ARIZONA MISSING LINKAGES

Galiuro – Pinaleño – Dos Cabezas Linkage Design

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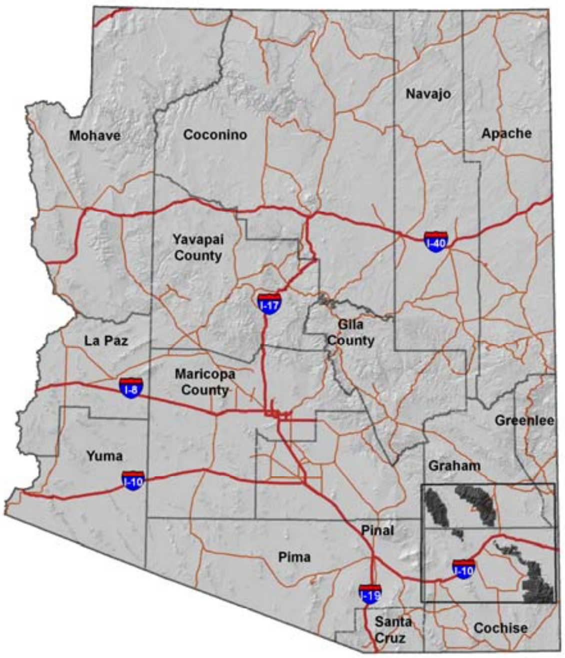
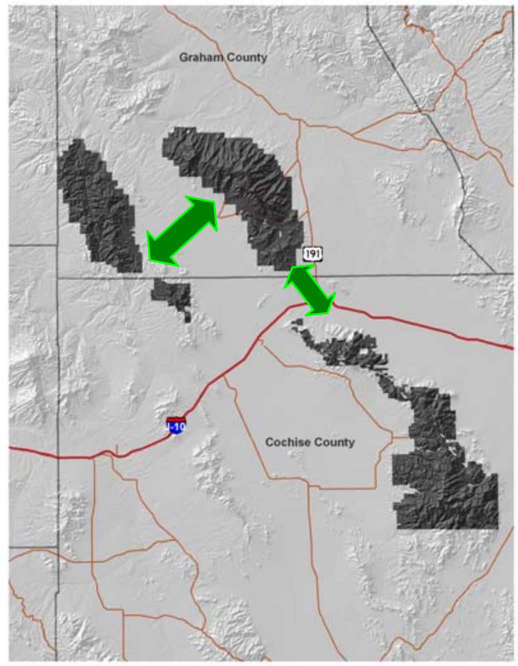
2008

GALIURO – PINALEÑO – DOS CABEZAS LINKAGE DESIGN





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Terminology

Key terminology used throughout the report includes:

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

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

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

Linkage planning area: Includes the wildland blocks and the potential linkage area. If the Linkage Design in this report is implemented, the biological diversity of the entire linkage planning area will be enhanced.

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

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

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

Travel Cost: Effect of habitat on a species' ability to move through an area, reflecting quality of food resources, suitable cover, and other resources. Our model assumes that habitat suitability is the best indicator of the cost of movement through the pixel.

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between three large wildland administered by the U.S. Forest Service and the Bureau of Land Management in southeastern Arizona. Interstate 10, other highways, urban development, and agriculture threaten to impede animal movement between the Galiuro and Pinaleño Mountains, and between the Pinaleño Mountains and the Dos Cabezas-Chiricahua Mountains. These wildlands represent a large public investment in biological diversity, and this Linkage Design is a reasonable science-based approach to maintain the value of that investment.

To begin the process of designing this linkage, we asked academic scientists, agency biologists, and conservation organizations to identify species sensitive to habitat loss and fragmentation. They identified 18 focal species, including 2 amphibians, 2 reptiles, 2 birds, and 12 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. mountain lion, jaguar). Some species are habitat specialists (e.g. pronghorn), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer). Some species are rare and/or endangered while others like javelina are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of Apache Highlands and Sonoran Desert. Together, these 18 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final Linkage Design (Figure 1, Figure 2) provides live-in or move-through habitat for each focal species. The resulting Linkage Design (Figure 1) is composed of two main linkages: the **Pinaleños-Galiuro Linkage** has two strands running 30-50 km, and the **Pinaleños-Dos Cabezas Linkage** has three strands 35-55 km in length. The 5 strands together provide habitat for movement and reproduction of wildlife between the Pinaleño Mountains and the Galiuros Mountains to the east and the Chiricahua Mountains to the south. The Linkage Design also includes recommendations to minimize the risk that publicly owned roads isolate reptile and amphibian populations conserved on private lands in Sulphur Springs Valley (Figure 2). We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

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

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

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

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

Table 1: Focal species selected for Galiuro - Pinaleños - Dos Cabezas Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
Bats	Ornate Box Turtle	Western Burrowing Owl
*Badger	Plains Leopard Frog	Sandhill Crane
*Black Bear	Texas Horned Lizard	
Black-tailed Prairie Dog	Chiricahua Leopard Frog	
*Bobcat		
*Jaguar		
*Javelina		
*Kit Fox		
*Mountain Lion		
*Mule Deer		
*Pronghorn		
*Wolf		

* Species modeled in this report. The other species were not modeled because there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), because the species does not occur in both wildland blocks, or because the species probably can travel (e.g., by flying) across unsuitable habitat. Although we did not develop corridor models for ornate box turtleor plains leopard frog, we made special recommendations for roads in Sulphur Springs Valley to promote connectivity for these species.

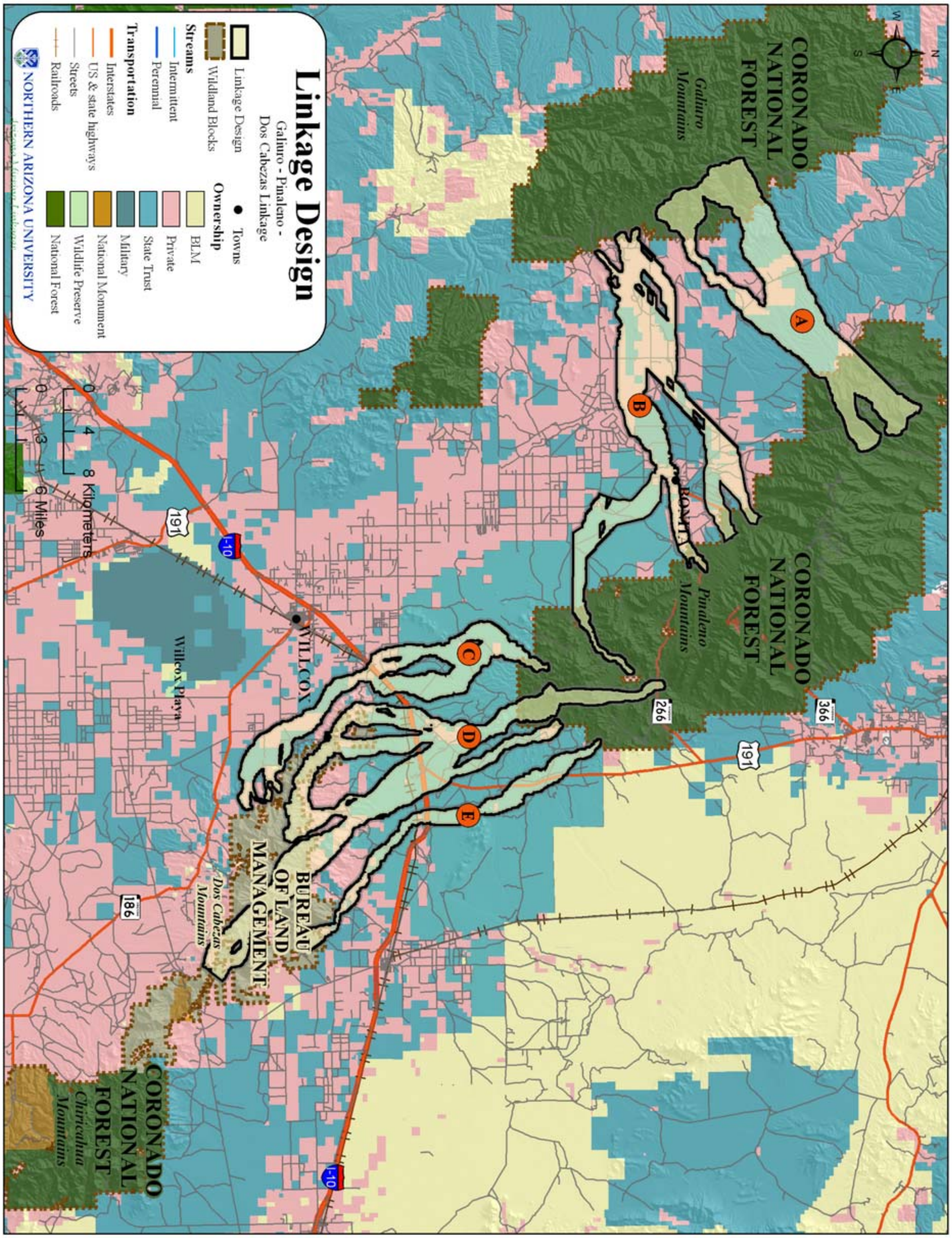

Figure 1: The Galiuro-Pinaleño Linkage Design contains two main strands, and the Pinaleño-Dos Cabezas Linkage Design contains three main strands. Multiple strands serve species with diverse habitat needs. The Linkage Design also calls for small culverts on roads in Sulphur Springs Valley (Figure 2).

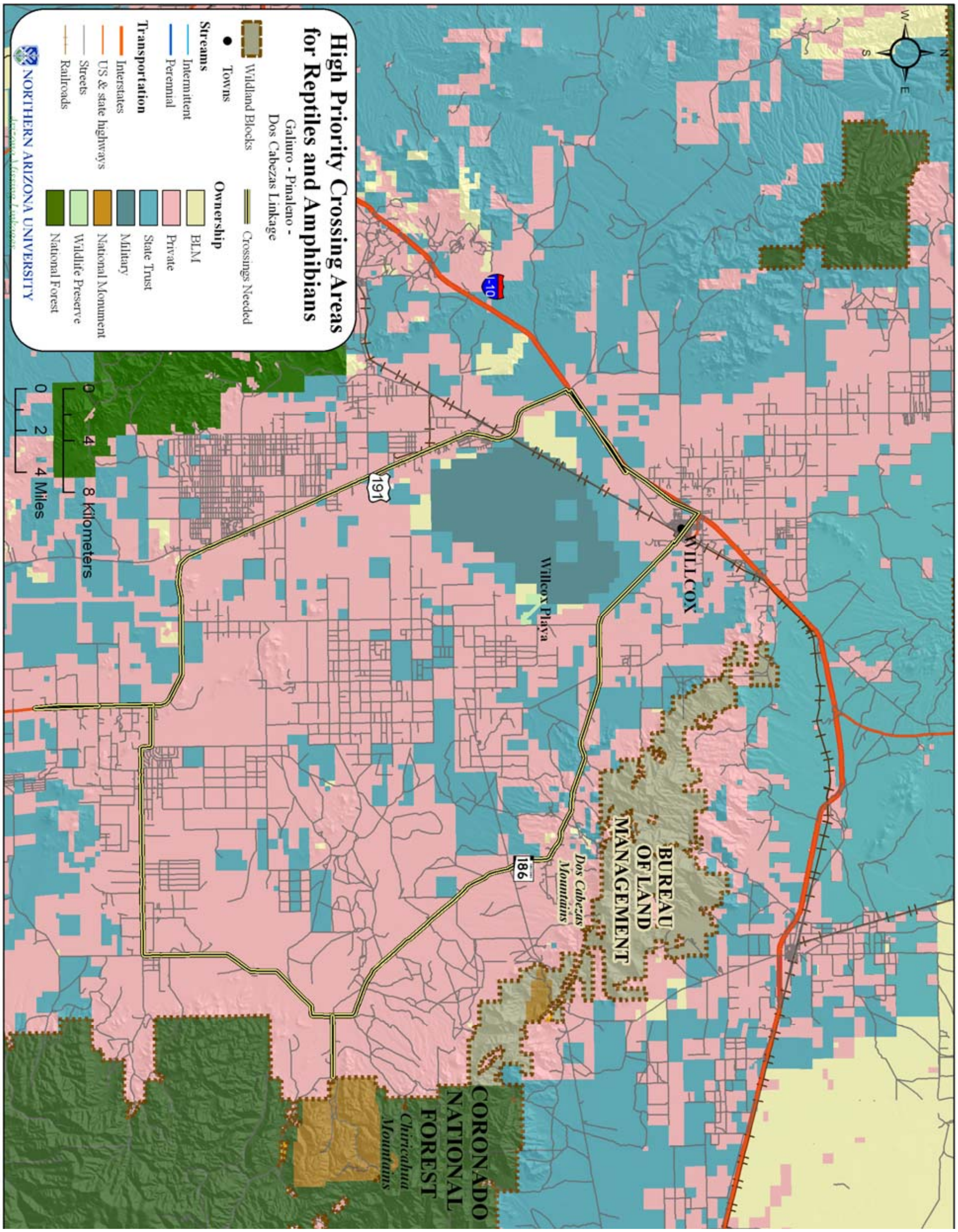

Figure 2. The Linkage Design calls for small culverts every 150 m along gray-green road segments (US-191, SR-186, SR-181) in Sulphur Springs Valley to prevent isolation and minimize mortality to reptile and amphibian populations there.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

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

Ecological Significance of the Galiuro-Pinaleño-Dos Cabezas Linkage

The Galiuro-Pinaleño-Dos Cabezas linkage planning area lies within Madrean Archipelago of southeastern Arizona. This ecoregion is a unique ecological zone lying south of the Rocky Mountains and north of the Sierra Madre Occidental. Natural communities here range from desert grasslands in the lowlands to coniferous forests in the higher elevations. The isolated mountain ranges separated by valleys are known as "sky islands." The linkage planning area includes three of these sky islands, separated by valleys, farmlands, highways, Interstate 10, and the town of Willcox.

The **Galiuro wildland block** consists of 152,778 protected acres of steep, rugged terrain administered mostly by the Coronado National Forest, with significant holdings by The Nature Conservancy and BLM in the southern Galiuro Mountains. This wildland block includes the Winchester Mountains, also managed by Coronado National Forest. Two wilderness areas (Figure 4) occur here: the 73,317-acre Galiuro Wilderness area in the Coronado National Forest, which reaches over 7,600 feet at Bassett Peak, and the contiguous 6,600-acre Redfield Canyon Wilderness managed by the Bureau of Land Management.

The **Pinaleño wildland block** consists of 198,144 protected acres of steep rocky slopes and rugged canyons. With elevations up to 10,700 feet on Mt Graham, this land supports coniferous forests and the endangered Mt Graham Red Squirrel, as well as oak and pine-oak forests and woodlands, and semi-desert grasslands.

The **Dos Cabezas wildland block** includes 245,900 acres in the BLM-administered Dos Cabezas Mountains and the adjacent Chiricahua Mountains which mostly within the Coronado National Forest. This block contains two wilderness areas, the 11,700-acre Dos Cabezas Mountains Wilderness, a rugged area with peaks above 7,000 feet, and the 87,700-acre Chiricahua Wilderness with 9,000-ft peaks and an extensive trail system. The Fort Bowie National Historic Site, managed by the National Park Service, protects Apache Pass, which links the Dos Cabezas Mountains in the north from the Chiricahua Mountains to the south. Another National Park unit is the Chiricahua National Monument, 12,000 acres of desert grassland and fantastic rock formations. This area is a unique ecological zone where the Sonoran Desert transitions to Chihuahuan Desert and the southern Rocky Mountains give way to the northern Sierra Madres. It contains several springs and streams important for wildlife.

The linkage planning area is dominated by semi-desert grasslands and desert scrub, with Sonoran desert and thornscrub vegetation to the west and Chihuahuan desert to the east. There are isolated patches of pine-oak woodlands. The broad grasslands of Sulphur Springs Valley separate the Gailuro Mountains from the Pinaleño Mountains and the Dos Cabezas. The Willcox Playa, a closed lake basin, lies in the south-central portion of the valley. The Willcox Playa Wildlife Area protects roughly 595 acres including 120 acres of deeded land, 320 acres of land patented from the Bureau of Land Management, a 115-acre perpetual right-of-way from the Arizona State Land Department, and a 40-acre donation from a private land owner. This playa is important wildlife habitat, especially for waterfowl and migratory birds. It attracts over 500 species of birds, including tens of thousands of Sandhill Cranes, and a similar number of tourists for an annual birding festival.

The Linkage Design incorporates and connects important habitat for threatened or endangered species such as jaguar and Mexican grey wolf. The linkage planning area is also home to far-ranging mammals such as mule deer, badger, and mountain lion. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species such as javelina 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.

Threats to Connectivity

Major potential barriers in the linkage area include Interstate 10, habitat degradation, and urban and agricultural development. Willcox serves as the major trade and service center for agriculture and tourism within Cochise County. It is also an important cattle center. Human activities including grazing, water diversion, mining, and fire suppression have altered the natural landscape. These barriers could inhibit wildlife movement between the Galiuro, Pinaleño, and Dos Cabezas wildland blocks.

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

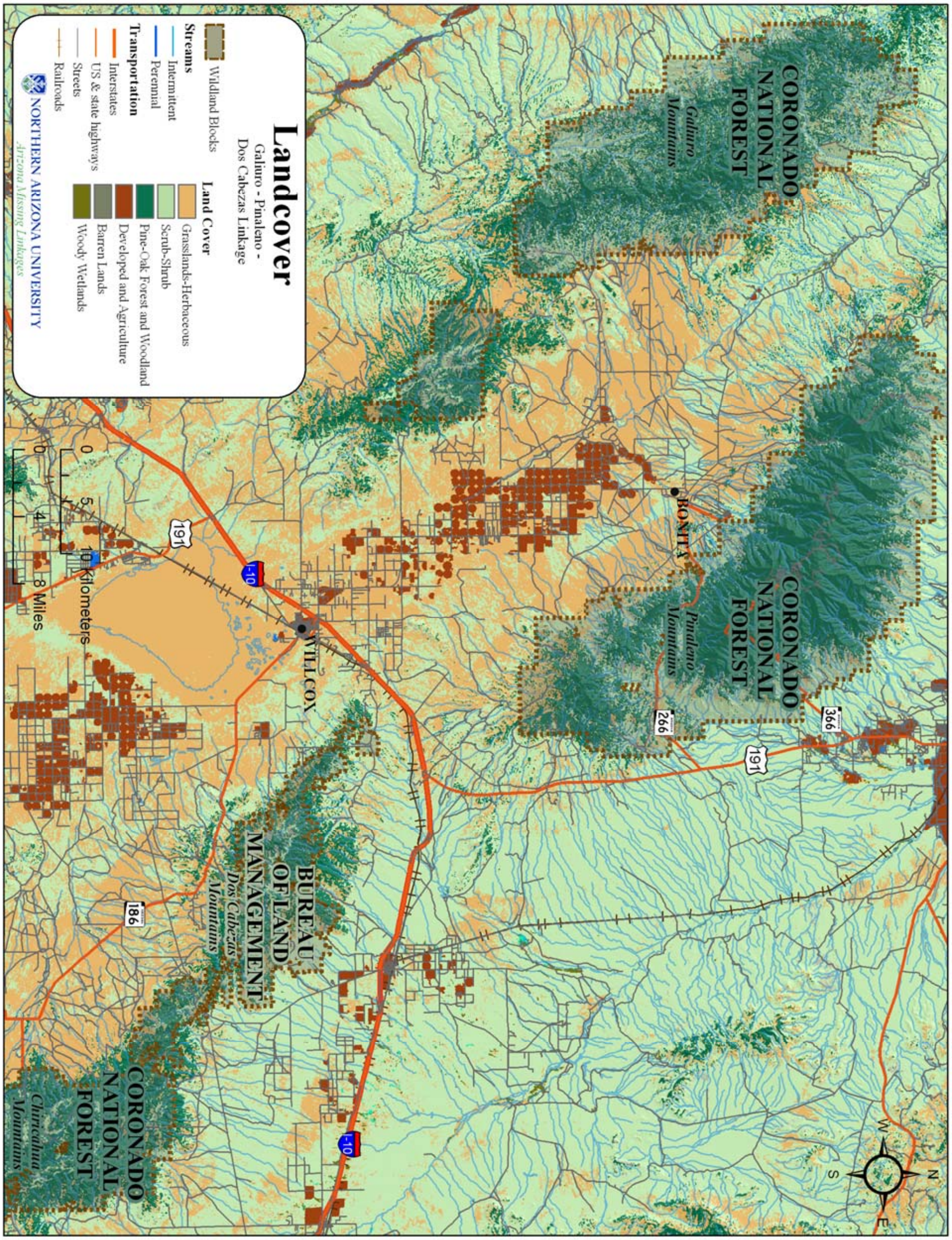

Figure 3: Land cover in the linkage planning area

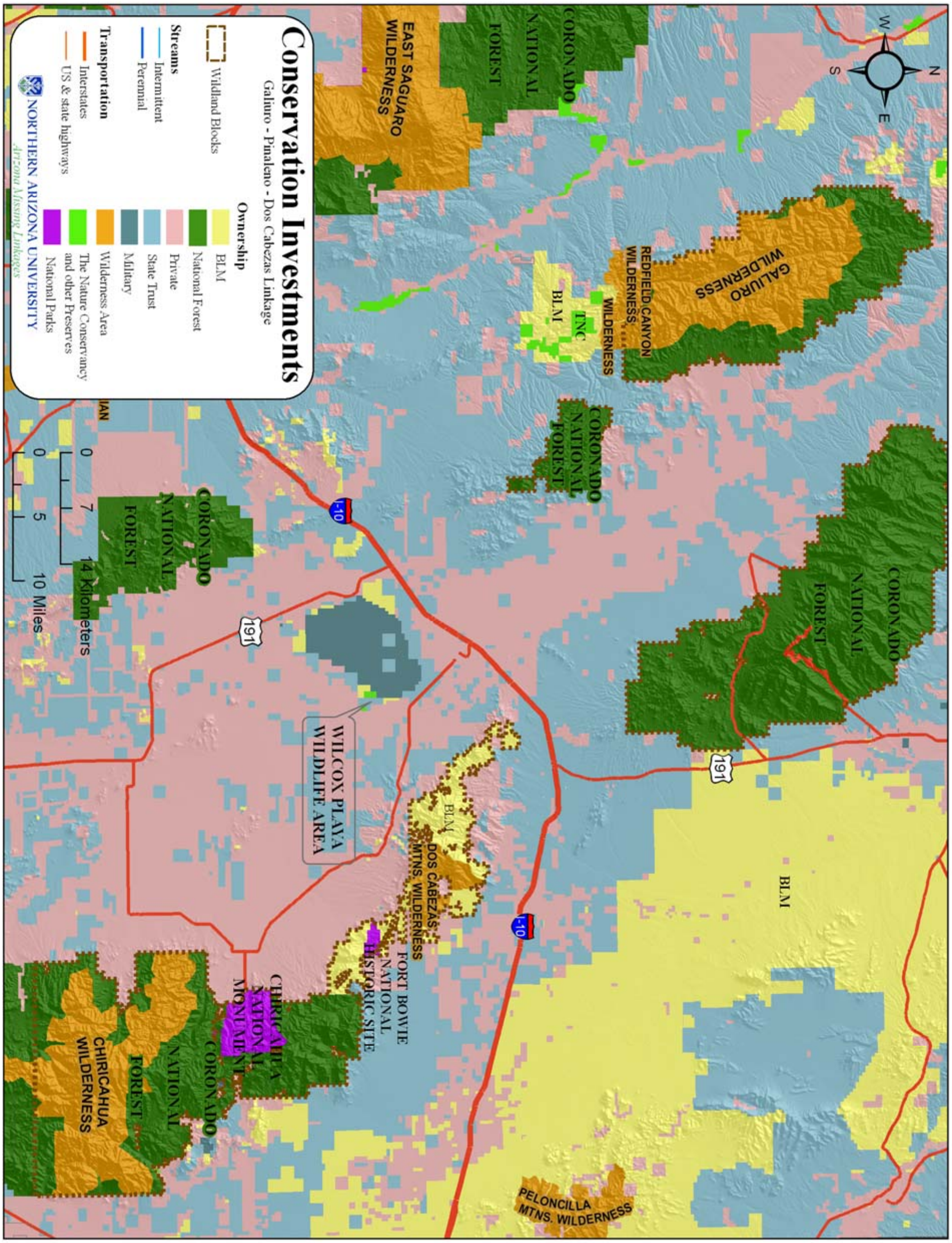

Figure 4: Existing conservation investments within the linkage planning area

Linkage Design & Recommendations

The Linkage Design[1] (Figure 1) is composed of two linkages, and a set of recommendations to minimize roadkill impacts on reptiles and amphibians conserved on private lands in Sulphur Springs Valley. In this section, we describe the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Two Linkages Provide Connectivity Across a Diverse Landscape

LINKAGE DESIGN GOALS
• Provide move-through habitat for diverse group of species • Provide live-in habitat for species with dispersal distances too short to traverse linkage in one lifetime • Provide adequate area for a metapopulation of corridor-dwelling species to move through the landscape over multiple generations • Provide a buffer protecting aquatic habitats from pollutants • Buffer against edge effects such as pets, lighting, noise, nest predation & parasitism, and invasive species • Allow animals and plants to move in response to climate change

The linkage design consists of two linkages, one connecting the Galiuro Mountains to the Pinaleño Mountains, and the other connecting the Pinaleños to the Dos Cabezas Mountains.

The **Pinaleños-Galiuro Linkage** has two strands. Strand A is made up of the best biological corridors for black bear, bobcat, jaguar, wolf, and mountain lion. About 31 km long, it encompasses much of the Black Hills and spans upper Aravaipa Canyon. The landcover in this strand is a mixture of Scrub-Shrub (42%), Evergreen Forest (42%), and Grassland-Herbaceous (13.5%). The rugged terrain has an average slope of 26% (Range: 0-85%, SD: 7.9). While 48% of the land was identified as steep slopes, almost 30% is composed of flat to gentle slopes.

Strand B provides habitat for badger, javelina, kit fox, mule deer, and pronghorn. It runs from the Galiuro Mountains across the Ash Creek Black Hills. East of there, it forks into 4 branches, each of which is important to different species. The longest branch stretches approximately 49 km. It is dominated by Grassland-Herbaceous vegetation (73%) and Scrub-Shrub (23%). Terrain is mostly gentle with an average slope of 3% (Range: 0-76%, SD: 5.1) and 96% of the strand is classified as flat to gentle slopes.

The **Pinaleños-Dos Cabezas Linkage** has three strands. About 36 km long, strand C provides habitat for badger and pronghorn. Its landcover is dominated by Grassland-Herbaceous (54%), and Scrub-Shrub (43%) vegetation. Average slope is 6% (Range: 0-79%, SD: 7.3) and 88% of the strand is classified as flat to gentle slopes, while 10% was classified as steep slopes.

Strand D provides habitat for black bear, bobcat, jaguar, javelina, wolf, mountain lion, and mule deer. This strand is made up of many branches, each of which provides habitat for different species. The longest branch stretches approximately 53 km. The dominant landcover types are Evergreen Forest (40%), Grassland-Herbaceous (23%), and Scrub-Shrub (36%). The variable topography has an average slope of 22% (Range: 0-98%, SD: 19.2). It has roughly as much flat to gentle slopes (41%) as steep slopes (40%).

[1] The reader will note that the strands of the linkage design extend well into each wildland block. As explained in Appendix A, for modeling purposes we had to redefine the wildland blocks such that the facing edges were parallel lines about 15 km apart.

The 35-km Strand E provides habitat for kit fox and is dominated by Scrub-Shrub (78%) and Grassland-Herbaceous (19%) vegetation. This strand has an average slope of 6% (Range: 0-85%, SD: 7.9) and 87% of the strand has a slope of less than or equal to 6%.

Special consideration for reptiles and amphibians in Sulphur Valley. Some of the reptiles and amphibians proposed as focal species find most of their habitat in the private and ASLD land in Sulphur Valley, rather than in the publicly-owned wildland blocks. This distribution precluded corridor modeling (which requires a clearly defined terminus at each end). However, to reduce the impact of roads on these species, we recommend regularly-spaced, soft-bottom culverts on paved roads throughout Sulphur Springs Valley (Figure 2).

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

The Linkage Design encompasses 165,391acres (66,931 ha), of which 47% is state trust land, 28% privately owned, 17% in Coronado National Forest, and 8% managed by the Bureau of Land Management (Figure 5).The linkage design supports six natural vegetation communities (Figure 6), with developed land accounting for less than 1% of the linkage design. Natural vegetation is dominated by desert Scrub-Shrub associations and Grassland-Herbaceous vegetation.

The Linkage Design captured a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, 62% of the land is classified as gentle slopes, 26.5% is classified as steep slopes, with nearly equal parts canyon bottom (6%)or ridgetop (6%)(Figure 7). More land in the linkage had southern aspects than northern aspects (Figure 7).

Table 2: Approximate land cover in Linkage Design. See text for land cover in each of the five strands of the Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (< 0.1%)			
Pinyon-Juniper Woodland	44	18	< 0.1%
Scrub-Shrub (98%)			
Creosotebush-White Bursage Desert Scrub	12326	4988	13.7%
Desert Scrub (misc)	4739	1918	5.3%
Mesquite Upland Scrub	958	388	1.1%
Paloverde-Mixed Cacti Desert Scrub	69891	28284	77.9%
Woody Wetland (0.9%)			
Riparian Mesquite Bosque	540	219	0.6%
Riparian Woodland and Shrubland	288	116	0.3%
Barren Lands (0.1%)			
Non-specific Barren Lands	131	53	0.1%
Developed and Agriculture (0.9%)			
Open Space-Low Intensity Developed	662	268	0.7%
Medium-High Intensity Developed	152	61	0.2%

Removing and Mitigating Barriers to Movement

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

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

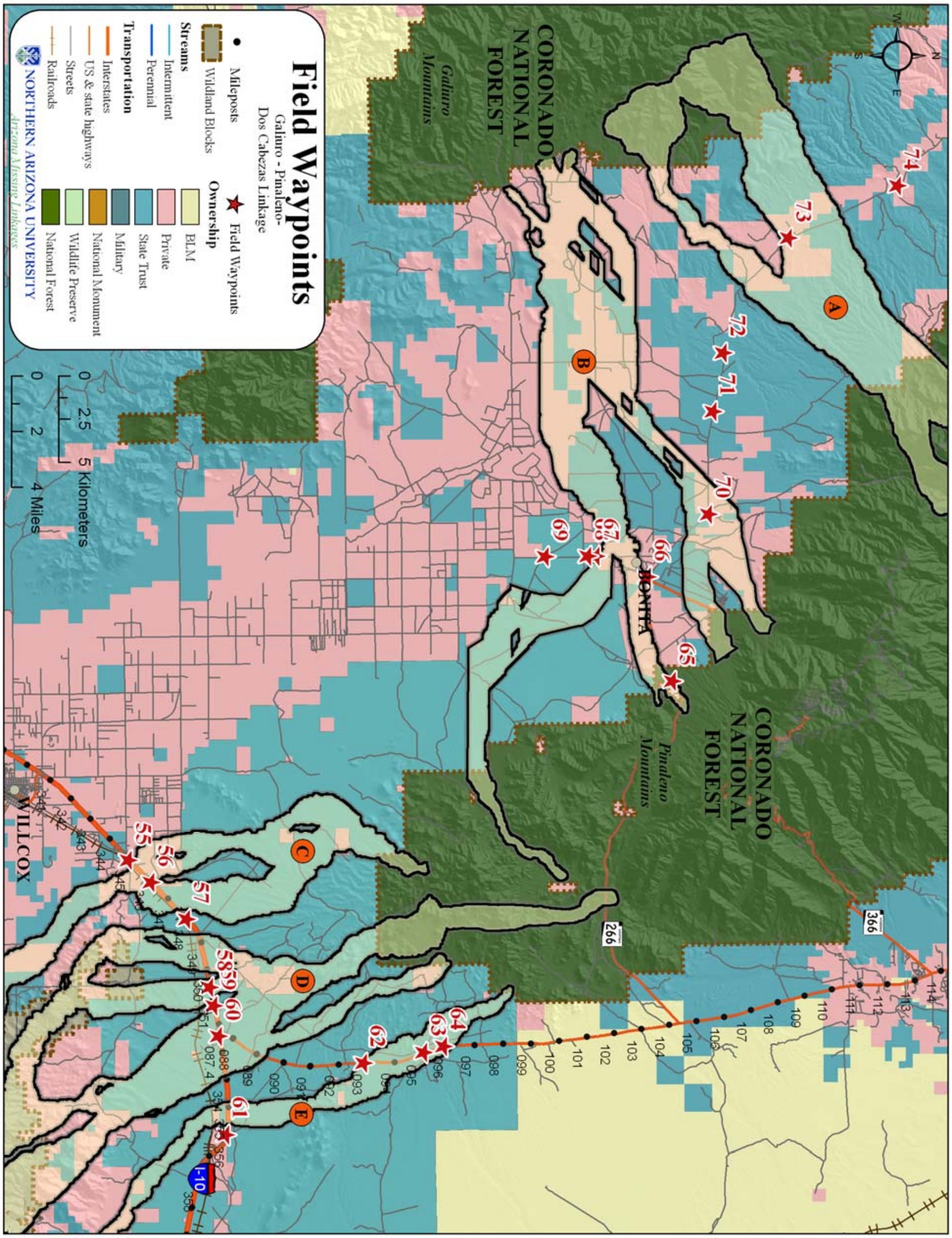

Figure 5: Property ownership and field investigation waypoints within Linkage Design, the accompanying CD-ROM includes photographs taken at most waypoints

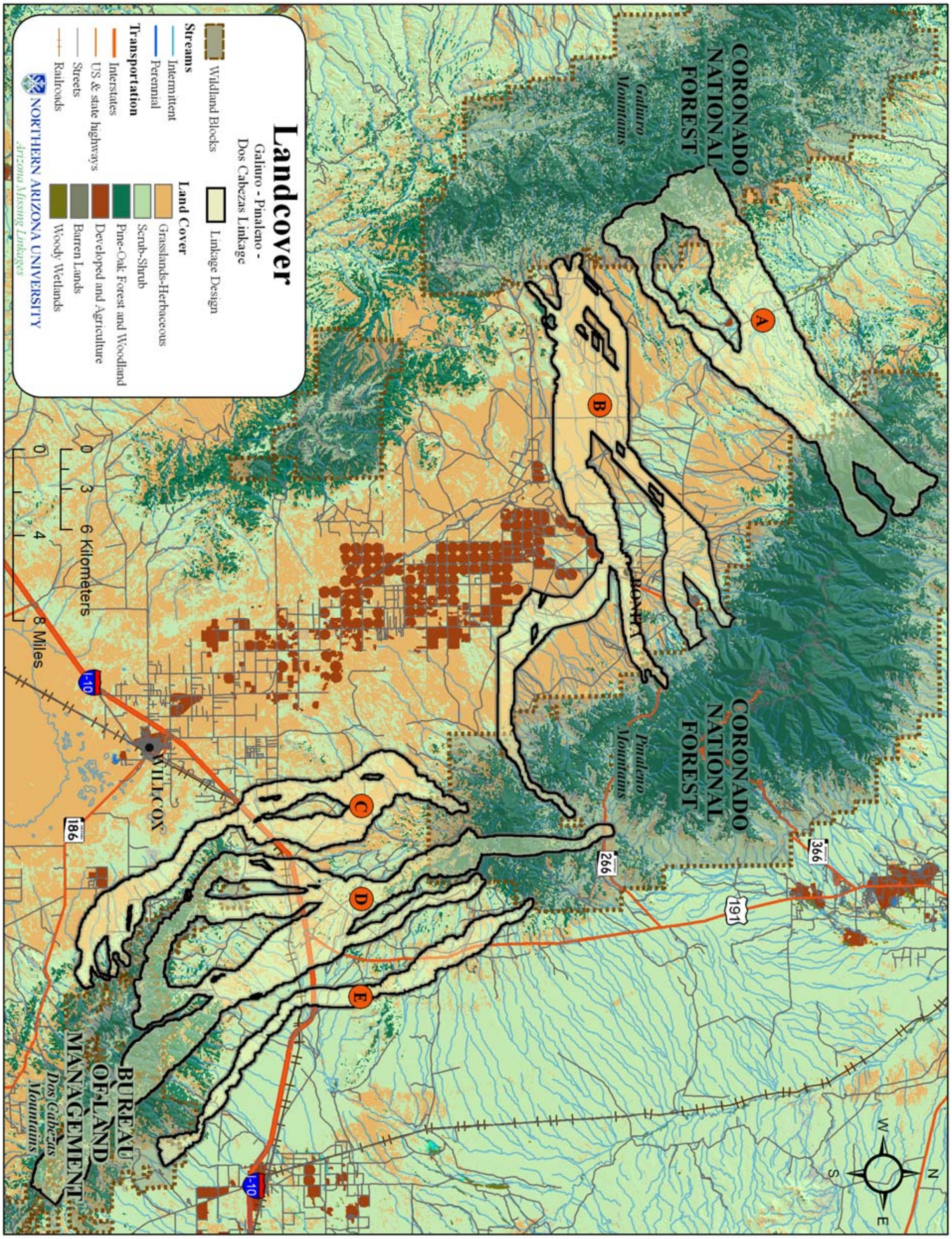

Figure 6: Land cover in the Linkage Design.

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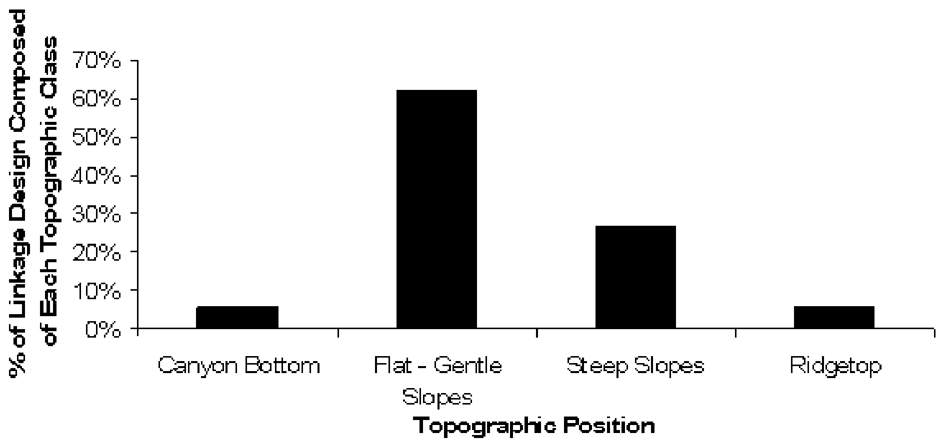

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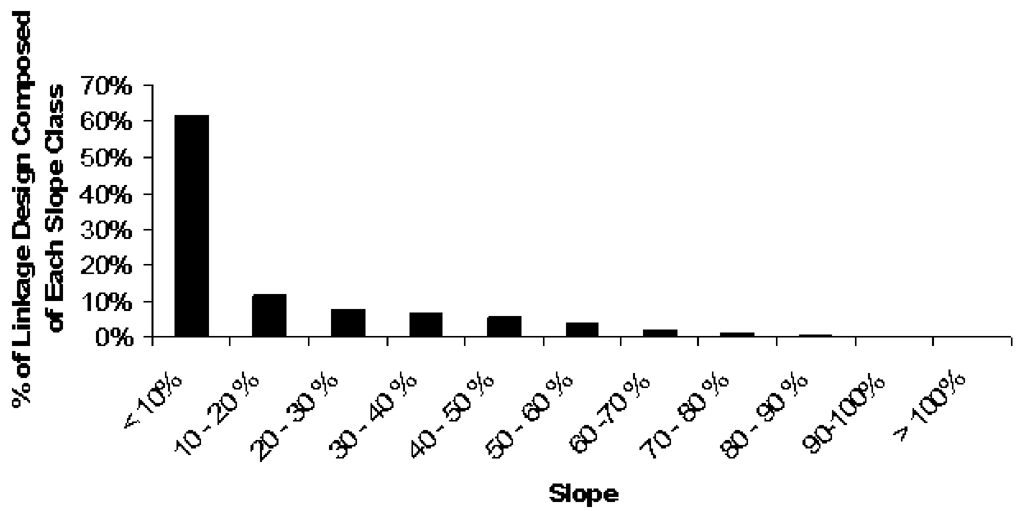

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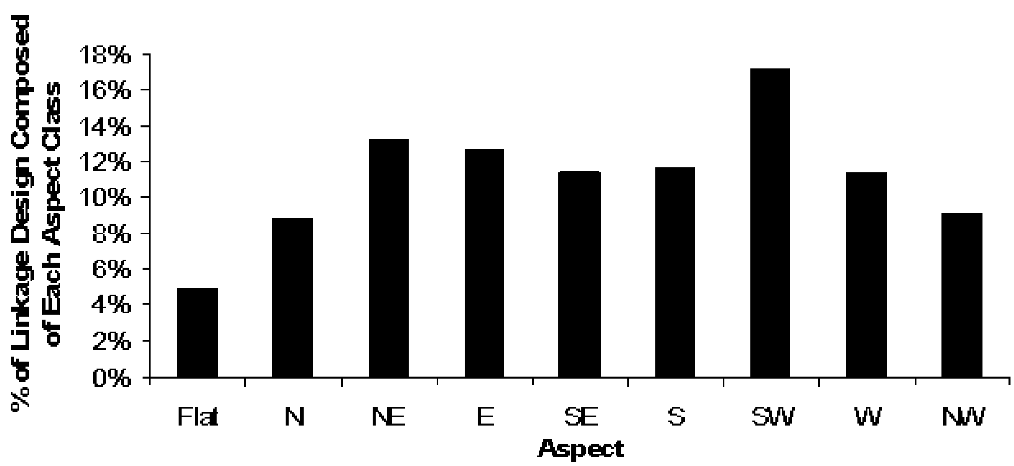

Figure 7: Topographic diversity encompassed by the Linkage Design: a) Topographic position, b) Slope, c) Aspect

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

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

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

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

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

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

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate drainage beneath highways. For ungulates such as deer that prefer open crossing structures, tall, wide bridges are best. Mule deer in southern California only used underpasses below large spanning bridges (Ng et al. 2004), and the average size of underpasses used by white-tailed deer in Pennsylvania was 15 ft wide by 8 ft high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures have increased connectivity for smaller species crossing bridges on floodplains (Forman et al. 2003). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). A bridge is a road supported on piers or abutments above a watercourse, while a culvert is one or more round or rectangular tubes under a road. The most important difference is that the streambed under a bridge is mostly native rock and soil (instead of concrete or corrugated metal in a culvert) and the area under the bridge is large enough that a semblance of a natural stream channel returns a few years after construction. Even when rip-rap or other scour protection is installed to protect bridge piers or abutments, stream morphology and hydrology usually return to near-natural conditions in bridged streams, and vegetation often grows under bridges. In contrast, vegetation does not grow inside a culvert, and hydrology and stream morphology are permanently altered not only within the culvert, but for some distance upstream and downstream from it.

Despite their disadvantages, well-designed and located culverts can mitigate the effects of busy roads 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. Some cases located in fill dirt have openings far above the natural stream bottom. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

Figure 8: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

Based on the small but increasing number of scientific studies on wildlife use of highway crossing structures, we offer these standards and guidelines for *all* existing and future crossing structures intended to facilitate wildlife passage across highways, railroads, and canals.

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

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

6) **Fencing should never block entrances to crossing structures, and instead should direct animals towards crossing structures** (Yanes et al. 1995). In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in roadkill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Fences, guard rails, and

embankments at least 2 m high discourage animals from crossing roads (Barnum 2003; Cain et al. 2003; Malo et al. 2004). One-way ramps on roadside fencing can allow an animal to escape if it is trapped on a road (Forman et al. 2003).

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

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

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

10) **Crossing structures for pronghorn must have high openness ratio, at-grade location, and special fencing.** Wildlife overpasses are the best design for pronghorn. If an underpass must be used, Sawyer and Rudd (2005) recommend underpasses for pronghorn should have natural substrate, minimum height of 18 ft and minimum width of 60 feet. For a typical 4-lane highway this corresponds to an openness ratio (opening length x opening width/ width of road) of about 7 or more. Because pronghorn prefer gentle topography, crossings structures should be at the grade of the surrounding terrain; thus the roadway should be either elevated (to provide a wildife underpass) as in Figure 8, row 2 left, or (better yet) built into a trench (to provide an at-grade wildlife overpass (Sawyer and Rudd 2005) as in Figure 8, top row. Pronghorn have been known to walk across bridges to cross streams and rivers (H. Sawyer, WEST, Inc., unpublished data). Highway fencing should be as far as possible from the right-of-way (AGFD 2006a). Near crossing structures, woven wire fencing can help funnel pronghorn to the structure. If a fence is intended to be permeable to pronghorn (e.g., to allow pronghorn to escape the right of way, or where suitable crossing structures are not available), use wire strands for roadside fencing, with a smooth bottom wire >18" above the ground (Yoakum 2004).

Existing Roads in the Linkage Design Area

There are about 366.3 km (227.6 mi) of roads and railroads in the Linkage Design, including 11.3 km (7.0 mi) of the Union Pacific Railroad, 12.0 km (7.5 mi) of Interstate, and 14.5 km (9.0 mi) of other highways (Table 4). The other roads are local roads, many of them unpaved local roads. Traffic volumes are light on all roads except I-10, which provides the only significant barrier to animal movement. US-191, SR-186, and SR-181 already cause significant mortality to reptiles and amphibians, and could become serious barriers as traffic volumes increase. Presently, a person could take a nap on SR-266, SR-366, or Klondyke Road without much risk, but if a new highway were built into upper Aravaipa or upper Sulphur Springs Valley, massive urbanization and increased traffic on all roads would follow rapidly.

Table 4: Roads in the Linkage Design

Transportation routes in the Pinaleno-Dos Cabezas Linkage		
ROAD NAME	**KILOMETERS**	**MILES**
State Route 266	0.9	0.6
United States Highway 191	7.7	4.8
I-10	12.0	7.5
Page Ranch	10.1	6.3
Monk Ranch	3.0	1.9
Sidewinder	1.3	0.8
Moonlight	1.2	0.8
Saddle	1.2	0.8
Eagle's Peak	1.1	0.7
Old Bowie	0.8	0.5
Guadalupe	0.6	0.4
Sheppard	0.6	0.3
Red Tail Ranch	0.5	0.3
Silver	0.5	0.3
Howling Wolf	0.5	0.3
Johnson Saddle	0.3	0.2
Unnamed	124.2	77.2
Union Pacific Railroad	11.3	7.0
Total	177.7	110.4

Transportation routes in the Galiuro-Pinaleno Linkage		
ROAD NAME	**KILOMETERS**	**MILES**
State Route 266	5.9	3.7
Bonita Aravaipa	9.2	5.7
High Creek	8.9	5.5
Hurricane Pass	4.7	2.9
West Peak Hurricane Pass	4.0	2.5
Wells Ranch	3.3	2.1
Sunset Loop	2.7	1.7
Fort Grant	2.4	1.5
Brewster	1.9	1.2
Crossroads	1.8	1.1
Bonita	1.2	0.8
Obaro Ranch	0.6	0.4
Hooker	0.6	0.3
Unnamed	141.3	87.8
Total	188.5	117.2

Existing Crossing Structures in the Linkage Design

Along the interstates and highways within the linkage design, we found 5 crossing structures:

- An 8x10 foot box culvert along Interstate 10 at Milepost 351, Waypoint 59 (Figure 9)
- A 3-box culvert along US 191 at Milepost 95, Waypoint 63 (Figure 10)
- A 4-box culvert along US 191at Milepost 96, Waypoint 64 (Figure 11)
- A large bridge along SR 266 at the junction with Klondike Rd, Waypoint 66 (Figure 12)

Recommendations for Highway Crossing Structures

The existing crossing structures are not adequate to serve the movement needs of wildlife. Although the other highways and roads have such low traffic volume that they do not impede animal movement today, all roads should have bridges and culverts to allow safe animal passage under future traffic scenarios. In particular, some alignments of the proposed 100-mile I-10 bypass of Tucson would pass through the Galiuro-Pinaleno linkage. If such a freeway is built, it would induce urbanization of provate lands; the combination of the bypass and new development would likely increase traffic volumes on all local roads by a factor of 100 or more. Because animals moving between the Pinaleño and Dos Cabezas wildland blocks must cross both Interstate 10 and the Union Pacific Railroad, crossing structures are crucial to success of that linkage. We recommend crossing structures as follows:

- There should be at least one bridged crossing on Interstate 10 in each sub-strand within strands C, D and E, to accommodate larger mammals including mule deer and pronghorn. These should be aligned with crossing structures on the parallel railroad tracks. At least 7 bridged crossings are needed.

- Where US 191 intersects strands D and E, we recommend bridged crossing structures to accommodate larger mammals including mule deer.

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

Figure 9: An 8x10' box culvert under I-10 at Milepost 351, Waypoint 59

Figure 10: A 3-box culvert under US 191 at Milepost 95, Waypoint 63

Figure 11: A 4-box culvert under US 191 at Milepost 96, Waypoint 64

Figure 12: A large bridge along SR 266 near the junction with Klondike Rd, Waypoint 66

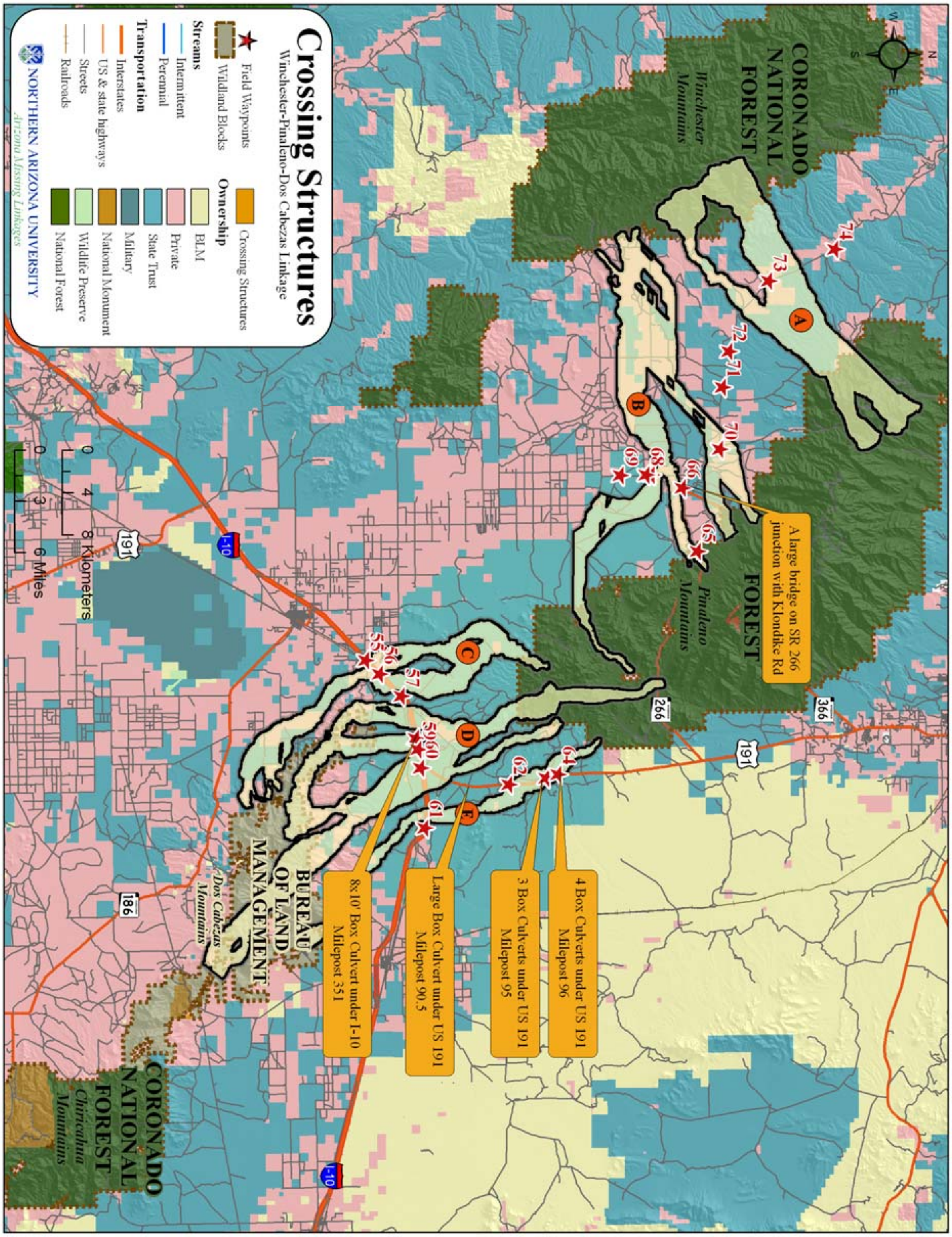

Figure 13: Existing crossing structures in the Linkage Design

Additional Road Crossing Structures Needed to Avoid Isolation of Reptile and Amphibian Populations Not Served by the Two Linkages

The linkage design emphasizes connecting large blocks of publicly owned wildlands. However, some important populations of reptiles and amphibians occur within the Sulphur Springs Valley, mostly on private land. The plains leopard frog and ornate box turtle (Table 1, Appendix B) are two focal species that find important habitat on the valley floor but not in the wildland blocks. Paved roads – both freeways and 2-lane roads – kill many reptiles and amphibians in this area, and threaten to isolate populations and prevent them from shifting their range during climate change. Recognizing that farmers, other private landowners, and ASLD are conserving these species on their private land and leased state land, we provide these recommendations to minimize the risk that publicly-built roads will isolate these populations. There are no appropriate crossing structures to accommodate the movement among these subpopulations.

The gray-green roads in Figure 2 cross through flat valley bottoms and bajadas that provide the best habitat for ornate box turtles, plains leopard frogs, and other reptiles and amphibians. In these areas, we recommend one box or pipe culvert every 150 m. Each culvert should be about 1 foot high, with natural vegetation near each culvert opening, and no pour-off or lip. Wing fencing about 2 feet high should guide animals toward the openings and away from the road. Although mammals may learn to use culverts and communicate their knowledge to others, reptiles and amphibians probably find culverts only by chance encounters. Thus a short interval between culverts, and wing fencing, are crucial to ensure utility of the structures. Material can be concrete or metal. Sand can be allowed to accumulate in some culverts, but the design should not allow the culvert to be blocked with sediment or debris. Except during runoff events, the culverts should not contain standing water.

Specific road segments important for reptiles and amphibians in Sulphur Valley include (Figure 1):

- I-10 from Willcox to 1 mile west of the interchange with US-191.
- US-191 from Sunizona to I-10. Phil Rosen reports that this area once had large numbers of roadkilled box turtles, and that past mortality has probably reduced the population to the point that roadkill is now lower.
- SR-181 from Sunizona to Chiricahua National Monument. Phil Rosen reports this is an area of high mortality for box turtles and other reptiles.
- SR-186 from its terminus at SR-181 to the city of Willcox. This is another area of high reptile mortality.
- Any new paved roads in Sulphur Springs Valley should similarly provide frequent undercrossings for reptiles and amphibians.

Urban Development as Barriers to Movement

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

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure 14). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling

unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

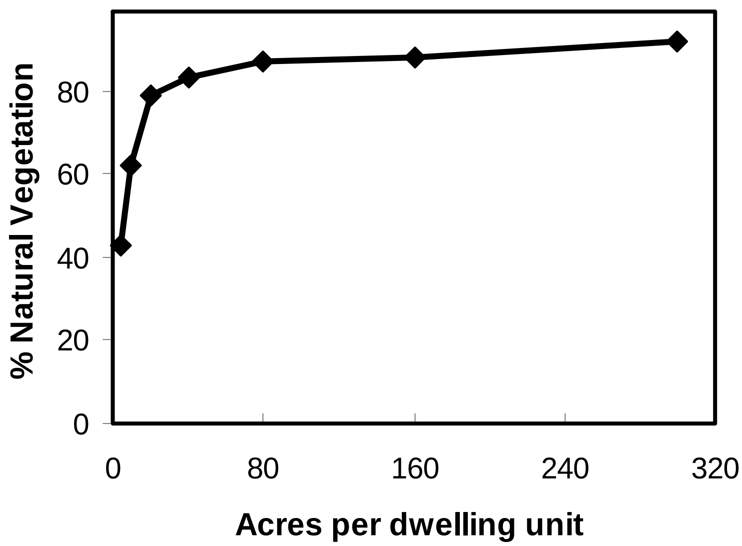

Figure 14: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres.

- decreased abundance and diversity of native species, and replacement by non-native species. In Arizona, these trends were evident for birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001), and loss of native species increased as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.
- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized "suburban native predators" such as raccoons, foxes, and crows, that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).

- mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).
- artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas currently accounts for less than 1% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Mitigation for Urban Barriers

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

1) Integrate this Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design.
2) Where development is permitted within the linkage design, encourage small building footprints on large (> 40 acre) parcels with a minimal road network.
3) Integrate this Linkage Design into county general plans, and conservation plans of governments and nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as recreation and protection of water quality.
6) One reason we imposed a minimum width on each strand of the linkage design was to allow enough room for a designated trail system without having to compromise the permeability of the linkage for wildlife. Nonetheless, because of the high potential for human access, the trail system should be carefully planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by

mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.

7) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area.
8) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.
9) Develop a public education campaign to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.
10) Discourage residents and visitors from feeding or providing water for wild mammals, or otherwise allowing wildlife to lose their fear of people.
11) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.
12) Do not install artificial night lighting on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
13) Encourage the use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.
14) Discourage the killing of ‘threat’ species such as rattlesnakes.
15) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.
16) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.

Appendix A: Linkage Design Methods

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

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[2]. By carefully selecting a diverse group of focal species and capturing a range of topography to accommodate climate change, the Linkage Design should ensure the long-term viability of all species in the protected areas. Our approach included six steps:

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

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 17 species (Table 1) that had one or more of the following characteristics:

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

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

[2] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute "truth" but rather an estimate or prediction of the optimal wildlife corridor. Despite this limitation, there are several reasons to use models instead of maps hand-drawn by species experts or other intuitive approaches. (1) Developing the model forces important assumptions into the open. (2) Using the model makes us explicitly deal with interactions (e.g., between species movement mobility and corridor length) that might otherwise be ignored. (3) The model is transparent, with every algorithm and model parameter available for anyone to inspect and challenge. (4) The model is easy to revise when better information is available.

focal species to 7 focal species that could be adequately modeled using the available GIS layers. For an explanation of why some suggested focal species were not modeled, see Appendix C.

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 15):

- *Vegetation and land cover.* We used the Southwest Regional GAP Analysis (ReGAP) data, merging some classes to create 46 vegetation & land cover classes as described in Appendix E.
- *Elevation.* We used the USGS National Elevation Dataset digital elevation model.
- *Topographic position.* We characterized each pixel as ridge, canyon bottom, flat to gentle slope, or steep slope.
- *Straight-line distance from the nearest paved road or railroad.* Distance from roads reflects risk of being struck by vehicles as well as noise, light, pets, pollution, and other human-caused disturbances.

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

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

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

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

[3] Clevenger et al. (2002) found that literature review significantly improved the fit between expert scores and later empirical observations of animal movement.
[4] In previous linkage designs, we used arithmetic instead of geometric mean.

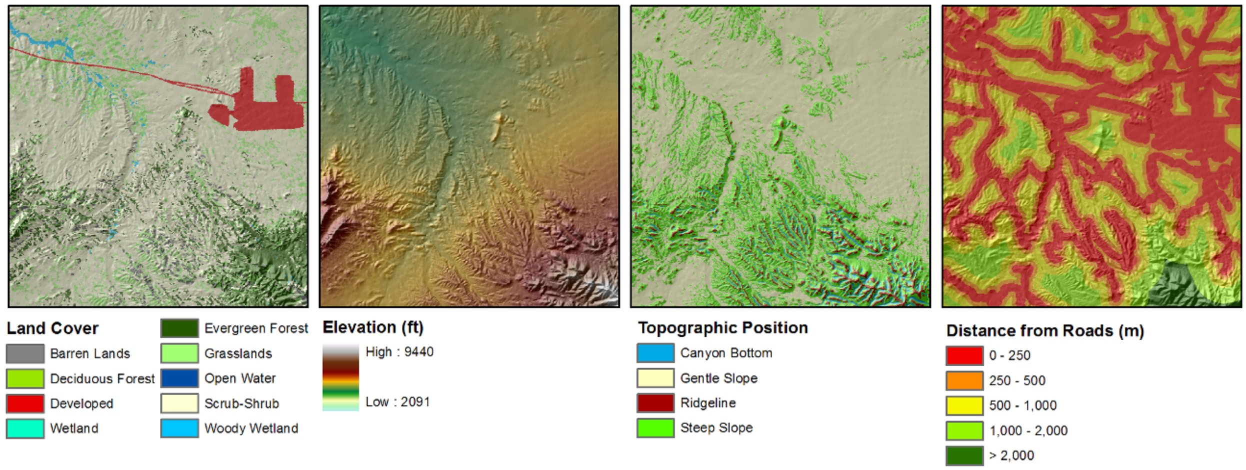

Figure 15: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads

Identifying Potential Breeding Patches & Potential Population Cores

The habitat suitability map provides scores for each 30x30-m pixel. For our analyses, we also needed to identify – both in the Wildland blocks and in the Potential linkage area – areas of good habitat large enough to support reproduction. Specifically, we wanted to identify

- *potential breeding patches*: areas large enough to support a breeding unit (individual female with young, or a breeding pair) for one breeding season. Such patches could be important stepping-stones for species that are unlikely to cross a potential linkage area within a single lifetime.
- *potential population cores*: areas large enough to support a breeding population of the focal species for about 10 years.

To do so, we first calculated the suitability of any pixel as the average habitat suitability in a neighborhood of pixels surrounding it (Figure 16). We averaged habitat suitability within a 3x3-pixel neighborhood (90 x 90 m^2, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[5]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) into polygons that represented potential breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

[5] An animal that moves over large areas for daily foraging perceives the landscape as composed of relatively large patches, because the animal readily moves through small swaths of unsuitable habitat in an otherwise favorable landscape (Vos et al. 2001). In contrast, a less-mobile mobile has a more patchy perception of its surroundings. Similarly, a small island of suitable habitat in an ocean of poor habitat will be of little use to an animal with large daily spatial requirements, but may be sufficient for the animal that requires little area.

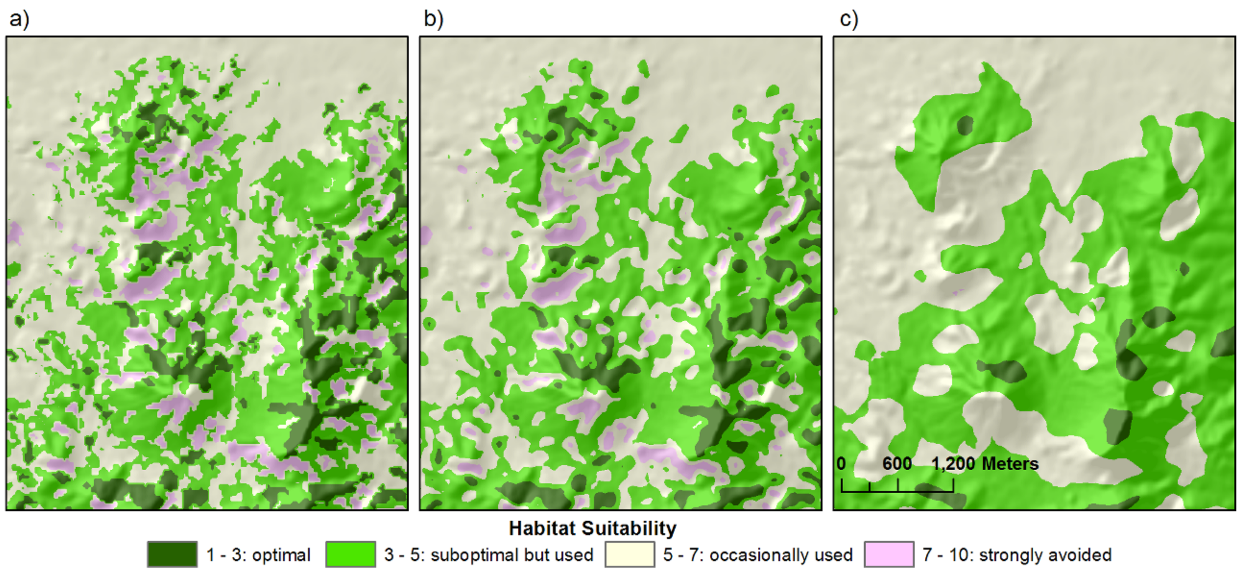

Figure 16: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window

Identifying Biologically Best Corridors

The *biologically best corridor*[6] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one protected wildland block to a potential population core in the other protected wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

We developed BBCs only for some focal species, namely species that (a) exist in both wildland blocks, or have historically existed in both and could be restored to them, (b) can move between wildland blocks in less time than disturbances such as fire or climate change will make the current vegetation map obsolete, and (c) move near the ground through the vegetation layer (rather than flying, swimming, or being carried by the wind), and (d) have habitat preferences that can reasonably be represented using GIS variables.

The close proximity of the wildland blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[7]. A BBC drawn in this way has 2 problems: (1) It could be unrealistic (previous footnote). (2) It could serve small wildlife populations near the road while failing to serve much larger populations in the rest of the protected habitat block. To address these problems, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel to each other, Thus for purposes of BBC analyses, we redefined the wildland blocks such that distances between the edges of each one are nearly uniform.

We then identified potential population cores and habitat patches that fell completely within each protected wildland block. If potential population cores existed within each block, we used these potential

[6] Our approach has often been called Least Cost Corridor Analysis (Beier et al. 2006) because it identifies areas that require the least cost of travel (energetic cost, risk of mortality) to the animal. However, we avoid the words "least cost" because it is easily misunderstood as referring to the dollar cost of conserving land or building an underpass.
[7] The GIS algorithm will almost always select a corridor 100 m long (width of a freeway) over a corridor 5 miles long, even if the habitat is much better in the longer corridor.

cores as the starting & ending points for the corridor analysis. Otherwise, the start-end points were potential habitat patches within the protected wildland block or (for a wide-ranging species with no potential habitat patch entirely within a wildland block) any suitable habitat within the protected block.

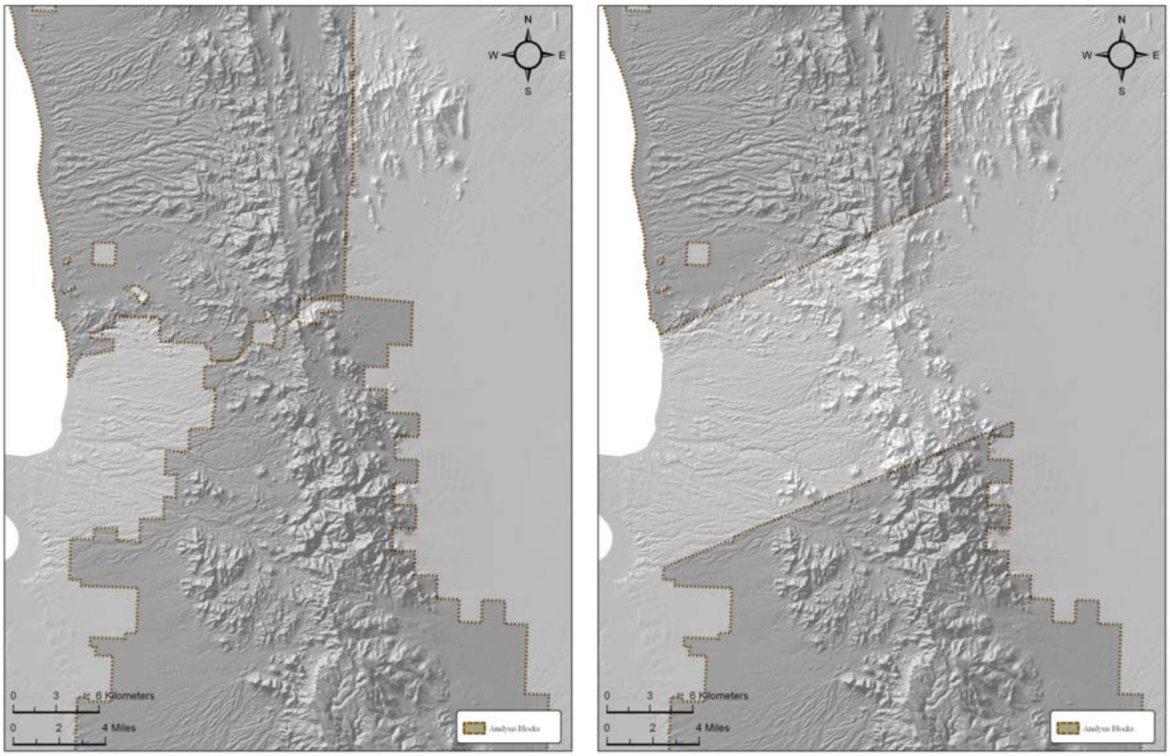

Figure 17: To give our corridors models "room to run," for the purposes of BBC analyses, we modified the wildland blocks used in our analyses, so that the facing edges were parallel lines about 15 km apart. This forces the models to identify corridors with the best habitat; without this modification, the models tend to identify the shortest corridors regardless of habitat quality.

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[8]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd protected wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1000 m. If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses

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

were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[9] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

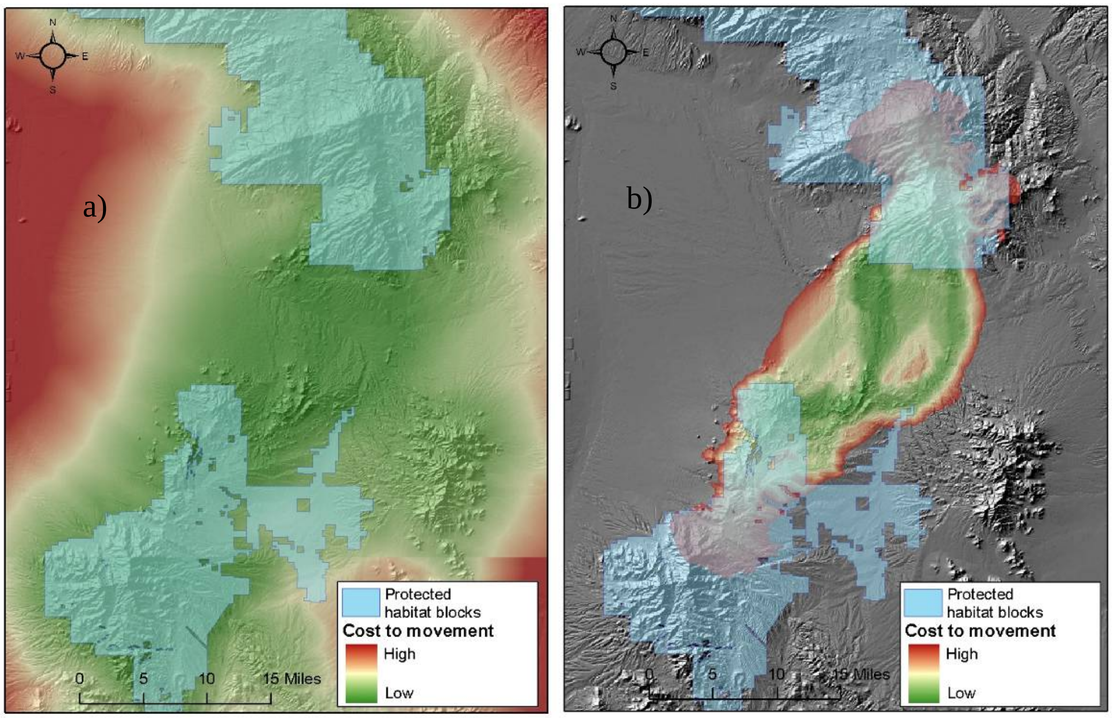

Figure 18: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape

Minimum Linkage Width

Wide linkages are beneficial for several reasons. They (1) provide adequate area for development of metapopulation structures necessary to allow corridor-dwelling species (individuals or genes) to move through the landscape; (2) reduce pollution into aquatic habitats; (3) reduce edge effects such as pets, lighting, noise, nest predation & parasitism, and invasive species; (4) provide an opportunity to conserve natural fire regimes and other ecological processes; and (5) improve the opportunity of biota to respond to climate change.

To address these concerns, we established a minimum width of 1km along the length of each terrestrial branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no

[9] Dispersal distance is how far an animal moves from its birthplace to its adult home range. We used dispersal distances reported by the species expert, or in published literature. In some cases, we used dispersal distance for a closely-related species.

natural areas were available.

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

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

Field Investigations

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

Appendix B: Individual Species Analyses

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

	Badger	Black Bear	Bobcat	Jaguar	Javelina
Factor weights					
Land Cover	65	75	95	60	50
Elevation	7	10	5	5	30
Topography	15	10	0	15	20
Distance from Roads	13	5	0	20	0
Land Cover					
Conifer-Oak Forest and Woodland	6	1	2	2	7
Encinal	6	1	2	2	4
Mixed Conifer Forest and Woodland	6	3	2	3	6
Pine-Oak Forest and Woodland	5	1	2	3	7
Pinyon-Juniper Woodland	4	6	2	2	5
Ponderosa Pine Woodland	5	4	2	4	6
Spruce-Fir Forest and Woodland	6	4	2	4	8
Aspen Forest and Woodland	6	5	6	6	10
Juniper Savanna	2	7	4	3	7
Semi-Desert Grassland and Steppe	1	5	4	1	2
Chaparral	5	3	2	4	3
Creosotebush, Mixed Desert and Thorn Scrub	2	6	4	2	3
Creosotebush-White Bursage Desert Scrub	2	9	4	4	4
Desert Scrub (misc)	3	5	4	4	2
Gambel Oak-Mixed Montane Shrubland	5	3	2	3	8
Mesquite Upland Scrub	3	6	4	4	2
Mixed Low Sagebrush Shrubland	3	8	3	6	10
Paloverde-Mixed Cacti Desert Scrub	4	5	4	5	1
Pinyon-Juniper Shrubland	4	6	2	4	10
Riparian Mesquite Bosque	6	5	3	1	1
Riparian Woodland and Shrubland	6	5	3	1	2
Recently Mined or Quarried	9	10	6	10	10
Agriculture	6	6	9	9	7
Developed, Medium - High Intensity	10	10	9	10	7
Developed, Open Space - Low Intensity	7	10	7	10	4
Open Water	9	10	10	7	10
Elevation (ft)					
	0-5500: 1	0-2500: 8	0-7500: 1	0-2000: 3	0-5000: 1
	5500-8000: 3	2500-4000: 6	7500-10000: 5	2000-4000: 3	5000-7000: 3
	8000-11000: 6	4000-6500: 2	10000-11000: 9	4000-6000: 1	7000-11000: 10
		6500-8500: 3		6000-8000: 3	
		8500-11000: 4		8000-11000: 4	
Topographic Position					
Canyon Bottom	5	3		1	1
Flat - Gentle Slopes	1	6		5	1
Steep Slope	8	3		2	7
Ridgetop	7	4		4	4
Distance from Roads (m)					
	0-250: 6	0-100: 10		0-250: 10	
	250-1500: 1	100-500: 4		250-500: 7	
		500-15000: 1		500-1000: 5	
				1000-2000: 2	
				2000-15000: 1	

	Kit Fox	Mexican Gray Wolf	Mountain Lion	Mule Deer	Pronghorn
Factor weights					
Land Cover	75	25	70	80	45
Elevation	0	15	0	0	0
Topography	15	15	10	15	37
Distance from Roads	10	35	20	5	18
Land Cover					
Conifer-Oak Forest and Woodland	8	1	1	4	8
Encinal	7	1	1	3	7
Mixed Conifer Forest and Woodland	8	1	3	3	8
Pine-Oak Forest and Woodland	8	1	1	3	8
Pinyon-Juniper Woodland	8	1	1	5	6
Ponderosa Pine Woodland	8	1	4	5	7
Spruce-Fir Forest and Woodland	10	1	4	8	8
Aspen Forest and Woodland	9	1	3	1	10
Juniper Savanna	3	6	4	4	4
Semi-Desert Grassland and Steppe	1	6	5	2	1
Chaparral	6	6	3	4	8
Creosotebush, Mixed Desert and Thorn Scrub	1	6	6	6	2
Creosotebush-White Bursage Desert Scrub	1	6	6	6	2
Desert Scrub (misc)	1	6	6	6	3
Gambel Oak-Mixed Montane Shrubland	5	5	3	4	5
Mesquite Upland Scrub	5	6	4	3	7
Mixed Low Sagebrush Shrubland	4	6	6	5	2
Paloverde-Mixed Cacti Desert Scrub	3	6	7	3	3
Pinyon-Juniper Shrubland	4	5	2	5	4
Riparian Mesquite Bosque	4	1	4	3	8
Riparian Woodland and Shrubland	5	1	2	3	8
Recently Mined or Quarried	10	8	8	6	10
Agriculture	7	6	10	6	8
Developed, Medium - High Intensity	9	8	10	9	10
Developed, Open Space - Low Intensity	7	8	8	5	8
Open Water	10	1	9	10	7
Elevation (ft)					
		0-3000: 6 3000-4500: 4 4500-6500: 3 6500-8500: 1 8500-11000: 2			
Topographic Position					
Canyon Bottom	7	2	1	2	7
Flat - Gentle Slopes	1	1	3	2	1
Steep Slope	5	5	3	4	8
Ridgetop	4	1	4	6	6
Distance from Roads (m)					
	0-50: 7 50-250: 3 250-500: 2 500-15000: 1	0-1000: 4 1000-2000: 3 2000-5000: 2 5000-15000: 1	0-200: 8 200-500: 6 600-1000: 5 1000-1500: 2 1500-15000: 1	0-250: 7 250-1000: 3 1000-15000: 1	0-100: 10 100-250: 6 250-1000: 3 1000-15000: 1

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 badger populations, or even an individual (NatureServe 2005). Consequently, badgers have suffered declines in recent decades in areas where grasslands have been converted to intensive agricultural areas, and where prey animals such as prairie dogs and ground squirrels have been reduced or eliminated (NatureServe 2005). Badgers are also threatened by collisions with vehicles while attempting to cross highways intersecting their habitat (New Mexico Department of Game and Fish 2004, NatureServe 2005).

Distribution

Badgers are found throughout the western United States, extending as far east as Illinois, Wisconsin, and Indiana (Long 1973). They are found in open habitats throughout Arizona.

Habitat Associations

Badgers are primarily associated with open habitats such as grasslands, prairies, and shrublands, and avoid densely wooded areas (NMGF 2004). They may also inhabit mountain meadows, marshes, riparian habitats, and desert communities including creosote bush, juniper, and sagebrush habitats (Long & Killingley 1983). They prefer flat to gentle slopes at lower elevations, and avoid rugged terrain (Apps et al. 2002).

Spatial Patterns

Overall yearly home range of badgers has been estimated as 8.5 km^2 (Long 1973). Goodrich and Buskirk (1998) found an average home range of 12.3 km^2 for males and 3.4 km^2 for females, found male home ranges to overlap more than female ranges (male overlap = 0.20, female = 0.08), and estimated density as 0.8 effective breeders per km^2. Messick and Hornocker (1981) found an average home range of 2.4 km^2 for adult males and 1.6 km^2 for adult females, and found a 20% overlap between a male and female home range. Nearly all badger young disperse from their natal area, and natal dispersal distances have been recorded up to 110 km (Messick & Hornocker 1981).

Conceptual Basis for Model Development

Habitat suitability model – Badgers prefer grasslands and other open habitats on flat terrain at lower elevations. They do not show an aversion to roads (Apps et al. 2002), which makes them sensitive to high road mortality. Vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received weights of 7%, 15%, and 13%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 2 km^2, which is an average of the home range found for both sexes by Messick and Hornocker (1981), and equal to the female home range estimated by Goodrich and Buskirk (1998), minus 1 standard deviation. Minimum potential habitat core size was defined as 10 km^2, approximately enough area to support 10 effective breeders, allowing for a slightly larger male home range size and 20% overlap of home ranges (Messick

& Hornocker 1981). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of both optimal and suitable habitat for badger within the potential linkage area, occurring mainly in the lowlands between the wildland blocks (Figure 20 and Figure 22). The BBC in Strand B runs between the Galiuro and Pinaleño Mountains wildland blocks. Habitat suitability scores range from 1.0 to 6.1, with an average cost of 1.6 (S.D: 0.8). Within the BBC in Strand C, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.0 to 6.3, with an average of 2.0 (S.D:0.8).

Union of biologically best corridors – The additional area of strand B captures optimal habitat for badger, while strand A is made up mostly of suitable badger habitat. The three southern strands (C, D, and E) capture additional optimal badger habitat existing between the wildland blocks. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10 and conversion of grasslands to agricultural or residential areas.

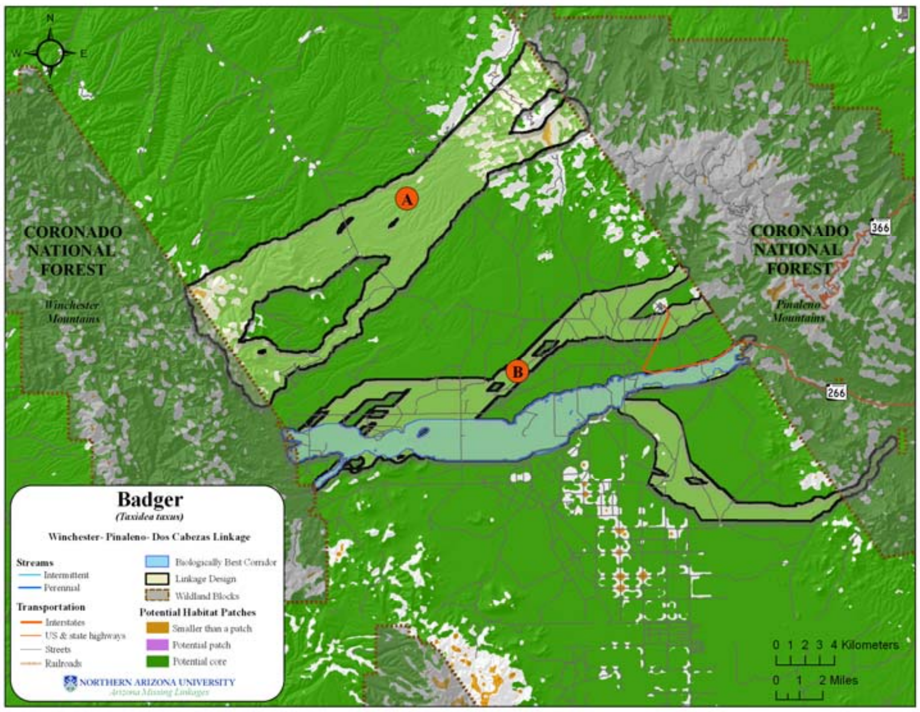

Figure 19: Potential habitat patches and cores for badger in the Galiuro-Pinaleño area

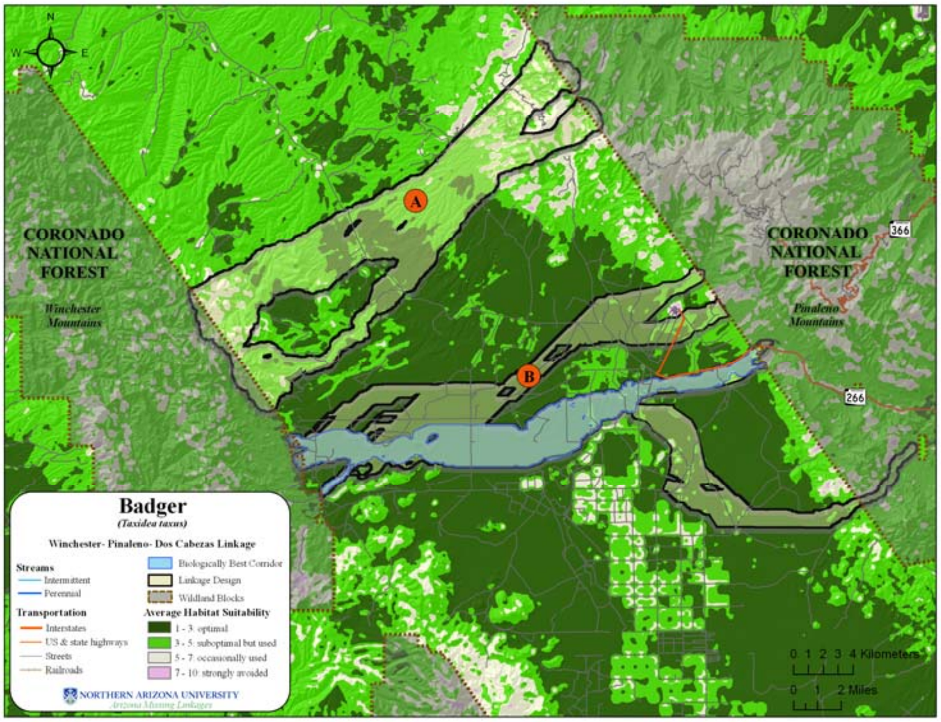

Figure 20: Modeled habitat suitability of badger in the Galiuro-Pinaleño area

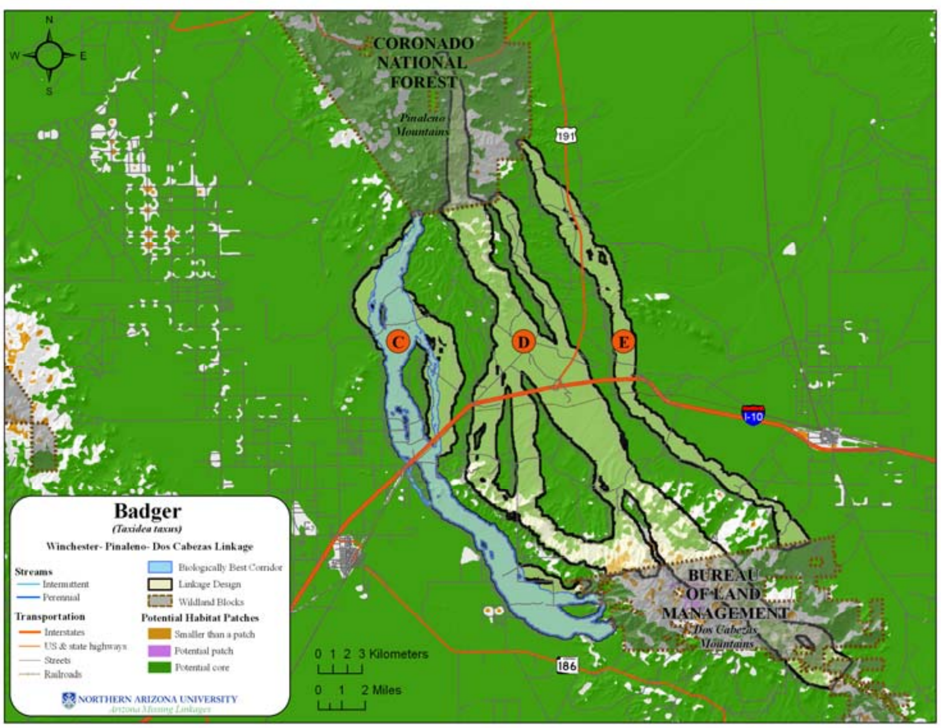

Figure 21: Potential habitat patches and cores for badger in the Pinaleño-Dos Cabezas area

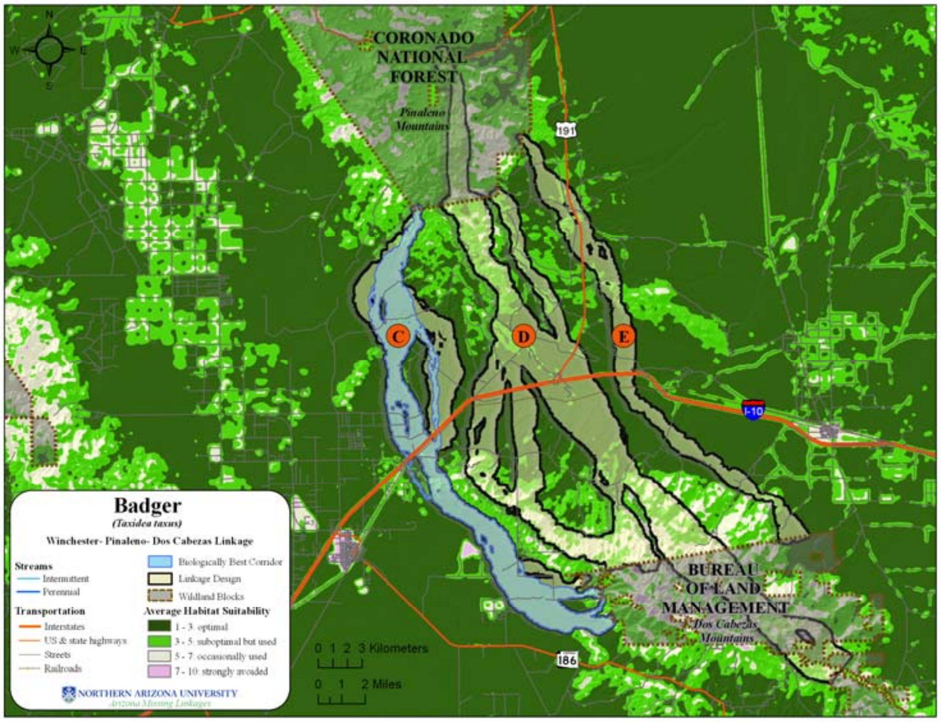

Figure 22: Modeled habitat suitability for badger in the Pinaleño-Dos Cabezas area

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 mountain 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 for habitat suitability scores.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results depict optimal bear habitat occurring in the montane forests of the wildland blocks, with suitable habitat along the foothills and less suitable or avoided habitat along the valley floors between the wildland blocks (Figure 24 and Figure 26). The BBC in Strand A runs between the Galiuro and Pinaleño Mountains wildland blocks where habitat suitability scores ranged from 1.3 to 9.7, with an average cost of 4.0 (S.D: 1.3). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.3 to 8.7, with an average of 3.8 (S.D:1.4).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures small patches of suitable and optimal habitat for black bear occurring at lower elevations where the bears may roam in the fall in search of prickly pear fruit and acorns. Threats to black bear habitat connectivity and population persistence are most likely high-traffic roads such as Interstate 10, and habitat fragmentation.

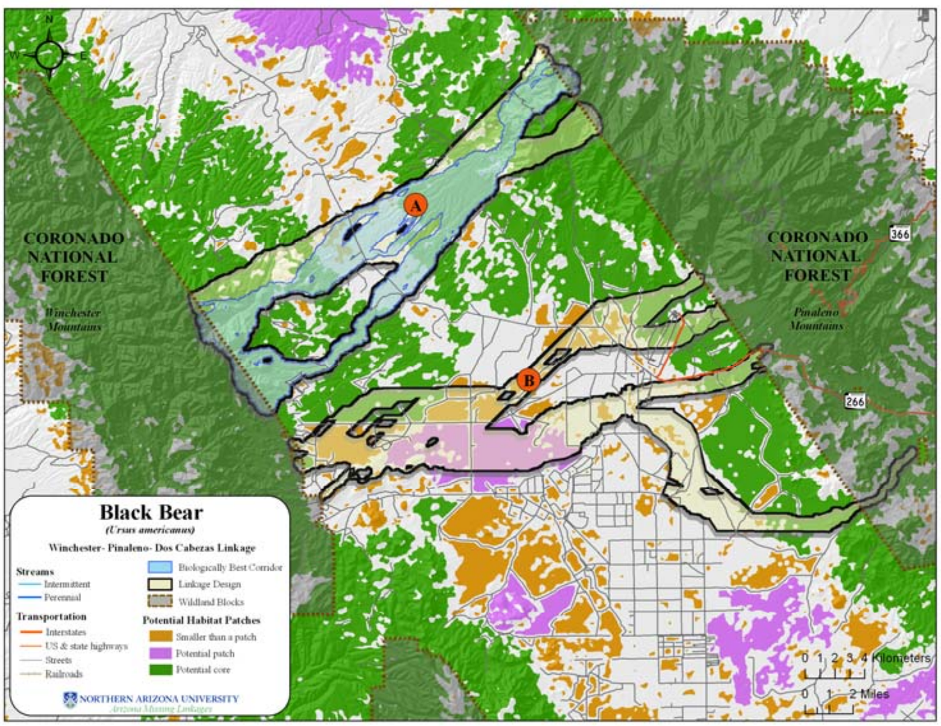

Figure 23: Potential habitat patches and cores for black bear in the Galiuro-Pinaleño area

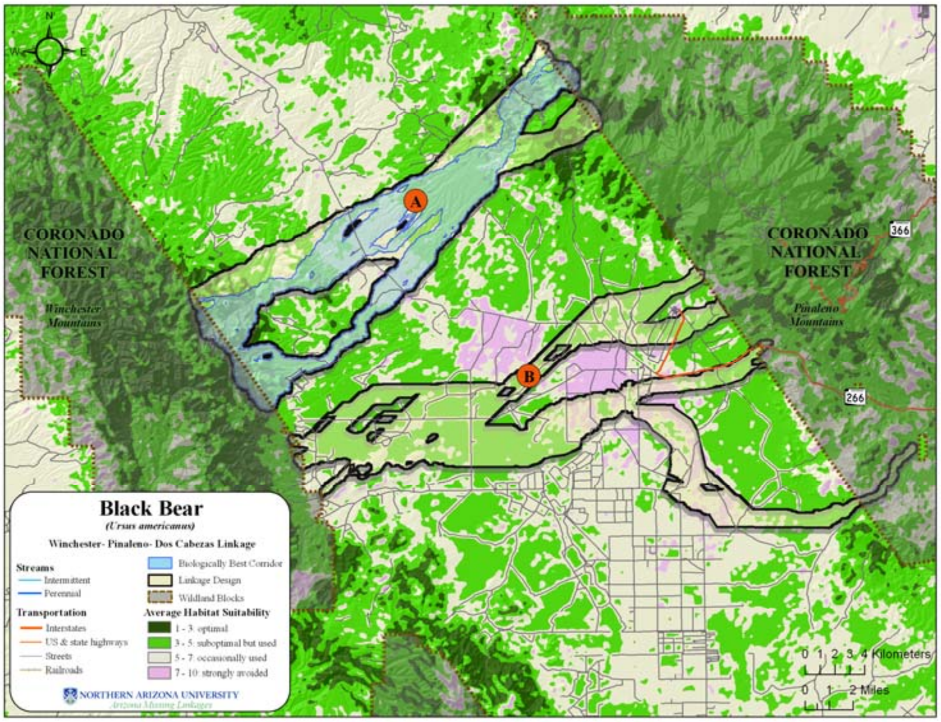

Figure 24: Modeled habitat suitability of black bear in the Galiuro-Pinaleño area

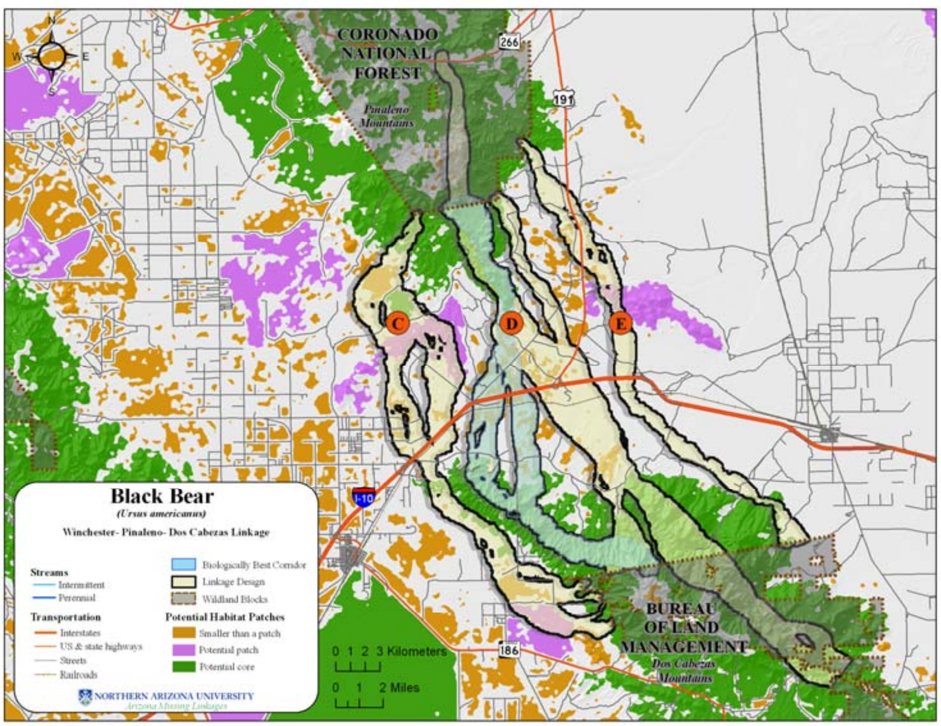

Figure 25: Potential habitat patches and cores for black bear in the Pinaleño-Dos Cabezas area

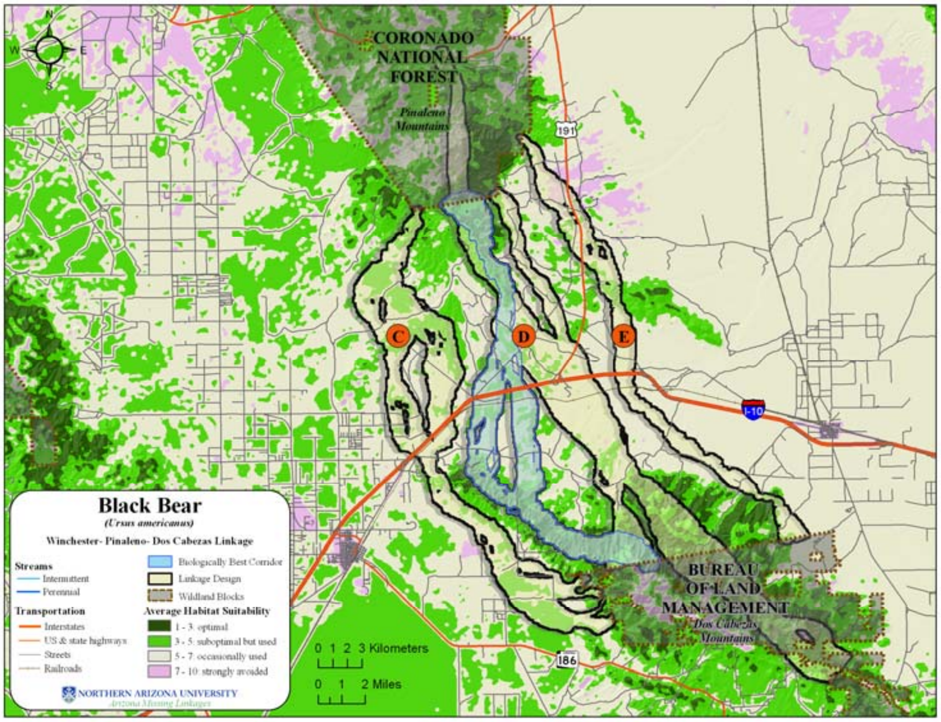

Figure 26: Modeled habitat suitability for black bear in the Pinaleño-Dos Cabezas area

Justification for Selection

Bobcats are the most common felid in North America. Fur trapping remains an important source of mortality for the species. They are also susceptible to vehicle collisions, intraspecific competition, and disease (Fuller et al. 1995). Bobcats are known habitat generalists that sometimes utilize residential areas adjacent to large undeveloped areas (Harrison 1998). They may be able to coexist with some development when a minimum amount of functional natural habitat remains (Riley et al.2003). However, rampant urbanization can be detrimental to populations. For example, the disappearance of bobcats in Illinois coincided with human settlement and associated habitat loss (Woolf & Hubert 1998).

Distribution

Bobcats occur over a broad geographic range, including most of the U.S., as far north as Canada, and south into Mexico. They are found throughout Arizona (Hoffmeister, 1986), though they are probably rare on the eastern plains and at higher altitudes in the northern mountains (Findley et al., 1975).

Habitat Associations

Bobcats are primarily associated with broken country where cliffs and rock outcrops are interspersed with open grassland, woods, or desert. In Arizona, they occur from the base to the tops of most desert ranges, in mesquite woods, in arrowweed thickets, among cottonwoods, in open desert miles from "typical" habitat, and in juniper woodland, oak-manzanita, and ponderosa pine (Hoffmeister, 1986). Bobcats are very flexible in their habitat requirements, needing only adequate prey and cover for hunting and escape (Harrison pers. comm.).

Spatial Patterns

Bobcats are generally solitary and territorial (Riley 2003). Observed home ranges for one breeding pair ranged from 2 to over 50 km^2. Home range size varies greatly with prey density and habitat quality (Harrison, pers. comm.). In Marin County, California, Riley (2003) found that roads represented home range boundaries for 75% of radio-collared bobcats that lived near them, males had larger average home range requirements than females, and the spatial requirements for both genders varied widely according to whether they were located in an urban or rural landscape (mean home range size (MCP 95%) of males: urban zone 6.4 km^2, rural zone 13.5 km^2 , females: urban zone 1.3 km^2, rural zone 5.3 km^2). Dispersal distances for young bobcats average near 25 km, while they have been recorded up to 182 km (Kamler et al 2000).

Conceptual Basis for Model Development

Habitat suitability model – Bobcats occur across a wide spectrum of vegetation types, and tend to cross paved roads infrequently (Riley 2003). Vegetation received an importance weight of 95%, while elevation was weighted at 5%, and topography and distance from roads did not receive any weight. While bobcats show some unwillingness to cross major roads, there is dearth of information on their use of habitat in relation to distance to roads, though Riley (2003) found that roads frequently represented their home range boundaries. 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 20 km^2 (Anderson and Lovallo 2003). Minimum potential habitat core size was defined as 300 km^2 (Harrison, pers. comm.), approximately enough area to support 20 effective breeders over a 10 year period, provided the population is not harvested.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of optimal bobcat habitat in and around the wildland blocks, and the habitat between wildland blocks is mainly rated as suitable, with some avoided habitat noted near residential and agricultural areas (Figure 27 through Figure 30**Error! Reference source not found.**). The BBC in Strand A runs between the Galiuro and Pinaleño Mountains wildland blocks where habitat suitability scores ranged from 2.0 to 4.0, with an average suitability cost of 2.3 (S.D: 0.5). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 2.0 to 5.4, with an average of 2.9 (S.D:0.8).

Union of biologically best corridors – The remainder of Strand A captures additional optimal and suitable habitat for bobcat, while the other 4 strands are made up of suitable bobcat habitat with some optimal habitat near the wildland blocks. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10, and development, and habitat fragmentation.

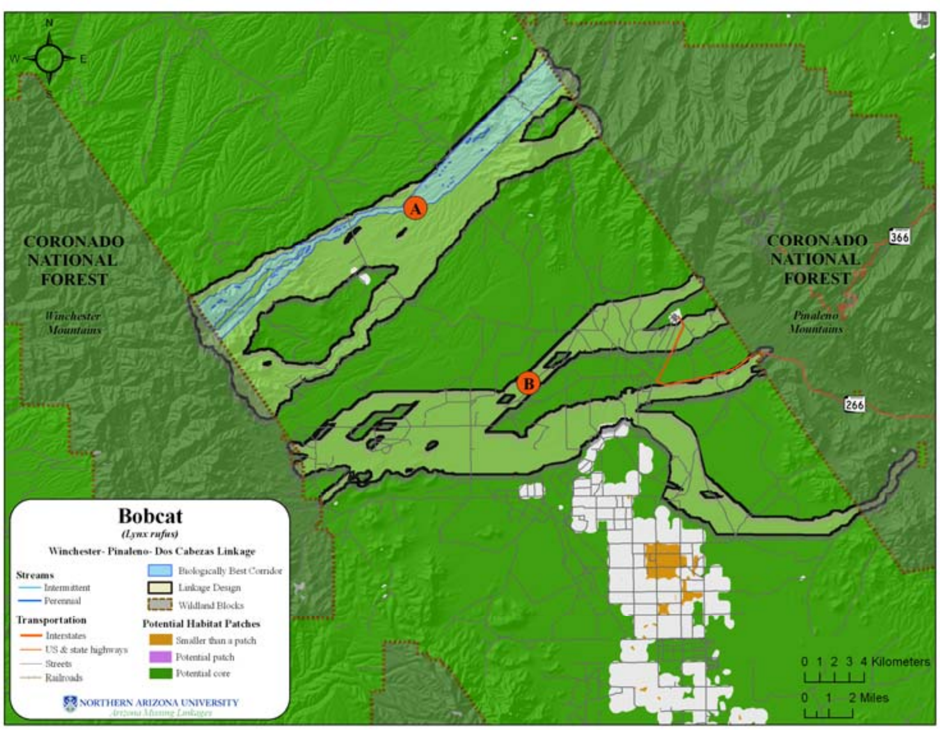

Figure 27: Potential habitat patches and cores for bobcat in the Galiuro-Pinaleño area

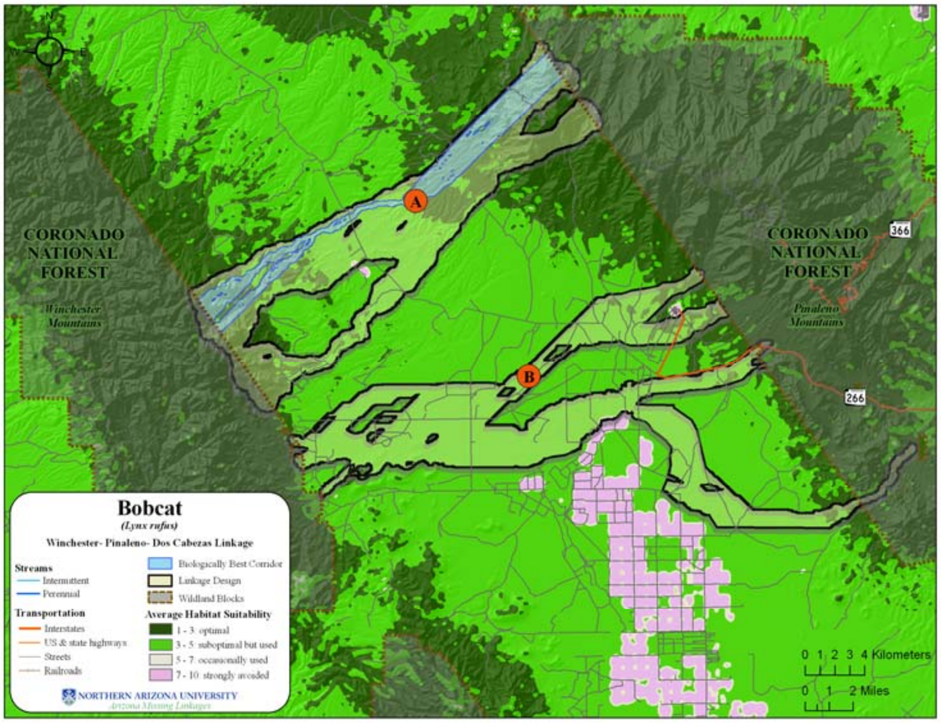

Figure 28: Modeled habitat suitability for bobcat in the Galiuro-Pinaleño area

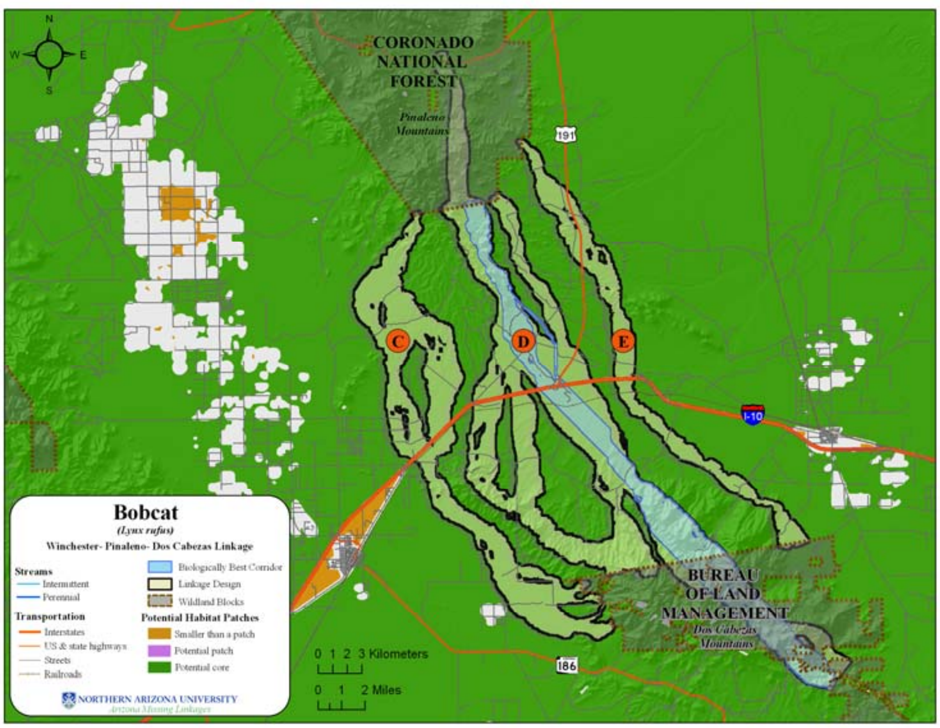

Figure 29: Potential habitat patches and cores for bobcat in the Pinaleño-Dos Cabezas area

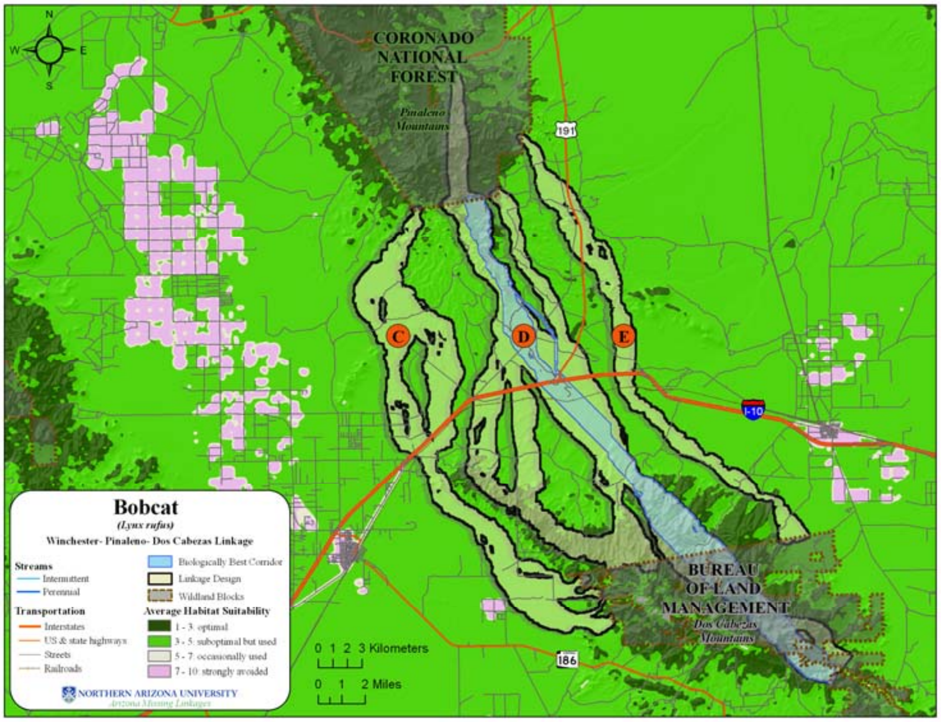

Figure 30: Modeled habitat suitability for bobcat in the Pinaleño-Dos Cabezas area

Jaguar (*Panthera onca*)

Justification for Selection

Jaguars are listed both as a federally endangered species without critical habitat, and as Wildlife Special Concern species by the state of Arizona. They have suffered from a loss of habitat and hunting by ranchers, and persistence in Arizona is contingent on habitat corridors which allow movement from source populations in Mexico (AZGFD 2004).

Distribution

Jaguars have a limited range in Mexico, Guatemala, and Argentina, and are rare in the United States, Bolivia, Panama, Costa Rica, and Honduras, Peru, Colombia, and Venezuela (Seymour 1989). The largest known populations of jaguars exist in the Amazonian rainforest of Brazil. Within Arizona, they historically occurred in the southeastern part of the state, with several recorded sightings in central Arizona and as far north as the south rim of the Grand Canyon (Hoffmeister 1986).

Habitat Associations

Jaguars are adaptable to a variety of conditions, and are most often found in areas with sufficient prey, cover, and water supply (Seymour 1989). Within Arizona, habitat preferences are not clear; however, the species appears to prefer scrub and grasslands, evergreen forest, and conifer forest & woodlands (Hatten et al. 2003). It has been suggested that their apparent preference for grasslands may reflect movement corridors from the Sierra Madres of Mexico into southeast Arizona, rather than a preference for this habitat type (Hatten et al. 2003). Jaguars have a strong preference for water, and are often found within several kilometers of a water source such as perennial rivers or cienegas (Hatten et al. 2003; AZGFD 2004). They also appear to prefer intermediate to rugged terrain, and seem to be especially sensitive to human disturbance (Hatten et al. 2003; Menke & Hayes 2003).

Spatial Patterns

The home range of jaguars may vary from 10 to 170 km^2, with smaller home ranges in rain forests, and larger home ranges recorded in open habitats (AZGFD 2004). In Brazil, the average density of jaguars was approximately one animal per 25 km^2, with one female ranging up to 38 km^2, and one male ranging more than 90 km^2 (Schaller & Crawshaw 1980).

Conceptual Basis for Model Development

Habitat suitability model –Vegetation received an importance weight of 60%, while elevation, topography, and distance from roads received weights of 5%, 15%, and 20%, respectively. For specific scores of classes within each of these factors, see

.

Patch size & configuration analysis – Minimum patch size for jaguar was defined as 41 km2 and minimum core size as 205 km2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results depict discontinuous patches of optimal and suitable habitat for jaguar within the potential linkage area (Figure 32 and Figure 34). The BBC in Strand A runs between the Galiuro and Pinaleño Mountains wildland blocks where habitat suitability scores ranged from 1.4 to 10.0, with an average cost of 3.0 (S.D: 1.2). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.2 to 10.0, with an average of 3.2 (S.D:2.0).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures some additional patches of suitable and optimal habitat for jaguar. Because roads are a significant threat to the species, the greatest threats to its connectivity and persistence are likely heavily roaded areas, high-traffic roads such as Interstate 10, and habitat fragmentation.

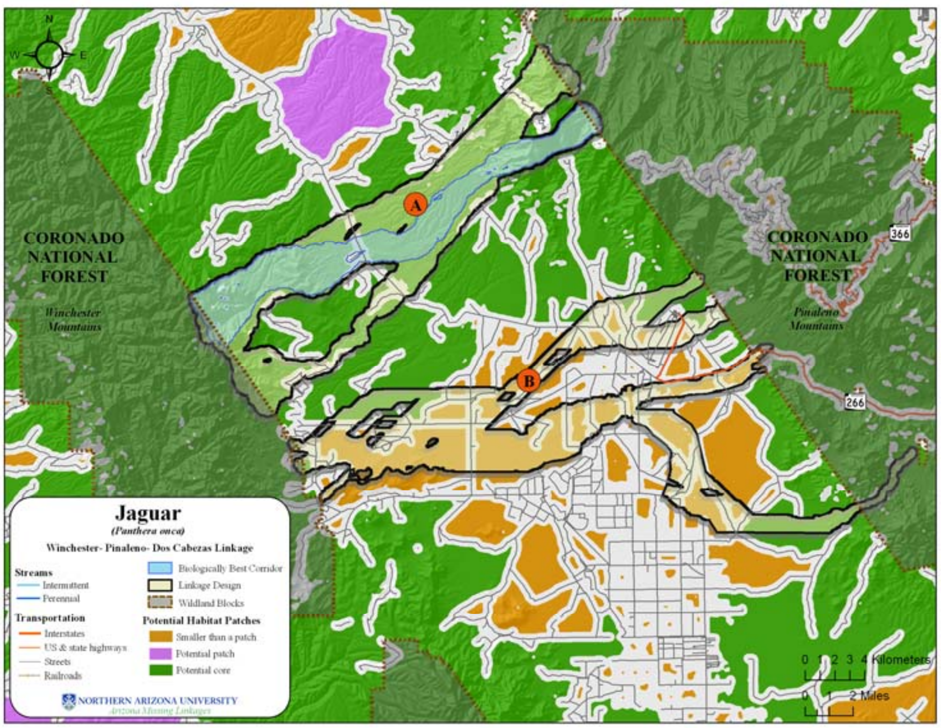

Figure 31: Potential habitat patches and cores for jaguar in the Galiuro-Pinaleño area

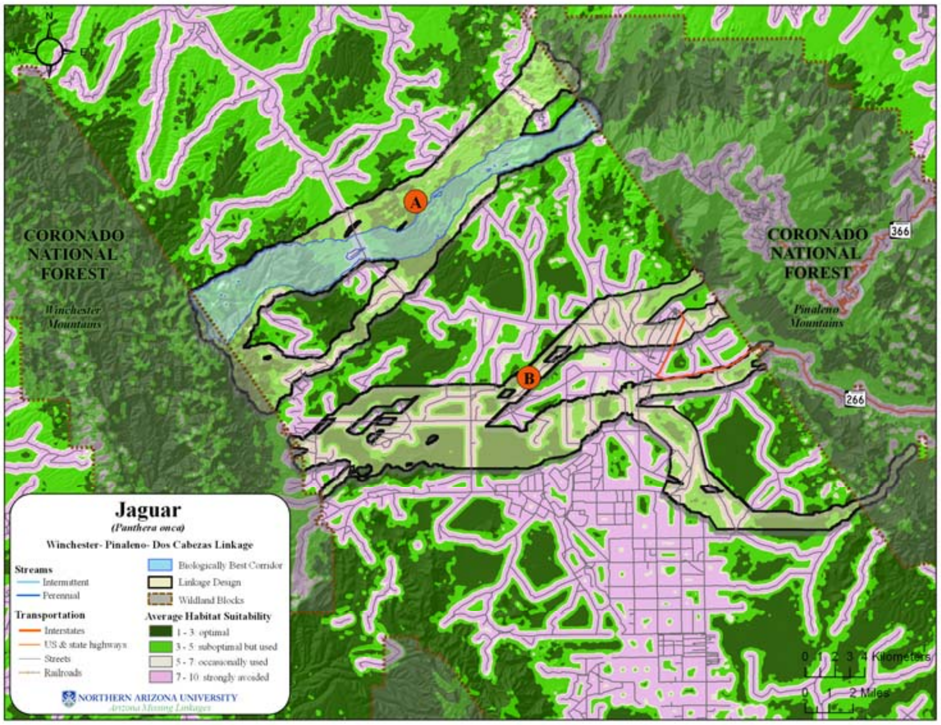

Figure 32: Modeled habitat suitability for jaguar in the Galiuro-Pinaleño area

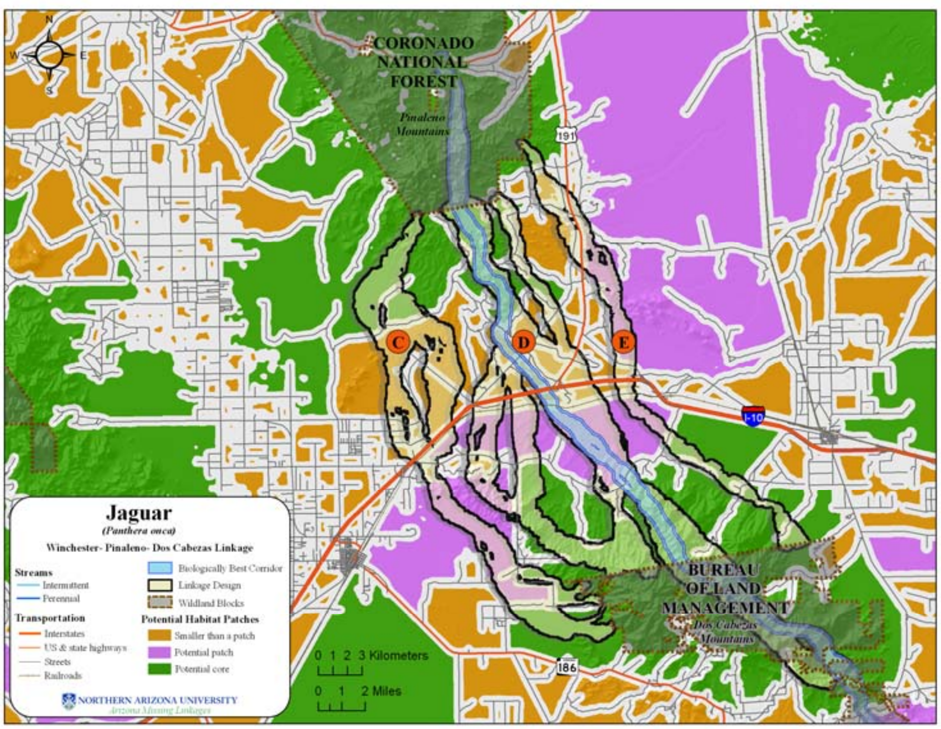

Figure 33: Potential habitat patches and cores for jaguar in the Pinaleño-Dos Cabezas area

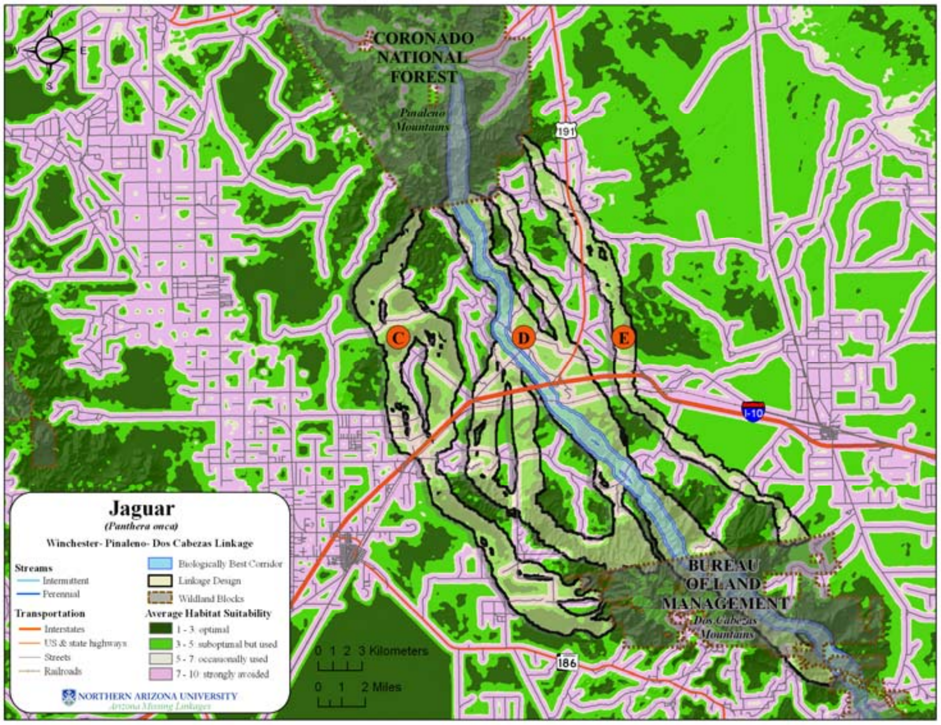

Figure 34: Modeled habitat suitability for jaguar in the Pinaleño-Dos Cabezas area

Javelina (*Tayassu tajacu*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size & configuration analysis – Minimum habitat patch size for javelina was defined as 44 ha, based on an estimate for a single breeding season for one "herd" of one breeding pair. The estimate for minimum habitat core size is 222 ha, based on an estimate of 10 breeding seasons for 1 herd of mean size 9 to 12 animals (Chasa O'Brien, personal comm.). The calculation of area is based upon 3 different estimates of density of animals/ha in south-central and southern Arizona. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate optimal and suitable habitat for javelina throughout potential linkage area, with some less suitable habitat occurring in the higher elevations of the wildland blocks (Figure 36 and Figure 38). Within the BBC in Strand B, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 1.5 to 6.4, with an average cost of 1.6 (S.D: 0.3). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.5 to 7.0, with an average of 2.1 (S.D:0.8).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures additional suitable and optimal habitat for javelina. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10, and habitat fragmentation.

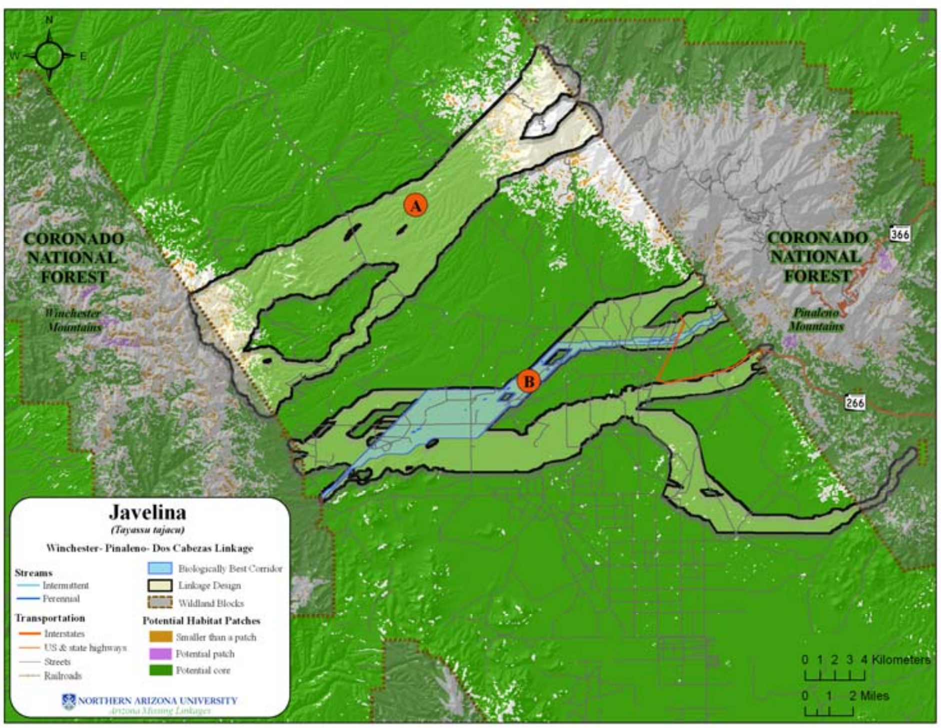

Figure 35: Potential habitat patches and cores for javelina in the Galiuro-Pinaleño area

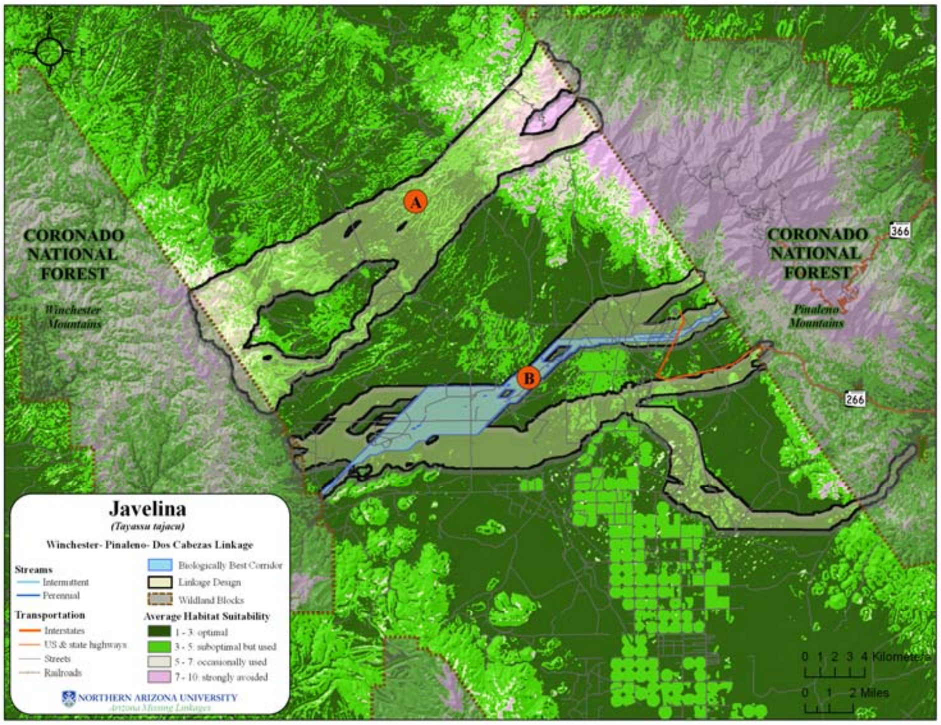

Figure 36: Modeled habitat suitability for javelina in the Galiuro-Pinaleño area

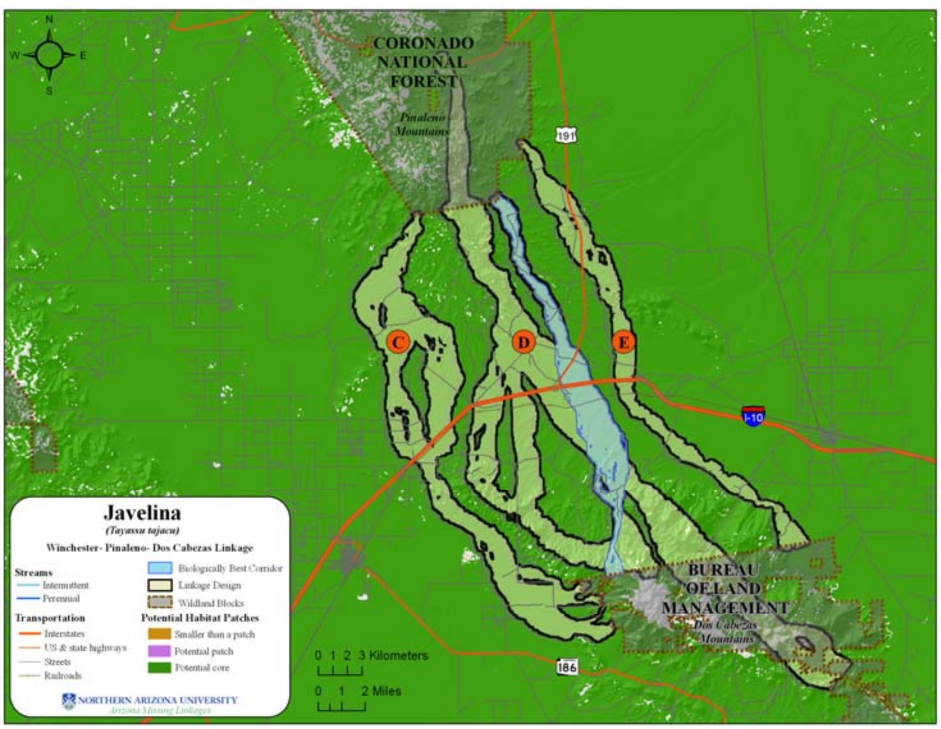

Figure 37: Potential habitat patches and cores for javelina in the Pinaleño-Dos Cabezas area

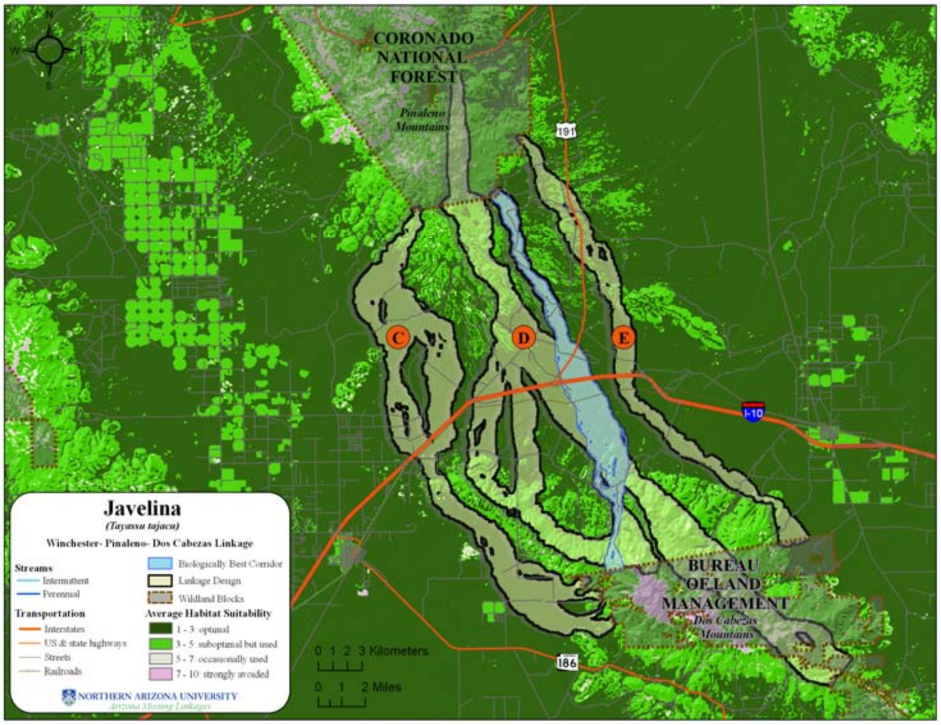

Figure 38: Modeled habitat suitability for javelina in the Pinaleño-Dos Cabezas area

Kit Fox (*Vulpes macrotis*)

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

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

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

Spatial Patterns
Spatial use is highly variable for kit fox, depending on prey base, habitat quality, and precipitation (Zoellick and Smith 1992; Arjo et al. 2003). One study in western Utah found a density of 2 adults per 259 ha in optimum habitat, while an expanded study in Utah found density to range from 1 adult per 471 ha to 1 adult per 1,036 ha (McGrew 1979). Arjo et al. (2003) reported home range size from 1,151-4,308 ha. In Arizona, one study found an average home range size of 980 ha for females, and 1,230 ha for males; however, home ranges the authors also reported 75% overlap of paired males and females (Zoellick and Smith 1992).

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

Patch size & configuration analysis – In our analyses, we defined minimum patch size for kit fox as 259 ha and minimum core size as 1,295 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion
Initial biologically best corridor – Modeling results indicate significant amounts of optimal habitat for kit fox in the undeveloped areas between the wildland blocks (Figure 40 and Figure 42). Within the BBC in

Strand B, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 1.5 to 6.4, with an average cost of 1.6 (S.D: 0.3). Within the BBC in Strand E, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.5 to 7.0, with an average of 2.1 (S.D:0.8).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures additional suitable and optimal habitat for kit fox. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10, development, and habitat fragmentation.

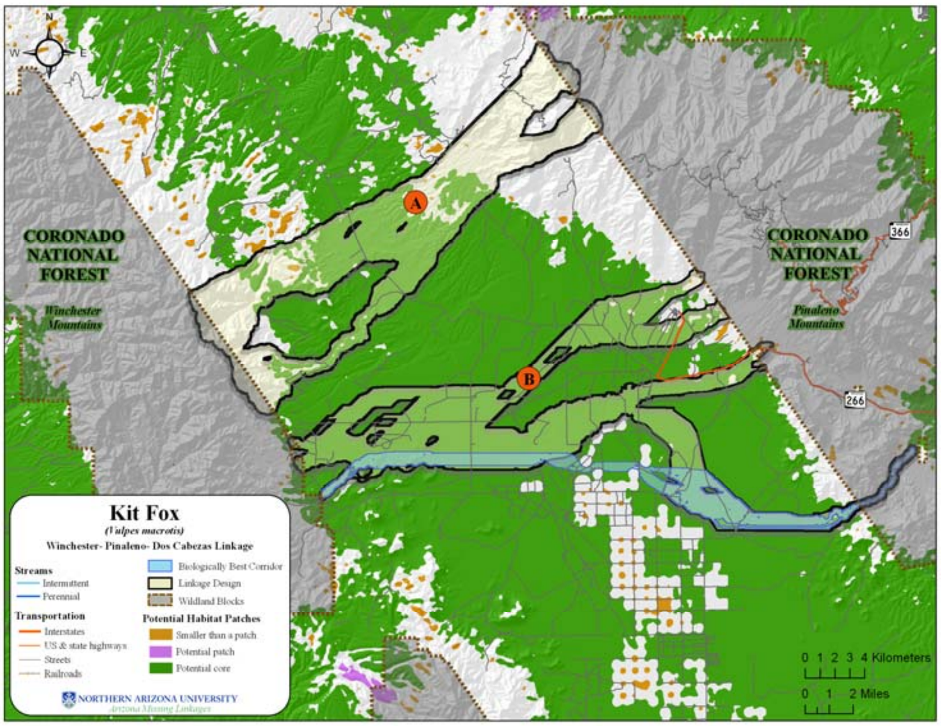

Figure 39: Potential habitat patches and cores for kit fox in the Galiuro-Pinaleño area

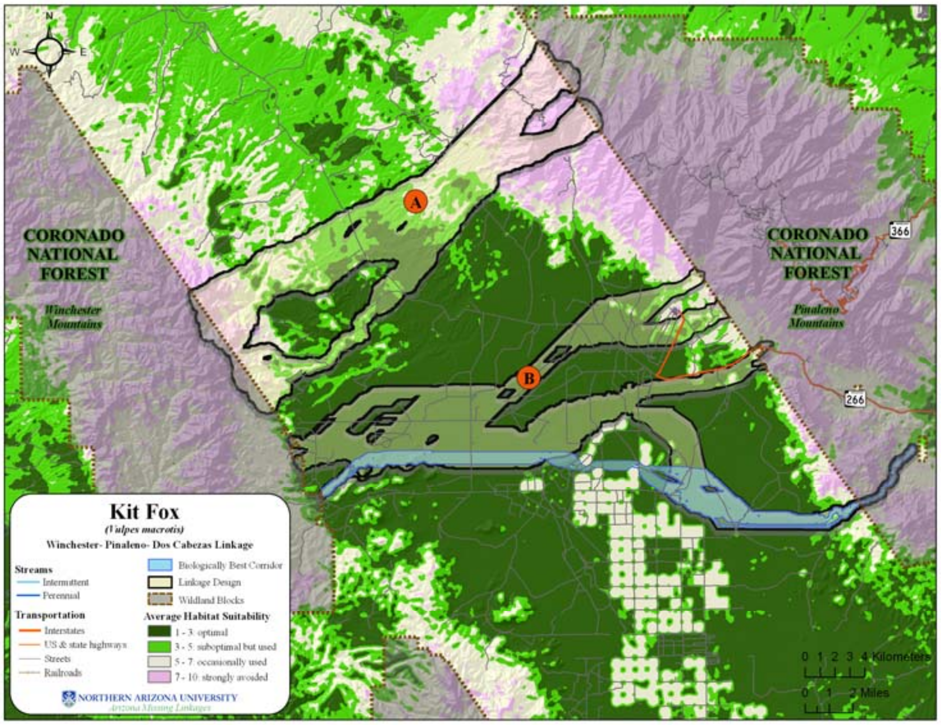

Figure 40: Modeled habitat suitability of kit fox in the Galiuro-Pinaleño area

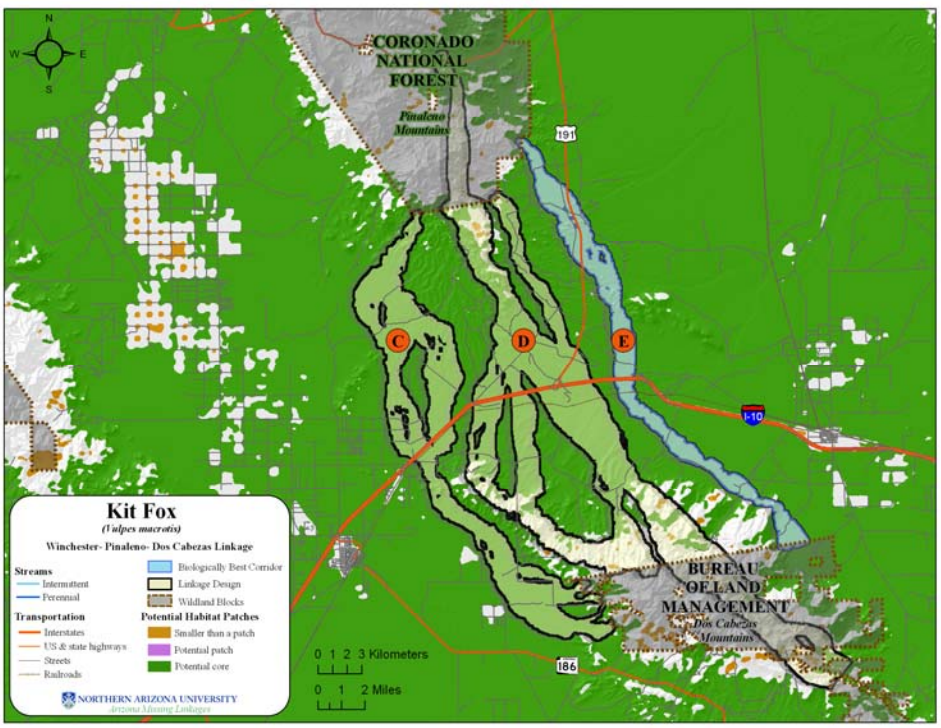

Figure 41: Potential habitat patches and cores for kit fox in the Pinaleño-Dos Cabezas area

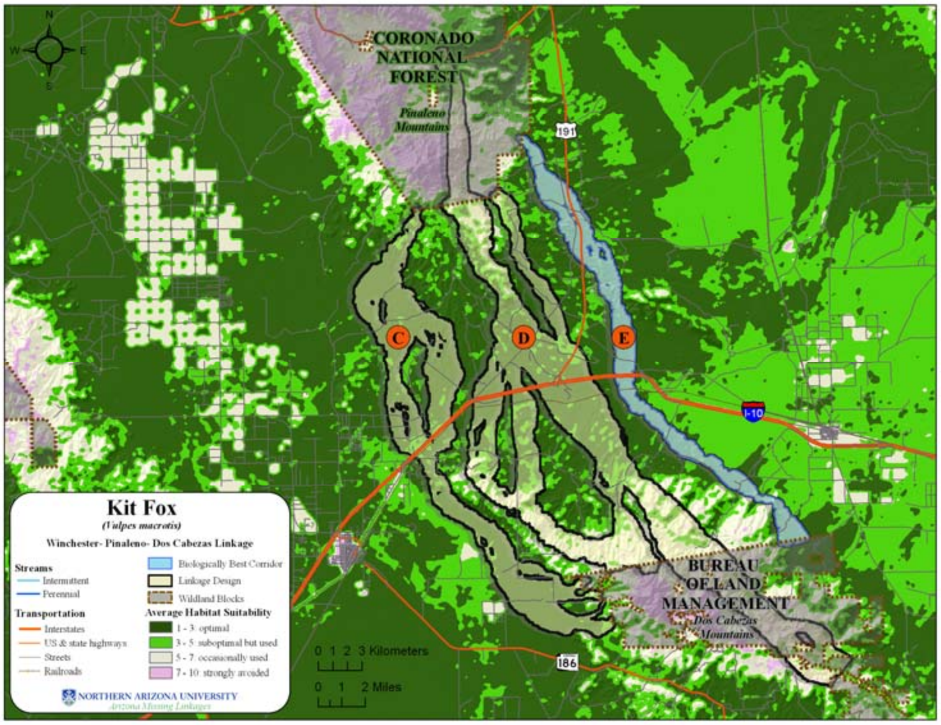

Figure 42: Modeled habitat suitability for kit fox in the Pinaleño-Dos Cabezas area

Mexican Gray Wolf (*Canis lupus baileyi*)

Justification for Selection

The Mexican wolf is the most endangered subspecies of gray wolf in North America (Brown and Parsons, 1997). Extermination of the wolf was attempted across the U.S. due to conflicts with livestock interests and perceived threats to humans. Numerous wolves were killed in New Mexico and Arizona by Coyote-Getters, M-44s, strychnine, and 1080 (USDA 1994). The Mexican grey wolf was likely extirpated in Arizona by the 1970s. Occasional wolves may have continued to enter the southern part of the state from Mexico (Hoffmeister, 1986). In a Final Environmental Impact Statement released in1996, the USFWS recommended reintroducing the Mexican gray wolf to part of its historic range on public lands in Arizona and New Mexico (NMDGF 1997). In 1998, captive-reared Mexican grey wolves were released to the wild for the first time in the Blue Range Wolf Recovery Area.

Distribution

The Mexican grey wolf is the southern-most of North American gray wolf subspecies. Historically, this subspecies occupied montane woodlands in southeastern Arizona, New Mexico, west Texas, and central and northern Mexico (Brown and Parsons, 1997). At one time wolves occurred over much of Arizona, except for desert areas. They traveled along stream beds, washes, old game trails, and old roads in open country (Hoffmeister, 1986). The Mexican grey wolf had not been seen in the wild since 1970, until recent reintroductions in Apache County, Arizona (AGFD 2006).

Habitat Associations

Except for another subspecies (Canis lupus nubilis) reported to inhabit the grasslands of Texas and eastern New Mexico, wolves in the southwest have been associated with montane forests and woodlands (Bailey 1931, McBride 1980). The most important habitat factors for wolf survival at present include a sufficient prey base and distance from humans. The Arizona reintroduction area consists of rugged topography, with steep canyons and high ridges that are bisected by the Mogollon Rim. The most common vegetation types of the Blue Range area are montane and Great Basin conifer forests, plains and Great Basin grasslands, Madrean evergreen woodland, and semidesert grasslands (Groebner 1995). They tend to inhabit areas from 3,000 to 12,000 ft. (915 - 3660 m), and occasionally use lower elevation areas when in transit.

Spatial Patterns

Per Arritt (1999), the expected home range per wolf pack is about 250 square miles, and wolves will not share home ranges. Historical information on territory size of Mexican grey wolves does not exist, however, wolf pack territories from other regions of North America have ranged from 25 to over 5,000 square miles (Mech 1970, Fuller et al. 1992) (NMDGF, 1996).

Conceptual Basis for Model Development

Habitat suitability model – Historically, Mexican gray wolves preferred montane woodlands in Arizona and New Mexico. They do not show an aversion to roads (quote someone), which makes them sensitive to high road mortality, while also providing access to poachers. Vegetation received an importance weight of 25%, elevation 15%, topography 15%, and distance from roads received 35%. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 59 km^2, which is the average core use area determined for 19 packs over 39 pack years on the Mexican Wolf Blue Range Reintroduction Project (2005). Minimum potential habitat core size was defined as 462 km^2, approximately enough area to support an entire pack, based on annual home range size of successful packs during the reintroduction project. To determine potential habitat patches and cores, the habitat suitability model for this species was averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results depict suitable habitat for wolf occurring mainly within and around the wildland blocks (Figure 44 and Figure 46). Within the BBC in Strand A, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 3.2 to 5.5, with an average cost of 4.5 (S.D: 0.6). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 3.5 to 5.6, with an average of 4.7 (S.D:0.5).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures little additional suitable habitat for wolf. Because of their large spatial requirements, susceptibility to roads, and conflicts with livestock the greatest threats to its connectivity and persistence are most likely heavily roaded areas, high-traffic roads such as Interstate 10, poaching, and habitat fragmentation.

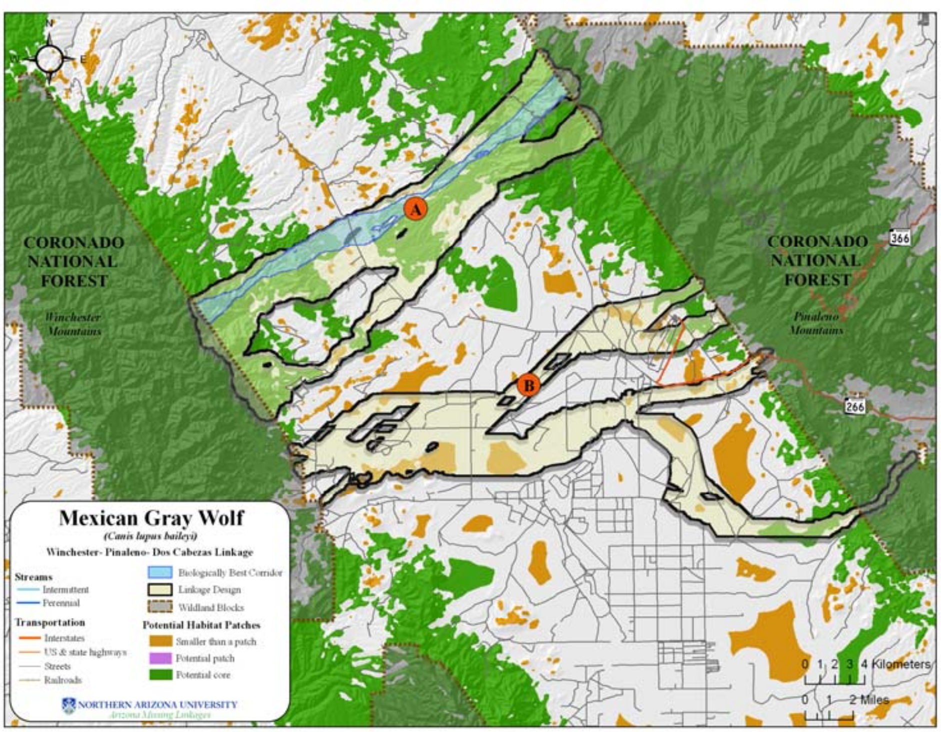

Figure 43: Potential habitat patches and cores for Mexican gray wolf in the Galiuro-Pinaleño area

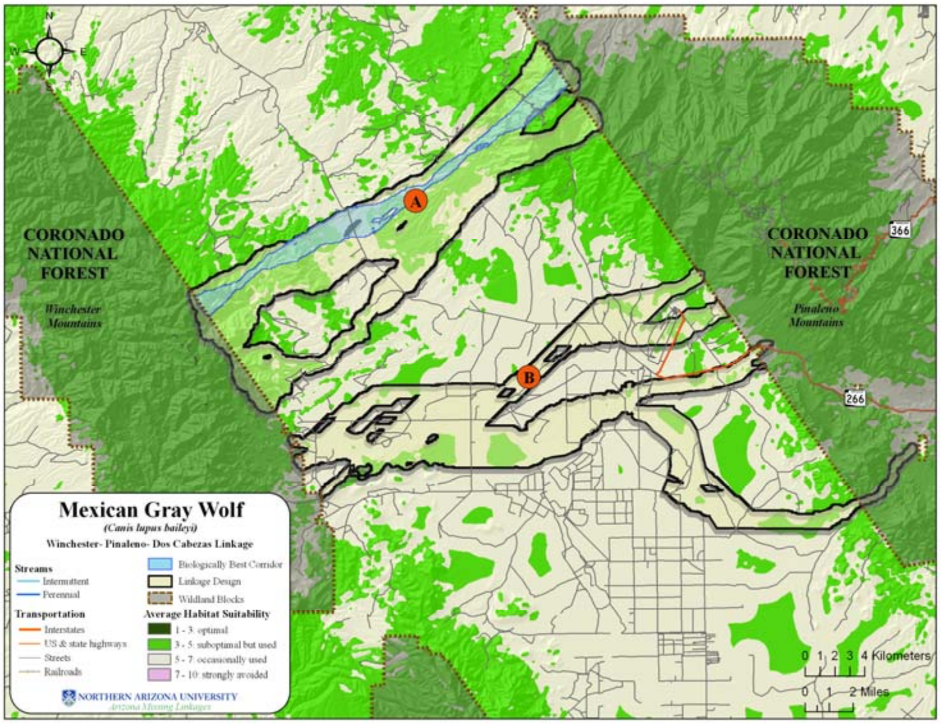

Figure 44: Modeled habitat suitability for Mexican gray wolf in the Galiuro-Pinaleño area

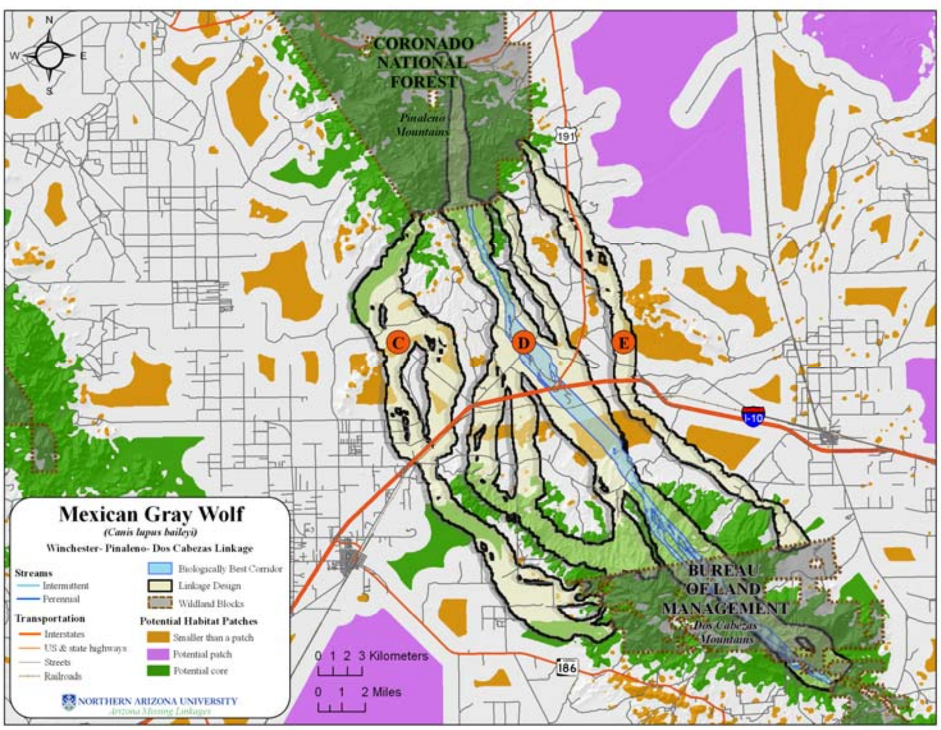

Figure 45: Potential habitat patches and cores for Mexican gray wolf in the Pinaleño-Dos Cabezas area

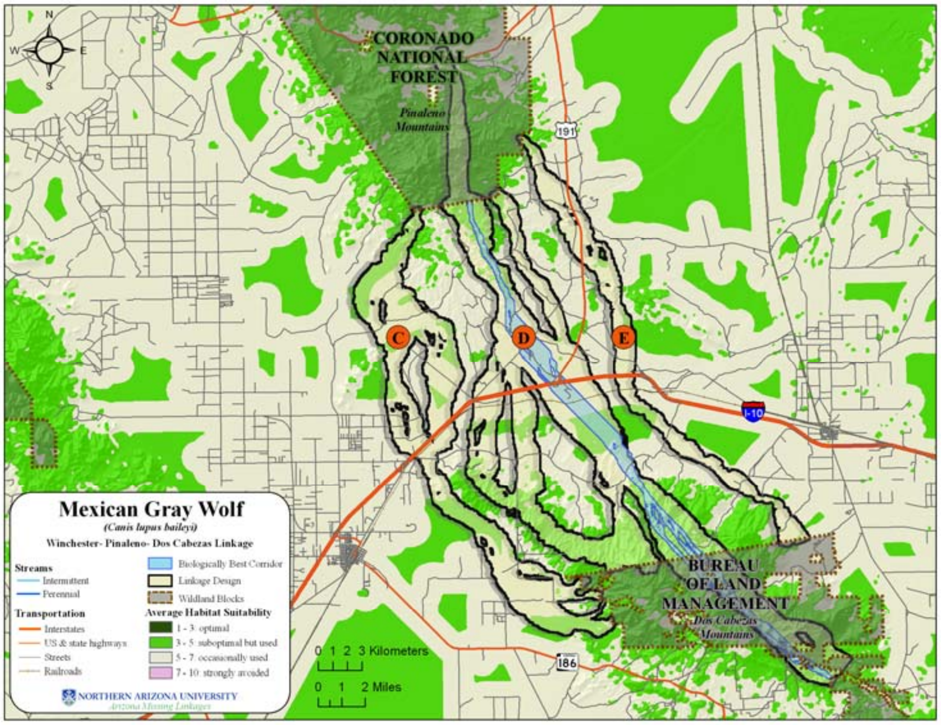

Figure 46: Modeled habitat suitability for Mexican gray wolf in the Pinaleño-Dos Cabezas area

Mountain Lion (*Puma concolor*)

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

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

Habitat Associations
Mountain lions are associated with mountainous areas with rocky cliffs and bluffs (Hoffmeister 1986; New Mexico Game and Fish Department 2004). They use a diverse range of habitats, including conifer, hardwood, mixed forests, shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Game and Fish Department 2004). Mountain lions are found at elevations ranging from 0 to 4,000 m (Currier 1983).

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

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate optimal lion habitat within the wildland blocks and patchily distributed suitable habitat for mountain lion throughout the potential linkage area (Figure 48 and Figure 50). Within the BBC in Strand A, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 1.1 to 5.3, with an average cost of 2.6 (S.D: 0.8). Within the BBC in Strand D, , between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.0 to 7.2, with an average of 2.8 (S.D:1.4).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures additional patches of suitable habitat for lion, with some additional optimal habitat near the wildland blocks. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10, and habitat fragmentation.

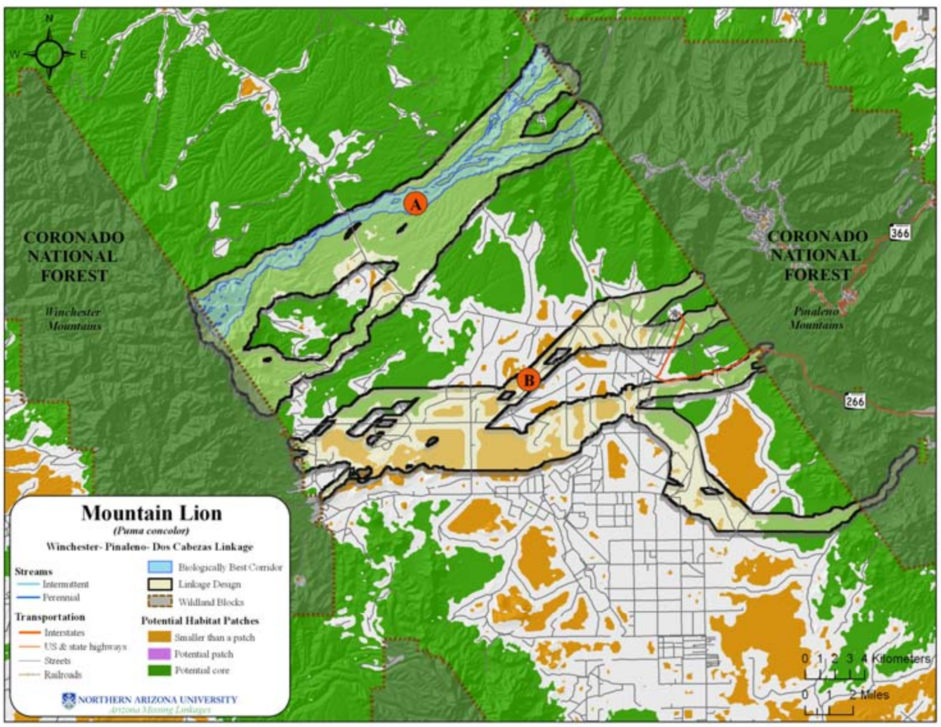

Figure 47: Potential habitat patches and cores for mountain lion in the Galiuro-Pinaleño area

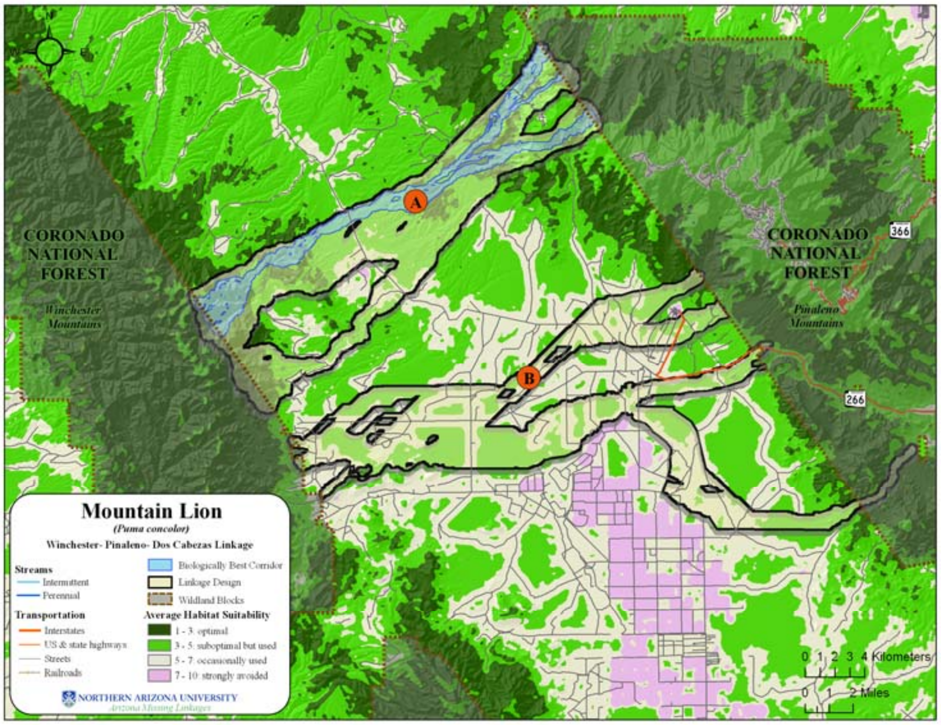

Figure 48: Modeled habitat suitability for mountain lion in the Galiuro-Pinaleño area

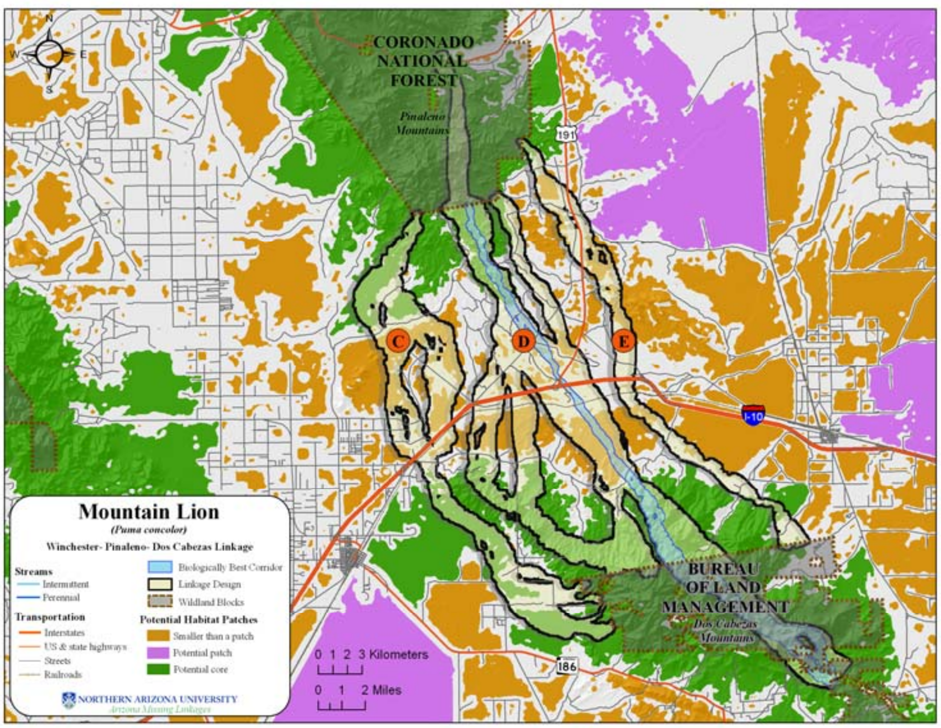

Figure 49: Potential habitat patches and cores for mountain lion in the Pinaleño-Dos Cabezas area

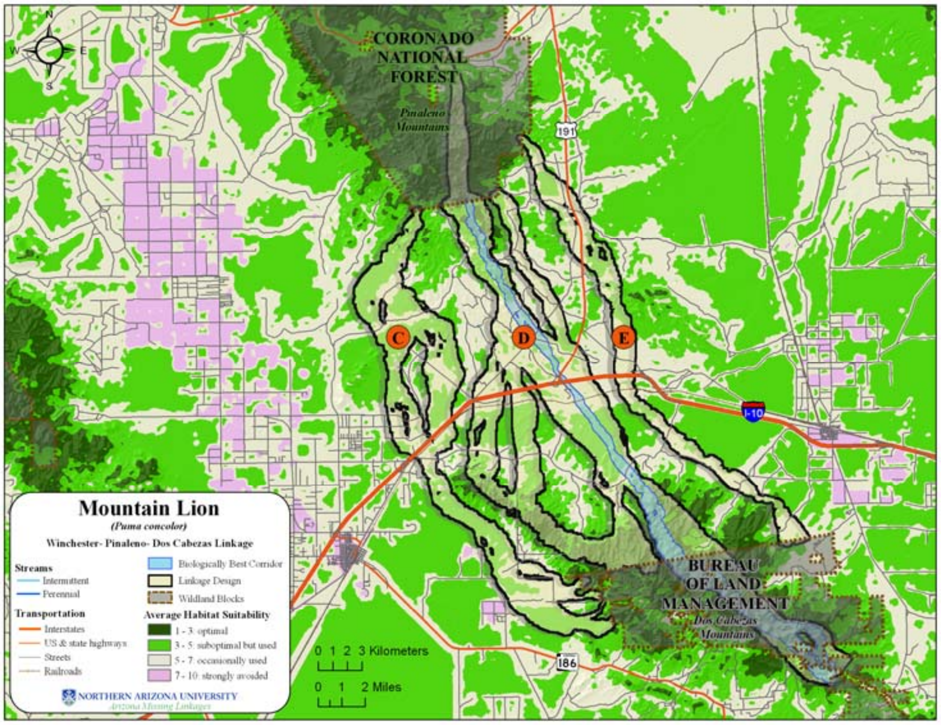

Figure 50: Modeled habitat suitability for mountain lion in the Pinaleño-Dos Cabezas area

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

Conceptual Basis for Model Development
Habitat suitability model – Vegetation has the greatest role in determining deer distributions in desert systems, followed by topography (Jason Marshal, personal comm.). For this reason, vegetation received an importance weight of 80%, while topography and distance from roads received weights of 15% and 5%, respectively. For specific scores of classes within each of these factors, see
.

Patch size & configuration analysis – Minimum patch size for mule deer was defined as 9 km^2 and minimum core size as 45 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of intermixed suitable and optimal habitat for mule deer within the potential linkage area (Figure 52 and Figure 54). Within the BBC in Strand B, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 2.0 to 4.9, with an average suitability cost of 2.3 (S.D: 0.3). Within the BBC in Strand D, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 2.1 to 6.4, with an average of 3.4 (S.D:0.6).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures additional suitable and optimal habitat for mule deer. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as Interstate 10, and habitat fragmentation.

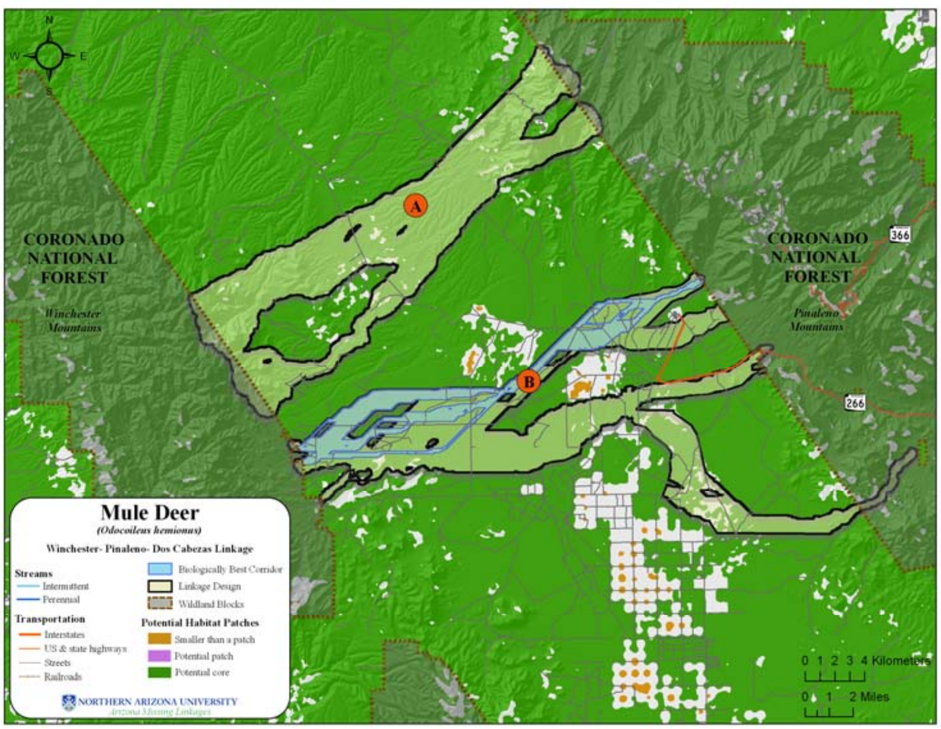

Figure 51: Potential habitat patches and cores for mule deer in the Galiuro-Pinaleño area

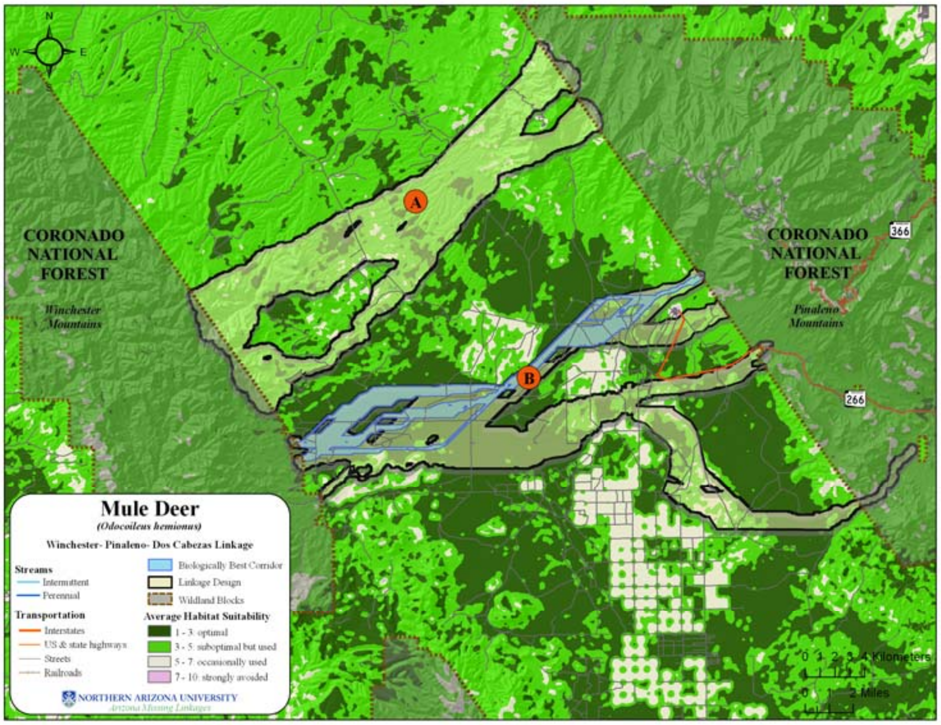

Figure 52: Modeled habitat suitability for mule deer in the Galiuro-Pinaleño area

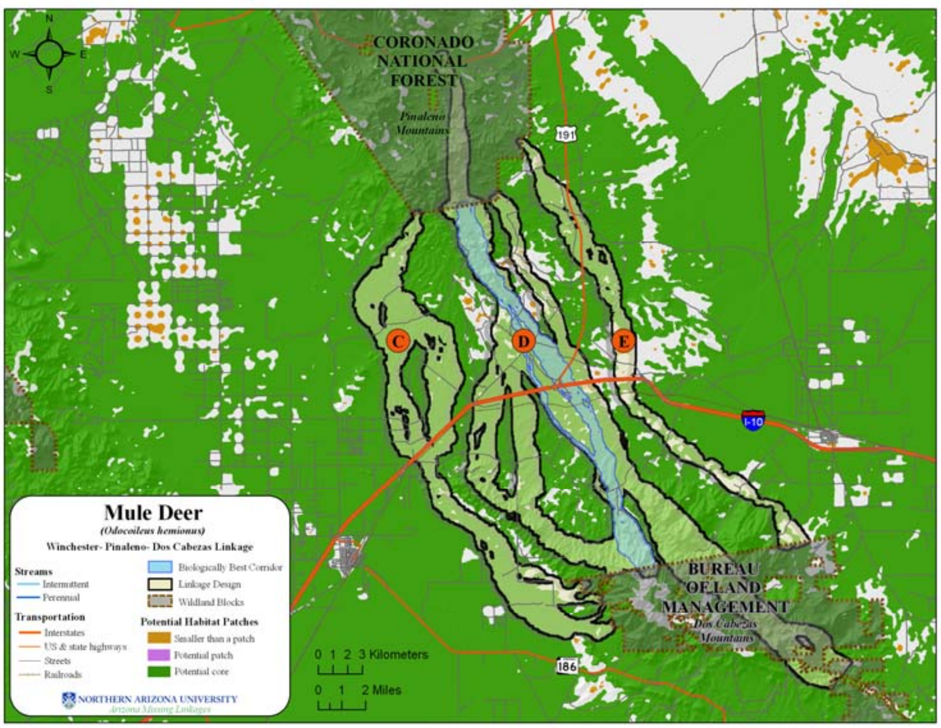

Figure 53: Potential habitat patches and cores for mule deer in the Pinaleño-Dos Cabezas area

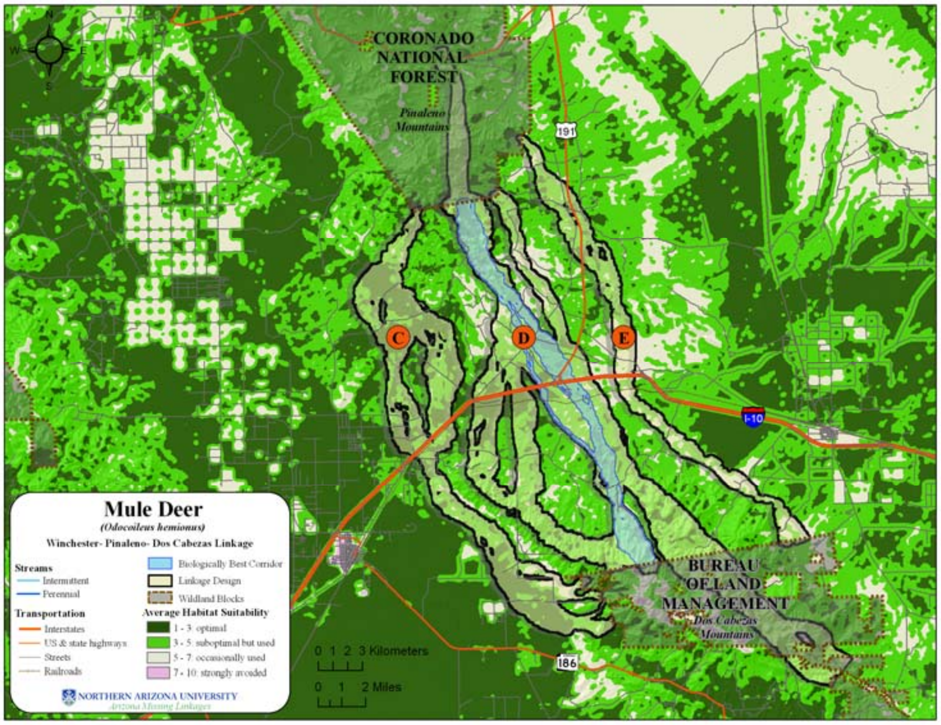

Figure 54: Modeled habitat suitability for mule deer in the Pinaleño-Dos Cabezas area

Pronghorn (*Antilocapra americana*)

Justification for Selection
Pronghorn are known to be susceptible to habitat degradation and human development (AZGFD 2002a). One example of harmful development is right of way fences for highways and railroads, which are the major factor affecting pronghorn movements across their range (Ockenfels et al. 1997). Existence of migration corridors is critical to pronghorn survival for allowing movement to lower elevation winter ranges away from high snowfall amounts (Ockenfels et al. 2002).

Distribution
Pronghorn range through much of the western United States, and are found throughout the grasslands of Arizona, except in the southeastern part of the state (Hoffmeister 1986). Pronghorn occur in the Sulphur Springs Valley, and find only seasonal and fringe habitat in the Coronado National Forest; the Forest Plan identifies about 57,000 acres of pronghorn habitat among the several ranger districts in the Forest.

Habitat Associations
Pronghorn are found in areas of grasses and scattered shrubs with rolling hills or mesas (New Mexico Department of Fish and Game 2004) (Ticer and Ockenfels 2001). They inhabit shortgrass plains as well as riparian areas of sycamore and rabbitbrush, and oak savannas (New Mexico Department of Fish and Game 2004). In winter, pronghorn rely on browse, especially sagebrush (O'Gara 1978). Pronghorn prefer gentle terrain, and avoid rugged areas (Ockenfels et al. 1997). Woodland and coniferous forests are also generally avoided, especially when high tree density obstructs vision (Ockenfels et al. 2002). Also for visibility, pronghorn prefer slopes that are less than 30% (Yoakum et al. 1996).

Spatial Patterns
In northern populations, home range has been estimated to range from 0.2 to 5.2 km^2, depending on season, terrain, and available resources (O'Gara 1978). However, large variation in sizes of home and seasonal ranges due to habitat quality and weather conditions make it difficult to apply data from other studies (O'Gara 1978). Other studies report home ranges that average 88 km^2 (Ockenfels et al. 1994) and 170 km^2 in central Arizona (Bright & Van Riper III 2000), and in the 75 – 125 km^2 range (n=37) in northern Arizona (Ockenfels et al. 1997). The Sonoran pronghorn subspecies is known to require even larger tracts of land to obtain adequate forage (AZGFD 2002b). One key element in pronghorn movement is distance to water. One study found that 84% of locations were less than 6 km from water sources (Bright & Van Riper III 2000), and another reports collared pronghorn locations from 1.5 – 6.5 km of a water source (Yoakum et al. 1996). Habitats within 1 km of water appear to be key fawn bedsite areas for neonate fawns (Ockenfels et al. 1992).

Conceptual Basis for Model Development
Habitat suitability model – Vegetation received an importance weight of 45%, while topography and distance from roads received weights of 37% and 18%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis **–** Minimum patch size for pronghorn was defined as 50 km2 and minimum core size as 250 km2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species between the Galiuro and Pinaleño Mountains wildland blocks, and the Pinaleño and Dos Cabezas Mountains wildland blocks.

Results & Discussion

Initial biologically best corridor – Modeling results indicate intermixed suitable and optimal habitat for pronghorn occurring in the lowlands between the wildland blocks (Figure 56 and Figure 58). Within the BBC in Strand B, between the Galiuro and Pinaleño Mountains wildland blocks, habitat suitability scores ranged from 1.0 to 7.3, with an average cost of 2.2 (S.D: 1.2). Within the BBC in Strand C, between the Pinaleño and Dos Cabezas Mountains wildland blocks, habitat suitability scores ranged from 1.0 to 7.1, with an average of 2.7 (S.D:1.2).

Union of biologically best corridors – The additional arms of Strand B, along with strands D and E capture significant amounts of suitable and optimal habitat for pronghorn. Because their preferred habitat occurs in areas with residential developments, the greatest threats to pronghorn connectivity and persistence are most likely continued development, fences, roads, and habitat fragmentation.

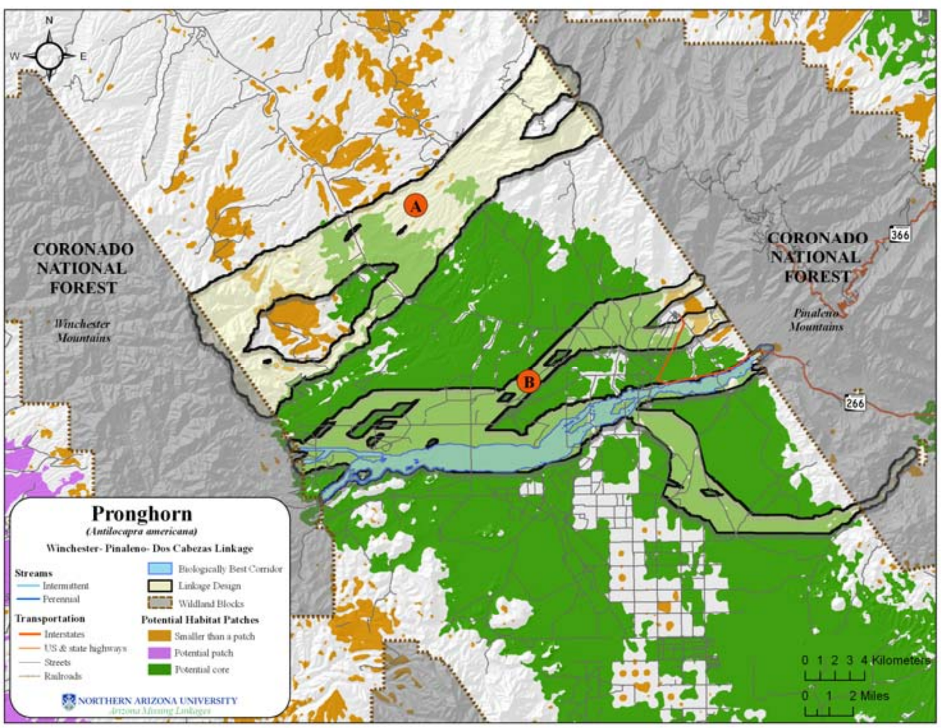

Figure 55: Potential habitat patches and cores for pronghorn in the Galiuro-Pinaleño area

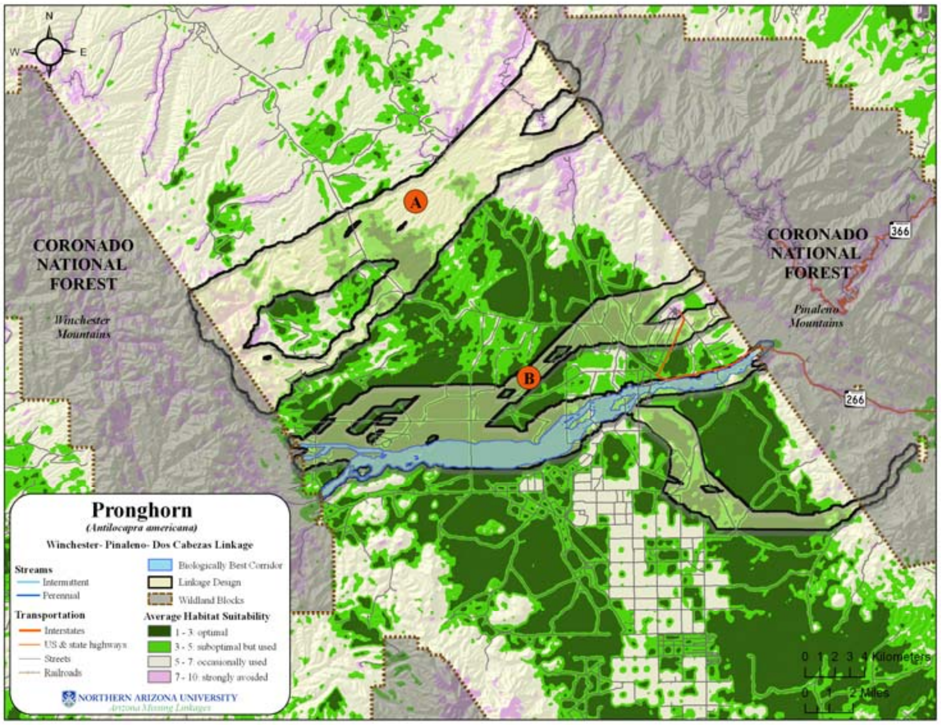

Figure 56: Modeled habitat suitability for pronghorn in the Galiuro-Pinaleño area

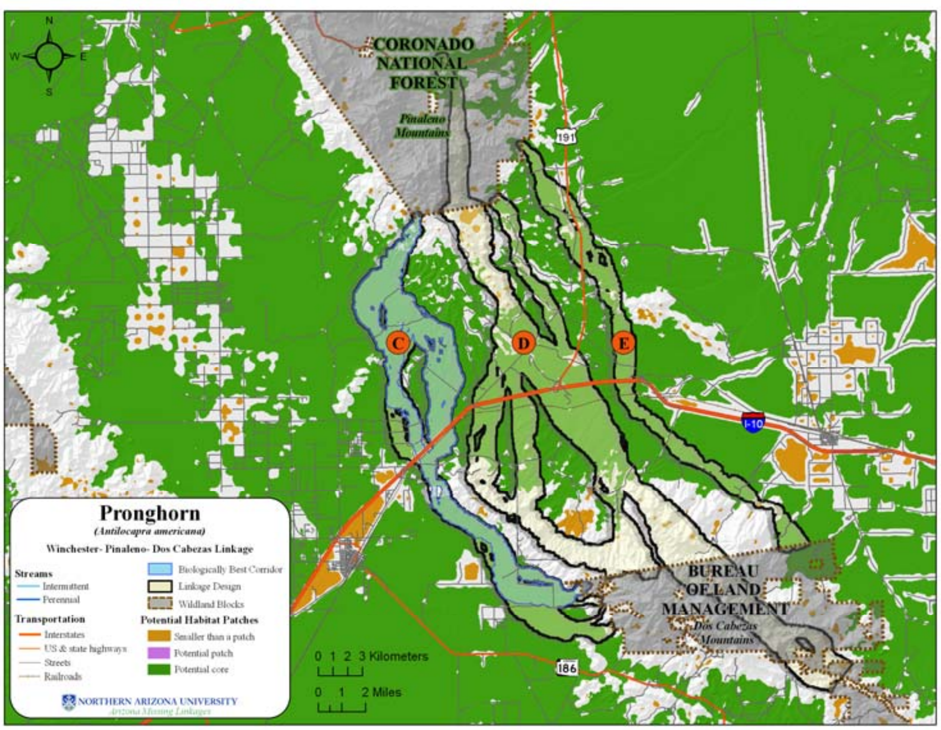

Figure 57: Potential habitat patches and cores for pronghorn in the Pinaleño-Dos Cabezas area

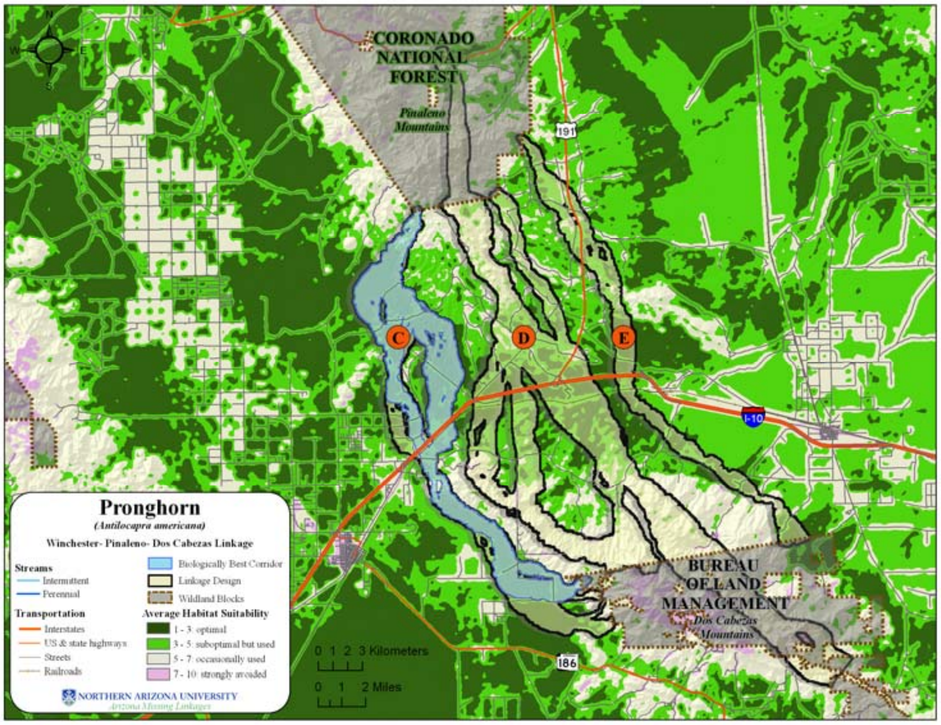

Figure 58: Modeled habitat suitability for pronghorn in the Pinaleño-Dos Cabezas area

Appendix C: Focal Species not Modeled

The habitat requirements and connectivity needs of several suggested focal species were not modeled in this study because there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), because the species does not occur in both wildland blocks, or because the species probably can travel (e.g., by flying) across unsuitable habitat. A list of these species follows:

Mammals

- Bats – 'Bats' were suggested as a focal taxon; however, their habitat preferences cannot be easily modeled using standard GIS layers, and they are highly mobile.
- Black-Tailed Prairie Dog (*Cynomys ludovicianus)* – This species inhabits shortgrass plains and desert grasslands at lower elevations between the wildland blocks. Cockrum (1960) asserts that they are extinct in southeastern Arizona, and Hoffmeister (1986) states they were extirpated in 1938. We reasoned that potential habitat would be identified by the remaining suite of focal species, particularly badger.

Birds

- Sandhill Crane (*Grus canadensis*) – The sandhill crane prefers open grasslands, meadows, and wetlands where it feeds and builds its nests. Its preferred habitat does not occur within the wildland blocks, though the Willcox Playa Wildlife Area serves as important habitat.
- Western Burrowing Owl (*Athene cunicularia hypugaea*) – Western burrowing owls are designated a sensitive species by the BLM. They prefer open, well-drained grasslands, steppes, deserts, and prairies (AZGFD 2001). We reasoned they would be well-covered by the remaining suite of focal species, and we could not model their movement realistically.

Reptiles and Amphibians

- Ornate Box Turtle (*Terrapene ornata*) –a terrestrial species known to occur in the plains, grasslands and pastures of southeastern Arizona, (Stebbins 1985). It prefers open prairies with herbaceous vegetation (Garret and Barker 1987). It is uncommon to rocky slopes, rare to bajada desertscrub, common to mesquite-dominated bajada, abundant in bajada grasslands, grassland flats, mesquite-dominated flats, and uncommon to agricultural edge in the Sulphur Springs Valley (Rosen & et al, 1996). Possible threats include pesticide use, collecting for the pet trade, and highways, with significant road-kill along SR 186, SR 181, and US 191 (Stickle 1978, P. Rosen, personal communication, March 2008). Because wild box turtles can live over 100 years in the absence of road mortality, Phil Rosen believes that highway mortality may be the number one threat to box turtles in this region. In this area, the best habitat for box turtles is on the level floor of Sulphur Springs Valley, especially areas with some sand, and on friable, rich grassy bajadas, including areas near agriculture and semi-rural areas (Rosen, personal communication).
- Plains Leopard Frog (*Rana blairi*) – this species is listed as a Species of Special Concern in Arizona, where an isolated population occurs in low elevation wetlands in Sulphur Springs Valley, more than 300 km west of the next nearest known population (Rosen & et al, 1996). Threats include habitat loss and predation by bullfrogs and nonnative fishes (AGFD 1996). Phil Rosen (personal communication, March 2008) states that the species may occur north of I-10, but the northernmost known populations are about 8 miles south of I-10, near the power plant at the southwest corner of Willcox Playa.

Because our wildland blocks are relatively poor habitat for box turtles and leopard frogs, it did not make sense to develop corridor models for them as we did for the other focal species. Nonetheless, the linkage design area is important habitat for these species. With climate change, it may be important for *Rana blairi* to shift its geographic range to the north. Other species of reptiles and amphibians also find good habitat in the Sulphur Springs Valley, and this report provides a rare opportunity to consider ways to promote connectivity and reduce mortality for reptiles and amphibians. Accordingly, we made recommendations for many culverts along all paved roads in the flat valley bottoms and bajadas of Sulphur Springs Valley (Figure 2).

- Chiricahua Leopard Frog (*Rana chiricahuensis*) – A federally threatened species found in aquatic habitats including cienegas, pools, springs, seeps, livestock tanks, wells, lakes, reservoirs, ponds, streams and rivers (Degenhardt et al., 1996, Stebbins 1985). While it occurs in southeastern Arizona, the population status in Arizona is very poorly known. It is threatened by habitat destruction, pollution, and predation by bullfrogs (AGFD 1988).
- Texas Horned Lizard (*Phrynosoma coronatum*) – This species occurs at low elevations in arid and semiarid open country with sparse plant growth including bunchgrass, cactus, juniper, acacia, and mesquite (Stebbins 2003 and Finch 1992). It may be threatened by pesticide use, habitat loss and fragmentation, and competition or predation by nonnative species (Painter 1997).

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor adjustments to the union of biologically best corridors (Figure 59):

- We filled in small holes where the landscape appeared to be permeable.
- In the southern section of strand B, we removed a narrow arm of the UBBC through and areas of development and agriculture, replacing with a roughly parallel segment on ASLD land to maintain a continuous swath.
- We widened the UBBC in several locations to ensure all strands were at least 1 km wide.
- We removed the southernmost portion of strand D (the jaguar corridor) because this linear feature was an artifact depicting a connection toward occupied habitat in Mexico.

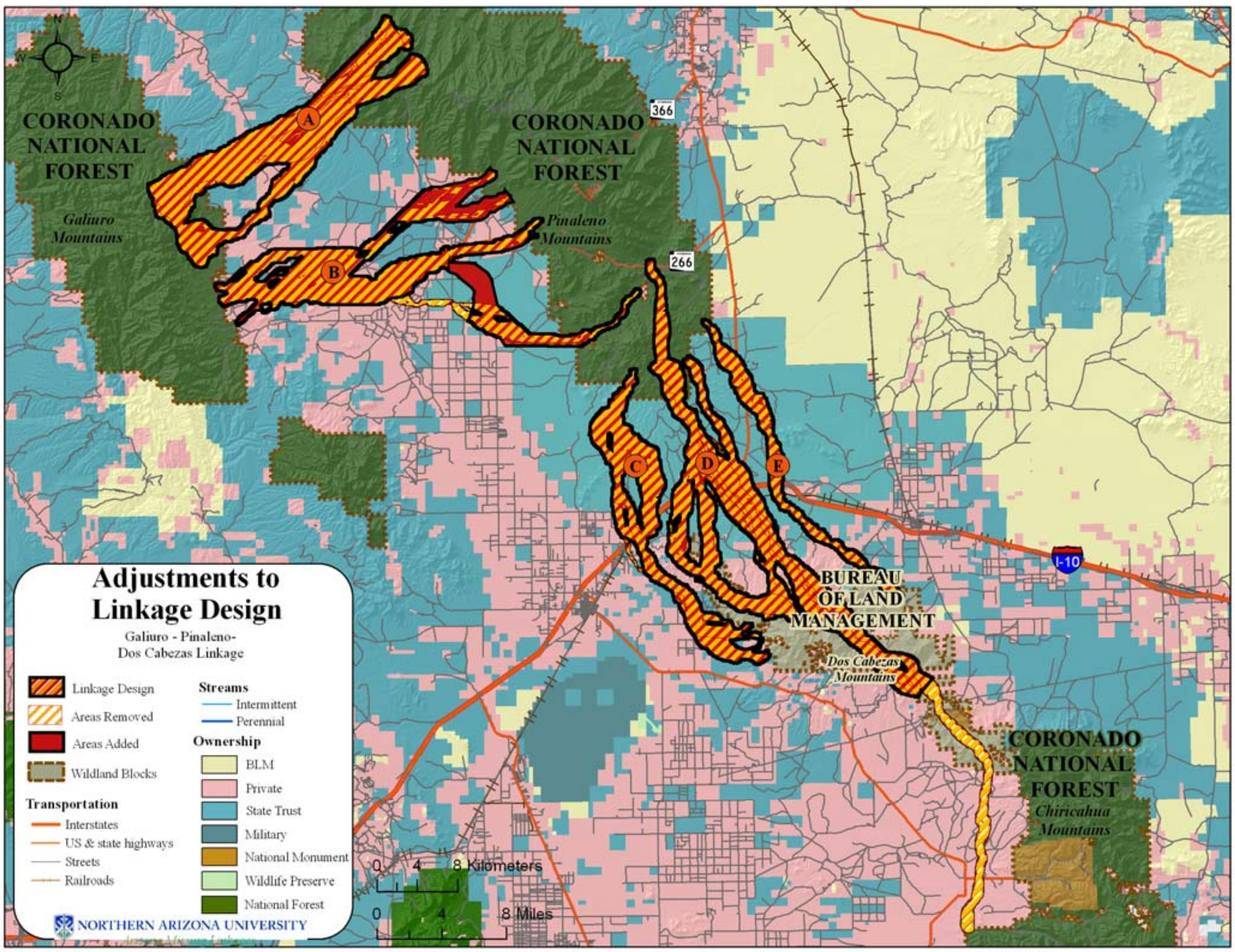

Figure 59: Adjustments to union of biologically best corridors to create the Linkage Design.

Appendix E: Description of Land Cover Classes

Vegetation classes have been derived from the Southwest Regional GAP analysis (ReGAP) land cover layer. To simplify the layer from 77 to 46 classes, we grouped similar vegetation classes into slightly broader classes by removing geographic and environmental modifiers (e.g. Chihuahuan Mixed Salt Desert Scrub and Inter-Mountain Basins Mixed Salt Desert Scrub got lumped into "Desert Scrub"; Subalpine Dry-Mesic Spruce-Fir Forest and Woodland was simplified to Spruce-Fir Forest and Woodland). What follows is a description of each class found in the linkage area, taken largely from the document, Landcover Descriptions for the Southwest Regional GAP Analysis Project (Available from http://earth.gis.usu.edu/swgap)

EVERGREEN FOREST (2 CLASSES) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

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

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

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

GRASSLANDS-HERBACEOUS (2 CLASSES) – Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Juniper Savanna – The vegetation is typically open savanna, although there may be inclusions of more dense juniper woodlands. This savanna is dominated by *Juniperus osteosperma* trees with high cover of perennial bunch grasses and forbs, with *Bouteloua gracilis* and *Pleuraphis jamesii* being most common. In southeastern Arizona, these savannas have widely spaced mature juniper trees and moderate to high cover of graminoids (>25% cover). The presence of Madrean *Juniperus* spp. such as *Juniperus coahuilensis, Juniperus pinchotii*, and/or *Juniperus deppeana* is diagnostic.

Semi-Desert Grassland and Shrub Steppe – Comprised of *Semi-Desert Shrub Steppe* and *Piedmont Semi-Desert Grassland and Steppe*. Semi-Desert Shrub is typically dominated by graminoids (>25% cover) with an open shrub layer, but includes sparse mixed shrublands without a strong graminoid layer. Steppe

Piedmont Semi-Desert Grassland and Steppe is a broadly defined desert grassland, mixed shrub-succulent or xeromorphic tree savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico [Apacherian region], but extends west to the Sonoran Desert, north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is found on gently sloping bajadas that supported frequent fire throughout the Sky Islands and on mesas and steeper piedmont and foothill slopes in the Chihuahuan Desert. It is characterized by typically diverse perennial grasses. Common grass species include *Bouteloua eriopoda, B. hirsuta,B. rothrockii, B. curtipendula, B. gracilis, Eragrostis intermedia, Muhlenbergia porteri, Muhlenbergia setifolia, Pleuraphis jamesii, Pleuraphis mutica*, and *Sporobolus airoides*, succulent species of *Agave, Dasylirion*, and *Yucca*, and tall shrub/short tree species of *Prosopis* and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica*).

SCRUB-SHRUB (5 CLASSES) – Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

<u>Chaparral</u> – 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.

<u>Creosotebush-White Bursage Desert Scrub</u> – 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.

<u>Desert Scrub (misc)</u> – 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.

<u>Mesquite Upland Scrub</u> – 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.

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

WOODY WETLAND (2 CLASSES) – Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

<u>Riparian Mesquite Bosque</u> – 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*.

<u>Riparian Woodland and Shrubland</u> – This system is dependent on a natural hydrologic regime, especially annual to episodic flooding. Occurrences are found within the flood zone of rivers, on islands, sand or cobble bars, and immediate streambanks. In mountain canyons and valleys of southern Arizona, this system consists of mid- to low-elevation (1100-1800 m) riparian corridors along perennial and seasonally

intermittent streams. The vegetation is a mix of riparian woodlands and shrublands. Throughout the Rocky Mountain and Colorado Plateau regions, this system occurs within a broad elevation range from approximately 900 to 2800 m., as a mosaic of multiple communities that are tree-dominated with a diverse shrub component.

BARREN LANDS (2 CLASSES) – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulation of earthen material. Generally, vegetation accounts for less than 15% of total cover.

Barren Lands, Non-specific – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulation of earthen material. Generally, vegetation accounts for less than 15% of total cover.

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

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

Appendix F: Literature Cited

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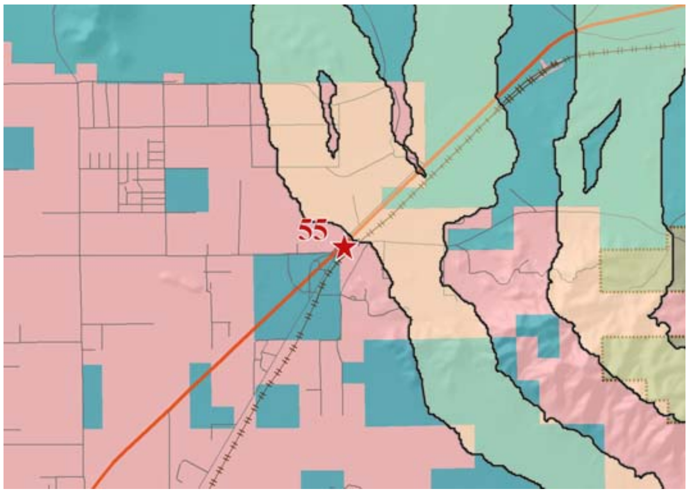
Appendix G: Database of Field Investigations

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

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	55		
Linkage Zone:	Wilcox	**Latitude:**	32.31245	**Longitude:**	-109.78977
Observers:	Paul Beier	**UTM X:**	613927.0000	**UTM Y:**	3575712.492
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Frontage Road near I-10, at MP 345

Site Photographs

Name: IMG_0877.jpg

Azimuth: 100 **Zoom:** 3

Notes: A railroad line near the Dos Cabezas Mountains

Name: IMG_0878.jpg

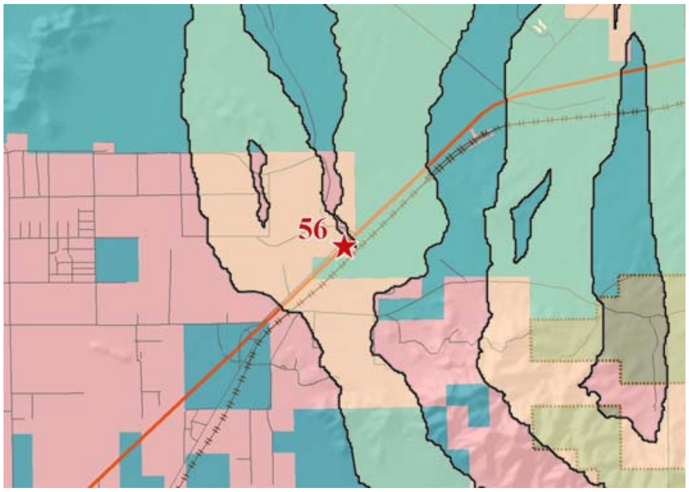
Azimuth: 0 **Zoom:** 6

Notes: I-10 and the southern Pinaleno Mountains

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	56		
Linkage Zone:	Wilcox	**Latitude:**	32.32408	**Longitude:**	-109.77592
Observers:	Paul Beier	**UTM X:**	615216.1496	**UTM Y:**	3577016.590
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

On I-10 at MP 346.2

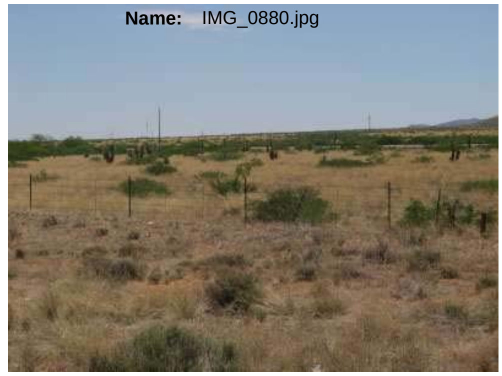
Site Photographs

Name: IMG_0879.jpg

Azimuth: 130 **Zoom:** 2

Notes: Railroad and Dos Cabezas Mountains

Name: IMG_0880.jpg



Azimuth: 75 **Zoom:** 2

Notes: Railroad, desert scrub, and grasslands

Name: IMG_0881.jpg

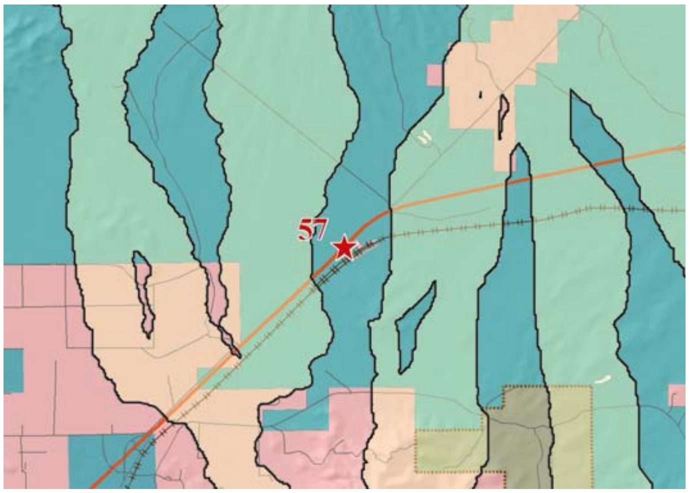
Azimuth: 0 **Zoom:** 2

Notes: I-10 and the Circle I Hills

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	57		
Linkage Zone:	Wilcox	**Latitude:**	32.34231	**Longitude:**	-109.75307
Observers:	Paul Beier	**UTM X:**	617343.5165	**UTM Y:**	3579062.365
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

I-10 at MP 348

Site Photographs

Name: IMG_0882.jpg

Azimuth: 335 **Zoom:** 2

Notes: I-10 and the Pinaleno Foothills

Name: IMG_0883.jpg

Azimuth: 20 **Zoom:** 2

Name: IMG_0884.jpg

Azimuth: 125 **Zoom:** 2

Notes: Railroad and Dos Cabezas

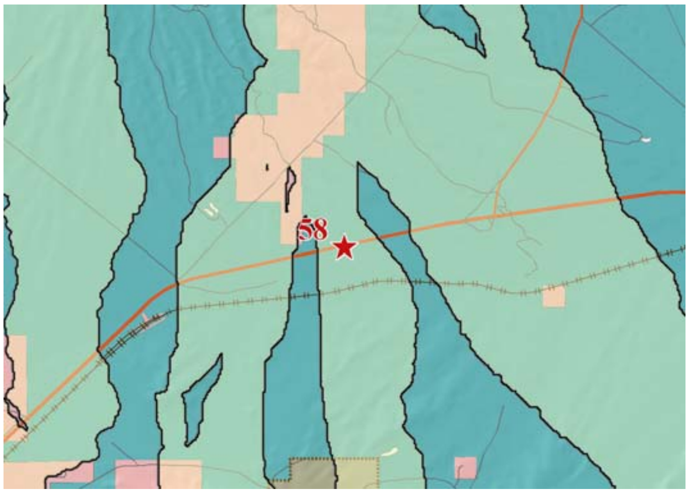
Name: IMG_0885.jpg

Azimuth: 50 **Zoom:** 1

Notes: Desert grasslands, I-10, and railroad

Linkage #:	89	**Waypoint #:**	58		
Linkage Zone:	Wilcox	**Latitude:**	32.35406	**Longitude:**	-109.71103
Observers:	Paul Beier	**UTM X:**	621284.3306	**UTM Y:**	3580411.826
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

I-10 at MP 350.5

Site Photographs

Name: IMG_0887.jpg

Azimuth: 200 **Zoom:** 1

Notes: Northern foothills of the Dos Cabezas and heavily grazed desert scrub

Name: IMG_0888.jpg

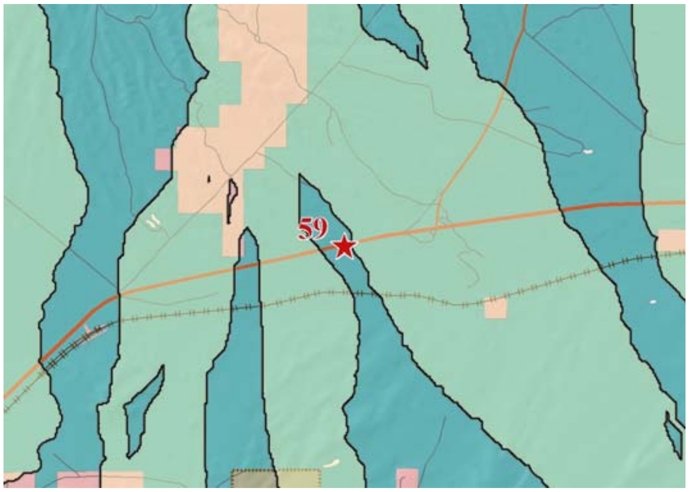
Azimuth: 145 **Zoom:** 1

Name: IMG_0889.jpg

Azimuth: 105 **Zoom:** 1

Linkage #:	89	**Waypoint #:**	59		
Linkage Zone:	Wilcox	**Latitude:**	32.35602	**Longitude:**	-109.69958
Observers:	Paul Beier	**UTM X:**	622359.1464	**UTM Y:**	3580642.145
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

I-10 at MP 351.2

Site Photographs

Name: IMG_0890.jpg

Azimuth: 325 **Zoom:** 2

Notes: The Pinalenos Mountains

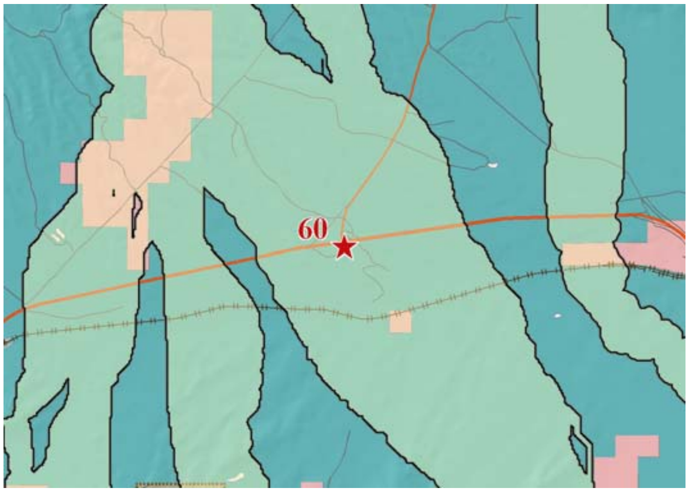
Name: IMG_0891.jpg

Zoom: 1

Notes: An 8x10' box culvert

Linkage #:	89	**Waypoint #:**	60		
Linkage Zone:	Wilcox	**Latitude:**	32.35815	**Longitude:**	-109.68085
Observers:	Paul Beier	**UTM X:**	624118.7129	**UTM Y:**	3580899.846
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map

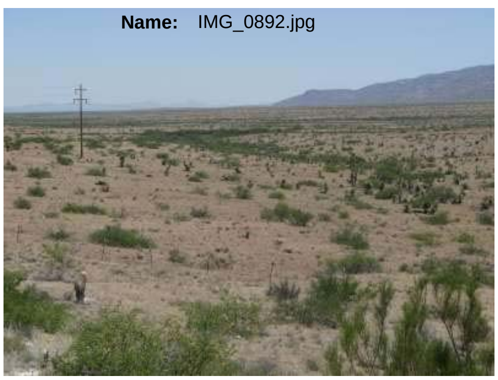


Waypoint Notes

I-10 and US 191 Junction

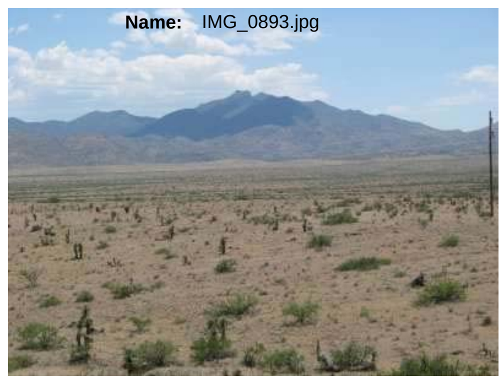
Site Photographs

Name: IMG_0892.jpg



Azimuth: 90 **Zoom:** 2
Notes: Desert

Name: IMG_0893.jpg



Azimuth: 130 **Zoom:** 2
Notes: Desert and Dos Cabezas Peak

Name: IMG_0894.jpg

Azimuth: 160 **Zoom:** 2
Notes: Northern Dos Cabezas Mountains and desert

Name: IMG_0895.jpg

Azimuth: 205 **Zoom:** 4

Linkage #:	89	**Waypoint #:**	61		
Linkage Zone:	Wilcox	**Latitude:**	32.36129	**Longitude:**	-109.62034
Observers:	Paul Beier	**UTM X:**	629808.0696	**UTM Y:**	3581319.739
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map

Waypoint Notes

I-10 and US 191 Junction

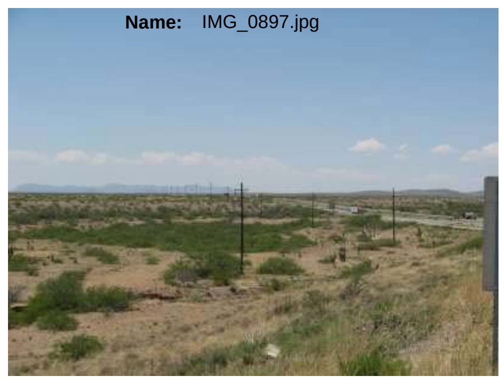
Site Photographs

Name: IMG_0896.jpg

Azimuth: 205 **Zoom:** 2

Notes: Desert and northern Dos Cabezas Mountains

Name: IMG_0897.jpg



Azimuth: 250 **Zoom:** 2

Notes: I-10

Name: IMG_0898.jpg

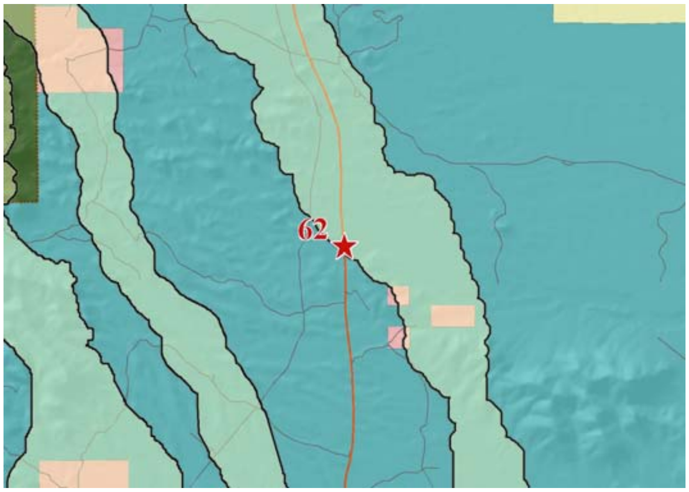
Azimuth: 295 **Zoom:** 3

Notes: Northern Pinalenos behind I-10

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	62		
Linkage Zone:	Wilcox	**Latitude:**	32.43344	**Longitude:**	-109.66335
Observers:	Paul Beier	**UTM X:**	625661.0695	**UTM Y:**	3589267.102
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

US 191 at MP 93

Site Photographs

Name: IMG_0899.jpg

Azimuth: 280 **Zoom:** 4

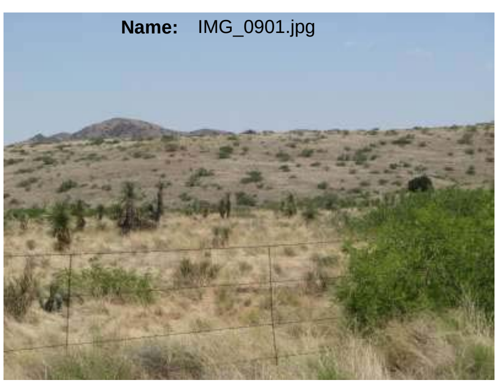
Notes: The southern Pinalenos Mountains

Name: IMG_0900.jpg

Azimuth: 135 **Zoom:** 4

Notes: Dos Cabezas

Name: IMG_0901.jpg



Azimuth: 105 **Zoom:** 4

Notes: Rolling hills to the east

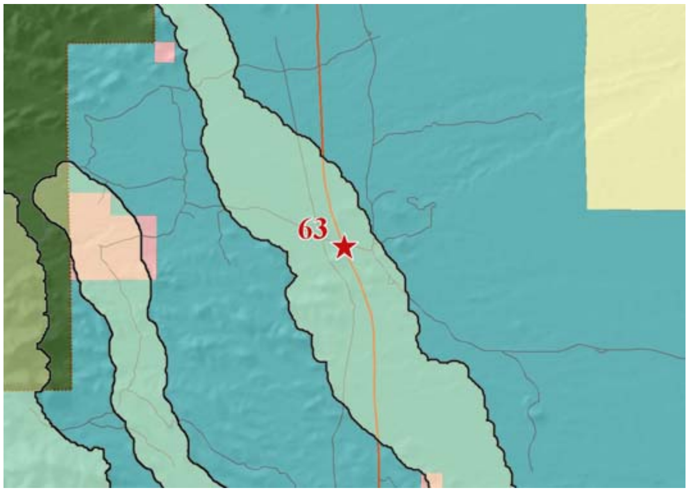
Name: IMG_0902.jpg

Azimuth: 305 **Zoom:** 4

Notes: Mt Graham

Linkage #:	89	**Waypoint #:**	63		
Linkage Zone:	Wilcox	**Latitude:**	32.46487	**Longitude:**	-109.66948
Observers:	Paul Beier	**UTM X:**	625041.3088	**UTM Y:**	3592744.335
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

US 191 at MP 95.2

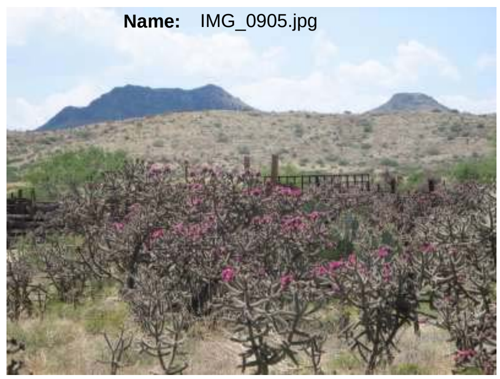
Site Photographs

Name: IMG_0903.jpg

Zoom: 2

Notes: A 3-box culvert

Name: IMG_0905.jpg



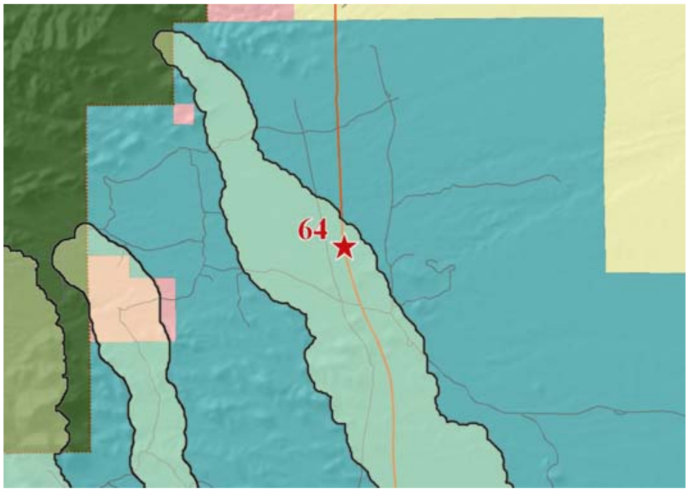
Azimuth: 220 **Zoom:** 6

Notes: Cholla blooming before the southern Pinalenos mountains

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	64		
Linkage Zone:	Wilcox	**Latitude:**	32.47532	**Longitude:**	-109.67305
Observers:	Paul Beier	**UTM X:**	624691.3700	**UTM Y:**	3593898.68
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

US 191 near MP 96

Site Photographs

Name: IMG_0906.jpg

Azimuth: 275 **Zoom:** 1

Notes: Mesquite scrub

Name: IMG_0907.jpg

Zoom: 1

Notes: A 4-box culvert

Name: IMG_0908.jpg

Azimuth: 235 **Zoom:** 2

Notes: Upstream

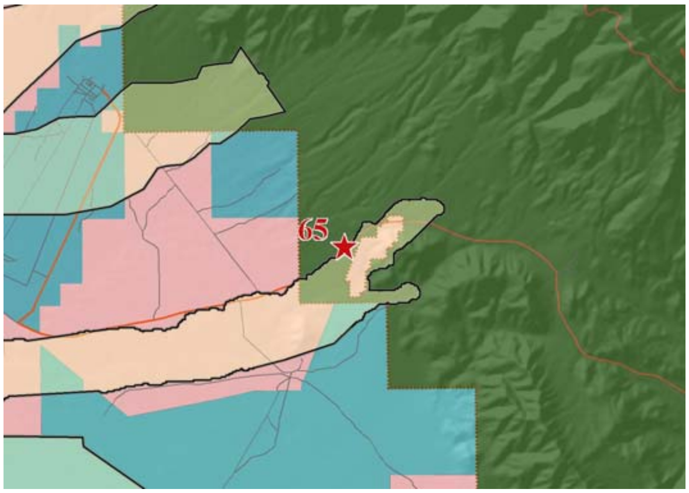
Name: IMG_0909.jpg

Azimuth: 290 **Zoom:** 2

Notes: Mt. Graham

Linkage #:	89	**Waypoint #:**	65		
Linkage Zone:	Wilcox	**Latitude:**	32.59647	**Longitude:**	-109.89627
Observers:	Paul Beier	**UTM X:**	603575.3566	**UTM Y:**	3607090.494
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

SR 266 at MP 9.1

Site Photographs

Name: IMG_0910.jpg

Azimuth: 35 **Zoom:** 1

Notes: SR 266 and the southern Pinalenos

Name: IMG_0911.jpg

Azimuth: 315 **Zoom:** 1

Notes: Mt. Graham

Name: IMG_0912.jpg

Azimuth: 280 **Zoom:** 6

Notes: Fort Grant

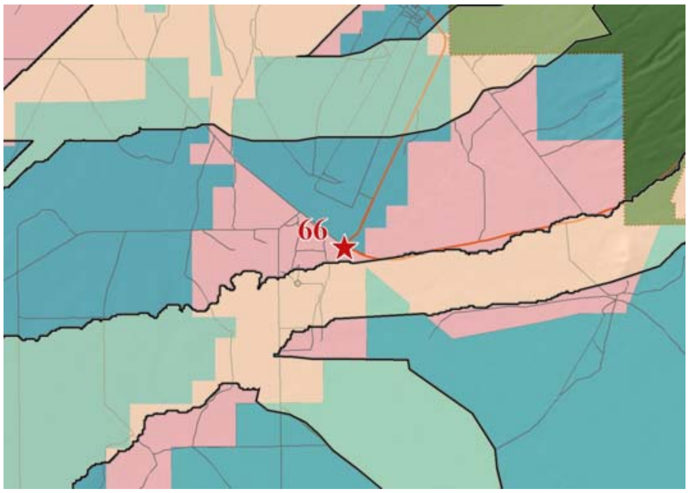
Name: IMG_0913.jpg

Azimuth: 260 **Zoom:** 6

Notes: Sulphur Springs Valley and Winchester Mountains

Linkage #:	89	**Waypoint #:**	66		
Linkage Zone:	Wilcox	**Latitude:**	32.58403	**Longitude:**	-109.96049
Observers:	Paul Beier	**UTM X:**	597562.0644	**UTM Y:**	3605650.657
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Junction of SR 266 and Klondike

Site Photographs

Name: IMG_0914.jpg

Zoom: 1

Notes: Downstream side of bridge

Name: IMG_0916.jpg

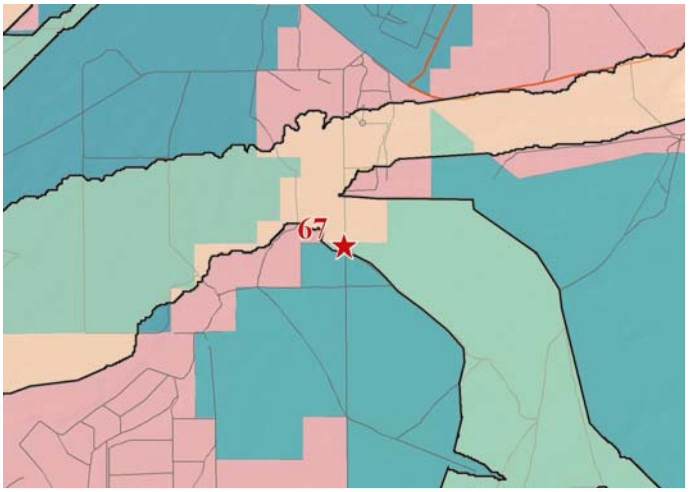
Azimuth: 60 **Zoom:** 6

Notes: Bajada

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	67		
Linkage Zone:	Wilcox	**Latitude:**	32.55752	**Longitude:**	-109.97358
Observers:	Paul Beier	**UTM X:**	596361.8069	**UTM Y:**	3602699.828
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map

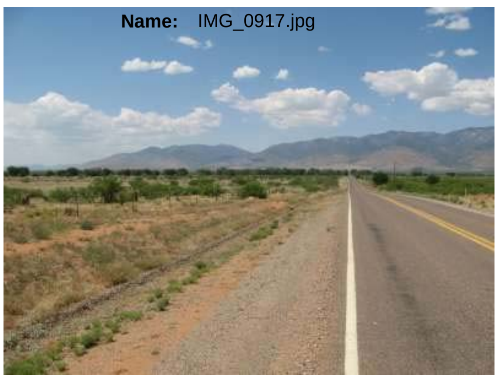


Waypoint Notes

Fort Grant Road

Site Photographs

Name: IMG_0917.jpg



Azimuth: 315 **Zoom:** 1

Notes: Fort Grant Road headed toward a Cottonwood forest

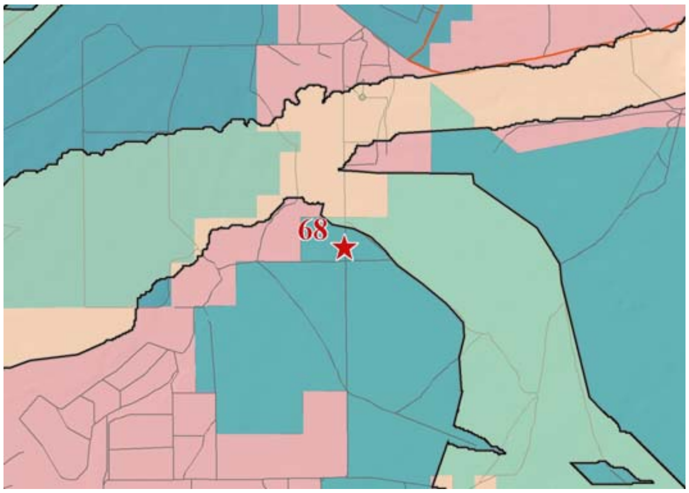
Name: IMG_0918.jpg

Azimuth: 245 **Zoom:** 6

Notes: Winchester and Gallinas Mountains in the distance

Linkage #:	89	**Waypoint #:**	68		
Linkage Zone:	Wilcox	**Latitude:**	32.55309	**Longitude:**	-109.97357
Observers:	Paul Beier	**UTM X:**	596367.4806	**UTM Y:**	3602208.728
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Fort Grant Road

Site Photographs

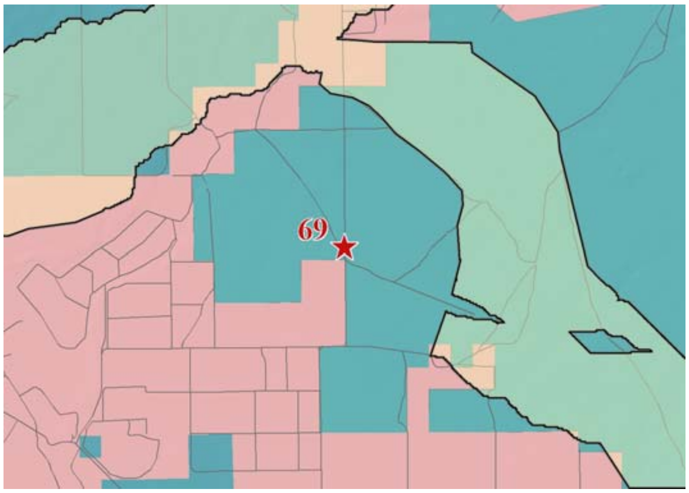
Name: IMG_0919.jpg

Azimuth: 70 **Zoom:** 6

Notes: An antelope friendly fence in the grassland scrub

Linkage #:	89	**Waypoint #:**	69		
Linkage Zone:	Wilcox	**Latitude:**	32.53109	**Longitude:**	-109.97349
Observers:	Paul Beier	**UTM X:**	596398.499	**UTM Y:**	3599769.890
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Fort Grant Road

Site Photographs

Name: IMG_0921.jpg

Azimuth: 35 **Zoom:** 4

Notes: Cropland east of the road

Name: IMG_0922.jpg

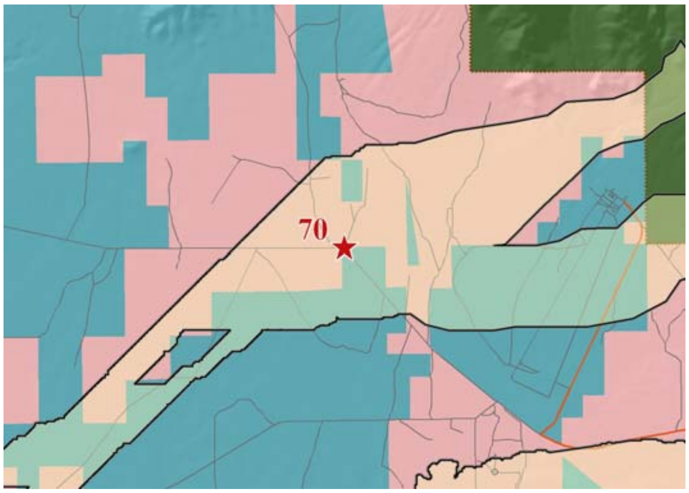
Azimuth: 295 **Zoom:** 4

Notes: Semi-desert grassland habitat

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	70		
Linkage Zone:	Wilcox	**Latitude:**	32.61603	**Longitude:**	-109.99887
Observers:	Paul Beier	**UTM X:**	593926.394	**UTM Y:**	3609163.632
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Bonita Road

Site Photographs

Name: IMG_0923.jpg

Azimuth: 220 **Zoom:** 4

Notes: Grassland Scrub

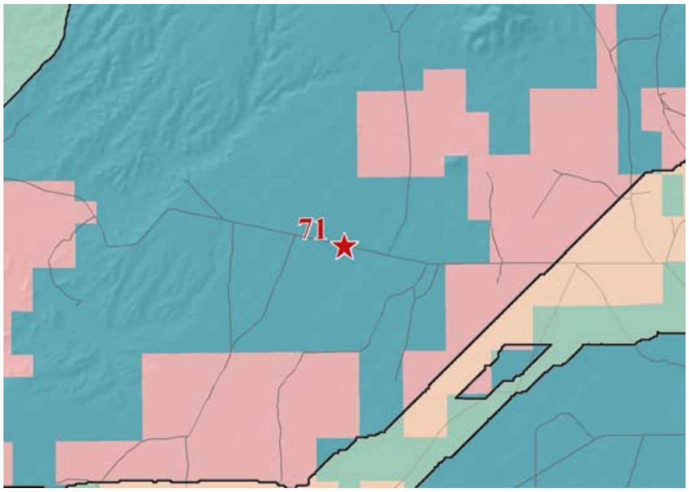
Name: IMG_0924.jpg

Azimuth: 0 **Zoom:** 4

Notes: The Pinalenos

Linkage #:	89	**Waypoint #:**	71		
Linkage Zone:	Wilcox	**Latitude:**	32.61907	**Longitude:**	-110.06203
Observers:	Paul Beier	**UTM X:**	587997.4937	**UTM Y:**	3609446.589
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Bonita Road

Site Photographs

Name: IMG_0925.jpg

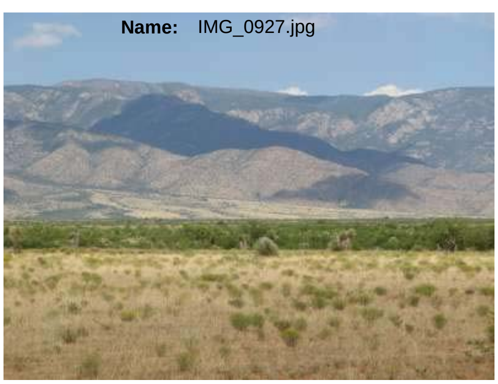
Azimuth: 0

Notes: Grazed area

Name: IMG_0926.jpg

Azimuth: 180 **Zoom:** 2

Name: IMG_0927.jpg

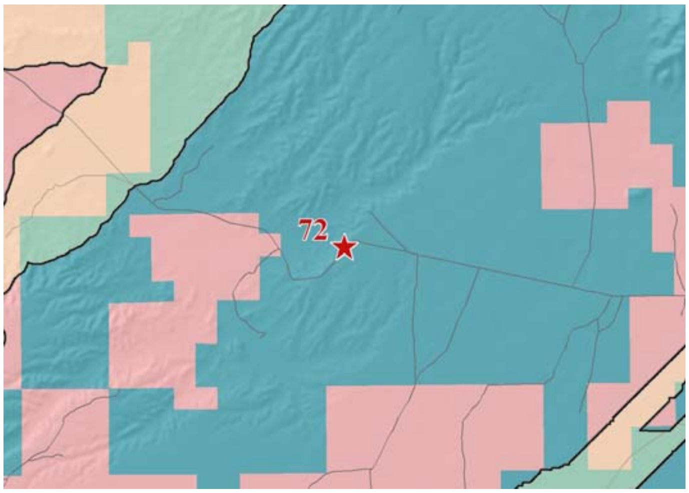


Azimuth: 55 **Zoom:** 4

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	72		
Linkage Zone:	Wilcox	**Latitude:**	32.6246	**Longitude:**	-110.09824
Observers:	Paul Beier	**UTM X:**	584595.0589	**UTM Y:**	3610030.237
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map

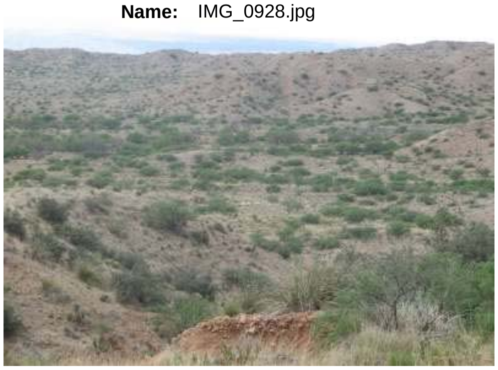


Waypoint Notes

Bonita Road

Site Photographs

Name: IMG_0928.jpg



Azimuth: 285 **Zoom:** 4

Notes: An area with rugged topography

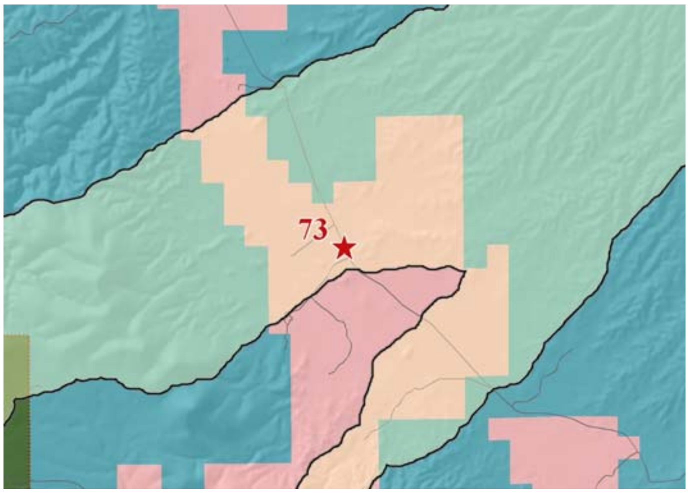
Name: IMG_0929.jpg

Azimuth: 240 **Zoom:** 6

Appendix G: Database of Field Investigations

Linkage #:	89	**Waypoint #:**	73		
Linkage Zone:	Wilcox	**Latitude:**	32.65904	**Longitude:**	-110.16855
Observers:	Paul Beier	**UTM X:**	577969.1132	**UTM Y:**	3613794.418
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Bonita Road

Site Photographs

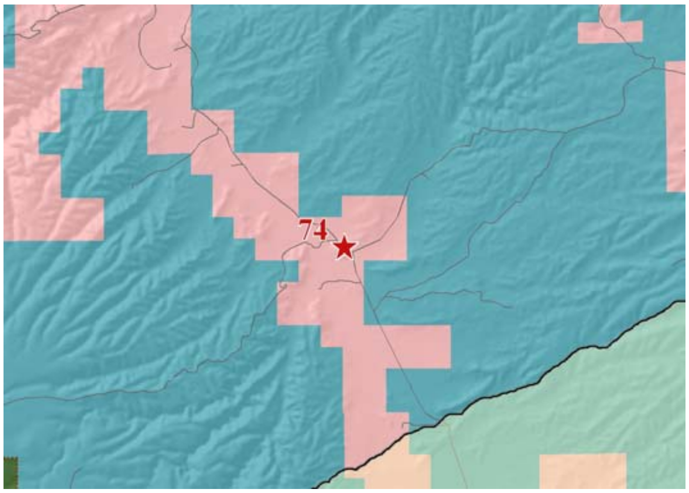
Name: IMG_0934.jpg

Azimuth: 260 **Zoom:** 4

Notes: Fencing that is not pronghorn-friendly in dense desert scrubland

Linkage #:	89	**Waypoint #:**	74		
Linkage Zone:	Wilcox	**Latitude:**	32.71584	**Longitude:**	-110.20026
Observers:	Paul Beier	**UTM X:**	574947.96	**UTM Y:**	3620068.370
Field Study Date:	5/14/2007	**Last Printed:**	1/8/2008		

Waypoint Map



Waypoint Notes

Bonita Road

Site Photographs

Name: IMG_0935.jpg

Azimuth: 275 **Zoom:** 3
Notes: Rugged desert topography

Name: IMG_0936.jpg

Azimuth: 345 **Zoom:** 3
Notes: Rolling Desert