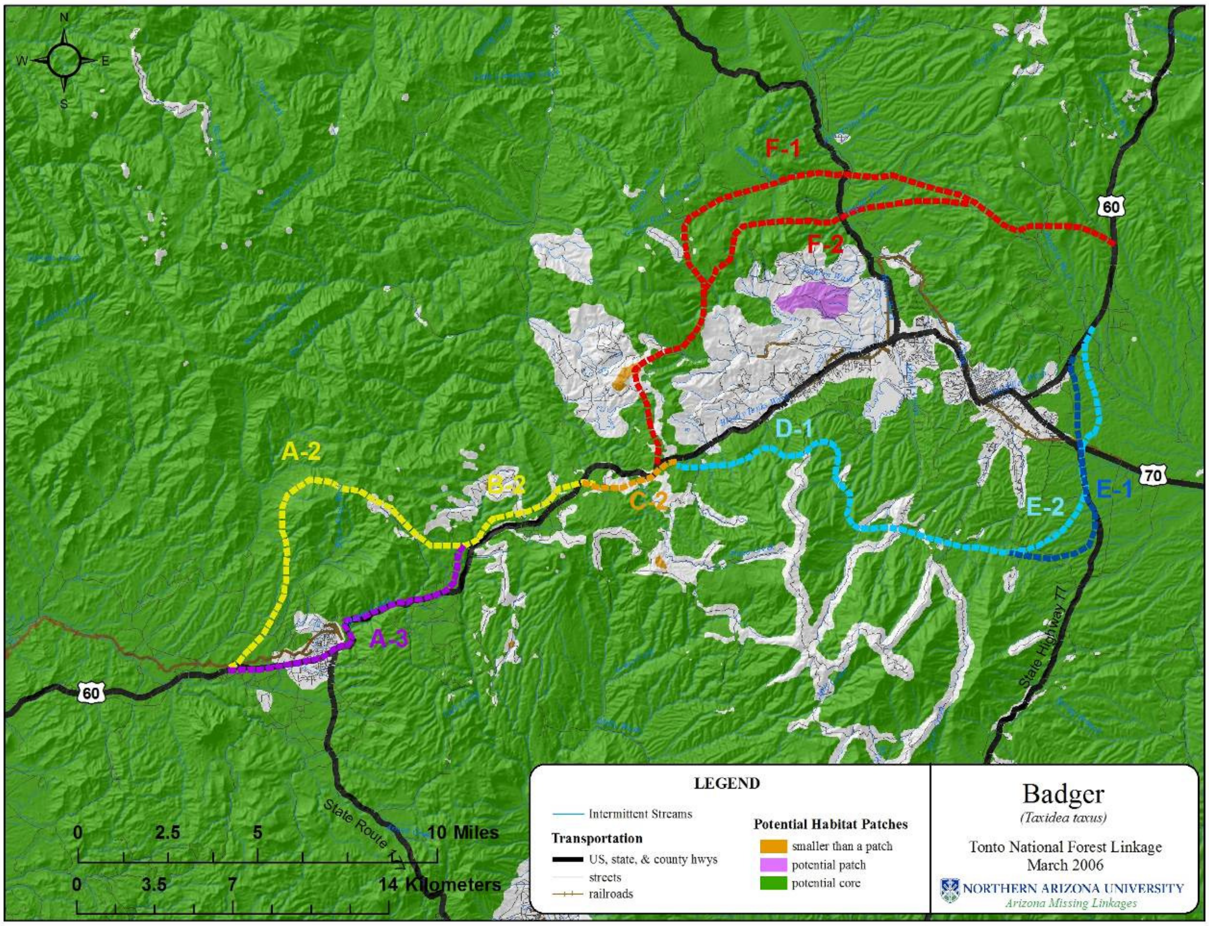

Figure 13: Potential habitat patches and cores for badger.

Black Bear (*Ursus americanus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Cover is the most important factor for black bears, so vegetation was assigned an importance weight of 75%. Elevation and topography each received a weight of 10%, and distance from roads received a weight of 5%. For specific scores of classes within each of these factors, see Table 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 10 km^2, since this is the minimum amount of optimum habitat necessary to support a female and cub (Bunnell & Tait 1981; S. Cunningham, pers. comm.). Minimum potential habitat core size was defined as 50km2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Potential Habitat Suitability

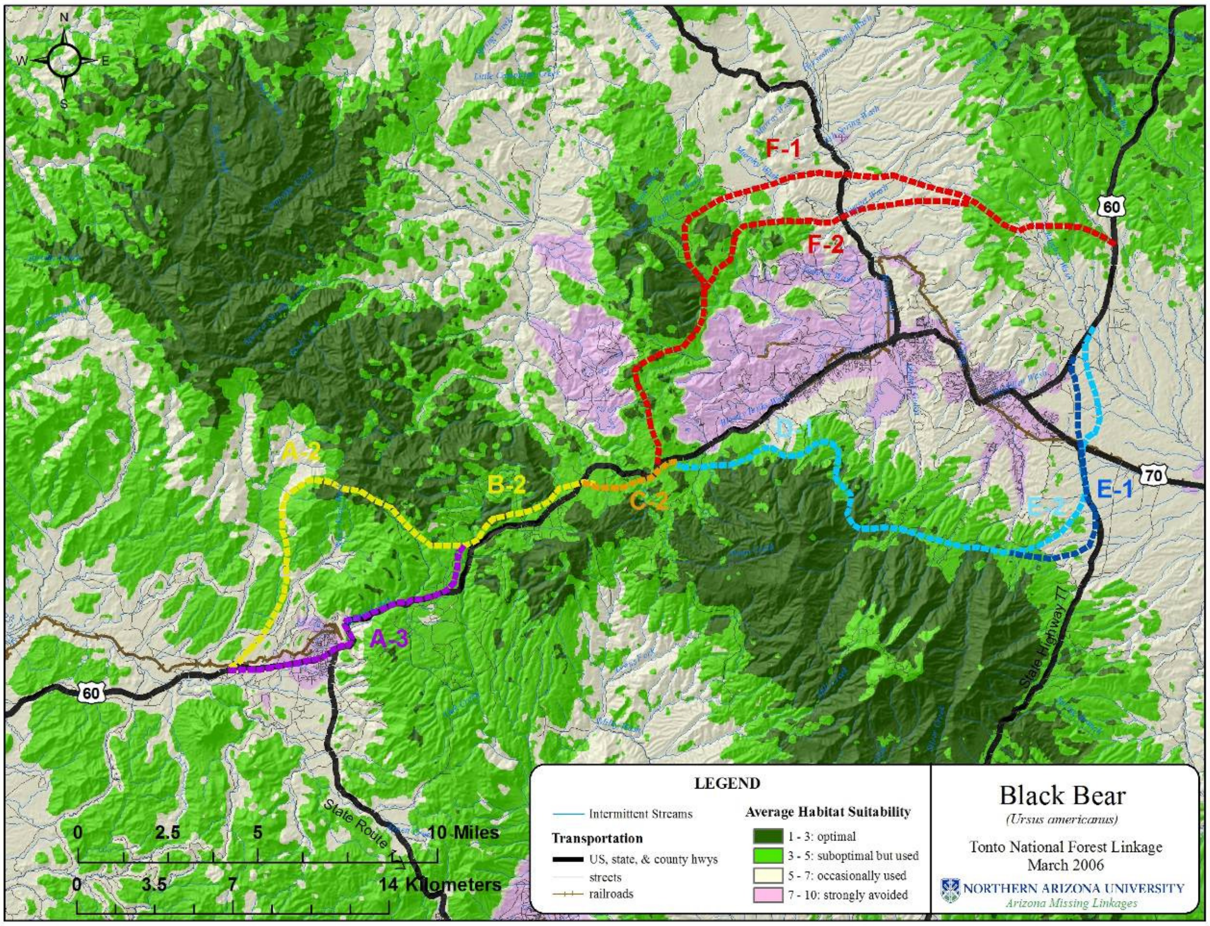

Figure 14: Modeled habitat suitability of black bear.

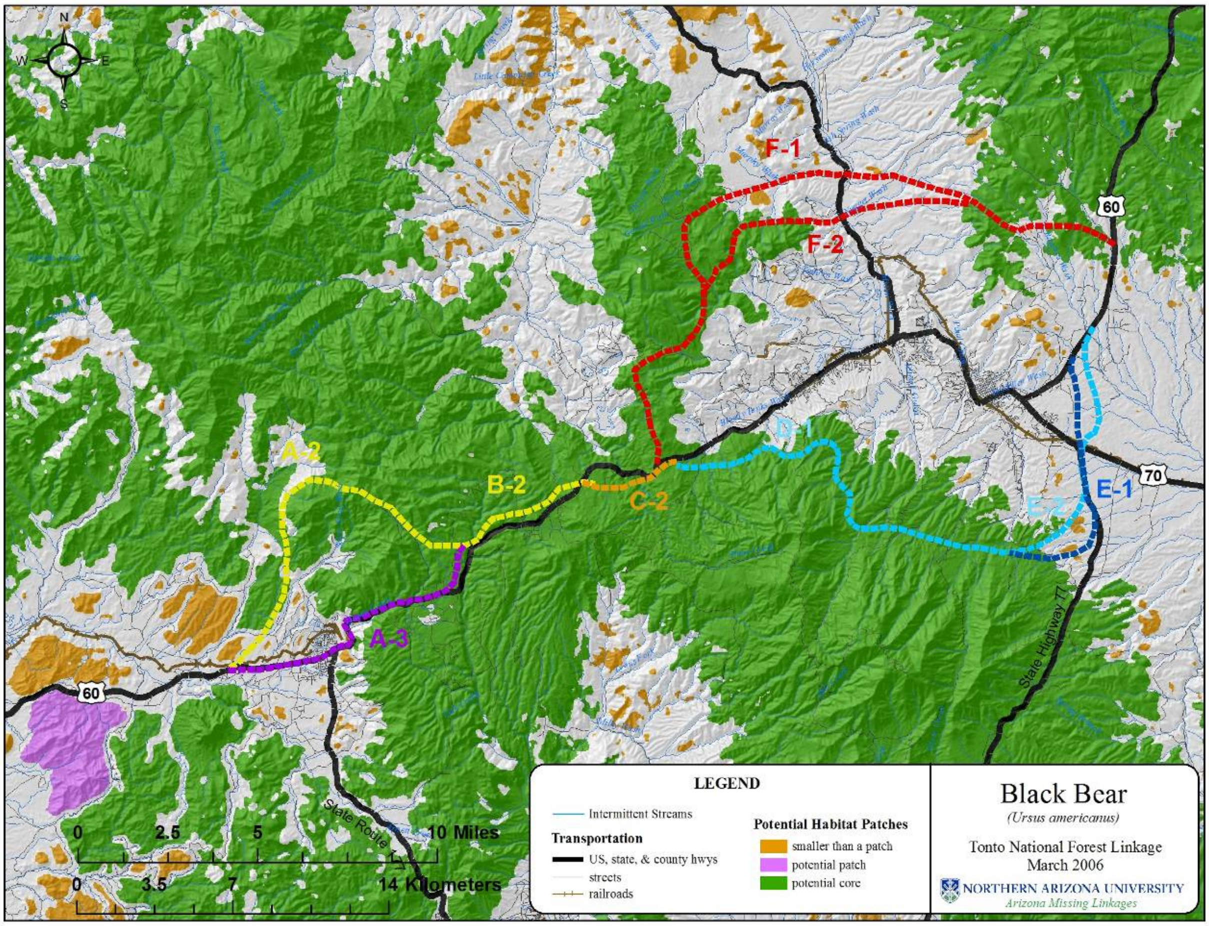

Figure 15: Potential habitat patches and cores for black bear.

Black-tailed Jackrabbit (*Lepus californicus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong vegetation preferences, vegetation received an importance weight of 70%, while elevation, topography, and distance from roads each received weights of 10%. For specific costs of classes within each of these factors used for the modeling process, see Table 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 100 hectares (Best 1993), and minimum potential habitat core size was defined as 500 ha, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Potential Habitat Suitability

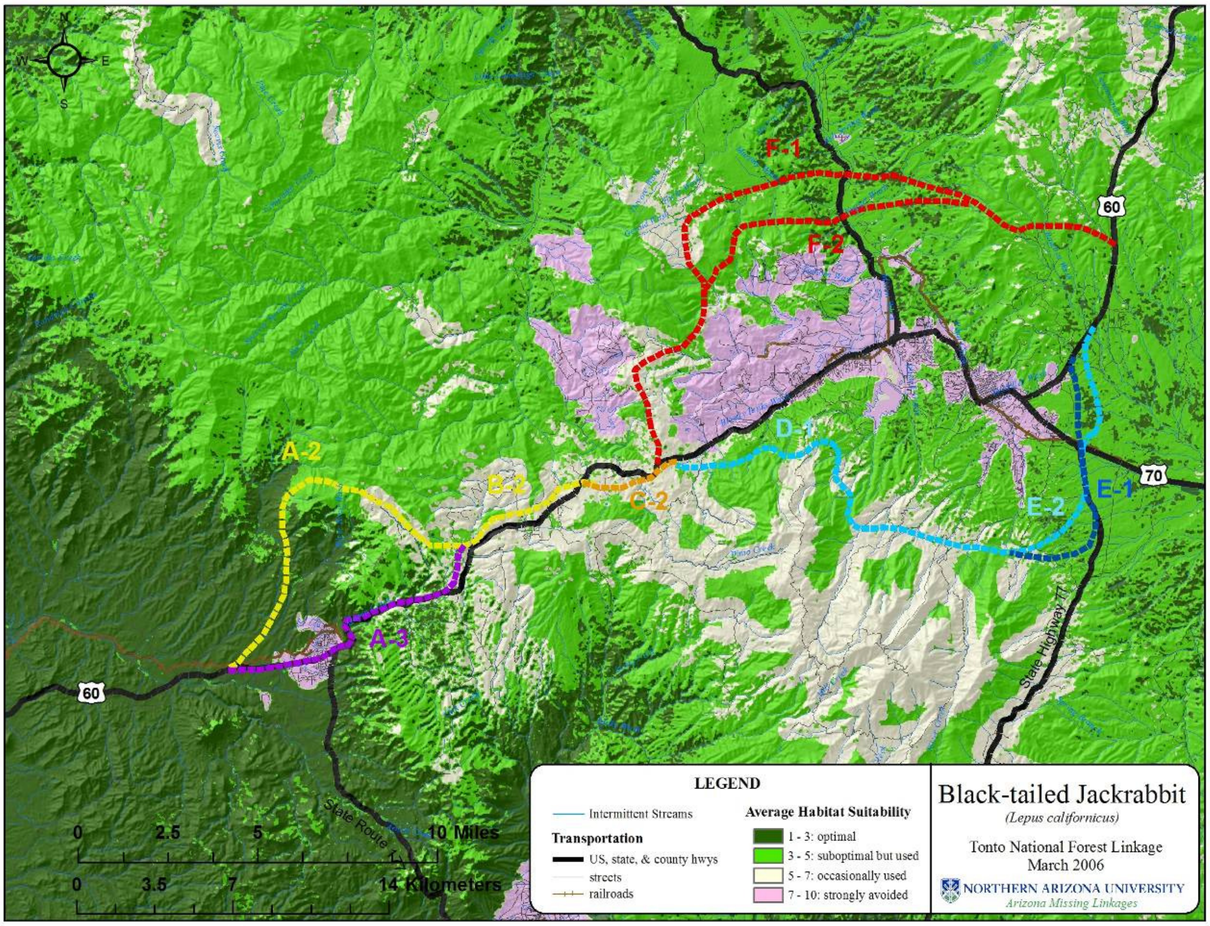

Figure 16: Modeled habitat suitability of black-tailed jackrabbit.

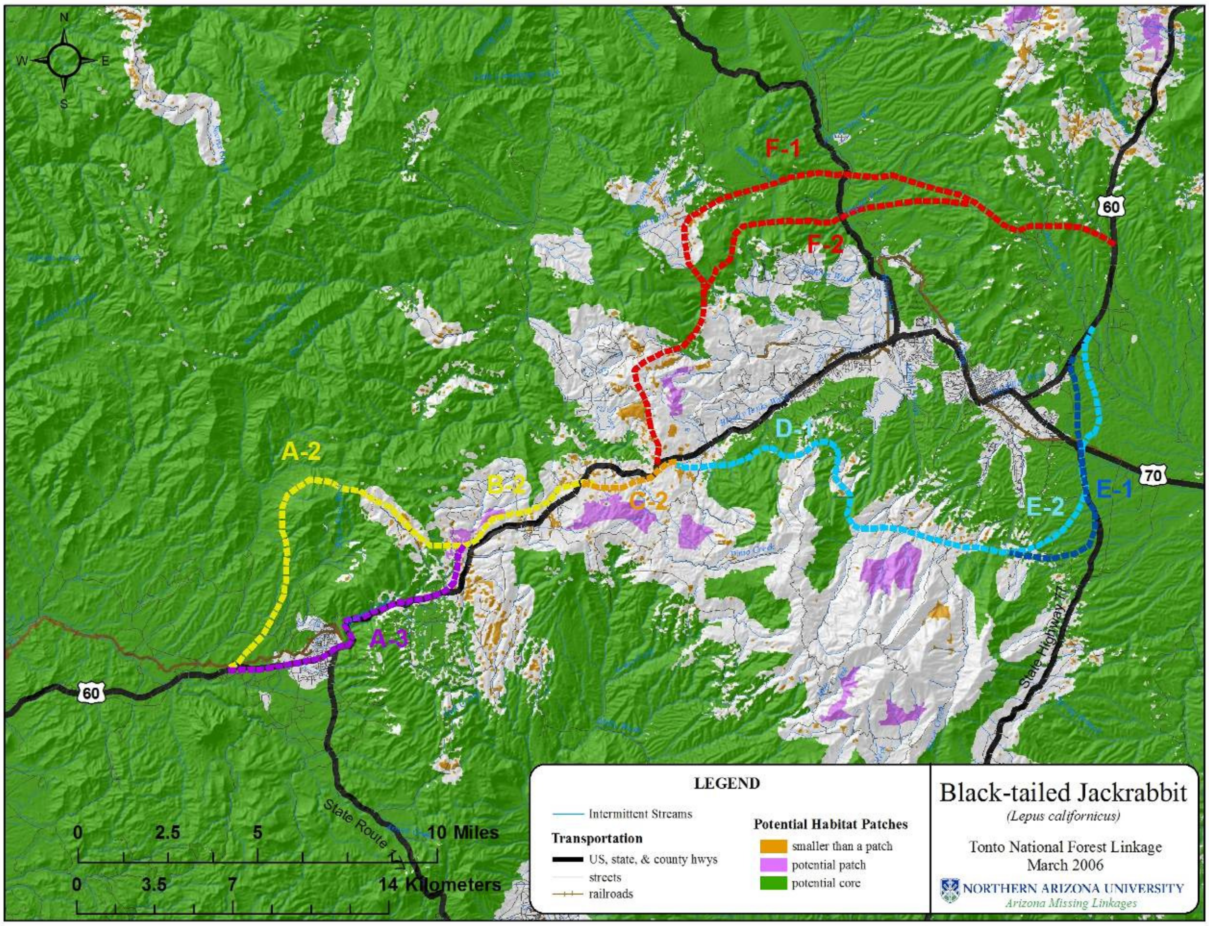

Figure 17: Potential habitat patches and cores for black-tailed jackrabbit.

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, paloverde, catclaw coffeeberry, bush muhly, jojoba, brittlebrush, calliandra, and galleta (Hoffmeister 1986). Water is an important and limiting resource for desert bighorn sheep (Rubin et al. 2002). Where possible, desert bighorn will seek both water and food from such plants as cholla, prickly pear, agave, and especially saguaro fruits (Hoffmeister 1986). Bighorn sheep will also occasionally graze on shrubs such as sagebrush, mountain mahogany, cliffrose, and blackbrush (New Mexico Department of Game and Fish 2004). Elevation range for bighorn sheep varies across their range from 0 – 3660 m (New Mexico Department of Game and Fish 2004), but in Arizona the desert bighorn subspecies is found from 100 – 1000m elevation, with the best habitat found from 900 – 1000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong topographic preferences, topographic position received an importance weight of 50%, while vegetation, elevation, and distance from roads received weights of 30%, 10%, and 10%. 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

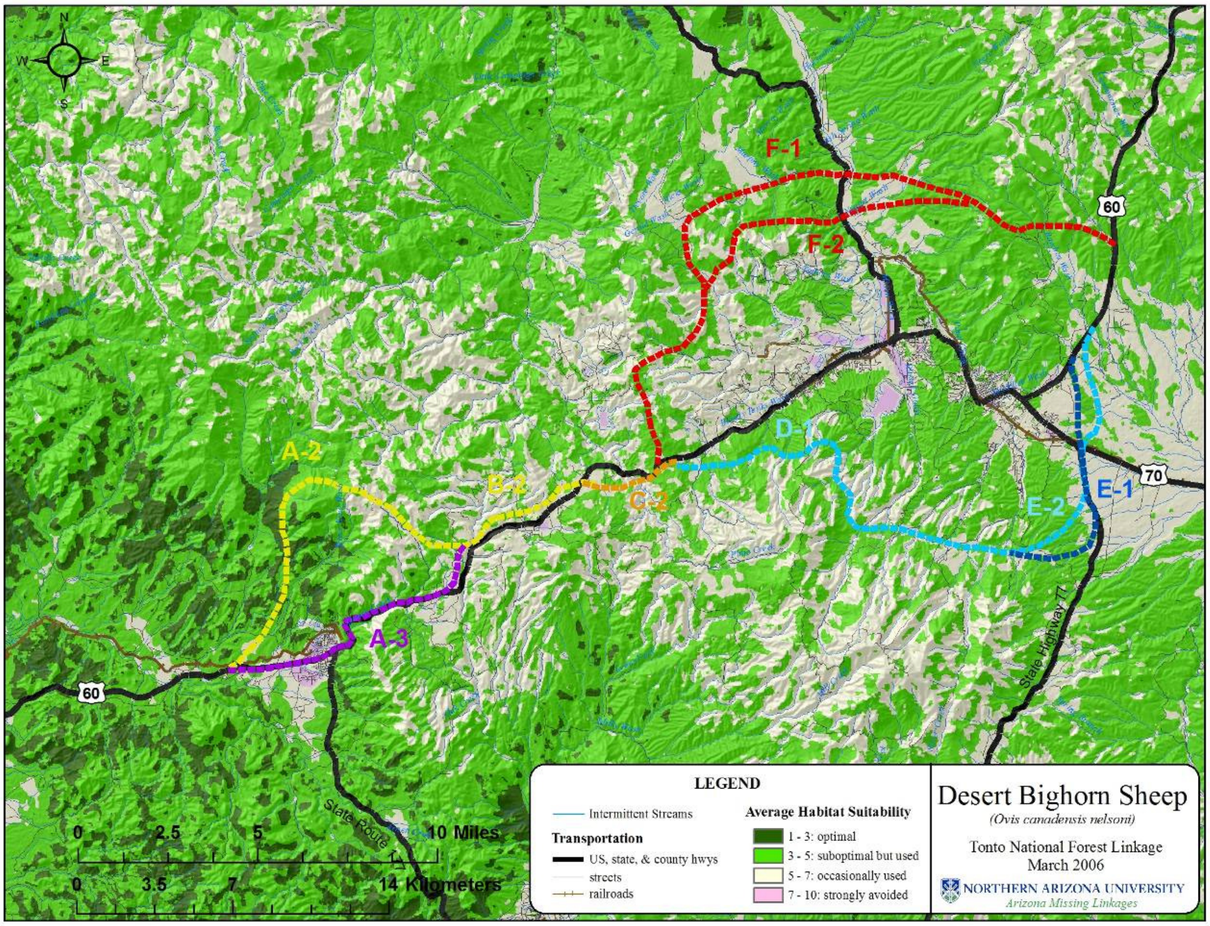

Figure 18: Modeled habitat suitability of desert bighorn sheep.

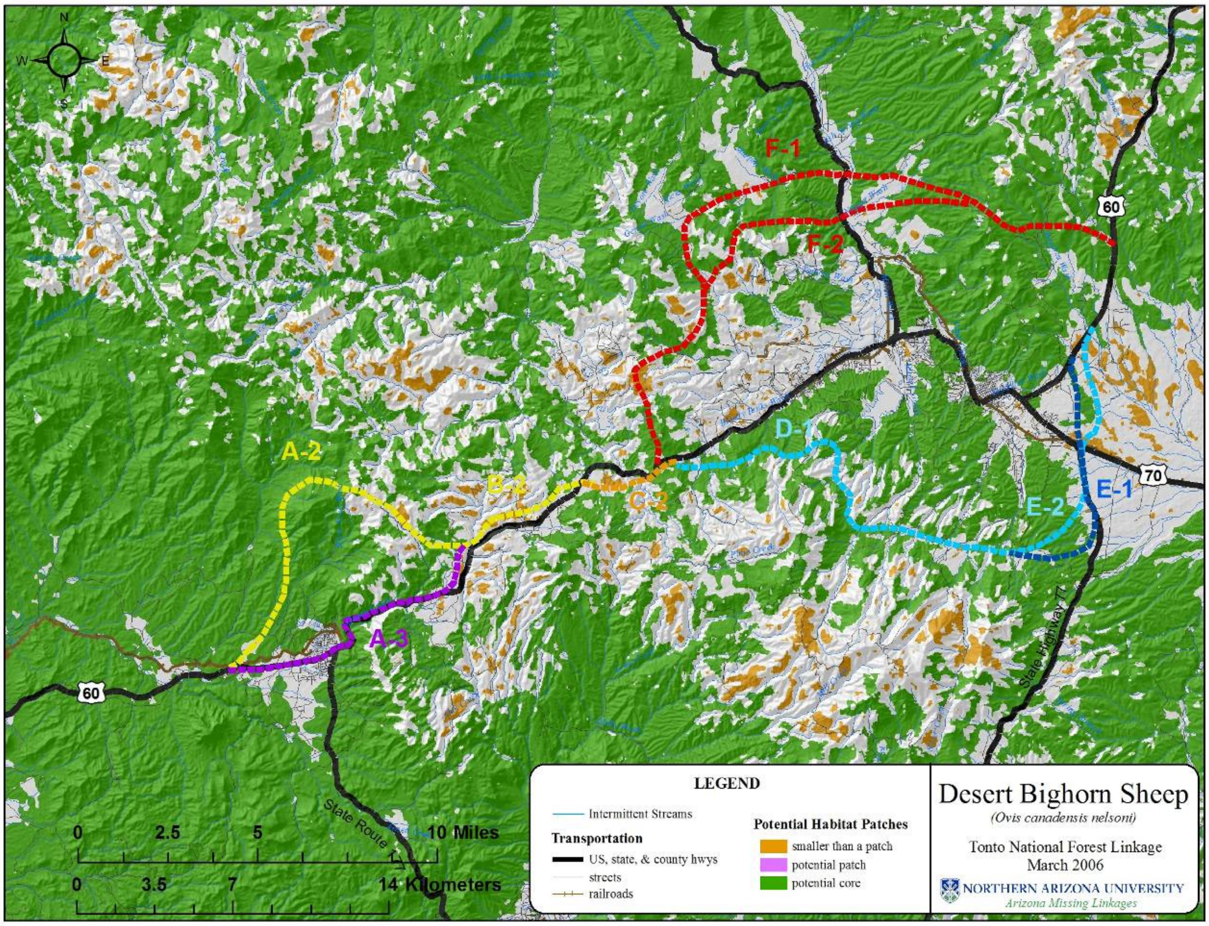

Figure 19: Potential habitat patches and cores for desert bighorn sheep.

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 4000 m (Currier 1983).

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

Conceptual Basis for Model Development
Habitat suitability model – While mountain lions can be considered habitat generalists, vegetation is still the most important factor accounting for habitat suitability, so it received an importance weight of 70%, while topography received a weight of 10%, and distance from roads received a weight of 20%. For specific scores of classes within each of these factors, see Table 4.

Patch size & configuration analysis – Minimum patch size for mountain lions was defined as 79 km2, based on an average home range estimate for a female in excellent habitat (Logan & Sweanor 2001; Dickson & Beier 2002). Minimum core size was defined as 395 km2, or five times minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Potential Habitat Suitability

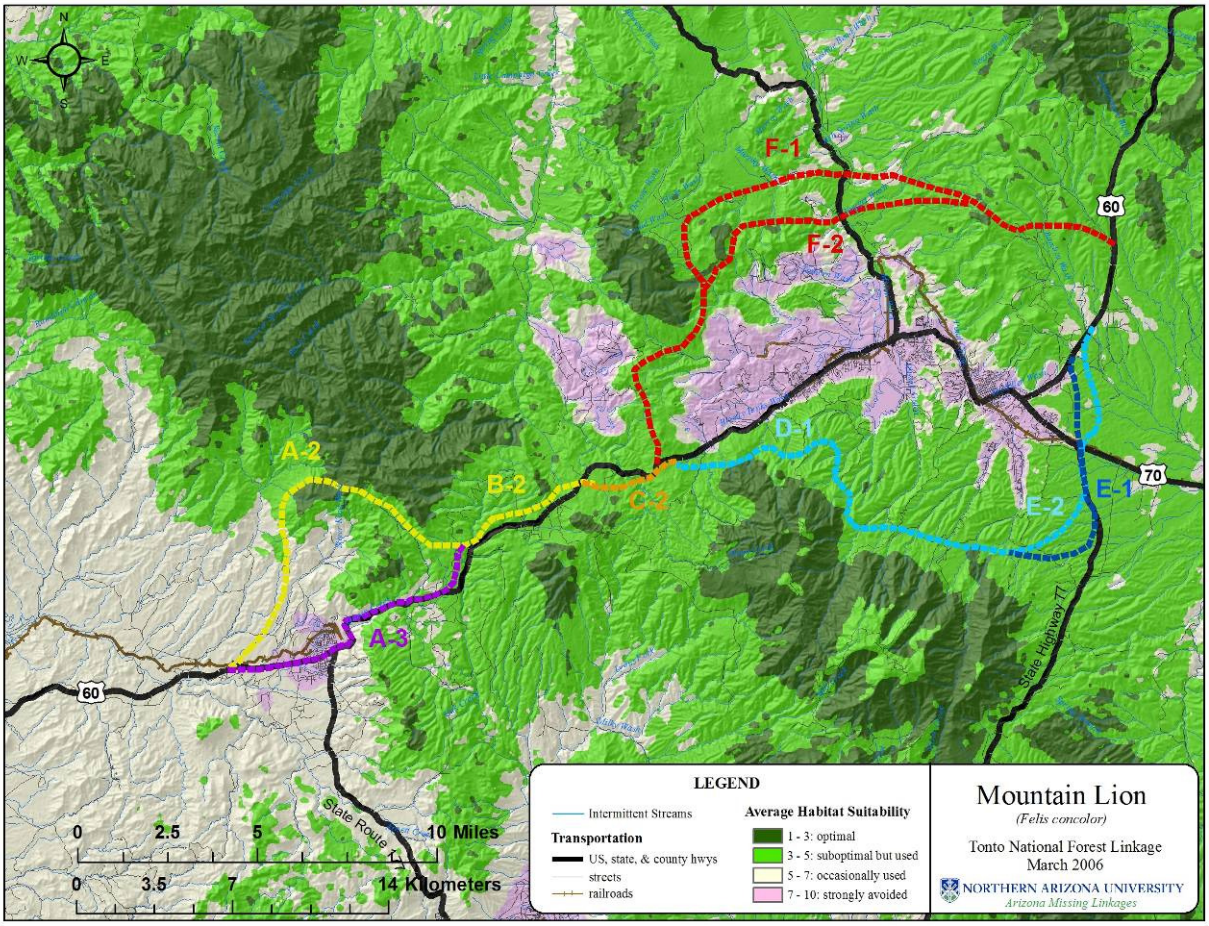

Figure 20: Modeled habitat suitability of mountain lion.

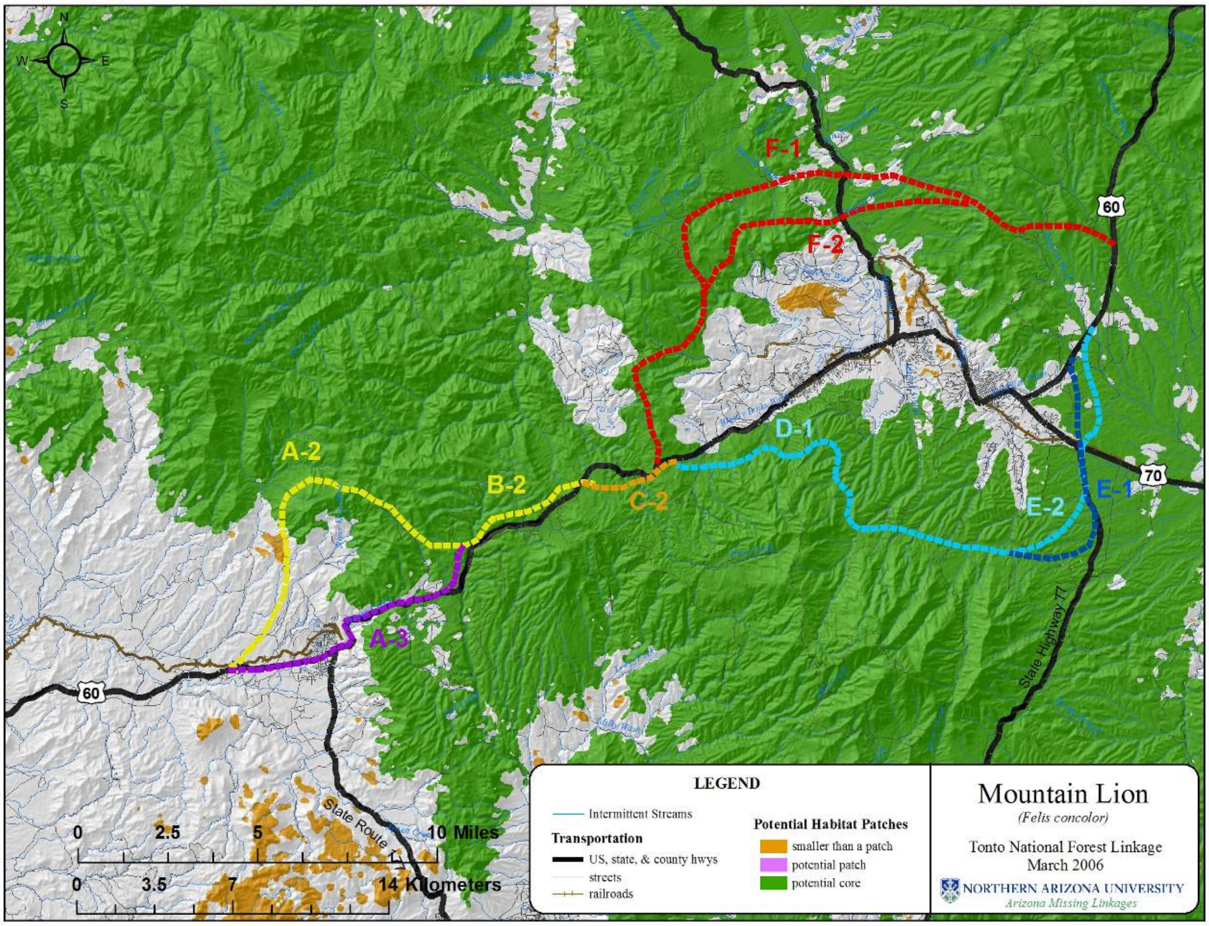

Figure 21: Potential habitat patches and cores for mountain lion.

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, 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

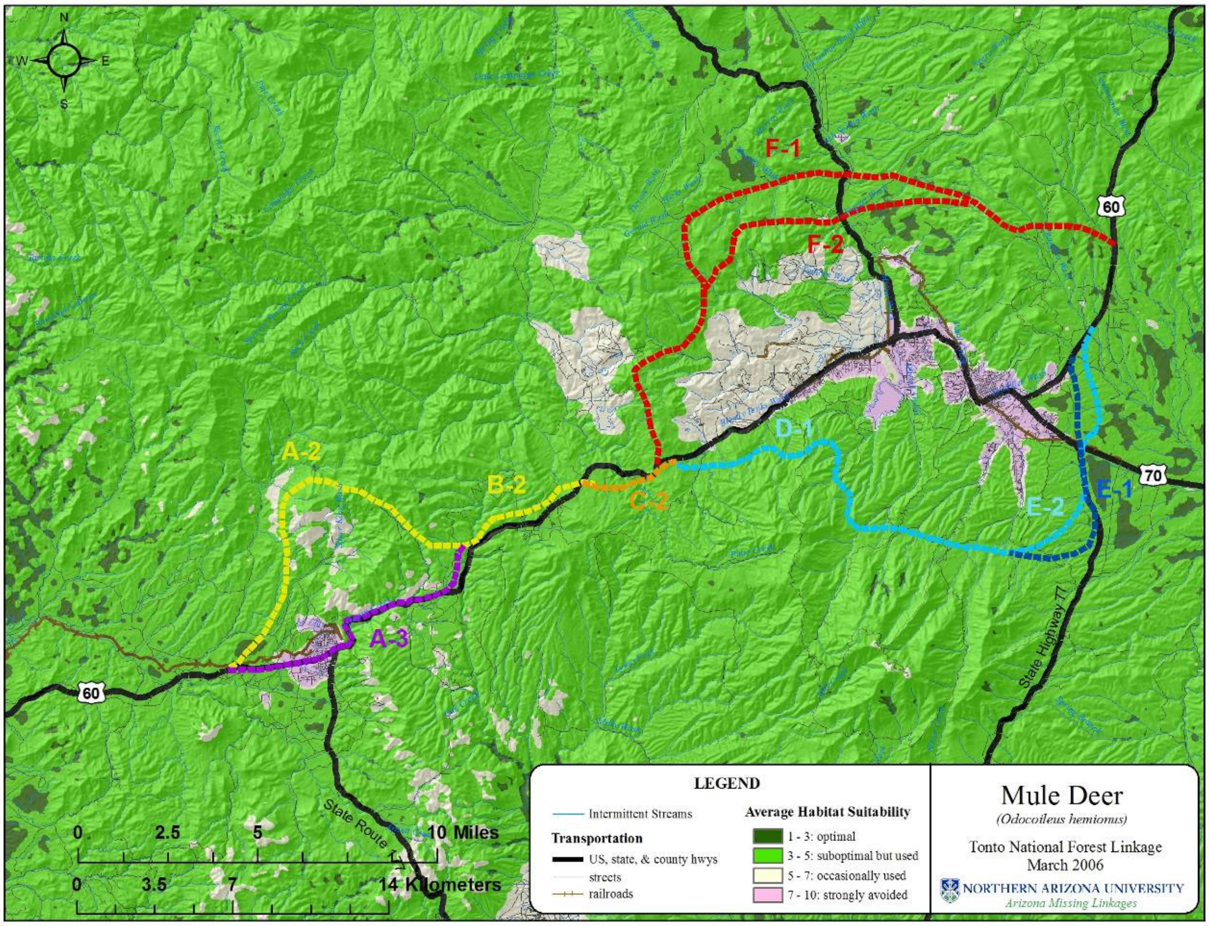

Figure 22: Modeled habitat suitability of mule deer.

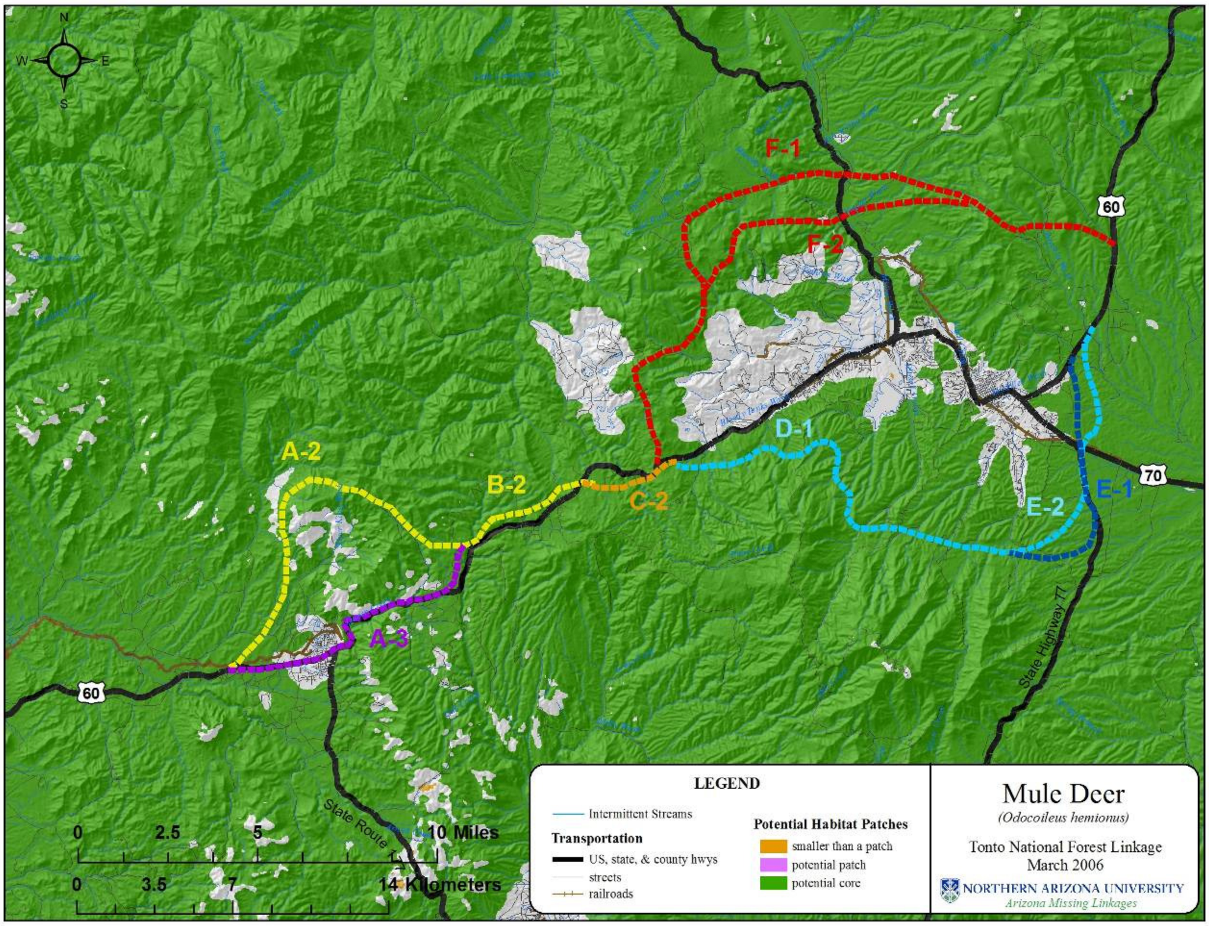

Figure 23: Potential habitat patches and cores for mule deer.

Black-tailed Rattlesnake (*Crotalus molossuss*)

Justification for Selection
The black-tailed rattlesnake is a vegetation generalist, able to live in a variety of habitats, making this species an important part of many ecosystems throughout Arizona. This rattlesnake requires various habitat types during different times of the year (Beck 1995), and relies on connectivity of these habitat types during its life cycle.

Distribution
This rattlesnake is found from central and west-central Texas northwest through the southern two-thirds of New Mexico to northern and extreme western Arizona, and southward to the southern edge of the Mexican Plateau and Mesa del Sur, Oaxaca (Degenhardt et. al 1996).

Habitat Associations
Black-tailed rattlesnakes are known as ecological generalists, occurring in a wide variety of habitats including montane coniferous forests, talus slopes, rocky stream beds in riparian areas, and lava flows on flat deserts (Degenhardt et. al 1996). In a radiotelemetry study conducted by Beck (1995), these snakes frequented rocky areas, but used arroyos and creosotebush flats during late summer and fall. Pine-oak forests, boreal forests, mesquite-grasslands, chaparral, tropical deciduous forests, and thorn forests are also included as habitats for this species (New Mexico Department of Game and Fish 2004). In New Mexico, black-tailed rattlesnakes occur between 1000 and 3150 meters in elevation (New Mexico Department of Game and Fish 2004).

Spatial Patterns
The home range size for black-tailed rattlesnakes has been reported as 3.5 hectares, in a study within the Sonoran desert of Arizona (Beck 1995). These snakes traveled a mean distance of 15 km throughout the year, and moved an average of 42.9 meters per day (Beck 1995). No data is available on dispersal distance for this species, but a similar species, Tiger rattlesnake (*Crotalus tigris*), has been found to disperse up to 2 km (Matt Goode & Phil Rosen, personal comm.).

Conceptual Basis for Model Development
Habitat suitability model – While this species is a vegetation generalist, it is strongly associated with rocks and outcrops on mountain slopes, and rarely seen at any distance from these environments (Matt Goode & Phil Rosen, personal comm.). Because of this strong topographic association, topography received an importance weight of 90%, while distance from roads received a weight of 10%. For specific scores of classes within each of these factors, see Table 4.

Patch size & configuration analysis – Beck (1995) found home ranges from 3-4 ha in size; however, it is thought that home ranges for most black-tailed rattlesnakes are slightly larger (Phil Rosen, personal comm.), so minimum patch size was defined as 10 ha. Minimum core size was defined as 100 ha. 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

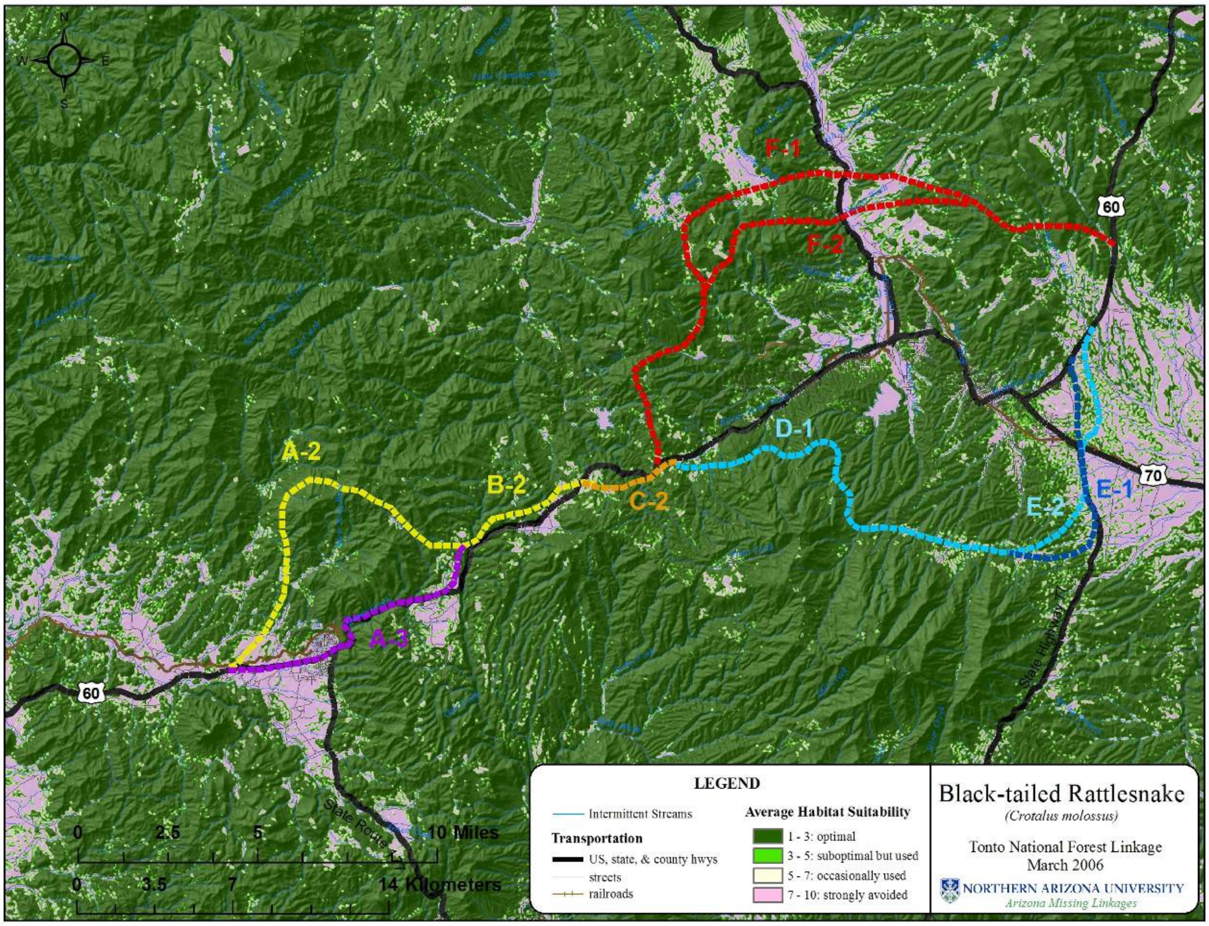

Figure 24: Modeled habitat suitability of black-tailed rattlesnake.

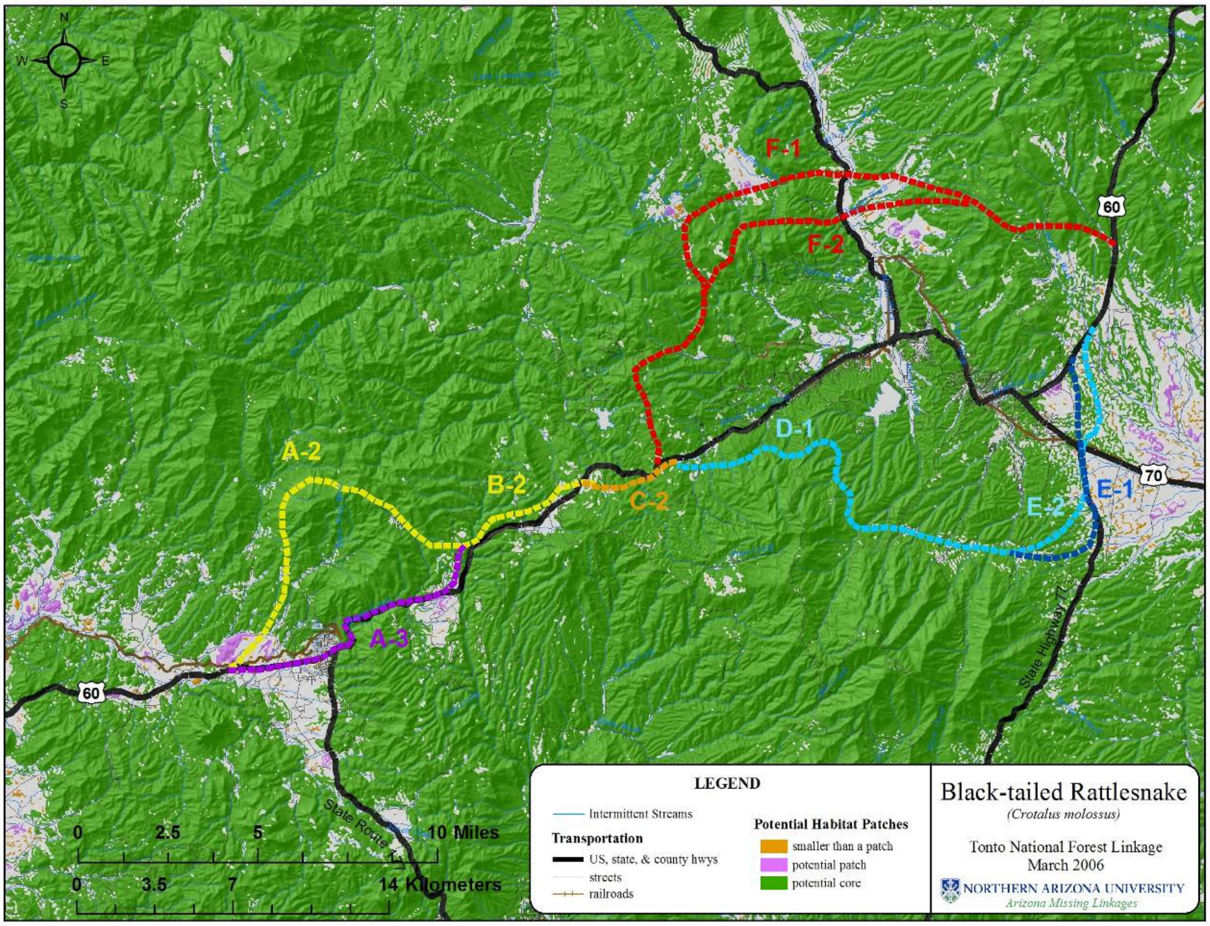

Figure 25: Potential habitat patches and cores for black-tailed rattlesnake.

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 in 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 across the Sonoran Desert are between 7 and 23 ha (Averill-Murray et al. 2002). 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

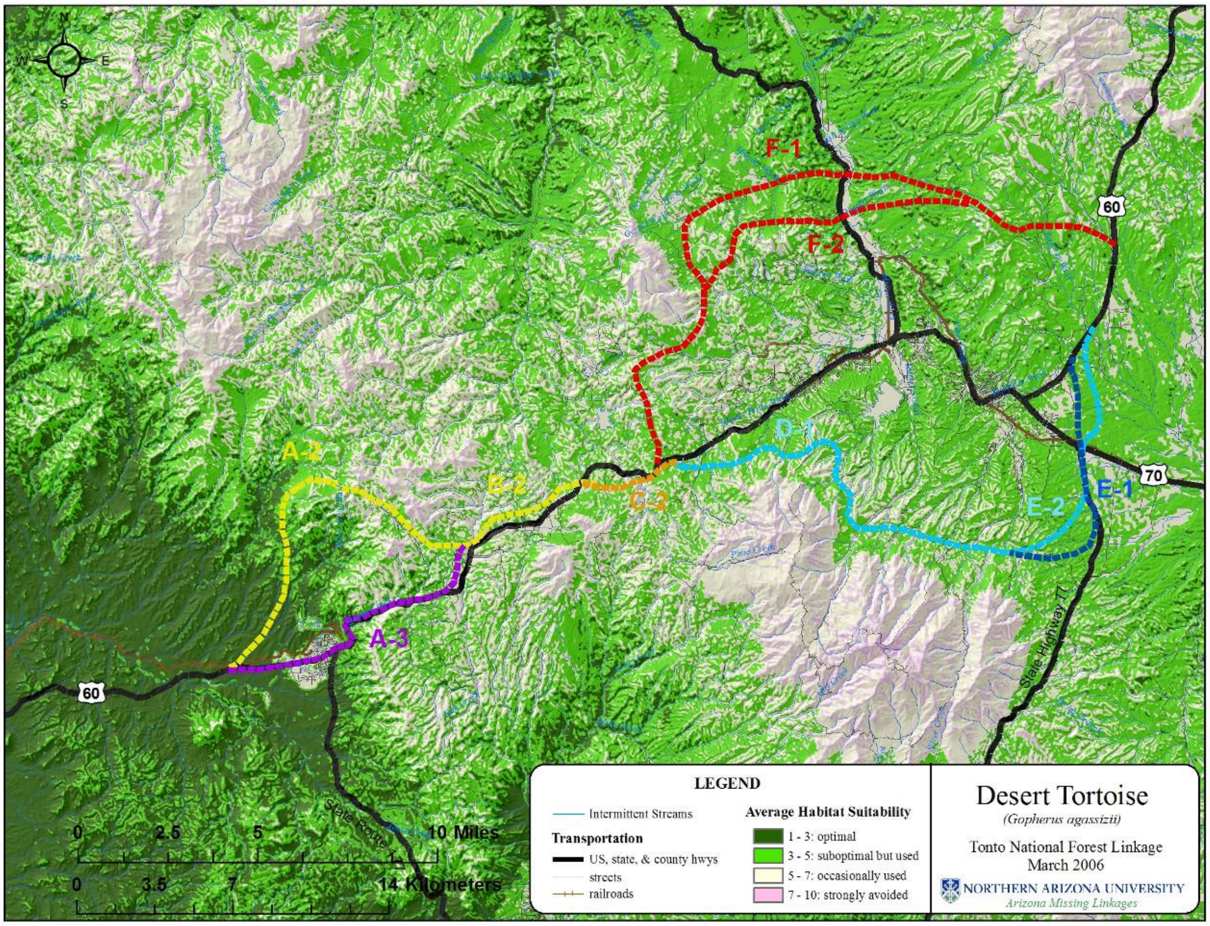

Figure 26: Modeled habitat suitability of desert tortoise.

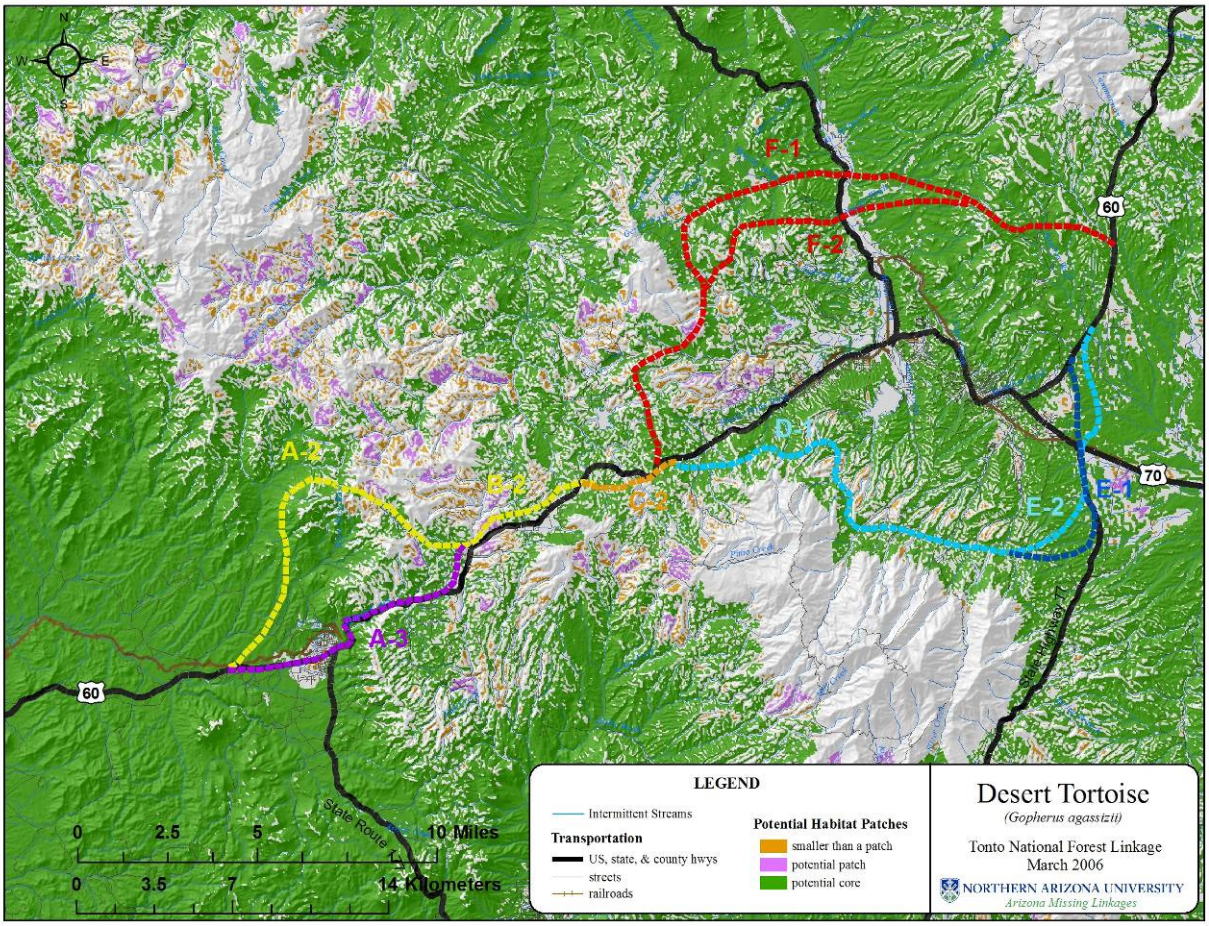

Figure 27: Potential habitat patches and cores for desert tortoise.

Gila Monster (*Heloderma suspectum*)

Justification for Selection

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

Distribution

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

Habitat Associations

Gila monsters live on mountain slopes and washes where water is occasionally present. They prefer rocky outcrops and boulders, where they dig burrows for shelter (NFDGF 2002). Individuals are reasonably abundant in mid-bajada flats during wet periods, but after some years of drought conditions, these populations may disappear (Phil Rosen & Matt Goode, personal comm.). The optimal elevation for this species is between 1700 and 4,000 ft.

Spatial Patterns

Home ranges from 13 to 70 hectares, and 3 to 4 km in length have been recorded (Beck 2005). Gila Monsters forage widely, and are 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

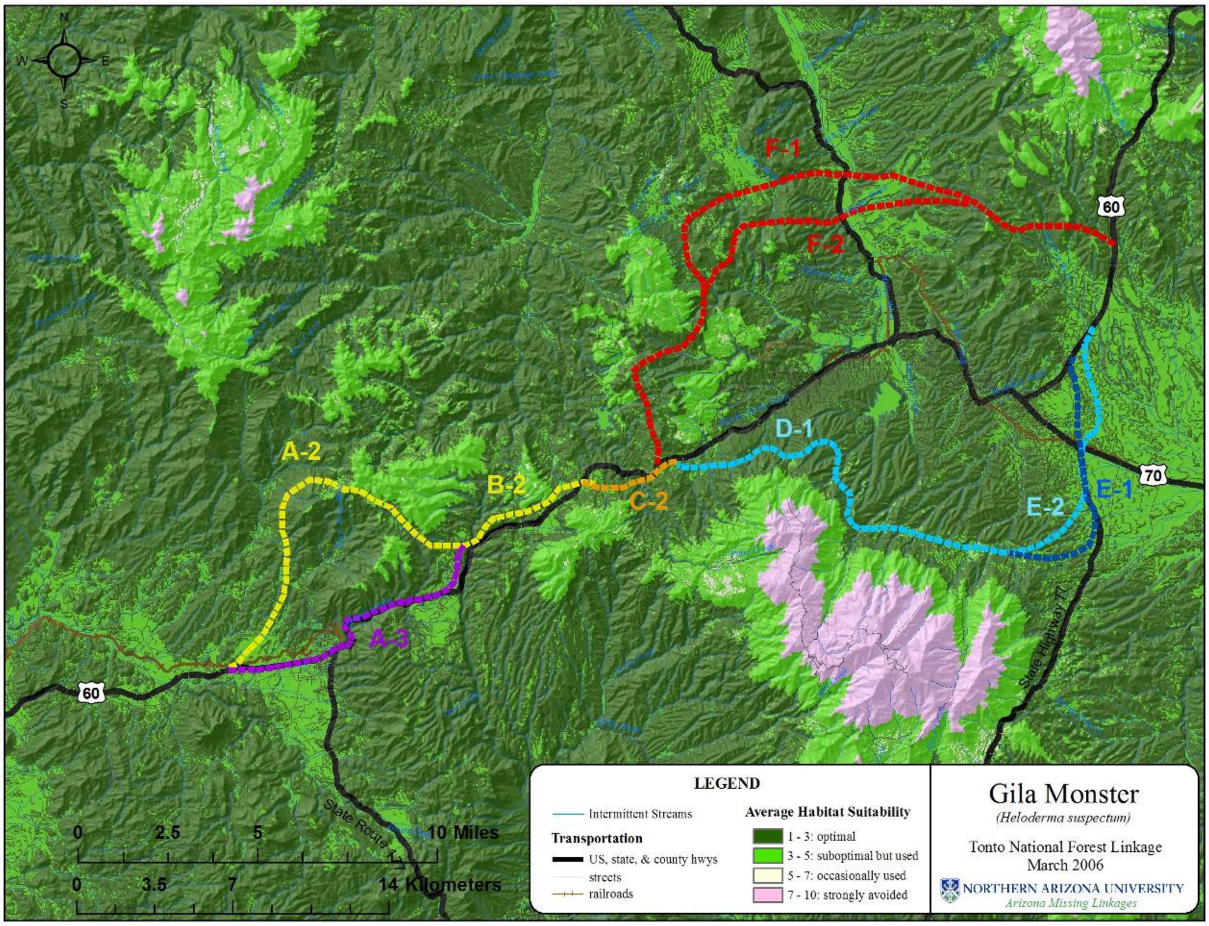

Figure 28: Modeled habitat suitability of gila monster.

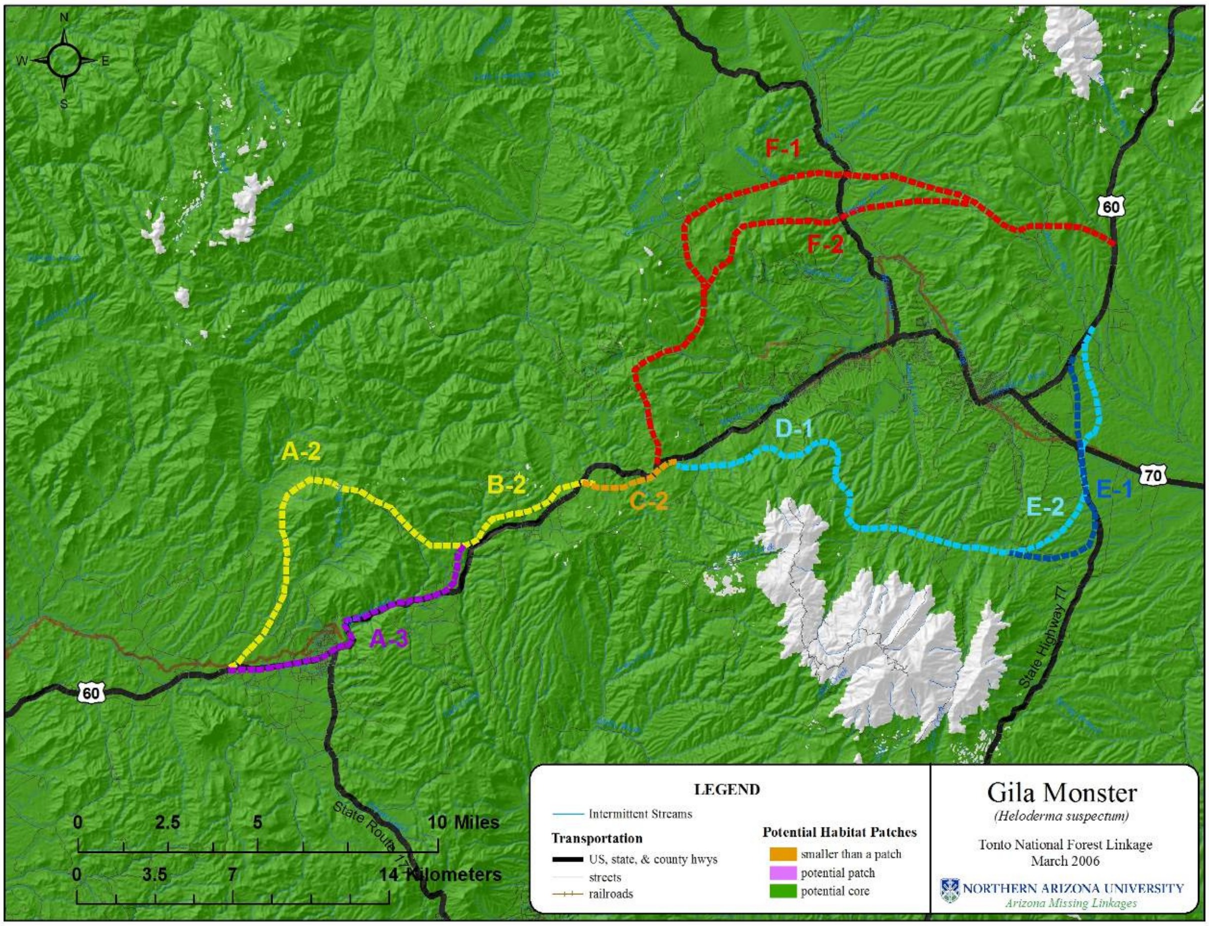

Figure 29: Potential habitat patches and cores for gila monster.

Lyre Snake (*Trimorphodon biscutatus*)

Justification for Selection
Lyre Snakes are susceptible to habitat fragmentation.

Distribution
This species ranges from southern Nevada and Utah through western Mexico. In Arizona, it is found from the western Arizona Strip south to the border with Sonora, Mexico (Johnson 2002).

Habitat Associations
This species lives on mountain slopes in virtually all vegetation types up to about 7,400' in Arizona, and occurs in riparian zones as well. It is strongly associated with rocks and outcrops, but has been seen in creosote flats at distances of several miles from the usual rock slope habitats (Phil Rosen & Matt Goode, personal comm.).

Spatial Patterns
There is no published data on spatial patterns for the Lyre Snake. Based on limited telemetry data, Matt Goode has estimated home range to range from 2 to 4 ha, and movements to be limited to approximately 500 m. Phil Rosen (unpublished) found that in wet years at Organ Pipe Cactus NM, individuals moved 2-3 mi from the rock slopes to which they were restricted in normal and dry years.

Conceptual Basis for Model Development
Habitat suitability model – Because this species is found on mountain slopes in virtually all vegetation types, topography received a weight of 80%, while elevation and distance-from-roads received weights of 10%. 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 4 ha, and minimum potential core size was defined as 20 ha (Matt Goode, 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

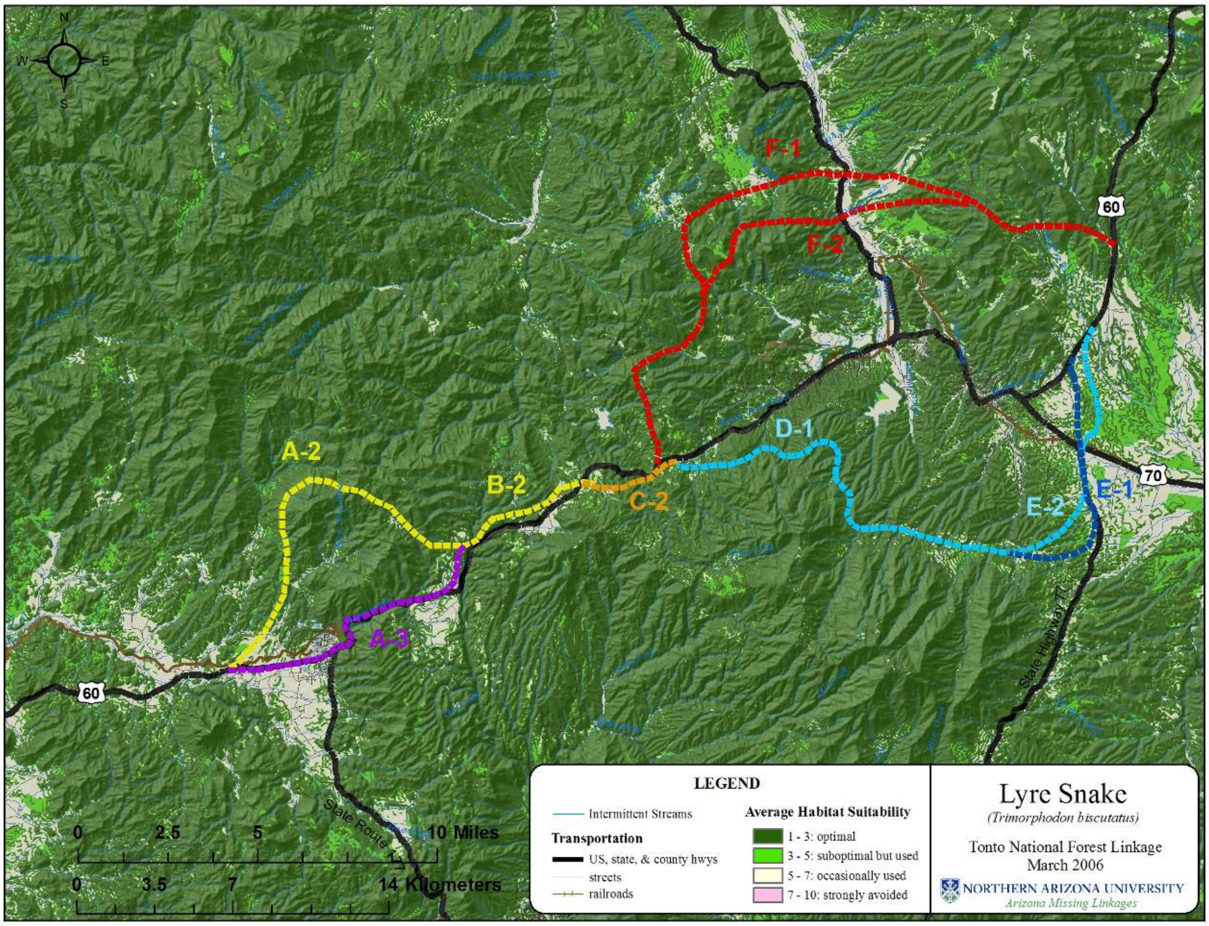

Figure 30: Modeled habitat suitability of lyre snake.

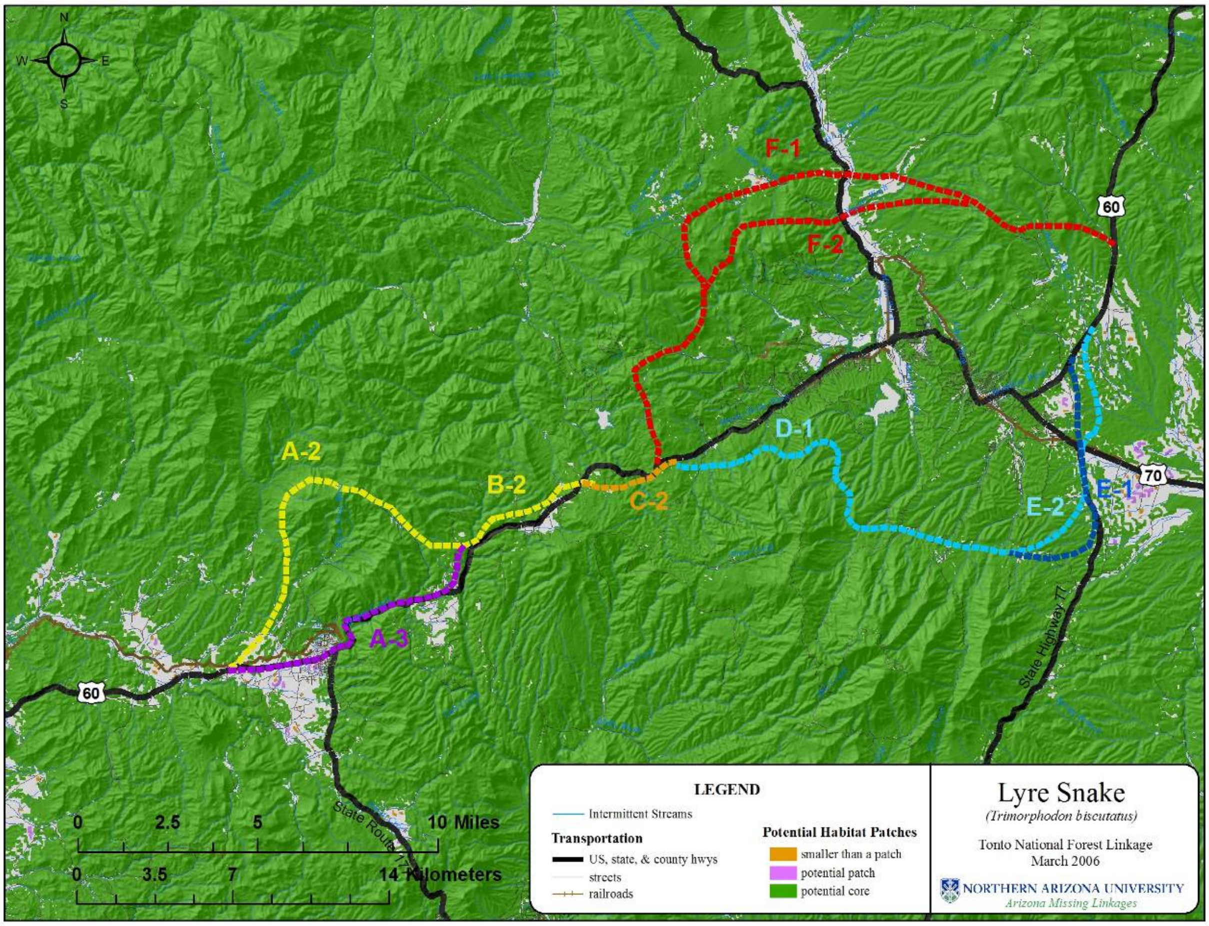

Figure 31: Potential habitat patches and cores for lyre snake.

Sonoran Desert Toad (*Bufo alvarius*)

Justification for Selection

This species is thought to be potentially susceptible to extirpation or demographic impact from road mortality due to its large size, conspicuous activity, numerous observations of road-killed adults, presumed long natural lifespan, and apparent declines in road-rich urban zones (Phil Rosen, personal comm.).

Distribution

Sonoran desert toads range from southeastern California to southwestern New Mexico (New Mexico Department of Game & Fish 2002).

Habitat Associations

Sonoran desert toads appear capable of occupying any vegetation type, from urbanized park to their maximum elevation. Roads can have a massive mortality impact and presumed population impact, but some populations live near roads that may be peripheral or marginal to the core habitat (P. Rosen, personal comm.). Breeding is naturally concentrated in canyons and upper bajada intermittant streams, and on valley floors in major pools, but not naturally frequent on intervening bajadas. With stock ponds, breeding can occur anywhere on the landscape, but valley centers and canyons likely remain as the core areas (P. Rosen, personal comm.).

Spatial Patterns

Little is know about this species' spatial patterns. Rosen (personal comm.) estimates the smallest area of suitable habitat necessary to support a breeding group for 1 breeding season to be 25 ha, based on limited knowledge of movements and smallest occupied patches in Tucson. Based on unpublished data by Cornejo, adults appear to be highly mobile, and long distance movements (5 km to be conservative) seem likely (P. Rosen, personal comm).

Conceptual Basis for Model Development

Habitat suitability model –Vegetation received an importance weight of 5%, while elevation, topography, and distance from roads received weights of 50%, 25%, and 20%, 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 25 ha, and minimum potential core size was defined as 100 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

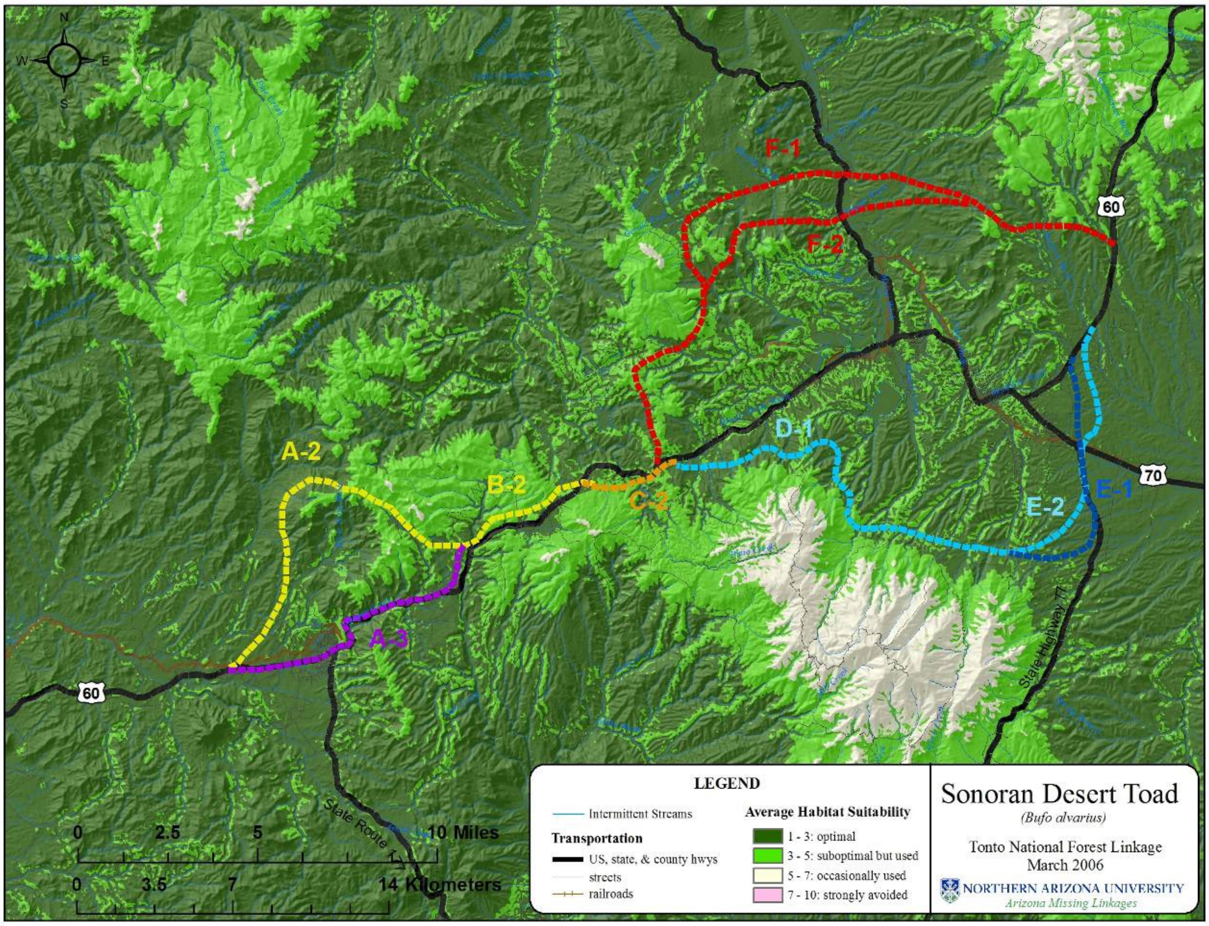

Figure 32: Modeled habitat suitability of Sonoran Desert Toad.

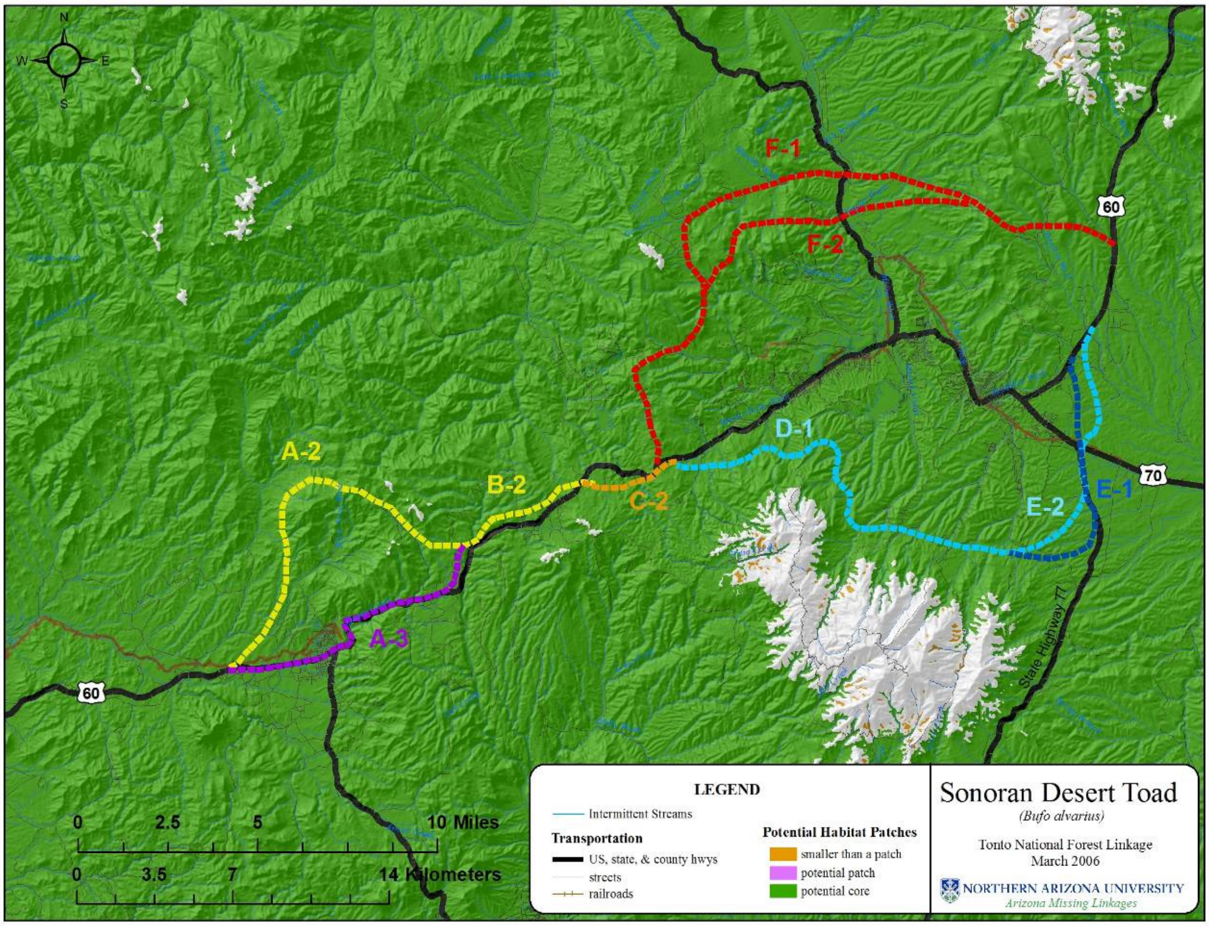

Figure 33: Potential habitat patches and cores for Sonoran Desert Toad.

Tiger Rattlesnake (*Crotalus tigris*)

Justification for Selection
Tiger rattlesnakes are a rare species in Arizona, and rely on the ability to move across varied habitats and elevations for migration. Radio telemetry research suggests avoidance of busy roads (M. Goode, pers. comm.), possibly impeding their movement requirements.

Distribution
The tiger rattlesnake has a limited distribution, encompassing south-central Arizona to the New Mexico border and south into Sonora, Mexico (Lowe 1978; Degenhardt et al. 1996).

Habitat Associations
Tiger rattlesnakes are most common in Arizona Upland habitats of saguaro, paloverde, and mixed cactus, but also can be found in lower elevations of oak grassland and creosote flats on the lower bajada if rocky washes are present (M. Goode, pers. comm.). They have a known elevational range in Arizona of 300-1,700 m, and are never found far from rock outcrops (M. Goode, pers. comm.).

Spatial Patterns
There is considerable variation in movement patterns of tiger rattlesnakes among individuals, sexes, age classes, seasons, and years (M. Goode, pers. comm.). Male home ranges vary from 5 to 25 hectares, depending on landscape patterns and year. Occasionally, rogue males may have home ranges as large as 125 hectares (M. Goode, pers. comm.). Female home ranges are generally smaller, averaging from 1 to 5 hectares (M. Goode, pers. comm.). In general, tiger rattlesnakes move from rocky slopes in spring to xeroriparian washes in summer and back to slopes in fall, demonstrating elevational migration (M. Goode, pers. comm.). Preliminary genetic data (microsatellite markers) indicate that tiger rattlesnakes moved between mountain ranges, but radiotelemetry data suggest that this no longer happens (M. Goode, pers. comm.).

Conceptual Basis for Model Development
Habitat suitability model – Tiger rattlesnakes have a known elevational range in Arizona (300-1,700 m), and they are never found far from rock outcrops. Although mostly found in Arizona Upland (saguaro/palo verde/mixed cactus), they can be found at the lower elevations of oak grassland and out into creosote flats on the lower bajada if rocky washes are present (Matt Goode, personal comm.). Vegetation received an importance weight of 20%, while elevation, topography, and distance from roads received weights of 30%, 40%, and 10%, respectively. For specific scores of classes within each of these factors, see Table 4. To ensure that suitable habitat was restrained to locations close to rocky areas, habitat suitability beyond 500 meters from rocky areas mapped in the ReGAP vegetation layer were reclassified to suitability scores between 5 and 10. Because this species does not occur above 5,100 ft, all habitat above 5,100 ft was reclassified to a score of 10, 'strongly avoided.'

Patch size & configuration analysis – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha. 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

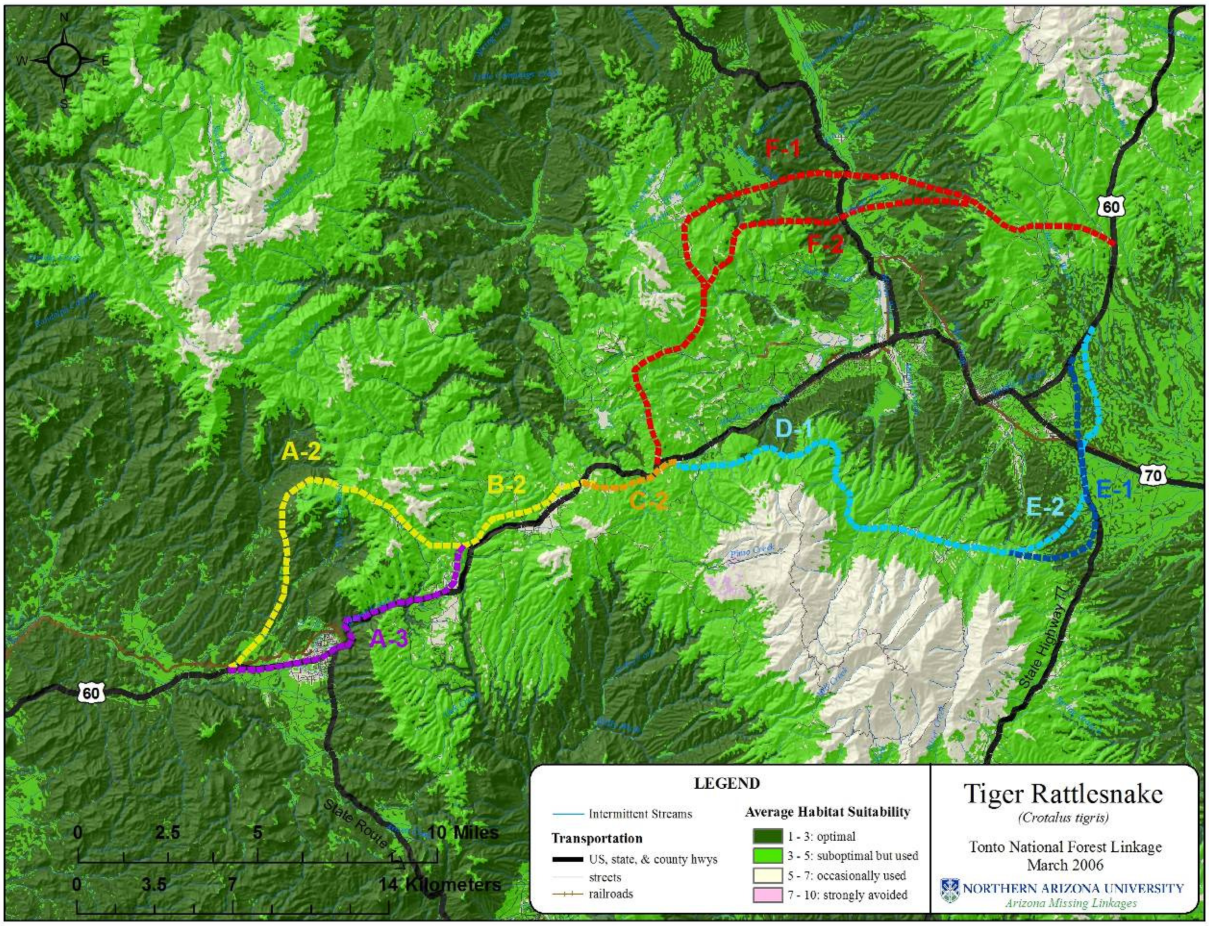

Figure 34: Modeled habitat suitability of tiger rattlesnake.

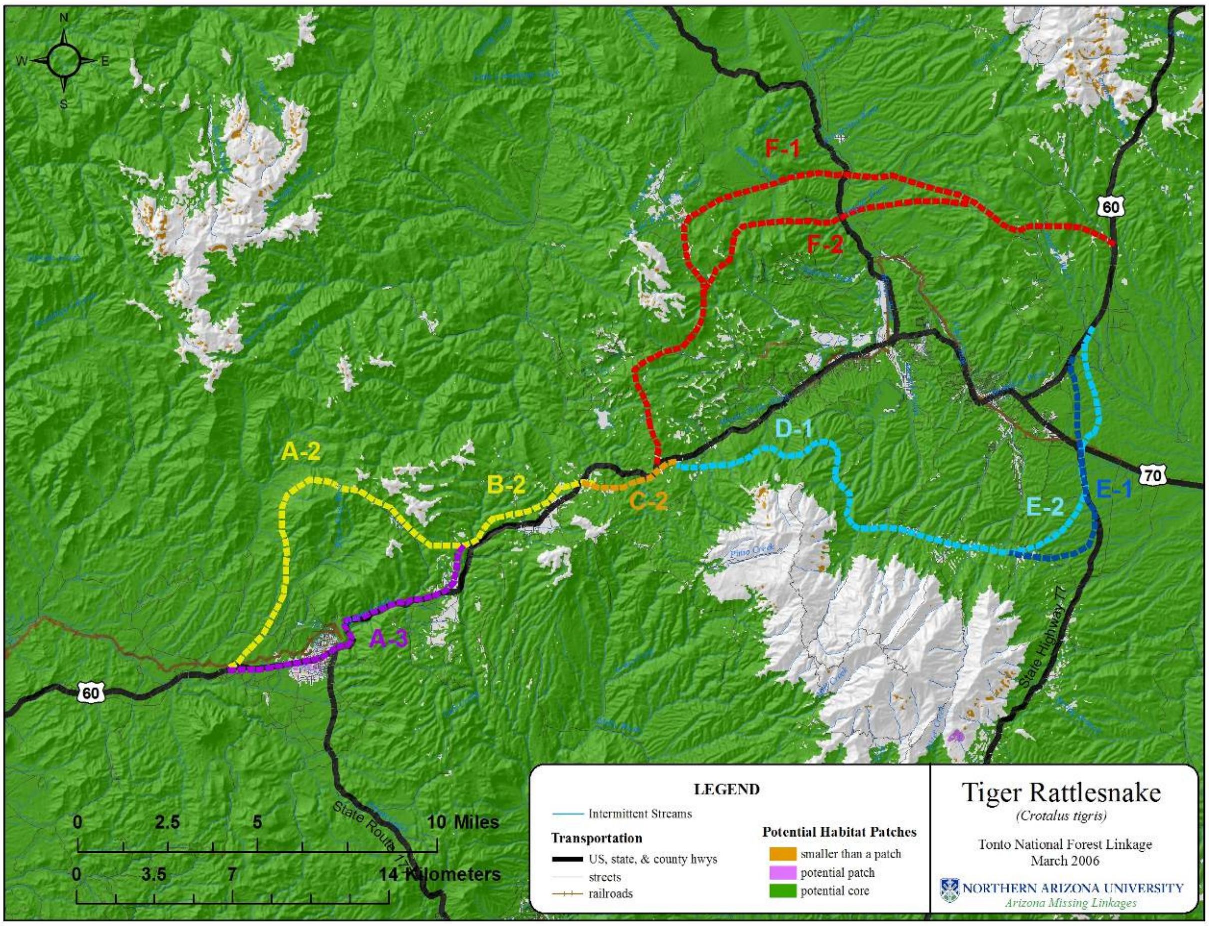

Figure 35: Potential habitat patches and cores for tiger rattlesnake.

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 (7 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.

Encinal (Oak Woodland) – Madrean Encinal occurs on foothills, canyons, bajadas and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, extending north intoTrans-Pecos Texas, southern New Mexico and sub-Mogollon Arizona. These woodlands are dominated by Madrean evergreen oaks along a low-slope transition below Madrean Pine-Oak Forest and Woodland and Madrean Pinyon-Juniper Woodland. Lower elevation stands are typically open woodlands or savannas where they transition into desert grasslands, chaparral or is some case desert scrub.

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

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

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

GRASSLANDS-HERBACEOUS (3 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 (14 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, Mixed Desert and Thorn Scrub – This widespread Chihuahuan Desert land cover type is composed of two ecological systems: the Chihuahuan Creosotebush Xeric Basin Desert Scrub and the Chihuahuan Mixed Desert and Thorn Scrub. This cover type includes xeric creosotebush basins and plains and the mixed desert scrub in the foothill transition zone above, sometimes extending up to the lower montane woodlands. Vegetation is characterized by *Larrea tridentata* alone or mixed with thornscrub and other desert scrub such as *Agave lechuguilla, Aloysia wrightii, Fouquieria splendens, Dasylirion leiophyllum, Flourensia cernua, Leucophyllum minus, Mimosa aculeaticarpa var. biuncifera, Mortonia scabrella (= Mortonia sempervirens ssp. scabrella), Opuntia engelmannii, Parthenium incanum, Prosopis glandulosa*, and *Tiquilia greggii*.

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

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

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

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

WOODY WETLAND (3 CLASSES) – Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

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

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

BARREN LANDS (10 CLASSES) – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulation of earthen material. Generally, vegetation accounts for less than 15% of total cover.

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

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

ALTERED OR DISTURBED (3 CLASSES) –

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

DEVELOPED AND AGRICULTURE (3 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.

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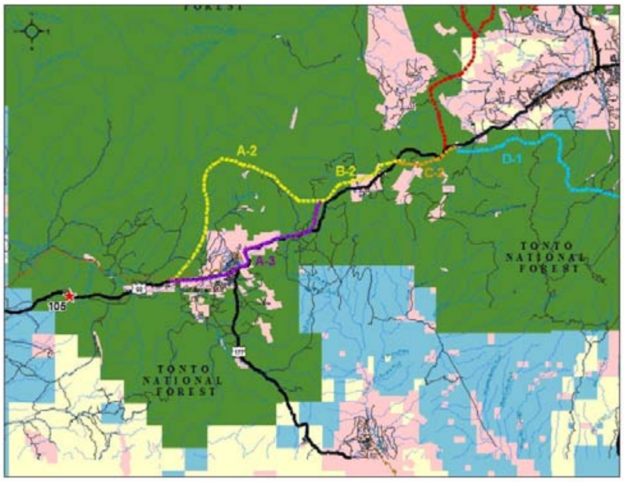
Appendix E: Database of Field Investigations

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 #:	66	**Waypoint #:**	105		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.2737499	**Longitude:**	-111.222864
Observers:	Paul Beier, Dan Majka	**UTM X:**	479245.4663	**UTM Y:**	3681657.697
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken from US60

Site Photographs

Name: DSCF0053.jpg

Azimuth: 24 **Zoom:** 1x

Notes: Mountains towards north

Name: DSCF0054.jpg

Azimuth: 100 **Zoom:** 1x

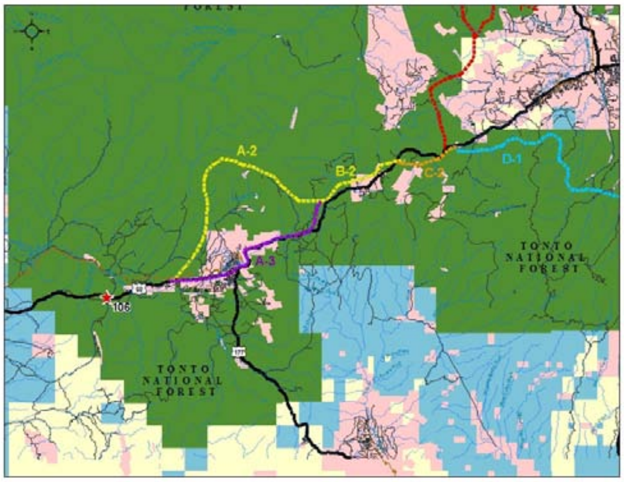
Notes: Picketpost Mtn.

Name: DSCF0055.jpg

Azimuth: 290 **Zoom:** 1x

Linkage #:	66	**Waypoint #:**	106		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.2726512	**Longitude:**	-111.194668
Observers:	Paul Beier, Dan Majka	**UTM X:**	481871.0946	**UTM Y:**	3681530.640
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken from US60

Site Photographs

Name: DSCF0056.jpg

Azimuth: 50 **Zoom:** 1x
Notes: Across Queen Creek Drainage

Name: DSCF0057.jpg

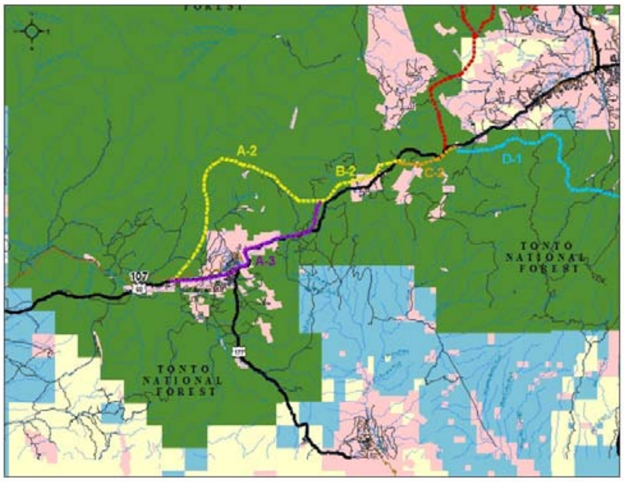
Azimuth: 96 **Zoom:** 1x
Notes: Picketpost Mtn.

Name: DSCF0058.jpg

Azimuth: 298 **Zoom:** 1x
Notes: US 60

Linkage #:	66	**Waypoint #:**	107		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.27915187	**Longitude:**	-111.172380
Observers:	Paul Beier, Dan Majka	**UTM X:**	483947.8574	**UTM Y:**	3682247.691
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken at Queen Creek/US60 junction

Site Photographs

Name: DSCF0059.jpg

Azimuth: 270 **Zoom:** 1x

Notes: US60 bridge over Queen Creek

Name: DSCF0060.jpg

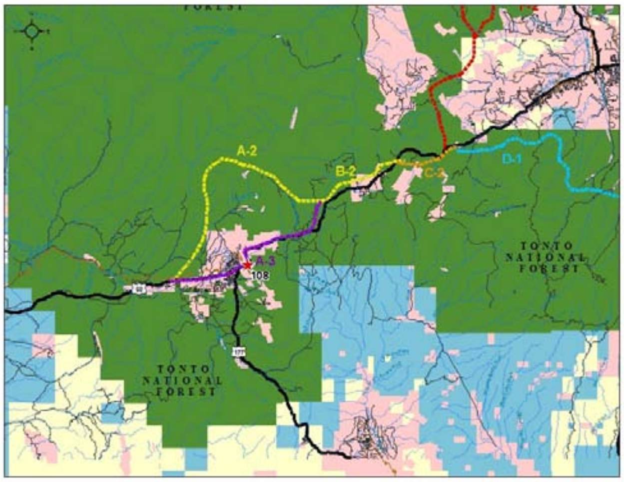
Azimuth: 90 **Zoom:** 1x

Notes: Upstream view of Queen Creek

Appendix E: Database of Field Investigations

Linkage #:	66	**Waypoint #:**	108		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.29352952	**Longitude:**	-111.088650
Observers:	Paul Beier, Dan Majka	**UTM X:**	491746.1967	**UTM Y:**	3683831.927
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Name: DSCF0067.jpg

Azimuth: 328 **Zoom:** 6x

Notes: US60 bridge, west of Superior

Name: DSCF0068.jpg

Notes: Old and new bridges.

Name: DSCF0069.jpg

Notes: Old and new bridges.

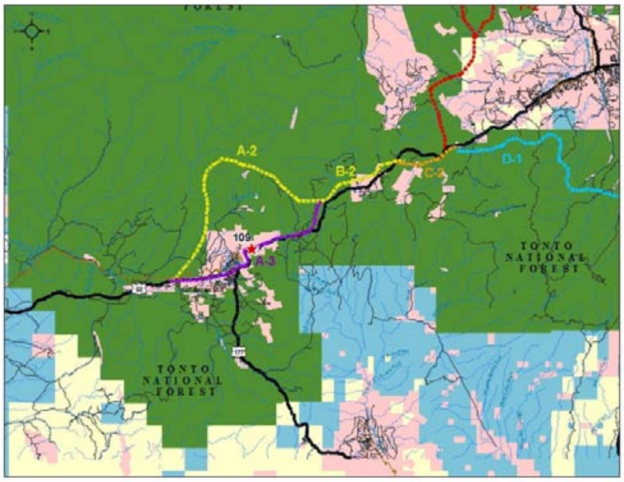
Name: DSCF0071.jpg

Azimuth: 258 **Zoom:** 1x

Notes: Town of Superior

Linkage #:	66	**Waypoint #:**	109		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.30367279	**Longitude:**	-111.08562
Observers:	Paul Beier, Dan Majka	**UTM X:**	492029.2889	**UTM Y:**	3684956.23
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken west of tunnel on US60

Site Photographs

Name: DSCF0072.jpg

Azimuth: 68 **Zoom:** 1x

Notes: US60 Tunnel / Potential bighorn sheep crossing.

Name: DSCF0073.jpg

Azimuth: 216 **Zoom:** 1x

Notes: US60 bridge

Name: DSCF0074.jpg

Azimuth: 276 **Zoom:** 1x

Notes: US60 runaway truck ramp

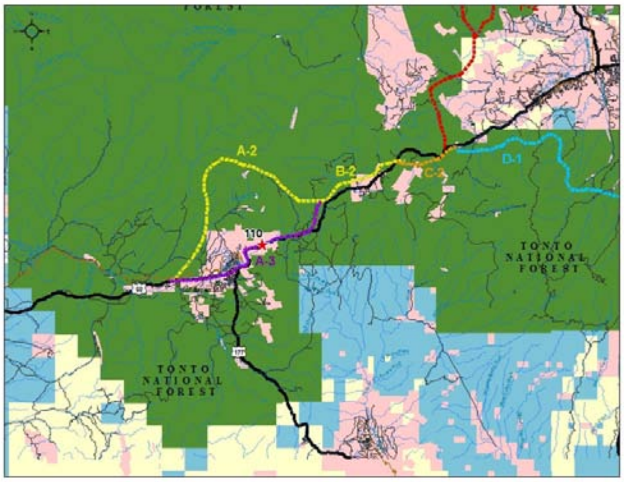
Name: DSCF0075.jpg

Azimuth: 104 **Zoom:** 1x

Notes: Canyon alongside US60

Linkage #:	66	**Waypoint #:**	110		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.30590833	**Longitude:**	-111.077768
Observers:	Paul Beier, Dan Majka	**UTM X:**	492760.3971	**UTM Y:**	3685203.502
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken avobe tunnel on US60.

Site Photographs

Name: DSCF0076.jpg

Azimuth: 220 **Zoom:** 1x

Notes: Downstream in Canyon

Name: DSCF0077.jpg

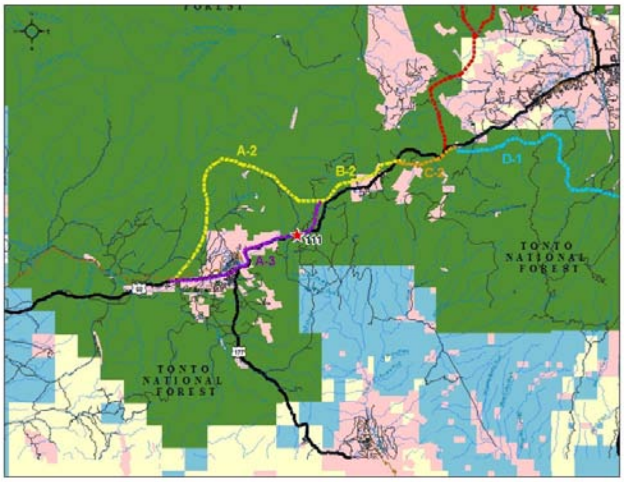
Azimuth: 72 **Zoom:** 1x

Notes: Upstream canyon

Appendix E: Database of Field Investigations

Linkage #:	66	**Waypoint #:**	111		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.31206123	**Longitude:**	-111.051826
Observers:	Paul Beier, Dan Majka	**UTM X:**	495175.7159	**UTM Y:**	3685884.147
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Name: DSCF0079.jpg

Azimuth: 180 **Zoom:** 1x
Notes: View south

Name: DSCF0080.jpg

Azimuth: 66 **Zoom:** 2x
Notes: View northeast

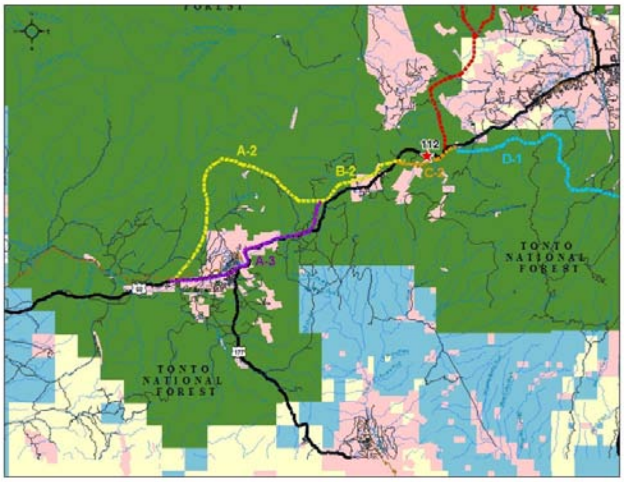
Name: DSCF0081.jpg

Azimuth: 262 **Zoom:** 1x
Notes: View west down US60.

Appendix E: Database of Field Investigations

Linkage #:	66	**Waypoint #:**	112		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.36219214	**Longitude:**	-110.954001
Observers:	Paul Beier, Dan Majka	**UTM X:**	504279.357	**UTM Y:**	3691441.713
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken off US60.

Site Photographs

Name: DSCF0082.jpg

Azimuth: 272 **Zoom:** 1x

Notes: Bridge on US60 / chapparal veg. association.

Name: DSCF0083.jpg

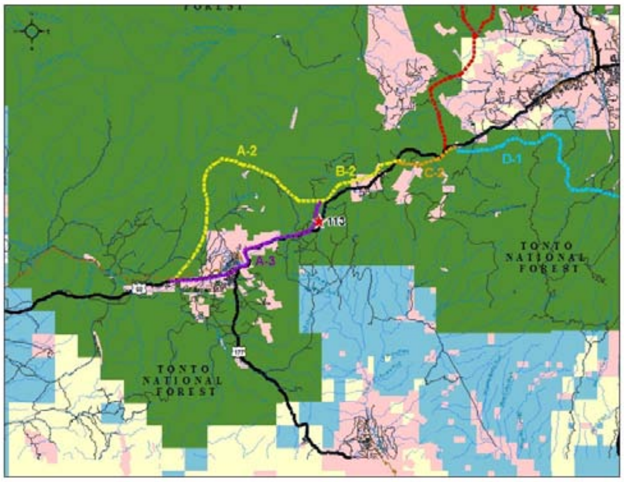
Azimuth: 148 **Zoom:** 1x

Notes: Chapparal veg. association

Appendix E: Database of Field Investigations

Linkage #:	66	**Waypoint #:**	113		
Linkage Zone:	Tonto National Forest	**Latitude:**	33.32091386	**Longitude:**	-111.035051
Observers:	Paul Beier, Dan Majka	**UTM X:**	496737.6154	**UTM Y:**	3686864.951
Field Study Date:	1/7/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Possible pipe below freeway for wash/drainage - could be expanded to bridge.

Site Photographs