ARIZONA MISSING LINKAGES

Tucson – Tortolita – Santa Catalina Mountains Linkage

Paul Beier, Emily Garding, Daniel Majka

NORTHERN
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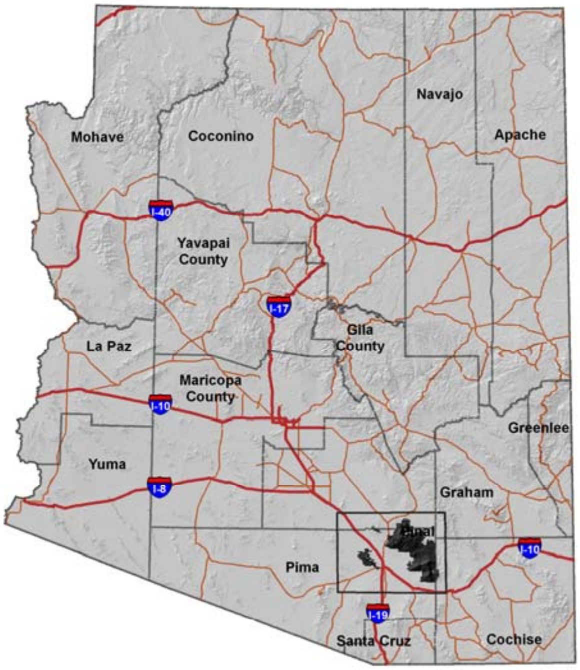
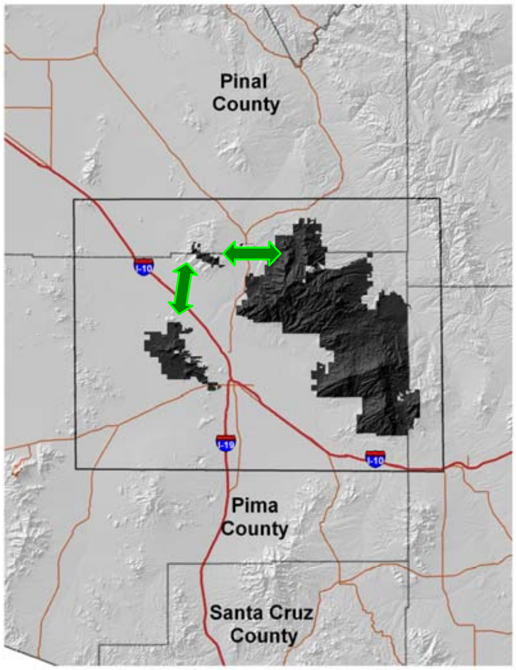
TUCSON – TORTOLITA – SANTA CATALINA MOUNTAINS LINKAGE DESIGN





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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 wildland block to a potential population core in the other wildland block. In some cases, the biologically best corridor consists of 2 or 3 *strands*.

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

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

Linkage Planning Area: Includes the wildland blocks and the Potential Linkage Area. If the Linkage Design in this report is implemented, the biological diversity of the entire Linkage Planning 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 preserved wildlands near Tucson, Arizona. In this region, Interstate 10, Highway 77, and urban areas impede animal movement between the Tucson Mountains in the west, the Tortolita Mountains to the north, and the Santa Catalina Mountains to the east. These areas represent a large public investment in biological diversity, and this Linkage Design is a reasonable science-based approach to maintain the value of that investment.

To begin the process of designing this linkage, academic scientists, agency biologists, and conservation organizations identified 21 focal species that are sensitive to habitat loss and fragmentation, including 12 reptiles and amphibians, 1 bird, and 8 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). Some species are habitat specialists (e.g. Gila Monster), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer, desert tortoise). Some species are rare and/or endangered (desert tortoise) 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 Sonoran Desert. Together, these 21 species use diverse habitats, so that the linkage design should address connectivity needs for other species as well.

To identify potential routes between existing protected areas we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final Linkage Design (Figure 1) provides live-in or move-through habitat for each focal species. The Linkage Design (Figure 1) is composed of 2 linkages for movement and reproduction of wildlife – one linkage between the Tucson Mountains and Tortolita Mountains, and another linkage between the Tortolita Mountains and Santa Catalina Mountains. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The Tucson Mountains-Tortolita Mountains linkage is the most compromised of the 16 linkage designs we have produced during 2006-2007. An animal moving southwest from the Tortolitas towards the Tucson Mountains would cross over Tangerine Road, under large powerlines, over the Southern Pacific rail line, a drainage ditch, and a frontage road, through an abandoned railroad underpass under Interstate 10, over another frontage road, through or around abandoned gravel pits in the Santa Cruz river channel, across some weedy undeveloped land, and over Milligan and Silverbell Roads. Although this route is highly degraded, a few simple enhancements, such as underpasses along roads and railroads, and restoring vegetation in the Santa Cruz River and other degraded parcels, would greatly enhance utility of the corridor. While acknowledging the challenges and costs, we believe that conserving and enhancing this linkage is achievable. Certainly without prompt and strong action to shape development in the linkage design, this linkage will be lost within a few years.

The Tortolita Mountains-Santa Catalina Mountains linkage is in relatively good condition. However, prompt and aggressive efforts will be needed to conserve the linkage in the face of rapid urban growth.

This region has significant ecological, educational, recreational, and spiritual values as 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 Tucson Mountains, Tortolita Mountains, and Santa Catalina Mountains, 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, 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.

The fate of these two linkages, and the wild plants and animals in the Tucson, Tortolita, and Santa Catalina Mountains, lies with local jurisdictions, conservation investors, and landowners. 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 Tucson – Tortolita – Santa Catalina Mountains Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	Arizona Whipsnake	Cactus Ferruginous Pygmy Owl
Bats	*Desert Tortoise	
*Black bear	*Gila Monster	
*Bobcat	Coachwhip	
*Javelina	Giant Spotted Whiptail	
*Kit fox	Gopher Snake	
*Mountain Lion	Lowland Leopard Frog	
*Mule Deer	Mohave Rattlesnake	
	Sonoran Desert Toad	
	Sonoyta Mud Turtle	
	Tiger Rattlesnake	
	Western Diamondback Rattlesnake	

* Species modeled in this report. The other species were not modeled because there were insufficient data to quantify habitat use in terms of available GIS data (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. We evaluated overlap between the Linkage Design and critical habitat proposed for the pygmy owl.

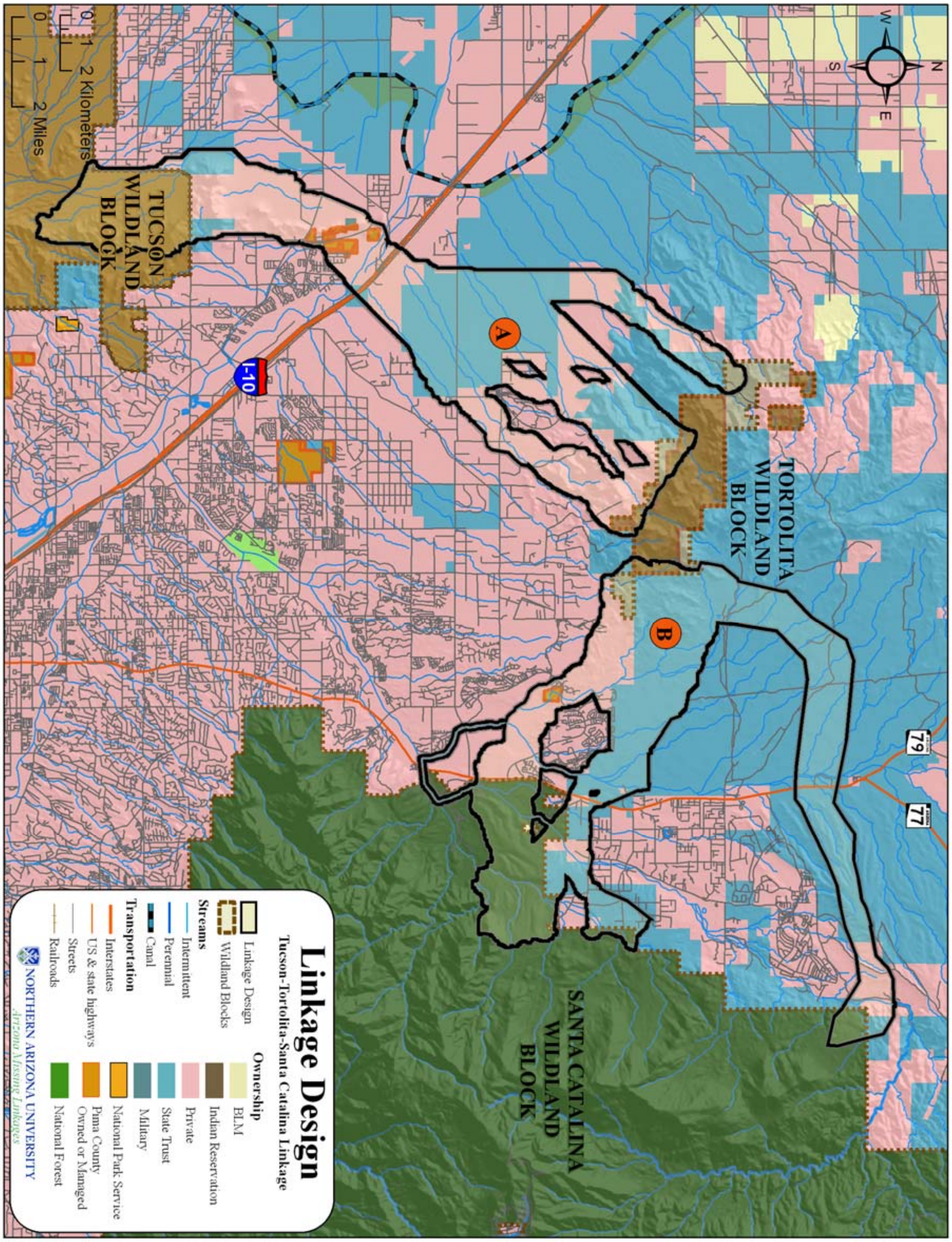

Figure 1: The Linkage Design between the Tucson, Tortolita, and Santa Catalina Mountains wildland blocks includes a Tucson-Tortolita Linkage (A) and a Tortolita-Santa Catalina Linkage (B).

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 2006. In 2007, eight additional linkages within 5 miles of an incorporated city were selected for linkage design planning. The Tucson – Tortolita – Santa Catalina Mountains Linkage is one of these "urban" linkages.

Ecological Significance of the Tucson – Tortolita – Santa Catalina Mountains Linkage

The Tucson – Tortolita – Santa Catalina Mountains Linkage Planning Area lies in Pima and Pinal Counties at the crossroads of two major ecoregions; the Apache Highlands, which create the mountainous sky islands, and the Sonoran Desert, which extends west and south into Mexico. The Sonoran Desert is the most tropical of North America's warm deserts (Marshall et al. 2000). Bajadas sloping down from the mountains support forests of ancient saguaro cacti, paloverde, and ironwood; creosotebush and bursage desert scrub dominate the lower desert (The Nature Conservancy 2006). The Sonoran Desert Ecoregion is home to more than 200 threatened species, and its uniqueness lends to a high proportion of endemic plants, fish, and reptiles (Marshall et al. 2000) (The Nature Conservancy 2006). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of 233 of the earth's most biologically valuable ecoregions, whose conservation is critical for maintaining the earth's biodiversity.

Within the Sonoran Desert Ecoregion, the Linkage Planning Area includes three wildland blocks that form mountainous islands separated by desert valleys, highways (Interstate 10, Arizona State Highway 77), the cities of Oro Valley and Marana, and growing network of residential developments and roads.

The Tucson Mountains wildland block encompasses the Tucson Mountains on the west side of Tucson. Elevation in this block ranges from roughly 2,000 to over 4,600 feet. The Landcover is comprised largely of desert scrub and desert grasslands. It is also known for its saguaro cacti forests.

The Tortolita Mountains wildland block includes the Tortolita Mountains, a small mountain range north of Tucson. Its rocky soils and rugged peaks support a variety of cacti. Honeybee Canyon in the eastern Tortolita Mountains is one of the few perennial streams in Pima County.

The Santa Catalina Mountains wildland block is located within the Coronado National Forest. The Santa Catalina Mountains reach 9,157 feet at Mount Lemmon. The adjacent Rincon Mountains reach 8,664 feet at Mica Mountain. The higher elevations boast pine-oak woodlands. Lower elevation areas are dominated by dense communities of creosote and white bursage, with palo verde, ironwood, and saguaros found on slopes and higher portions of bajadas (Turner et al 1995).

The diversity of vegetative types support many mammals, reptiles, birds, and amphibian species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the Sonoran desert tortoise. Wide-ranging mammals include the mountain lion, mule deer, and badger. The area is recognized as an exceptional birding area. Many of these animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as Gila monsters also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

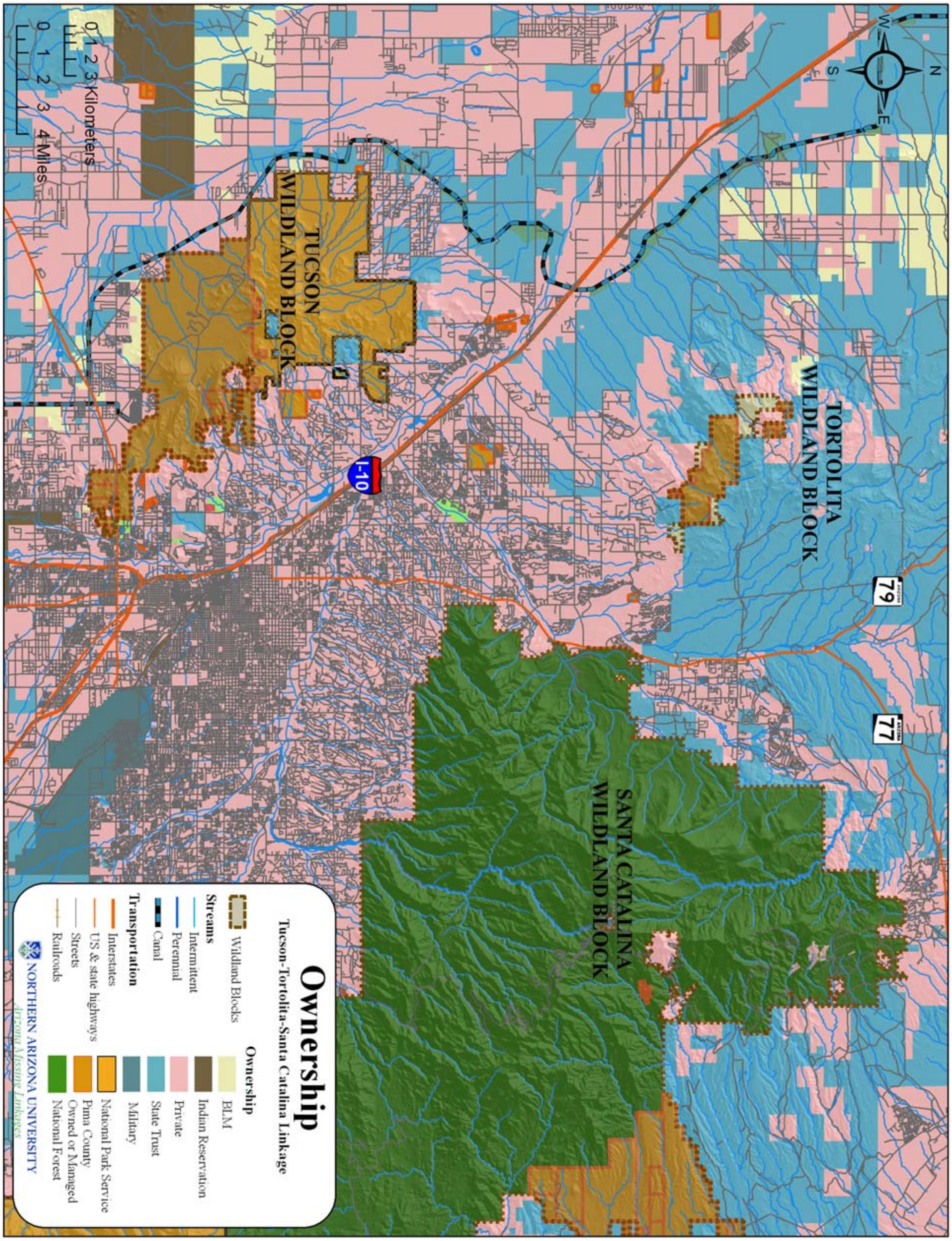

Figure 2: Land ownership within the Linkage Planning Area.

Existing Conservation Investments

The **Tucson Mountains wildland block** encompasses over 40,000 acres of the Tucson Mountains on the west side of Tucson and Interstate 10. This block includes the Tucson Mountain Park, a 20,000 acre preserve owned by Pima County. Saguaro National Park West, including the 13,470-acre Tucson Mountain portion of the Saguaro Wilderness occurs in this block. Elevation ranges from roughly 2,000 to over 4,600 feet. The rugged desert landscape is dominated by desert scrub and desert grasslands, arroyos, and the characteristic saguaro cactus.

The **Tortolita Mountains wildland block** includes the 5,000-acre Tortolita Mountain Park, a roadless wildland administered by Pima County. Pima County recently purchased Cochie Spring and Carpenter Ranch as additions to this park, and additional purchases are likely if willing sellers can be identified.

The **Santa Catalina Mountains wildland block** includes over 360,000 acres. Most of the land is administered by the Coronado National Forest, though it also includes, Saguaro National Park East, 5,500-acre Catalina State Park, and some adjacent lands managed for conservation by Pima County. Within the Coronado National Forest lies the 56,933 acre Pusch Wilderness in the Santa Catalina Mountains. Further south the adjacent Rincon Mountains include the 70,905-acre Saguaro National Park East, and the 38,590-acre Rincon Mountain Wilderness in the Coronado NF.

Connectivity between these wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in the Sonoran Desert of southern Arizona.

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include urban encroachment, subdividing rural parcels, and improvements to Interstate 10 and SR-77. The communities of Oro Valley, Marana, Rillito, Dove Mountain, and Catalina are growing rapidly.

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. Conserving and restoring linkages will ensure that wildlife will thrive in the wildland blocks and the potential linkage area.

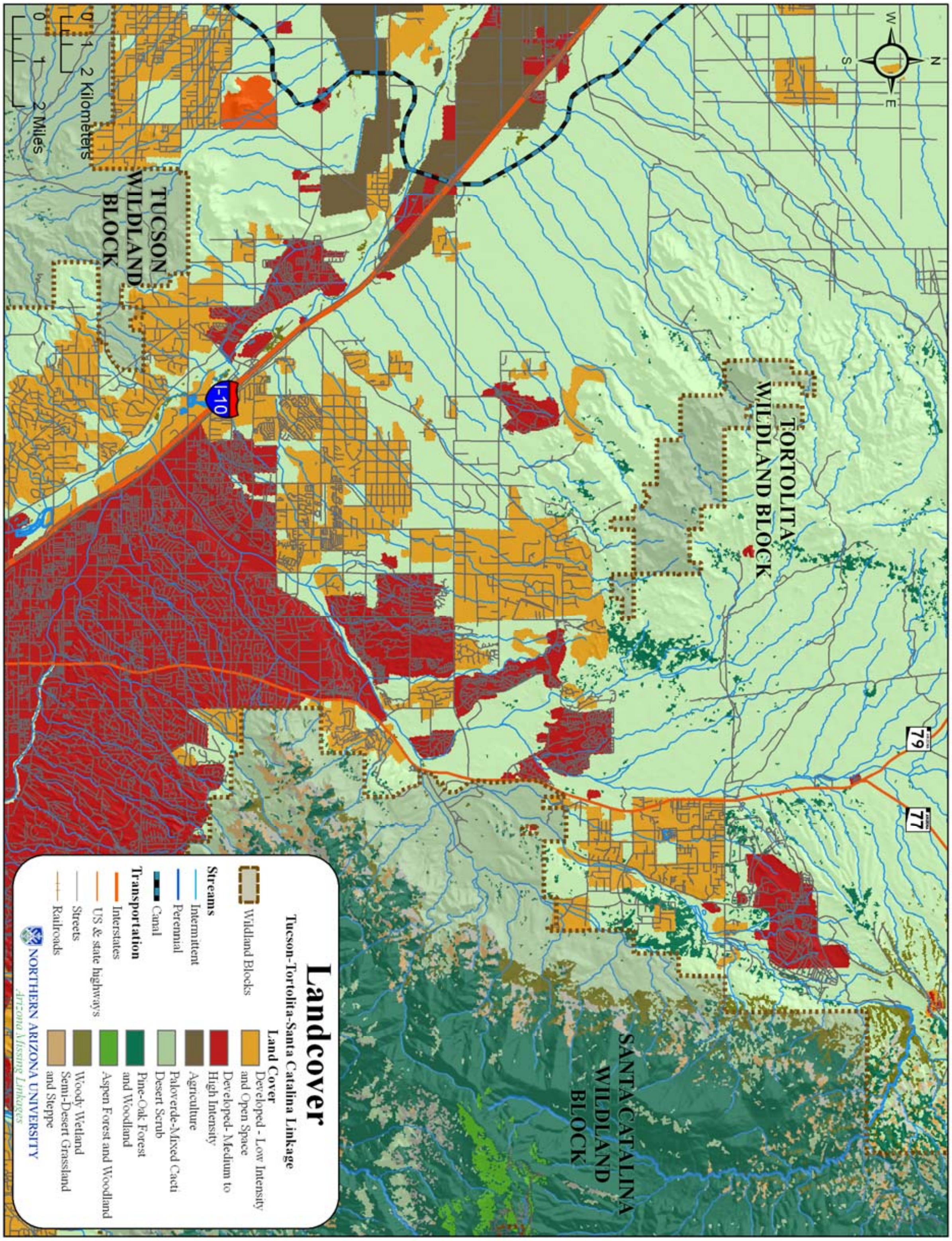

Figure 3: Land cover within the Linkage Planning Area.

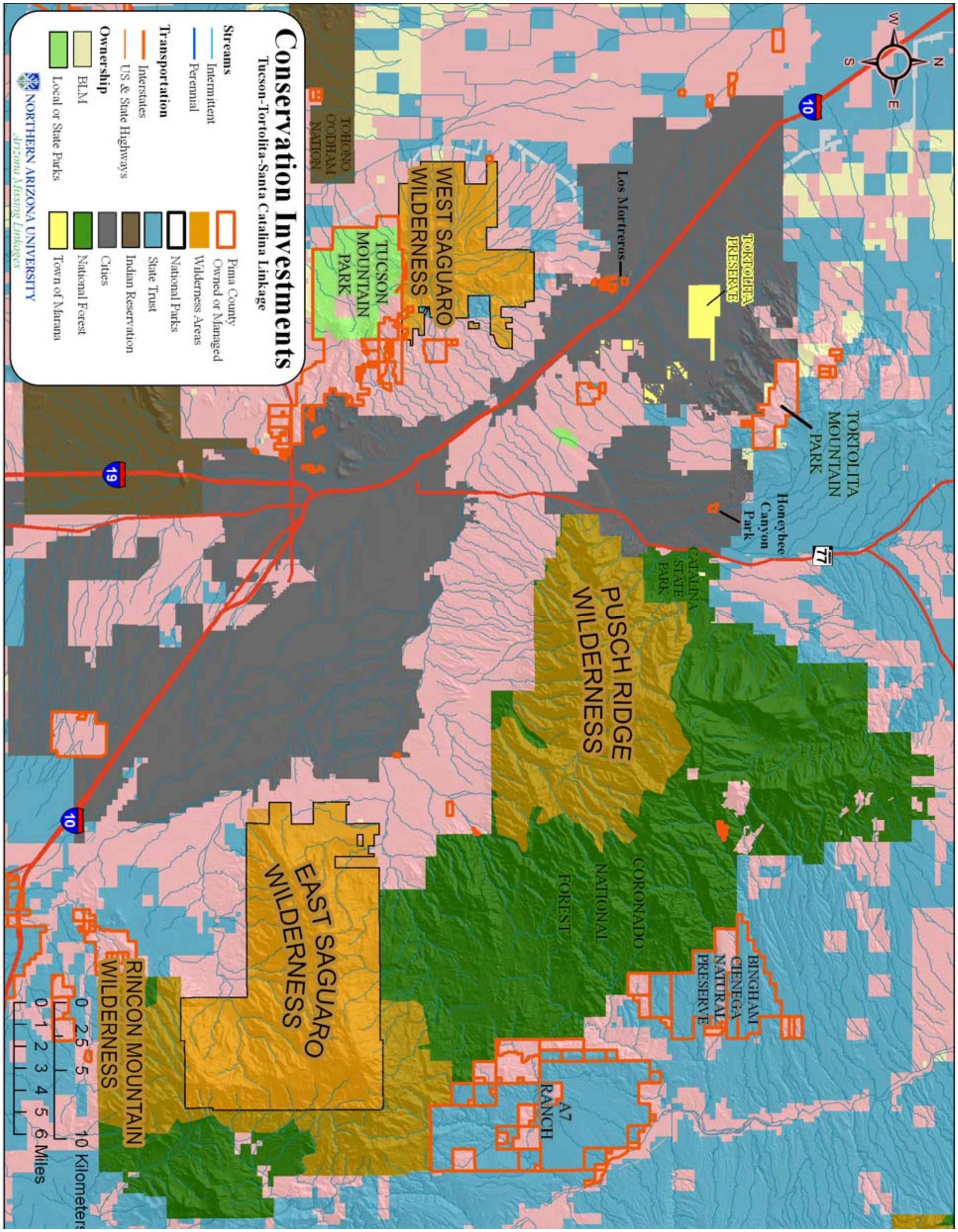

Figure 4: Existing conservation investments within the Linkage Planning Area. The West Saguaro Wilderness occupies most of the Tucson Mountain District of Saguaro National Park, and the East Saguaro Wilderness occupies most of the Rincon Mountain District of Saguaro National Park.

Linkage Design & Recommendations

The Linkage Design (Figure 1) includes a Tucson Mountains-Tortolita Mountains Linkage, and a Tortolita Mountains-Santa Catalina Mountains Linkage. 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

The linkage design consists of two distinct strands, labeled A an B (Figure 1, Figure 5).

The **Tucson Mountains-Tortolita Mountains Linkage** (Linkage A on our maps) runs from the Tucson Mountains, across Interstate 10, to the Tortolita Mountains. It is about 23 km long, and primarily composed of Paloverde-Mixed Cacti Desert Scrub (95%), and developed and agricultural lands (4%). This linkage has an average slope of 14% (Range: 0-172%, SD: 18). About 65% of the land is flat to gently sloped and about 25% is steep slopes.

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

This linkage is the most compromised of the 16 linkage designs we have produced during 2006-2007. An animal moving southwest from the Tortolitas towards the Tucson Mountains would cross about 6 miles of desert flats. In those 6 miles, native vegetation is relatively intact, but the animal would have to cross Tangerine Road. Then, in a distance of about 200 m, the animal would have to cross under large powerlines, over the Southern Pacific rail line, a drainage ditch, and a frontage road, through an abandoned railroad underpass under Interstate 10, and across another frontage road. At that point, the animal would reach the Santa Cruz River channel. The northern foothills of the Tucson Mountains, known locally as Los Morteros, lie just over a mile further west. To get there the animal would cross abandoned borrow pits in the river bottom, some weedy undeveloped land, and Milligan and Silverbell Roads. From the perspective of wildlife movement, the last one and a half miles of the route are bleak indeed. However, although this corridor is highly degraded, it is probably occasionally used by deer, jackrabbits, bobcats, coyotes, and perhaps mountain lions and black bears. A few simple enhancements, such as culverts under frontage roads and railroads and restoring vegetation in the Santa Cruz River and the land between the River and Los Morteros, would greatly enhance the utility of the corridor.

While acknowledging the challenges and costs, we believe that conserving and enhancing this linkage is an achievable goal. Ultimately, the fate of this corridor lies with local jurisdictions and conservation investors. Certainly without prompt and strong action to shape development in the linkage design, this linkage will be lost within a few years.

The **Tortolita Mountains-Santa Catalina Mountains Linkage** (Linkage B) runs through the Oro Valley and across SR-77 between the Tortolita Mountains and the Santa Catalina Mountains. Honey Bee Canyon, home to a perennial stream and riparian area, winds through the western end of Strand B. The linkage is approximately 14 km long, and is primarily composed of paloverde-mixed cacti desert scrub (87%), evergreen forest (5.8%), and developed or agricultural lands (5.1%). This strand has an average slope of 9% (Range: 0-184%, SD: 10). Over one quarter (27%) of the land in this strand is classified as steep slopes, and nearly 70% is classified as flat to gentle. This linkage strand provides live-in and pass-through habitat for each of the focal species modeled for this project. There are several constrictions due to urbanization along SR-77 and west of SR-77.

Compared to the Tucson-Tortolita Linkage (preceding paragraphs), the Tortolita-Catalina Linkage is in relatively good condition. Nonetheless, within 10 years sprawling residential development will sever this linkage unless aggressive measures are taken at once. Given the risk that jurisdictions may fail to conserve the Tucson-Tortolita Linkage, it becomes imperative to conserve the Tortolita-Catalina Linkage. Without it, the Tortolita Mountains will lose much of its species diversity and biotic interactions such as top-down regulation by predators. Species that persist in the Tortolitas will lose much of their genetic diversity. In our work on 16 linkage designs, we have not seen rates of development of formerly natural land similar to what we have seen in this linkage.

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

The Linkage Design encompasses over 44,000 acres (18,000 ha) of land, of which 37% is privately owned, 45% is State Trust land, roughly 9% falls within the Coronado National Forest, 7% within Saguaro National Park, and 1% is owned by the Bureau of Land Management. Paloverde-mixed cacti desert scrub accounts for over 90% of the land cover, and developed land accounts for approximately nearly 5% of the linkage design (Figure 6).

The Linkage Design captures a range of topographic diversity, providing for the present ecological needs of the focal species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. About 67% of the land is classified as gentle slopes, 26% as steep slopes, with the remaining 8% canyon bottom or ridgetop (Figure 7). Most of the land has southern or western aspects (Figure 7).

Table 2: Approximate landcover found within Linkage Design.

Strand A			
Land Cover Class	Acres	Hectares	% of Area
Evergreen Forest	226	91	1.0%
Scrub-Shrub	21892	8859	94.5%
Woody Wetland	26	11	0.1%
Barren Lands	1	0	0.0%
Developed and Agriculture	1021	413	4.4%
Grasslands-Herbaceous	0	0	0.0%
Strand B			
Land Cover Class	Acres	Hectares	% of Area
Evergreen Forest	1224	495	5.8%
Scrub-Shrub	18493	7484	87.4%
Woody Wetland	333	135	1.6%
Barren Lands	26	11	0.1%
Developed and Agriculture	1077	436	5.1%
Grasslands-Herbaceous	16	6	0.1%
Union			
Land Cover Class	Acres	Hectares	% of Area
Evergreen Forest	1450	587	3.27%
Scrub-Shrub	40385	16343	91.09%
Woody Wetland	359	145	0.81%
Barren Lands	27	11	0.06%
Developed and Agriculture	2098	849	4.73%
Grasslands-Herbaceous	16	6	0.04%

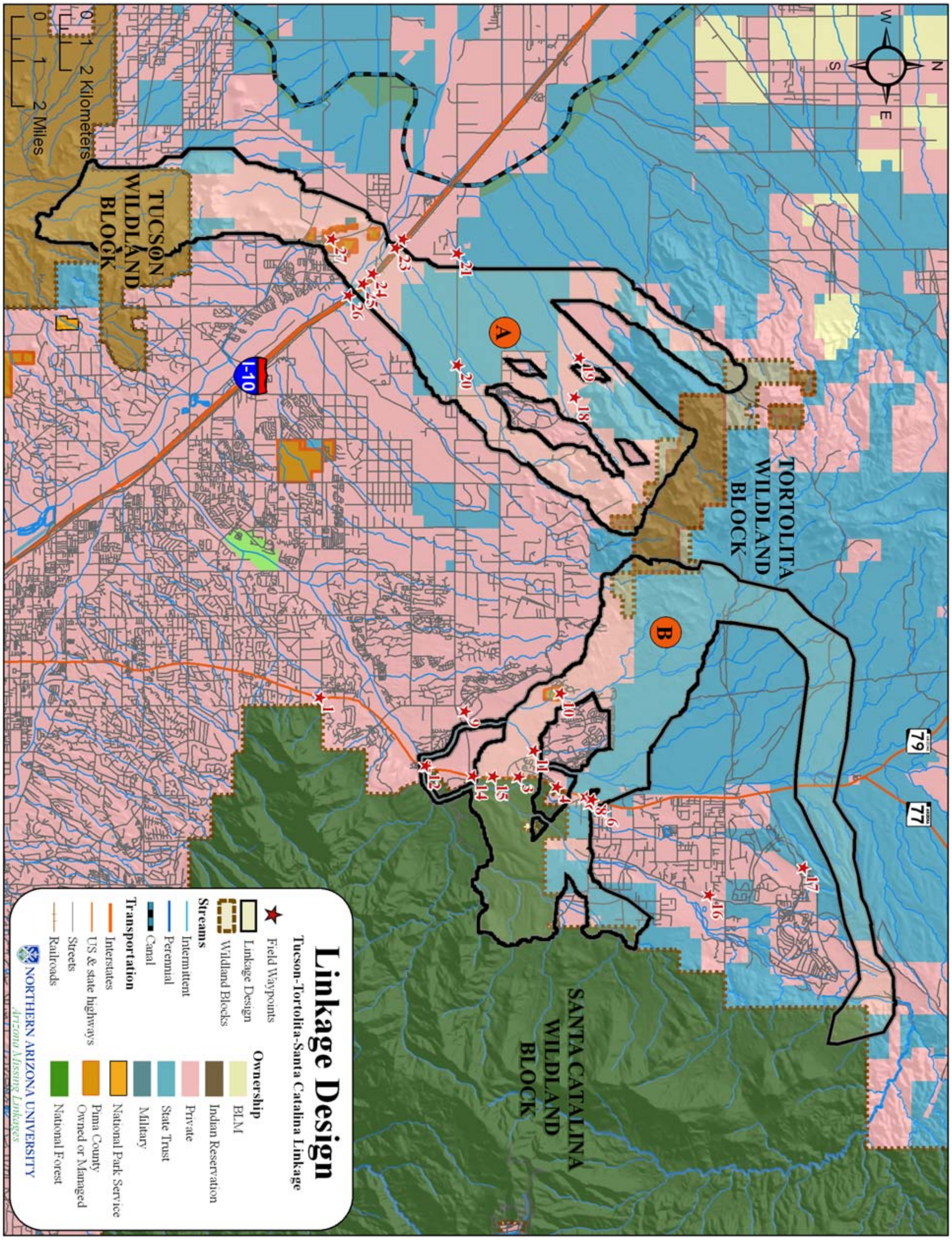

Figure 5: Property ownership and field investigation waypoints in and near the Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.

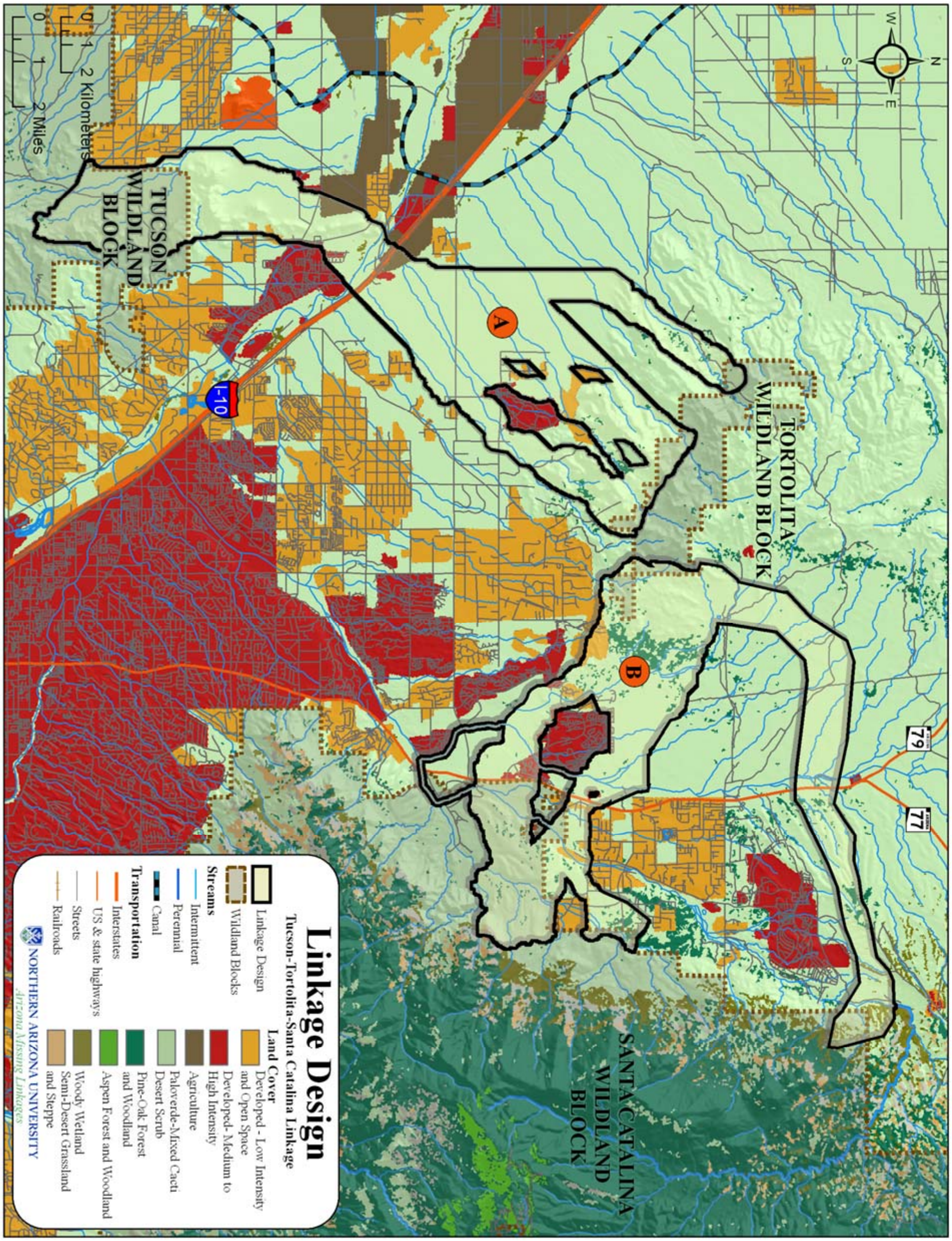

Figure 6: Land cover in the Linkage Design.

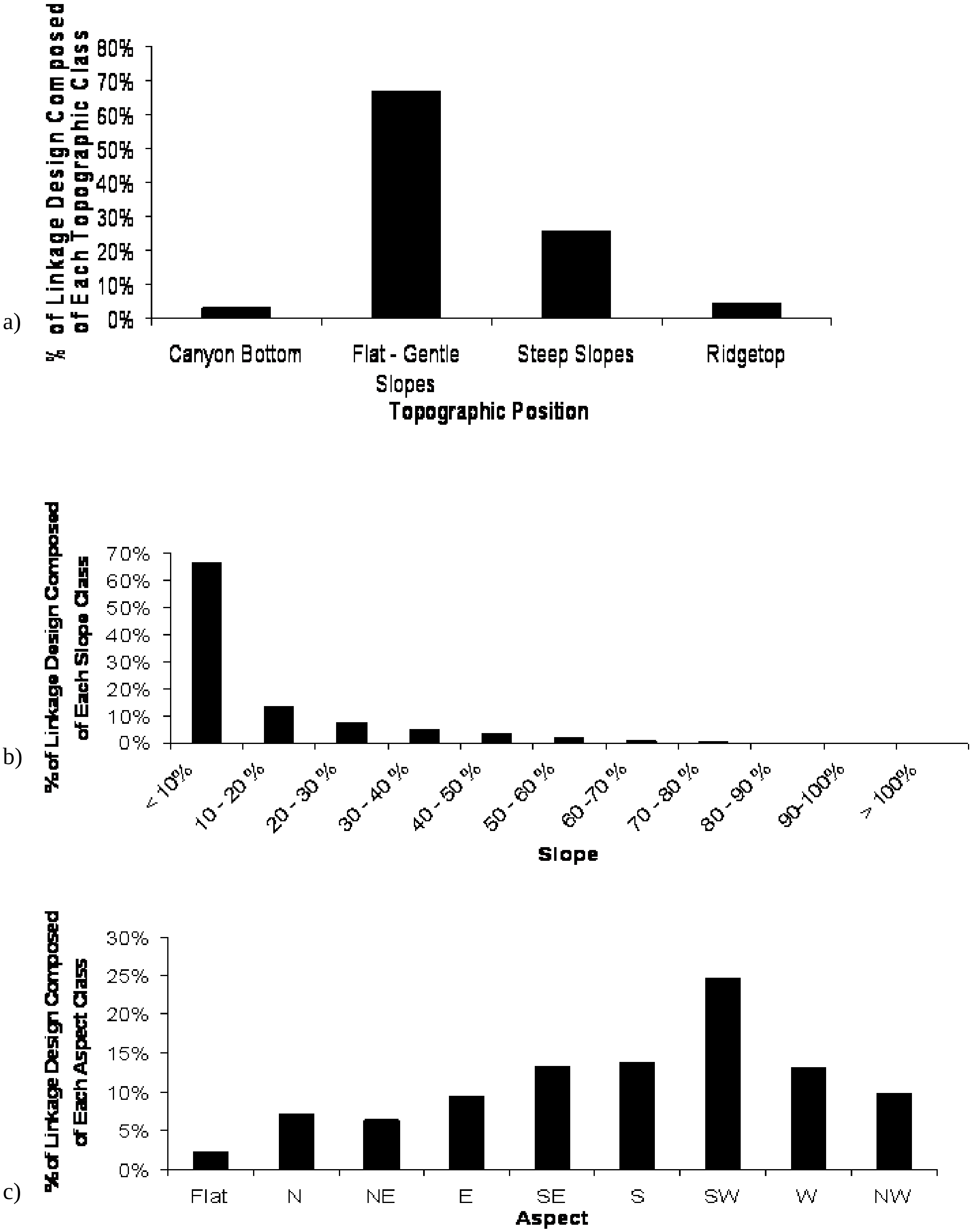

Figure 7: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect.

Removing and Mitigating Barriers to Movement

Although roads, rail lines, 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 impede animal movement, and the crossing structures we recommend are important, crossing structures are only part of the overall linkage design. To restore and maintain connectivity between the Tucson Mountains, Tortolita Mountains, and Santa Catalina Mountains, it is essential to consider the *entire* linkage design, including conserving the land in the linkage. Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either wildland block is lost.

Impacts of Roads on Wildlife

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

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

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 (Figure 8). 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.

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.

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 culverts 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.

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.

Existing Roads in the Linkage Design Area

There are about 110 km (70 mi) of transportation routes in the Linkage Design, including 2.3 km (1.4 mi) of Interstate 10, 2.3 km (1.4 mi) of state highways, and the remainder consisting of local roads (Table 4). We conducted field investigations of many of these roads to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 4: Roads found in the Linkage Design.

Strand A			Strand B		
Road Name	**Kilometers**	**Miles**	**Road Name**	**Kilometers**	**Miles**
Unnamed Roads	6.5	4.1	Unnamed Roads	4.9	3.1
I-10	2.3	1.4	Golder Ranch Rd	5.9	3.6
Casa Grande Highway	2.3	1.4	Oracle Rd	4.8	3.0
Tangerine Rd	5.3	3.3	Rancho Vistoso Blvd	3.0	1.9
Cochie Canyon Trl	4.1	2.6	Rollins Rd	2.8	1.8
Picture Rocks Rd	3.4	2.1	Swan Rd	2.3	1.4
Moore Rd	3.0	1.8	Lago del Oro Pky	2.0	1.2
Silverbell Rd	2.9	1.8	Jeep Trl	1.8	1.1
Casa Grande Hwy	2.3	1.4	Bowman Rd	1.3	0.8
Golden Gate Rd	2.2	1.3	Crown Ridge Dr	1.3	0.8
Twin Peaks Rd	1.9	1.2	Wilds Rd	1.1	0.7
White Stallion Ranch Rd	1.8	1.1	Mountainaire Dr	1.0	0.6
Wild Burro Rd	1.8	1.1	Miravista Ln	1.0	0.6
Jeep Trl	1.6	1.0	Silver Cloud Dr	0.9	0.6
Dove Mountan Blvd	1.4	0.9	Roads less than 1 km	25.6	15.9
Avra Valley Rd	1.1	0.7			
Tortolita Estates Dr	1.1	0.7			
Roads less than 1 km	12.8	8.0			
Length of transportation routes in Strand A	57.8	35.9	Length of transportation routes in Strand B	54.8	34.0
Total length of transportation routes	**109.6**	**69.9**			

Recommendations for Crossing Structures in the Tucson Mountains-Tortolita Mountains Linkage

We found only four major crossing structures across roads in the Tucson Mountains-Tortolita Mountains Linkage (Figure 9):

- One bridge on Dove Mountain Rd (Figure 10, Figure 11).
- The bridge on I-10 over Avra Valley Road, at the west edge of the linkage design. Because of heavy traffic on Avra Valley Road, this is probably rarely used by wildlife.
- One bridge (an abandoned railroad underpass) on Interstate 10 near milepost 243 (Figure 12, Figure 13; Waypoint 24). This is a high priority for maintenance as a wildlife crossing structure. Conservation of the adjacent land is critical, because this structure is in the only crossing structure on I-10 within the linkage design. Although this portion of the linkage contains scattered urbanization, views from waypoints 26 and 27 suggest that a linkage for most species could be conserved here (Figure 15, Figure 16). Semi-natural desert vegetation occurs on both sides of I-10 adjacent to this crossing structure. (There is a second rail underpass at the cement plant north of Avra Valley Road about ½ mile west of the linkage. The west end of this structure opens into a 10-acre paved industrial facility. The east end opens into a 500-m wide swath of row crops, followed by thousands of acres of natural land. This crossing structure would not provide meaningful connectivity without major restoration efforts on both sides of I-10.)
- Six 24” box culverts under I-10 near milepost 244 (Figure 14, Waypoint 26)

The existing crossing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between wildland blocks must traverse I-10 and at least two other arterial roads, crossing structures along these roads are crucial to success of the corridor. We recommend maintaining, upgrading, or adding crossing structures as follows:

- The abandoned railroad underpass on I-10 (Figure 12) is the highest priority for retention and enhancement. This underpass is an important asset because it lies squarely in the middle of the linkage design. From the underpass a medium to large mammal can see Los Morteros and the foothills of the Tucson mountains to the west, and the Tortolita Mountains to the northeast. A large block of ASLD land lies only 1 mile away towards the Tortolitas, and conservation of about 300 acres of private land between the underpass and the ASLD land would go a long way to securing this wildlife corridor.
- The railroad tracks running along the north side of I-10 also present a barrier that should be mitigated in the future. Large mammals can cross over the tracks. Some small culverts aligned with the underpass would greatly enhance the utility of this crossing structure for reptiles, amphibians, and small mammals.
- In the long term, during major future work on I-10, build a second bridged crossing structure on I-10 within the linkage design.
- Build two bridged crossing structures on Tangerine Road where it crosses the Linkage Design (on State Trust lands).
- Build one bridged crossing structure per mile on any new arterial road that crosses the Linkage Design. In 2007 we noted several new golf course communities sprouting up between Tangerine Road and the Tortolita Mountains. The roads serving these new communities will have moving walls of traffic as Marana and Rillito double and triple in population, and wildlife will need crossing structures.
- West of I-10, crossing structures may be needed on Silverbell Road along the east edge of Los Morteros, Milligan Road/Coachline Boulevard, and Twin Peaks Road through Rattlesnake Pass.
- Traffic volumes and traffic speeds on Picture Rocks Road are probably compatible with wildlife movement. However if Picture Rocks Road is widened and straightened, crossing structures should be part of the road upgrade.

In 2006, Pima County voters approved a $2.1 billion dollar plan for the Pima County Regional Transportation Authority, including $45 million dedicated to projecting that improve connectivity for wildlife. The County is fortunate to have a progressive transportation planning process, and funding to implement projects to enhance wildlife corridors. We hope RTA will be a major implementer of this Linkage Design.

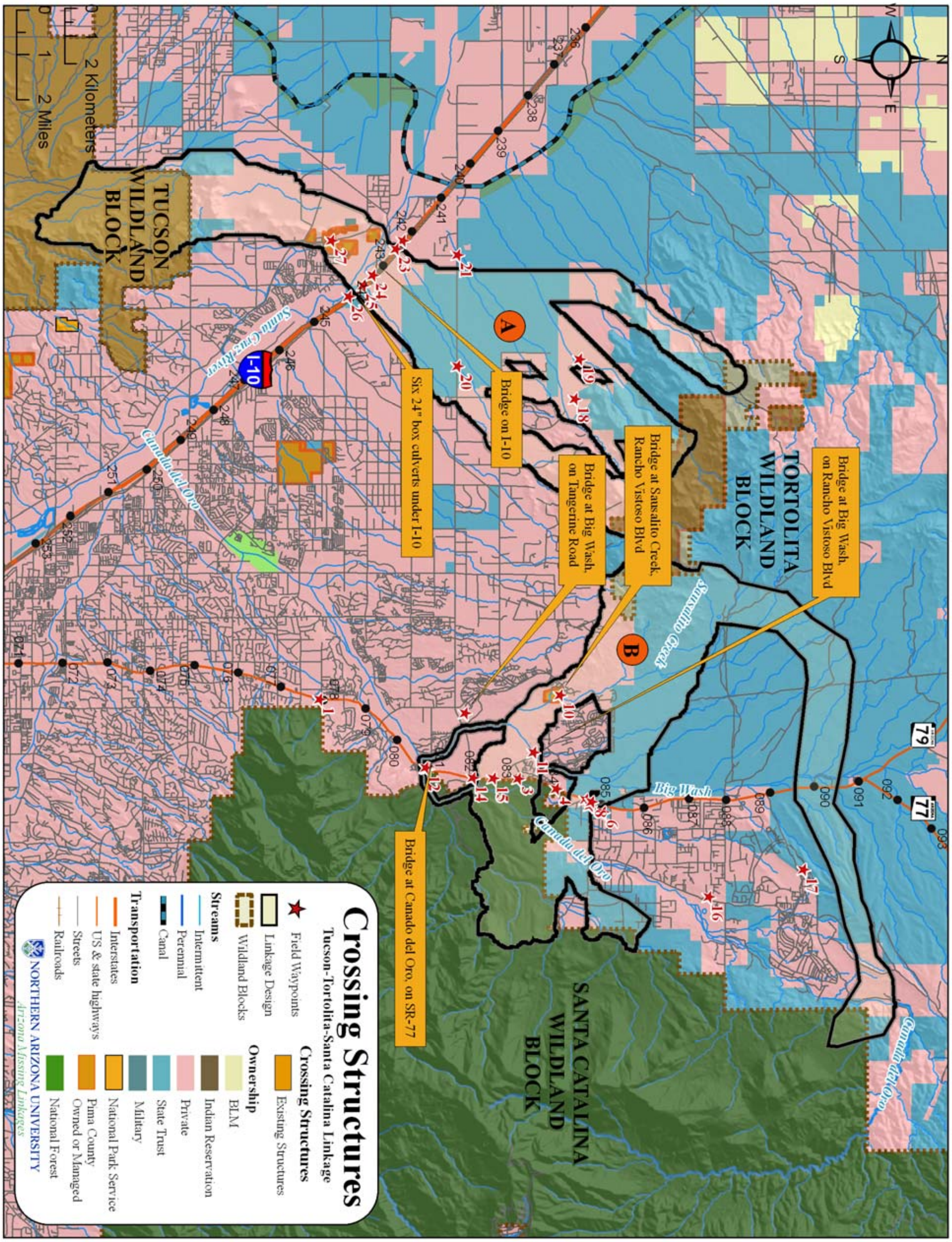

Figure 9: Existing crossing structures identified in and near the linkage design, and waypoints at which field observations were made.

Figure 10: View south from the bridge on Dove Mountain Road towards the Tucson Mountains (Waypoint 19).

Figure 11: The bridge on Dove Mountain Road (Waypoint 19).

Figure 12: An abandoned railroad underpass allowing passage under I-10 at Waypoint 24. The Tortolita Mountains are visible across the undeveloped desert flats on the other side of the freeway.

Figure 13: View of the Tucson Mountains from the underpass on Interstate 10 (Waypoint 24).

Figure 14: Six 24" box culverts under I-10 at Waypoint 26, blocked by brush.

Figure 15: View from Los Morteros, across I-10 (barely visible in mid-field) toward the Tortolita Mountains on the horizon (view north from Waypoint 27). The linkage design lies to the right of the urban area.

Figure 16: View northwest across the Tucson-Tortolita Linkage (Los Morteros at left and Tortolitas on horizon) from Waypoint 27. Housing tracts constrict, but probably do not block, the linkage here.

Recommendations for Crossing Structures in the Tortolita-Santa Catalina Mountains Linkage

We found only 4 major crossing structures in the Tortolita-Santa Catalina Mountains Linkage (Figure 9). SR-77 (Oracle Road), Rancho Vistoso Boulevard, and Tangerine Road are the major thoroughfares in this linkage.

- a bridge over Sausalito Creek on Rancho Vistoso Boulevard (Figure 17, and Figure 18; Waypoint 10).
- a bridge over Big Wash on Rancho Vistoso Boulevard (Figure 19; Waypoint 11).
- a bridge over Cañada del Oro on SR-77 (Figure 9, Waypoint 12, and a bridge over Big Wash on Tangerine Road (Figure 20;Waypoint 9). Because Big Wash and Cañada del Oro are the largest riparian systems in this linkage, the linkage design includes the confluence of these washes within a thin strand that loops south of the rest of the linkage design (Figure 1, Figure 9).

Figure 17: Bridge on RanchoVistoso Blvd over Sausalito Creek (Waypoint 10).

Figure 18: View downstream from the Rancho Vistoso Bridge over Sausalito Creek (Waypoint 10).

Figure 19: View to the northeast from the Rancho Vistoso bridge over Big Wash (Waypoint 11).

Figure 20: View downstream on Big Wash towards the Tangerine Road Bridge (foreground), SR-77 (linear feature in mid-field), and the Santa Catalina Mountains (on the horizon) Waypoint 9, looking southeast.

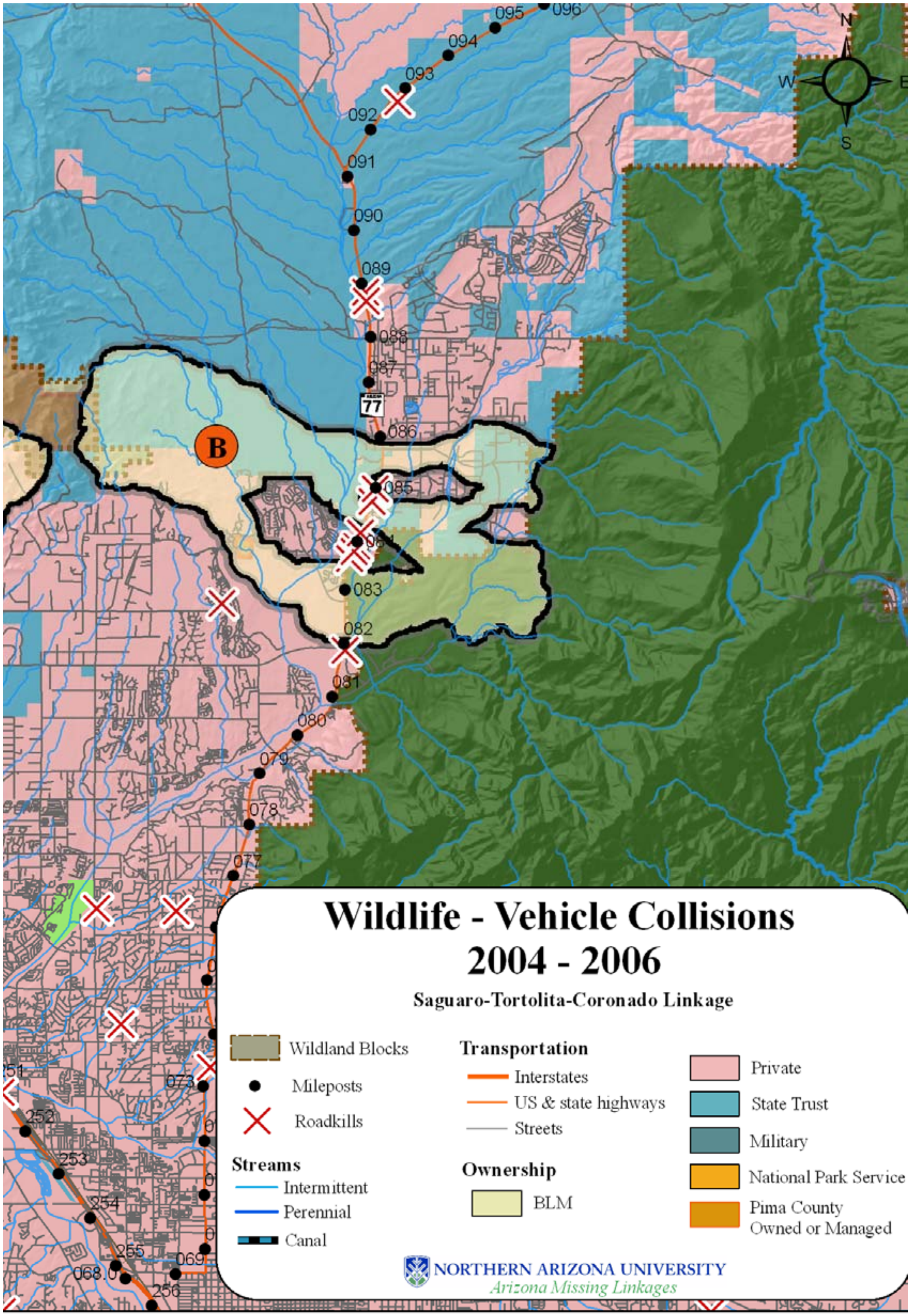

Figure 21: Wildlife mortalities documented opportunistically from 2004 to 2006 (data provided by AGFD). Only larger carcasses were recorded; hundreds to thousands of road-killed amphibians and reptiles are not documented on this map.

The existing crossing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between wildland blocks must traverse SR-77 and at least one other arterial surface road, crossing structures along these roads are crucial to success of the corridor. We recommend maintaining, upgrading, or adding crossing structures as follows:

- Maintain the two bridges on Rancho Vistoso Boulevard (Figure 17 and Figure 18).

- On Oracle Road (SR-77), build one bridged underpass between Milepost 81 and Milepost 82 and two bridged underpasses between Milepost 83.5 and Milepost 85.3. Each of these 3 underpasses should be suitable for use by mule deer, javelina, and smaller animals. There are currently no crossing structures suitable for large mammals and there are not adequate structures for smaller animals on this portion of the highway, which is a hotspot for wildlife-vehicle collisions (AGFD 2006, Figure 21).

- On Oracle Road (SR-77), build one culvert per 300m between Milepost 81 and Milepost 82 and between Milepost 83.5 and Milepost 85.3. These culverts should be designed for reptiles, amphibians, and small mammals.

- Build appropriate crossing structures on any new road crossing the linkage design. Require large bridged crossings for any new road across Big Wash, Honey Bee Canyon, Sausalito Creek, Sahuarita Wash, or other major tributaries of Big Wash.

- Avoid fencing or other activities that would decrease the utility of the two excellent bridges along the southern riparian loop of the linkage design, namely the SR-77 bridge over Cañada del Oro (Waypoint 12) and the Tangerine Road bridge over Big Wash (Figure 20). During our field visit, bulldozers were removing vegetation from the Big Wash floodplain southwest of intersection of Tangerine Road and SR-77 for the Oro Valley Marketplace, a 36-acre commercial development. Plans call for rehabilitating this area of Big Wash after construction is complete.

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 22). 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).

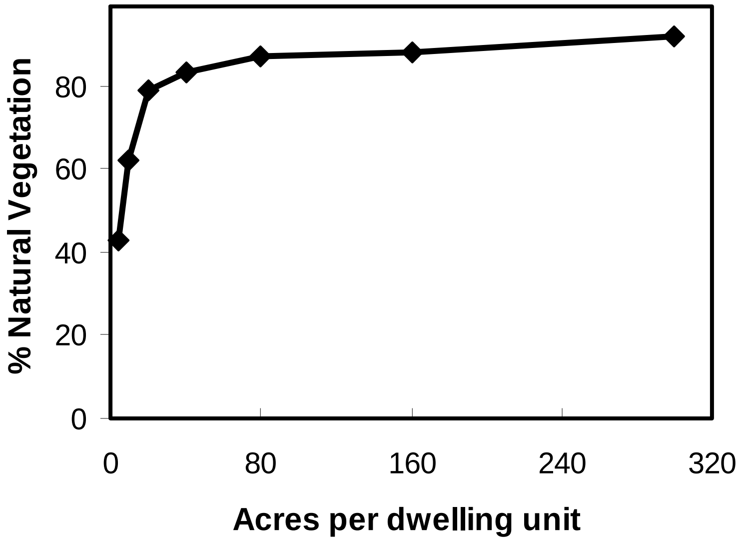

Figure 22: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

- decreased abundance and diversity of native species, and replacement by non-native species. In Arizona, these trends were evident for birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001), and loss of native species increased as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.
- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized “suburban native predators” such as raccoons, foxes, and crows that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).
- mortality of native plants and animals via pesticides and rodenticides, which kill not only their 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.

Recommended management of Potential Urban Barriers in the Linkage Design Area

In the Tucson Mountains-Tortolita Mountains Linkage, connectivity is threatened by phenomenal growth of the town of Marana (Figure 23). During our field investigations, we saw many new roads and developments in all stages of construction. Census Bureau estimates indicate that Marana was the fourth fastest-growing city or town in Arizona from 1990 to 2000. Marana is growing by annexing existing communities such as Rillito (population 27,000) but even more importantly by annexing large areas of pristine land proposed as master-planned communities. For example, Dove Mountain is a golf-resort community of 6,200 acres adjacent to the Tortolita Mountain Park. Another example, just north of the potential wildlife underpass under Interstate 10 (Figure 12), is the Cascada (Northgate) development, which will build 3,000 new homes and businesses. Although about half of Cascada-Northgate’s 1500 acres will remain open space, negotiations are still underway to configure the open space in a way that will contribute to a wildlife corridor.

North of I-10 in this linkage, all the land is owned by ASLD and 2 or 3 proposed master-planned communities. Prompt negotiations between the City of Marana and developers provide an opportunity to rationally plan land use to minimize the conflict between development and wildlife connectivity. Arizona State Land Department plays a key role as the largest single landowner within the linkage. It may also be possible for a complex land swap of ASLD land outside the Linkage Design for private land in the new planned communities. However, the best use for most ASLD land would be to put it in conserved status, such as by adding it to the area in the existing Tortolita Preserve (an existing 99-year lease from ASLD).

South of I-10, the land ownership is more complex. Although much of the land is too steep to develop, the corridor will experience a chokepoint in the one mile between the Santa Cruz River and the rugged terrain of Twin Peaks, Rillito, and Los Morteros. Much of the undeveloped land in this small area has been farmed or subject to past gravel mining and other industrial uses, but appears restorable (Figure 15, Figure 16). In 2007, residential construction and road-widening was occurring at a rapid pace adjacent to these undeveloped parcels, some of which may have entitlements to develop. If these parcels are developed, this linkage will be severed for all practical purposes. If the parcels remain open space and are restored, this will remain a narrow constriction, but can probably become a functioning linkage.

There is an apparently abandoned complex of gravel pits in the Santa Cruz River in the linkage design, just southwest of Waypoint 23. We did not investigate this area closely to determine if requires active restoration. On Google Earth, it appears to have wetlands and vegetation that could provide cover, food, and water to wildlife needing a stopover location within the linkage.

In the Tortolita Mountains- Santa Catalina Mountains Linkage, the largest urban barriers are the city of Oro Valley and the unincorporated village of Catalina. According to the US Census Bureau, Oro Valley's population increased from 29,700 in 2000 to 38,438 in 2005. Much of its growth is occurring in the massive Rancho Vistoso development (Figure 25), which is still ongoing, but some is occurring outside of Rancho Vistoso (Figure 24). Catalina is a community of about 7,025 (2000 Census) on the north edge of the Linkage Design.

In Rancho Vistoso, we noted two bridges (Figure 17 and Figure 19) and urban setbacks from parts of Big Wash, Honey Bee Canyon, and Sausalito Creek that contribute to the functionality of the wildlife corridor. Other setbacks were closer to the riparian areas than optimal for wildlife movement, but our impression was that significant efforts, possibly increasing over time, have been made to reduce the impact of Rancho Vistoso on wildlife movement. The urban development is still ongoing, and it is important for any new development or roads to match or improve on the best bridges and setbacks in the development project. Because the land west of SR-77 is either in state ownership (ASLD) or in one major development project within the City of Oro Valley, securing this part of the linkage should be relatively straightforward.

East of SR-77, most land in the Linkage Design is within ASLD land, Catalina State Park, and Coronado National Forest. However, there are also significant private holdings on which urbanization has already occurred (Figure 26) causing the linkage design to split into northern and southern arms to avoid this urban area. Future urbanization should not occur on private or state land within the linkage design.

Guidelines & Recommendations for Mitigation of Urban Barriers

In addition to the preceding comments specific to Linkage A and Linkage B, we offer the following recommendations to reduce the barrier effects of urban development throughout the Linkage Design:

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) Discourage further residential development and subdivision of large parcels in the Linkage Design. 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. Developments within the linkage should have permeable perimeters, not walls.
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.
17) Respect the property rights of the many people already living in these wildlife corridors. Work with homeowners and residents to manage residential areas for wildlife permeability. Develop innovative programs that respect the rights of residents and enlist them as stewards of the linkage area.

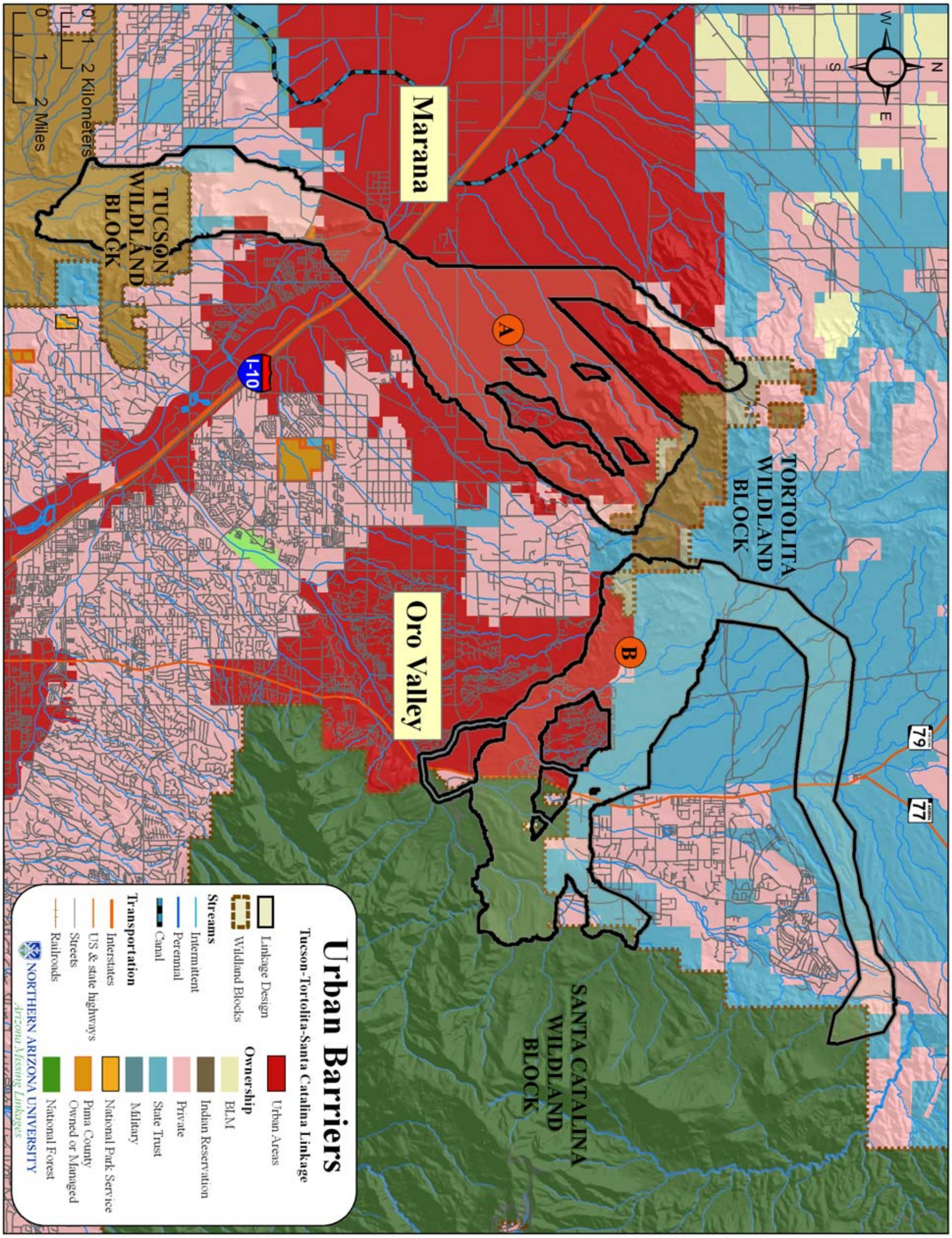

Figure 23: Boundaries of Marana, Oro Valley, and other urban areas within the Linkage Planning Area.

Figure 24: Residential development near SR-77 (Waypoint 4) creates a "bubble" within the Linkage Design.

Figure 25: Rancho Vistoso development includes setbacks from some major washes (Waypoint 10).

Figure 26: Massive residential development along Saddle Brook Road (view southeast from Waypoint 17).

Impediments to Riparian Systems

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Santa Cruz River, Honeybee Canyon, and Cañada del Oro provide important habitat for many species in the linkage area, including the lowland leopard frog and cactus ferruginous pygmy-owl.

Stream Impediments in the Linkage Design Area

Most streams in Arizona have areas without surface water or riparian vegetation, and thus are naturally fragmented from the perspective of many wildlife species. But nearly all riparian systems in the Southwest also have been altered by human activity (Stromberg 2000) in ways that increase fragmentation. For animals associated with streams or riparian areas, impediments are presented by road crossings, vegetation clearing, livestock grazing, invasion of non-native species, accumulation of trash and pollutants in streambeds, farming in channels, and gravel mining. Groundwater pumping, upland development, water recharge basins, dams, and concrete structures to stabilize banks and channels change natural flow regimes which negatively impacts riparian systems. Increased runoff from urban development not only scours native vegetation but can also create permanent flow or pools in areas that were formerly ephemeral streams. Invasive species, such as bullfrogs and giant reed, displace native species in some permanent waters.

Urbanization, exotic plants, and mining threaten the two major streams in the linkage design, namely the Santa Cruz River and Big Wash and its tributaries (Honey Bee Canyon, Sausalito Creek, and others). Aggressive protection of these areas and will enhance the utility of this linkage design.

Mitigating Stream Impediments

We endorse the following management recommendations for riparian connectivity and habitat conservation in riparian areas:

1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency, and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).
   - Urban development contributes to a "flashier" (more flood-prone) system. Check dams and settling basins should be required in urban areas within the watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000)].
   - Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
   - Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993). However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kupferberg 1997, Kiesecker and Blaustein 1998, Maret et al. 2006).
2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops, and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).
3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of the river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite *bosques* should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).
4) **Maintain biotic interactions within evolved tolerance ranges**. Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas (Belsky et al. 1999, National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).
5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, with a few becoming significant problems like tamarisk and Russian olive. Removing stressors and reestablishing natural flow regimes can help bring riparian communities back into balance, however some exotics are persistent and physical eradication is necessary to restore degraded systems (Stromberg 2000, Savage 2004, but see D'Antonio and Meyerson 2002). Elimination of unnatural perennial surface pools can eradicate water-dependent invasives like bullfrogs, crayfish, and mosquitofish.]
6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004).

Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.

7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

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[1]. 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 21 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

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[1] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute "truth" but rather an estimate or prediction of 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 27):

- *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[2].

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 1 and 10. We then weighted each of the by 4 factors by a weight between 0% and 100%, subject to the constraint that the 4 weights must sum to 100%. We calculated a weighted geometric mean[3] using the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10 (USFWS 1981). For each pixel of the landscape, the weighted geometric mean was calculated by raising each factor by its weight, and multiplying the factors:

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

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

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

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

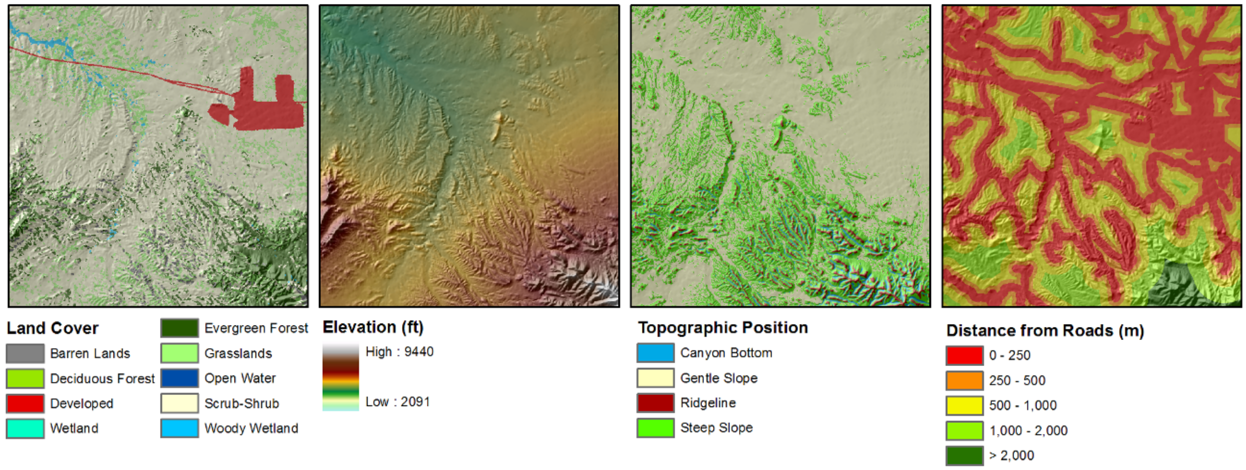

Figure 27: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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 28). 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[4]. 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.

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[4] 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.

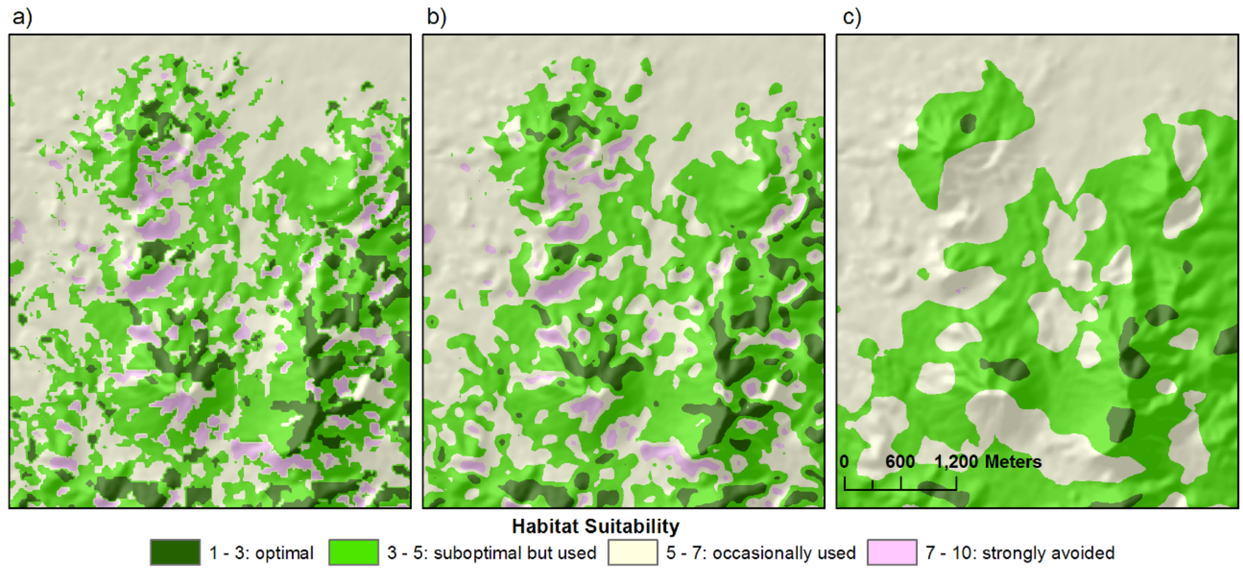

Figure 28: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

Identifying Biologically Best Corridors

The *biologically best corridor*[5] (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 wildland block to a potential population core in the other wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

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

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[6]. 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 wildland block. If potential population cores existed within each block, we used these potential cores as

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[5] 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.

[6] 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.

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[7]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1000m (Figure 29). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[8] distance of the species. For those species (*corridor-dwellers,* above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

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

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

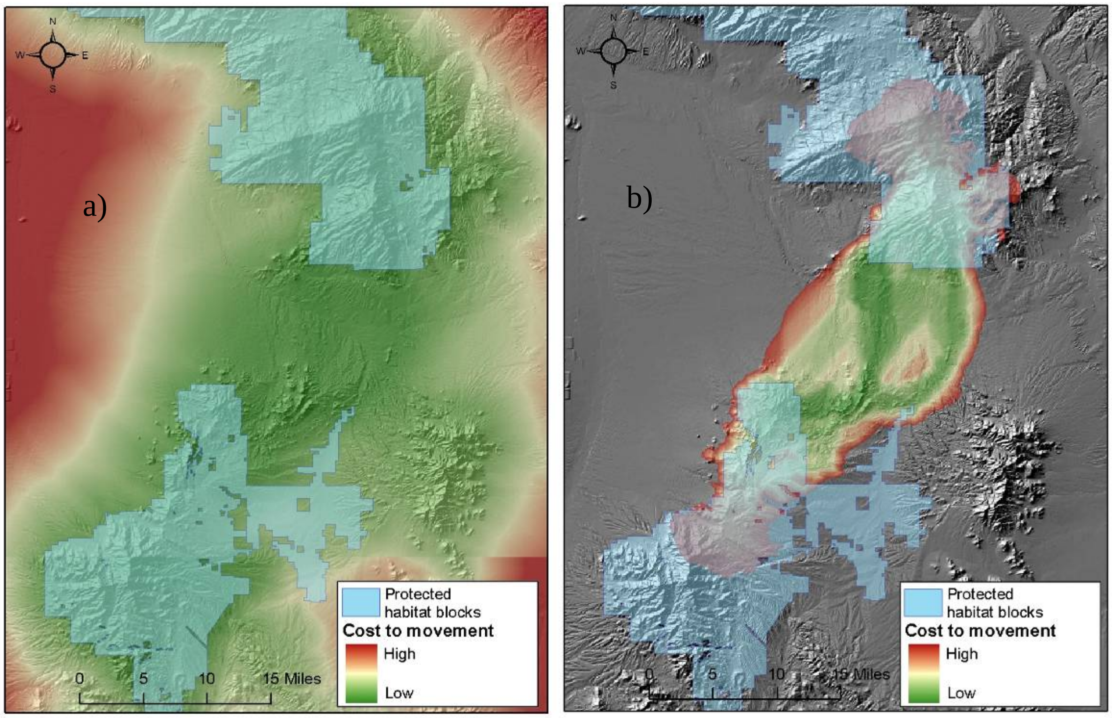

Figure 29: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

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 1 km (0.62 mi) along the length of each branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available.

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

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

Field Investigations

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

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	Desert Tortoise	Gila Monster
Factor weights					
Land Cover	65	75	95	30	10
Elevation	7	10	5	25	35
Topography	15	10	0	40	45
Distance from Roads	13	5	0	5	10
Land Cover					
Pine-Oak Forest and Woodland	5	1	2	10	10
Pinyon-Juniper Woodland	4	6	2	10	6
Ponderosa Pine Woodland	5	4	2	10	10
Juniper Savanna	2	7	4	10	10
Semi-Desert Grassland and Steppe	1	5	4	8	5
Chaparral	5	3	2	10	6
Creosotebush, Mixed Desert and Thorn Scrub	2	6	4	6	3
Creosotebush-White Bursage Desert Scrub	2	9	4	5	7
Desert Scrub (misc)	3	5	4	4	3
Gambel Oak-Mixed Montane Shrubland	5	3	2	10	10
Mesquite Upland Scrub	3	6	4	7	4
Paloverde-Mixed Cacti Desert Scrub	4	5	4	1	1
Pinyon-Juniper Shrubland	4	6	2	10	6
Riparian Mesquite Bosque	6	5	3	5	5
Riparian Woodland and Shrubland	6	5	3	10	5
Barren Lands, Non-specific	7	10	6	10	10
Bedrock Cliff and Outcrop	9	10	6	10	2
Cliff and Canyon	9	10	6	10	2
Mixed Bedrock Canyon and Tableland	9	10	6	10	2
Warm Desert Pavement	9	10	6	6	6
Recently Mined or Quarried	9	10	6	10	10
Agriculture	6	6	9	10	10
Developed, Medium - High Intensity	10	10	9	10	9
Developed, Open Space - Low Intensity	7	10	7	7	1
Open Water	9	10	10	10	10
Elevation (ft)					
	0-5500: 1	0-2500: 8	0-7500: 1	0-5000: 1	0-1700: 4
	5500-8000: 3	2500-4000: 6	7500-10000: 5	5000-7000: 7	1700-4000: 1
	8000-11000: 6	4000-6500: 2	10000-11000: 9	7000-11000: 10	4000-4800: 4
		6500-8500: 3			4800-5700: 7
		8500-11000: 4			5700-11000: 10
Topographic Position					
Canyon Bottom	5	3		8	1
Flat - Gentle Slopes	1	6		5	5
Steep Slope	8	3		3	1
Ridgetop	7	4		7	1
Distance from Roads (m)					
	0-250: 6	0-100: 10		0-250: 5	0-1000: 5
	250-1500: 1	100-500: 4		250-500: 4	1000-3000: 3
		500-15000: 1		500-1000: 3	3000-15000: 1
				1000-15000: 1	

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

Badger (*Taxidea taxus*)

Justification for Selection

Because of their large home ranges, many parks and protected lands are not large enough to ensure protection of a badger population, or even an individual (NatureServe 2005). Consequently, badgers have suffered declines in recent decades in areas where grasslands have been converted to intensive agricultural areas, and where prey animals such as prairie dogs and ground squirrels have been reduced or eliminated (NatureServe 2005). Badgers are also threatened by collisions with vehicles while attempting to cross highways intersecting their habitat (New Mexico Department of Game and Fish 2004, NatureServe 2005).

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for badger within the potential linkage area (Figure 30 and Figure 32). Within the BBC in Strand A, habitat suitability scores ranged from 1.8 to 8.3, with an average suitability cost of 3.3 (S.D: 0.8). Within the BBC in Strand B, habitat suitability scores ranged from 2.3 to 8.1, with an average of 3.5 (S.D:0.8).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures additional suitable and optimal habitat for badger. 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 SR-77, and habitat fragmentation.

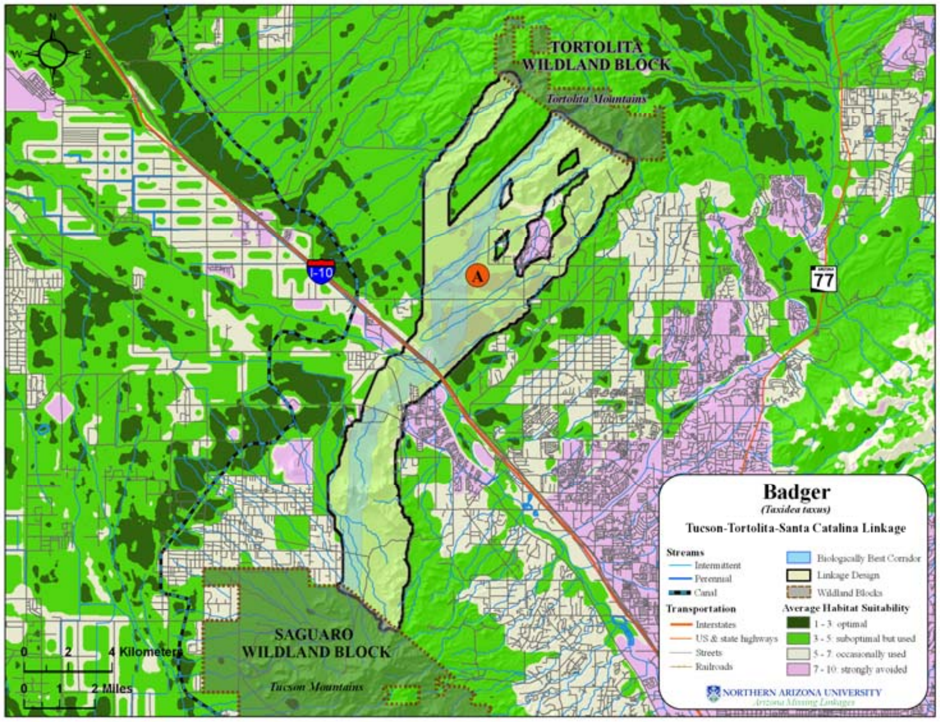

Figure 30: Modeled habitat suitability for badger in Strand A.

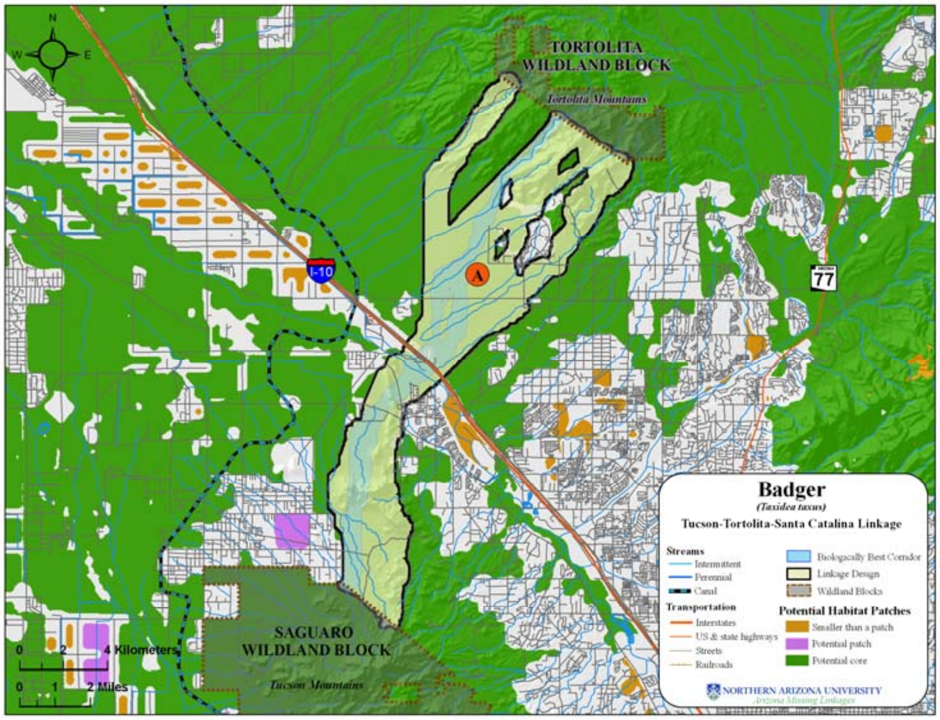

Figure 31: Potential habitat patches and cores for badger in Strand A.

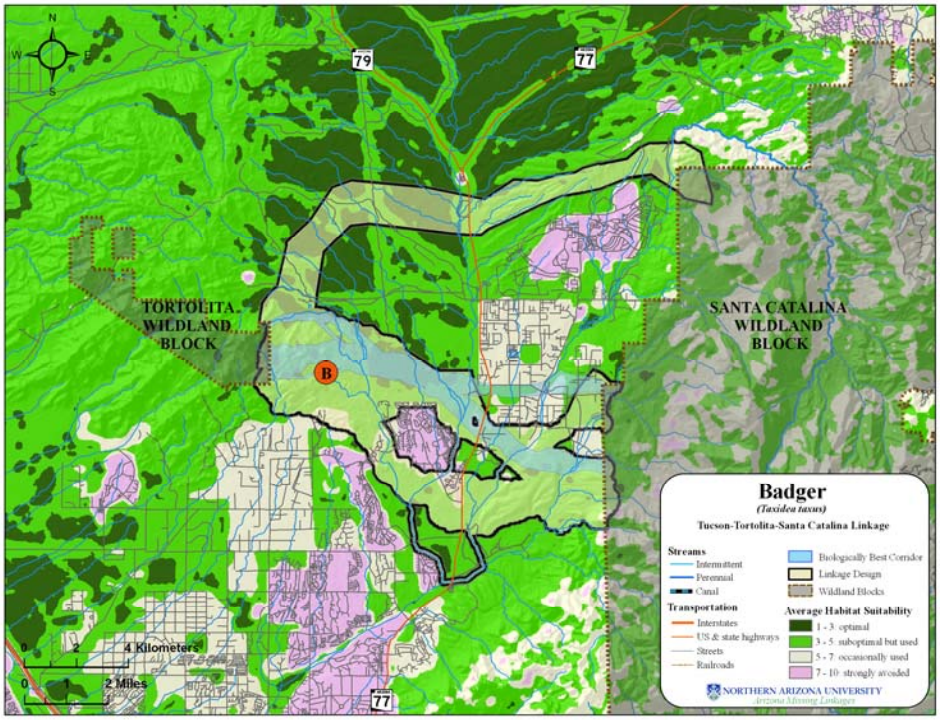

Figure 32: Modeled habitat suitability for badger in Strand B.

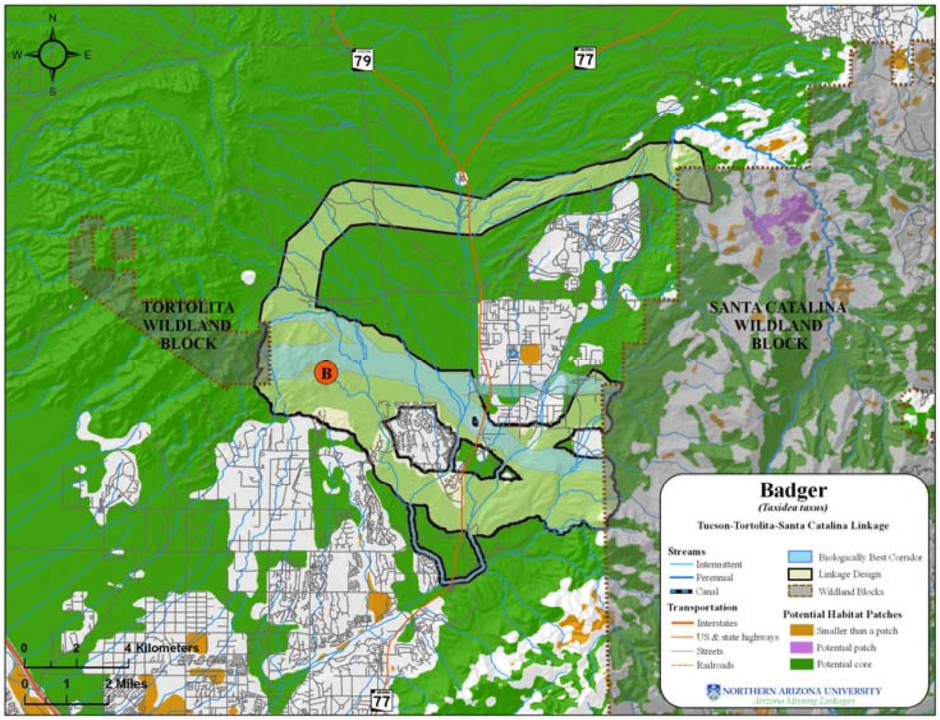

Figure 33: Potential habitat patches and cores for badger in Strand B.

Black Bear (*Ursus americanus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Cover is the most important factor for black bears, so vegetation was assigned an importance weight of 75%. Elevation and topography each received a weight of 10%, and distance from roads received a weight of 5%. For specific scores of classes within each of these factors, see Table 4 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 50km2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling identified suitable habitat for black bear in and around the mountain ranges that lie within the wildland blocks, and optimally rated habitat in the Santa Catalina Mountains

Figure **34** and Figure 36). Within the BBC in Strand A, habitat suitability scores ranged from 3.7 to 10.0, with an average suitability cost of 5.6 (S.D: 0.7). Within the BBC in Strand B, habitat suitability scores ranged from 1.3 to 8.9, with an average of 5.3 (S.D:1.3).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures little additional suitable habitat for black bear in the foothills of the wildland blocks. The greatest threat to connectivity and persistence of black bear populations is most likely high-traffic roads such as Interstate 10, SR-77, continued habitat fragmentation, and urbanization.

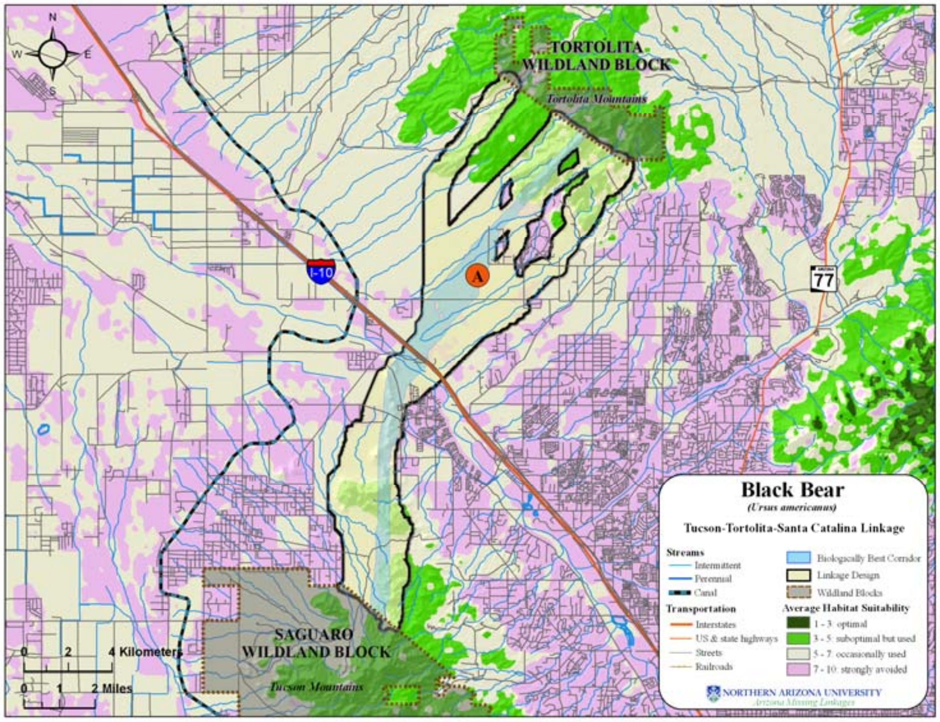

Figure 34: Modeled habitat suitability of black bear in Strand A.

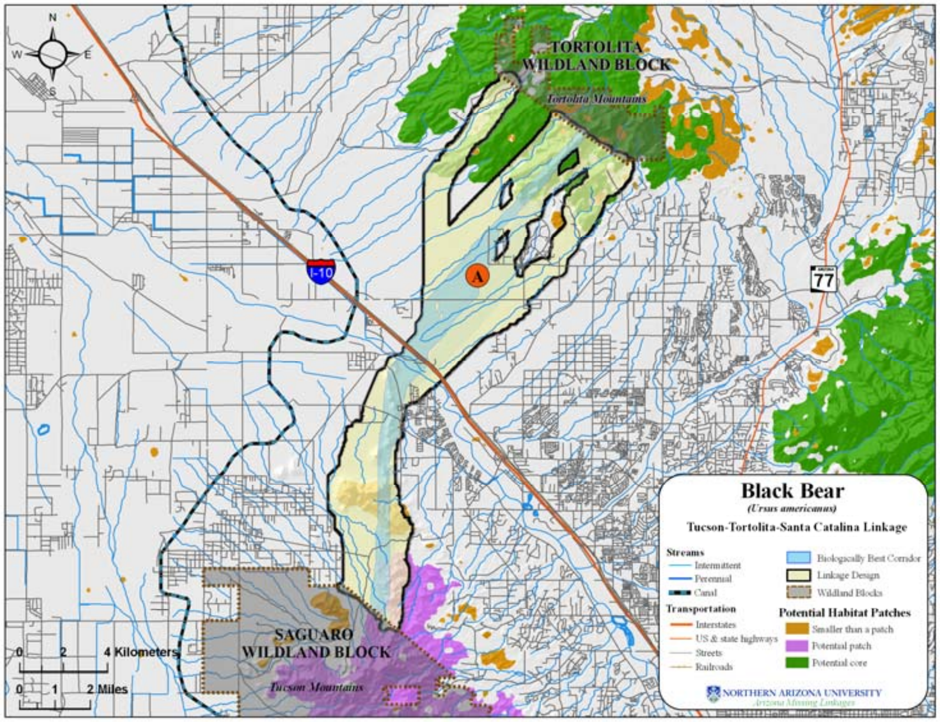

Figure 35: Potential habitat patches and cores for black bear in Strand A.

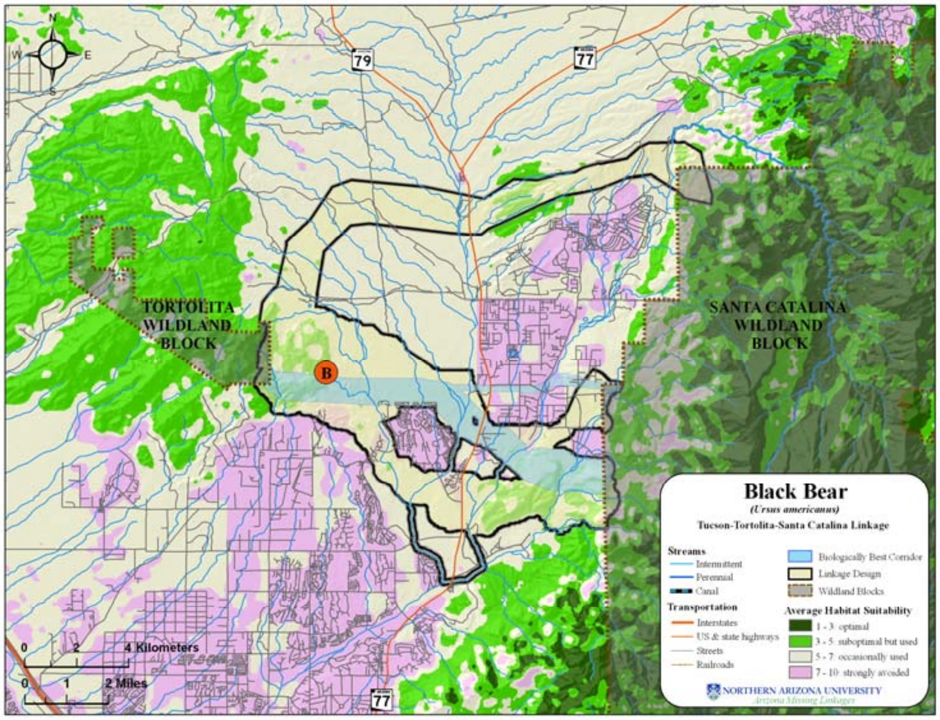

Figure 36: Modeled habitat suitability for black bear in Strand B.

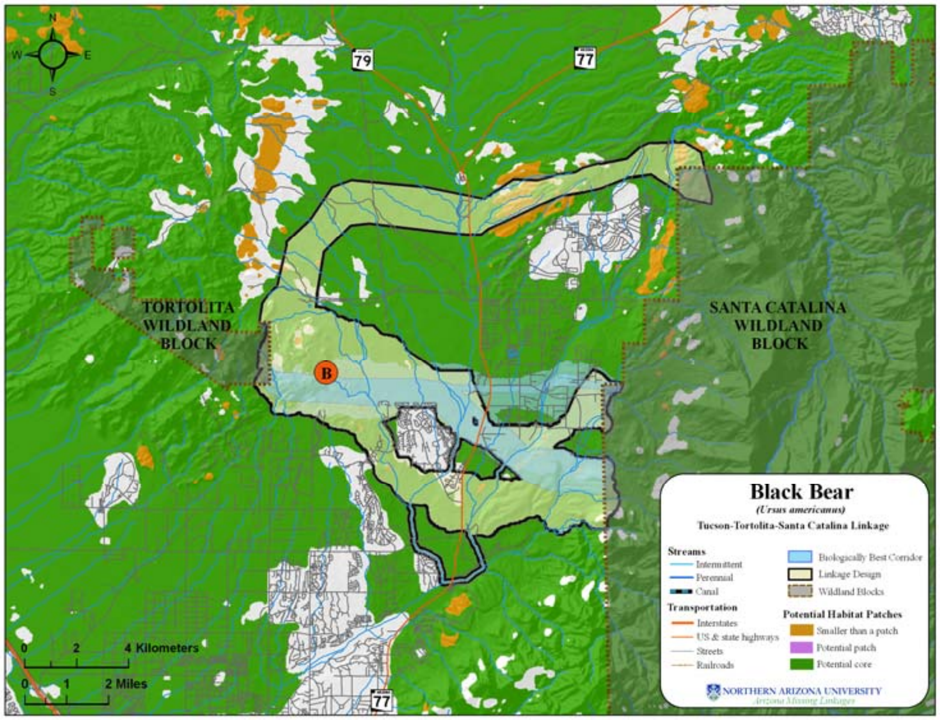

Figure 37: Potential habitat patches and cores for black bear in Strand B.

Bobcat (*Lynx rufus*)

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 zone5.3 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.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for bobcat within the potential linkage area, with optimal habitat largely occurring in the Santa Catalina Mountains (Figure 38 and Figure 40). Within the BBC in Strand A, habitat suitability scores ranged from 2.7 to 8.5, with an average suitability cost of 4.0 (S.D: 0.6). Within the BBC in Strand B, habitat suitability scores ranged from 2.0 to 8.3, with an average of 4.0 (S.D:0.9).

Union of biologically best corridors – The additional area encompassed by the Linkage Design is almost entirely comprised of suitable habitat for bobcat. 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 SR-77, and habitat fragmentation.

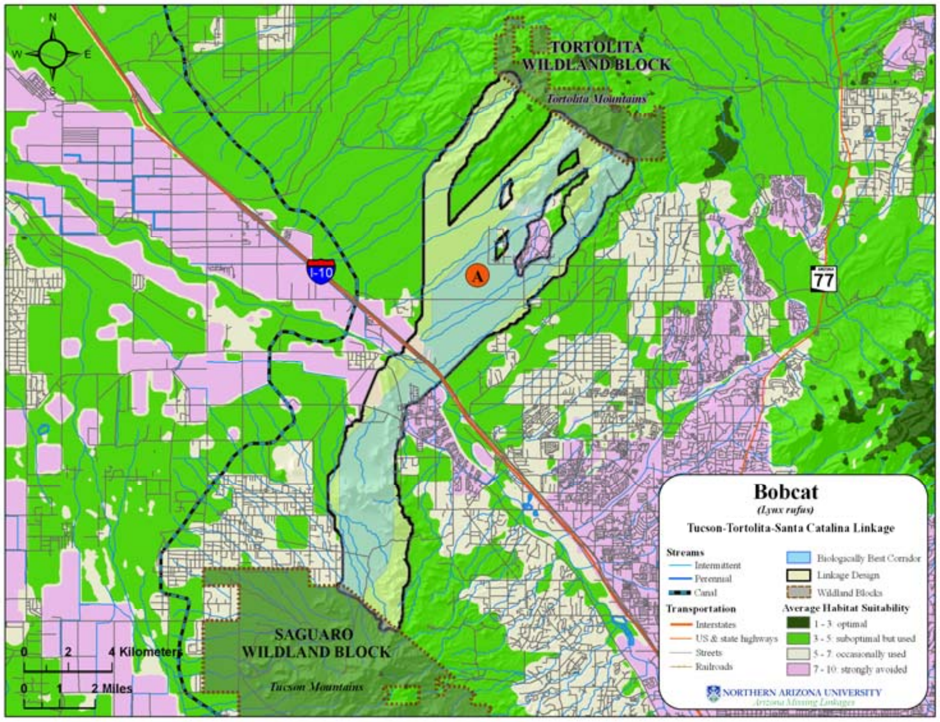

Figure 38: Modeled habitat suitability of bobcat in Strand A.

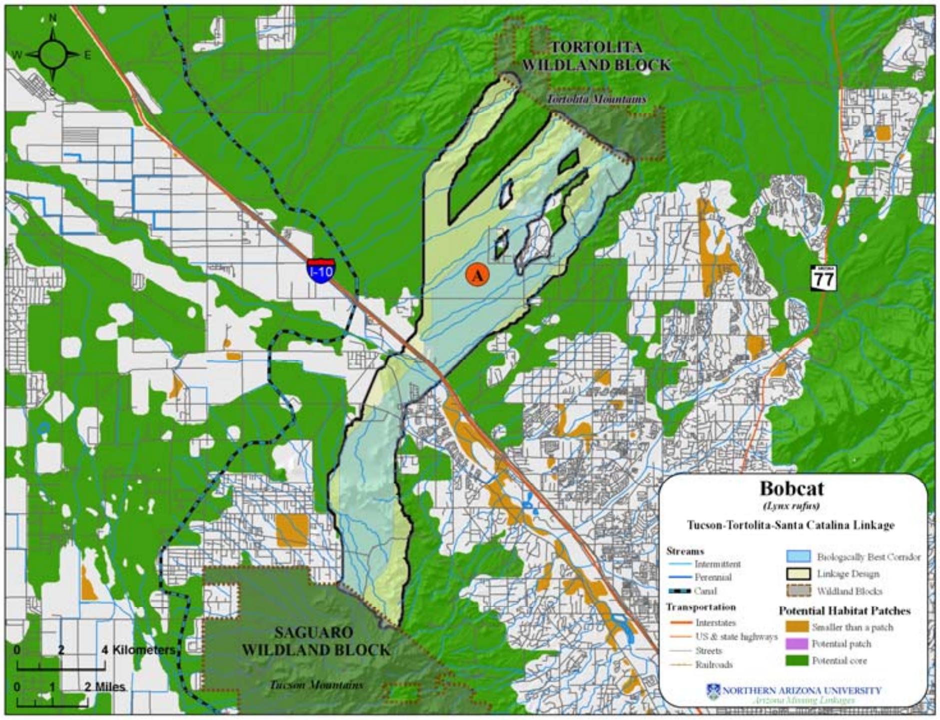

Figure 39: Potential habitat patches and cores for bobcat in Strand A.

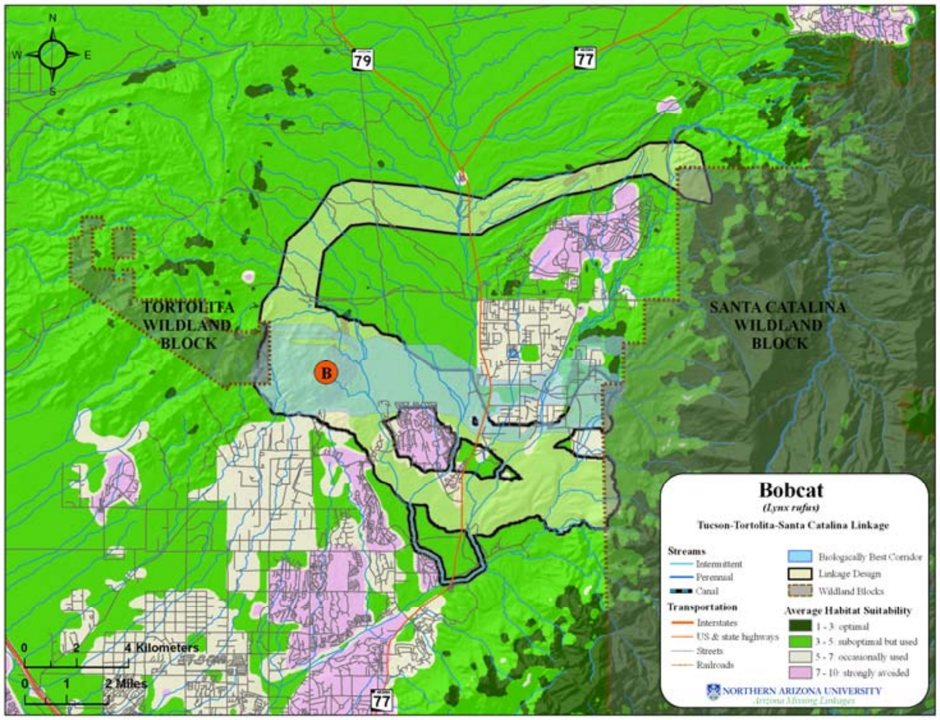

Figure 40: Modeled habitat suitability for bobcat in Strand B.

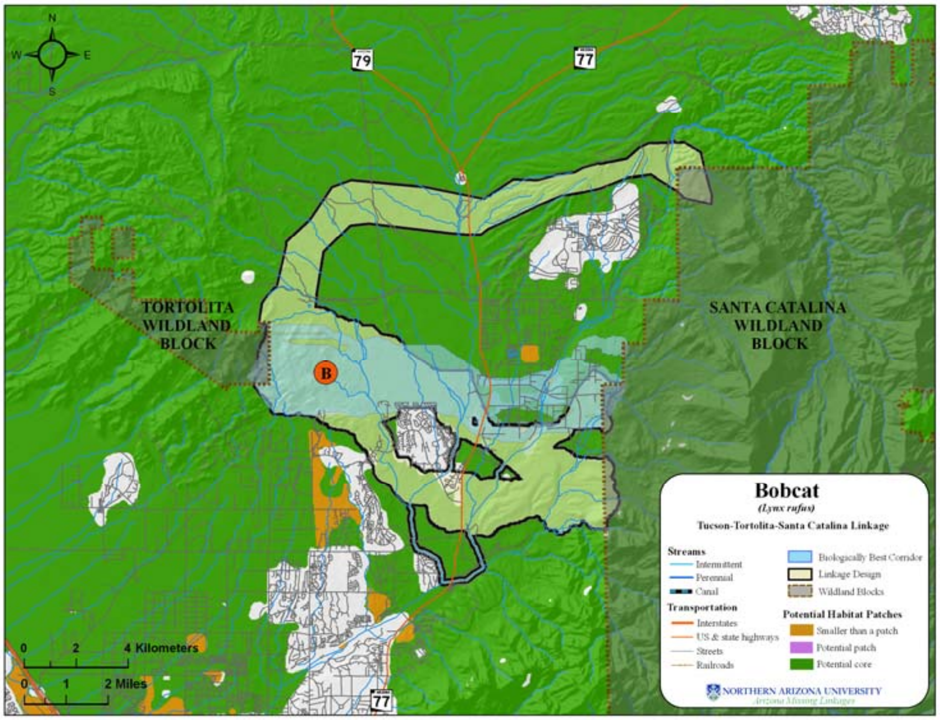

Figure 41: Potential habitat patches and cores for bobcat in Strand B.

Desert Tortoise (*Gopherus agassizii*)

Photograph by Jeff Servoss, US Fish and Wildlife Service

Justification for Selection

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

Distribution

Desert tortoises are found in deserts throughout California, southeastern Nevada, southwestern Utah, and Arizona. Desert tortoises are divided into two populations: the Mojave Desert population which occurs north and west of the Colorado River, and the Sonoran Desert population which occurs south and east of the Colorado River.

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 25%, 40%, and 5%, respectively. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Minimum potential habitat patch size was defined as 15 ha, and minimum potential core size was defined as 50 ha (Rosen & Mauz 2001; Phil Rosen, personal comm.). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat sprinkled with optimal habitat throughout the potential linkage area, while occasionally used and avoided habitat occur along major roads and heavily roaded areas and developments (Figure 42and Figure 44). Within the BBC in Strand A, habitat suitability scores ranged from 1.0 to 10.0, with an average suitability cost of 2.7 (S.D: 1.1). Within the BBC in Strand B, habitat suitability scores ranged from 1.0 to 10.0, with an average of 3.2 (S.D:1.5).

Union of biologically best corridors – The additional area encompassed by the UBBC captures additional suitable and optimal habitat for desert tortoise, and is comprised almost entirely of habitat that could serve as a potential population core (Figure 43 and Figure 45). 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 SR-77, urbanization, and habitat fragmentation.

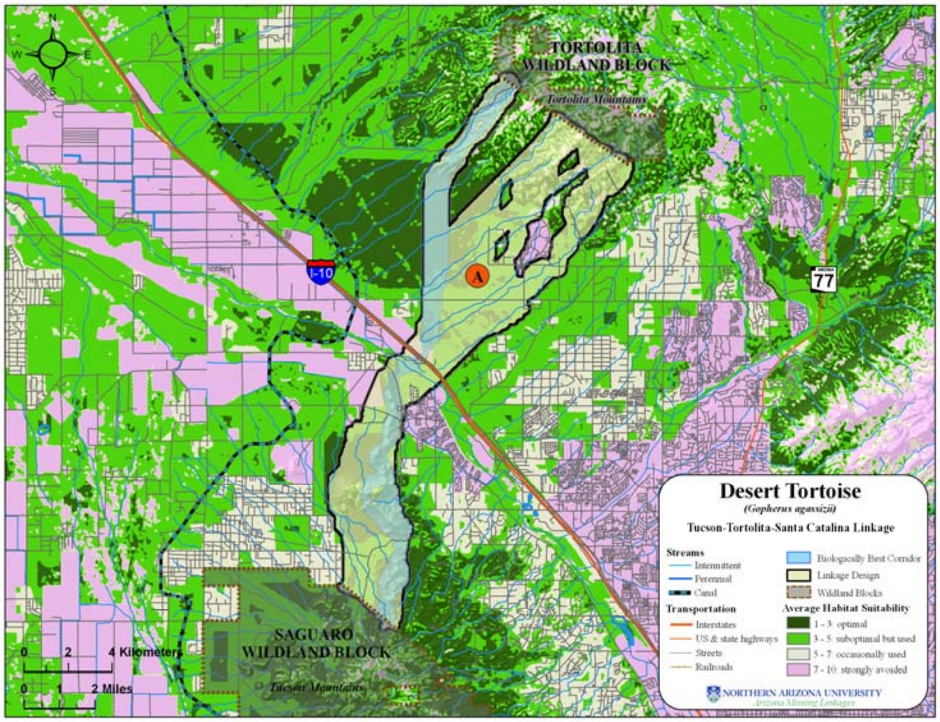

Figure 42: Modeled habitat suitability for desert tortoise in Strand A.

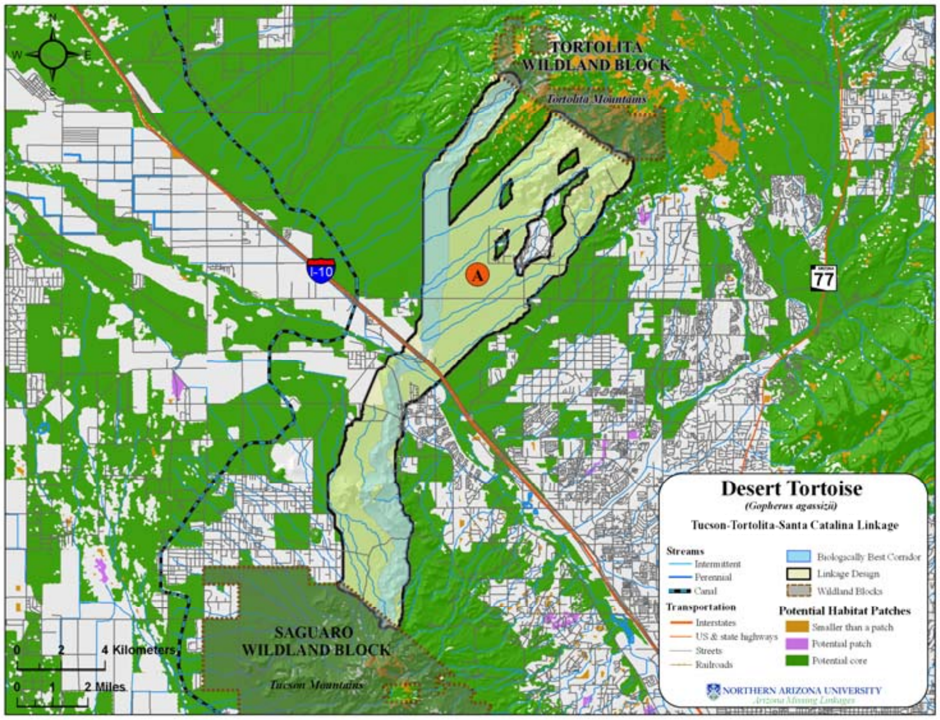

Figure 43: Potential habitat patches and cores for desert tortoise in Strand A.

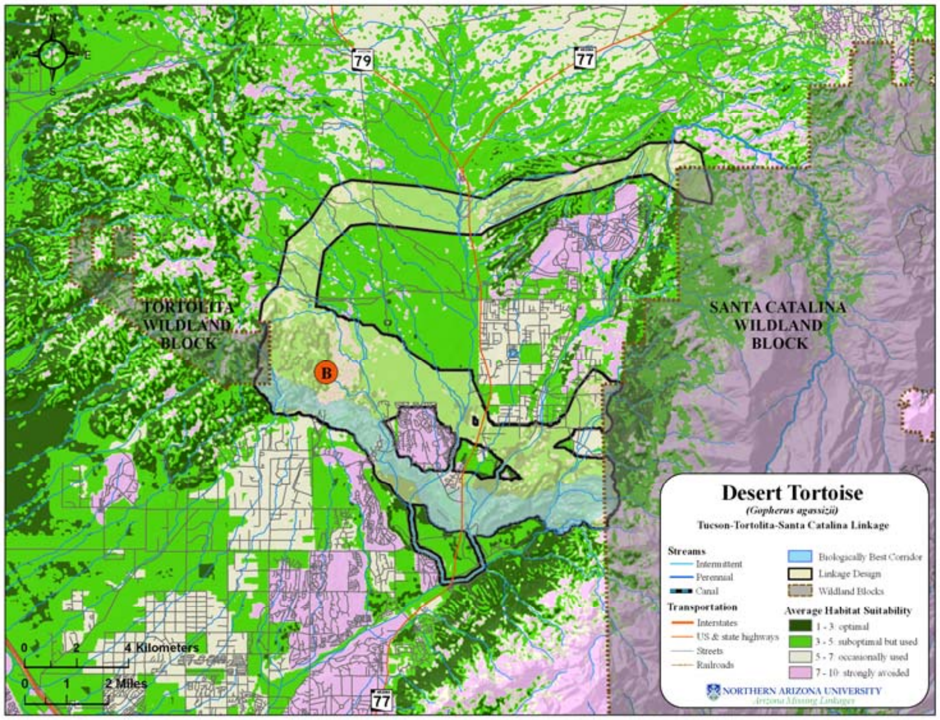

Figure 44: Modeled habitat suitability for desert tortoise in Strand B.

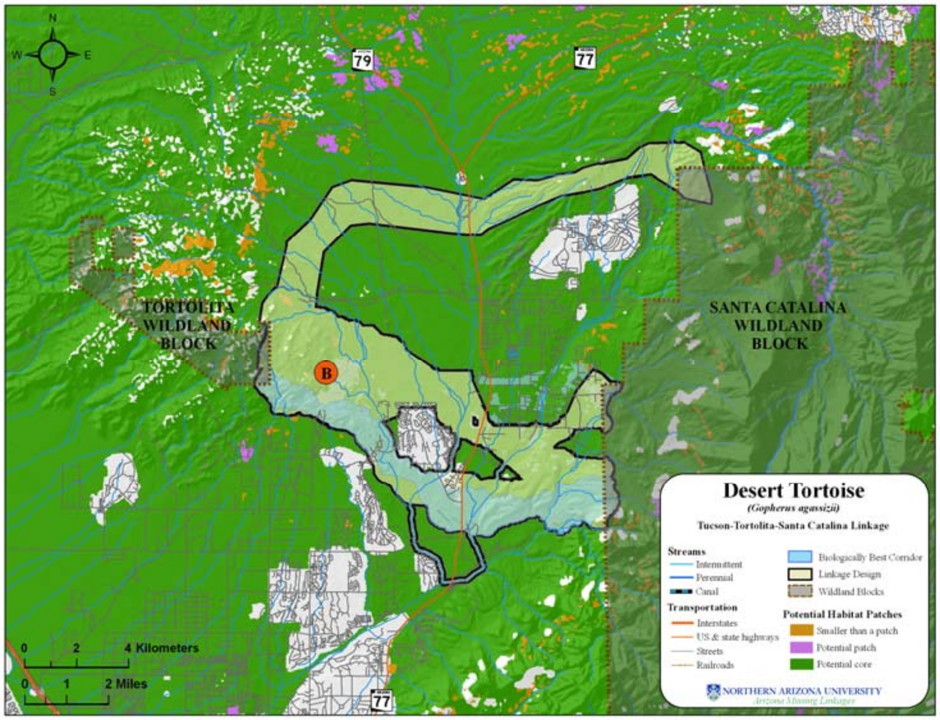

Figure 45: Potential habitat patches and cores for desert tortoise in Strand B.

Gila Monster (*Heloderma suspectum*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size & configuration analysis – Minimum potential habitat patch size was defined as 100 ha, and minimum potential core size was defined as 300 ha (Rosen & Goode, personal comm.; Beck 2005). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for gila monster within the potential linkage area with optimal habitat located in and around the foothills and lower elevations in the mountains within the wildland blocks (Figure 46 and Figure 48). Within the BBC in Strand A, habitat suitability scores ranged from 1.2 to 10.0, with an average suitability cost of 2.4 (S.D: 1.1). Within the BBC in Strand B, habitat suitability scores ranged from 1.2 to 4.7, with an average of 2.4 (S.D:1.1).

Union of biologically best corridors – The area encompassed by the Linkage Design captures additional suitable and optimal habitat for gila monsters. With the exception of high elevation areas in the Santa Catalina Mountains, most of the potential linkage area serves as a potential population core (Figure 47 and Figure 49). The greatest threats to connectivity and persistence of gila monsters are most likely high-traffic roads such as Interstate 10 and SR-77, urbanization, and habitat fragmentation.

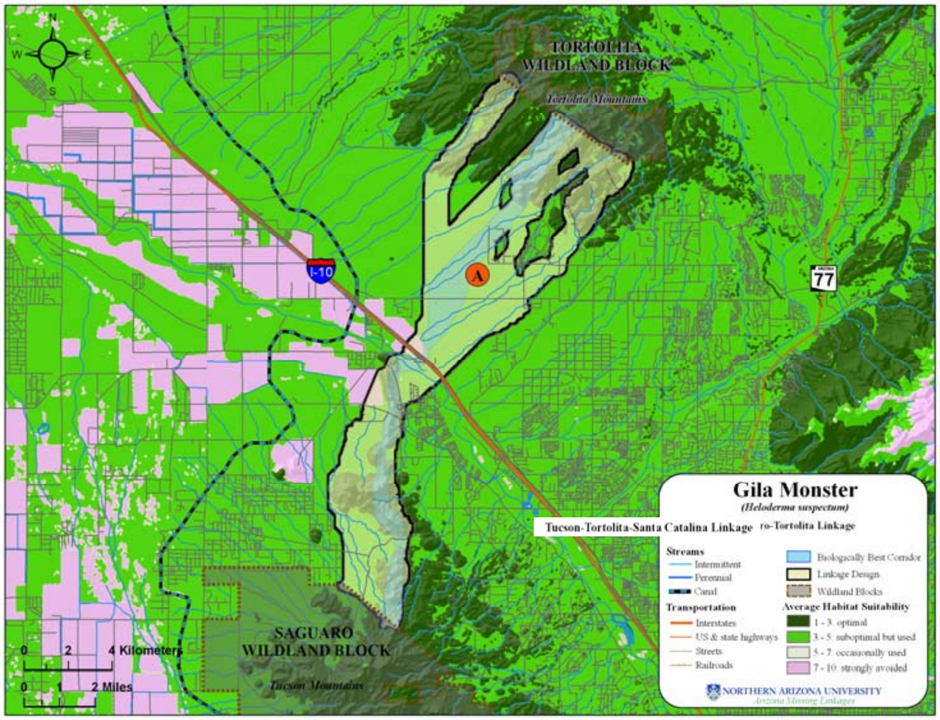

Figure 46: Modeled habitat suitability for gila monster in Strand A.

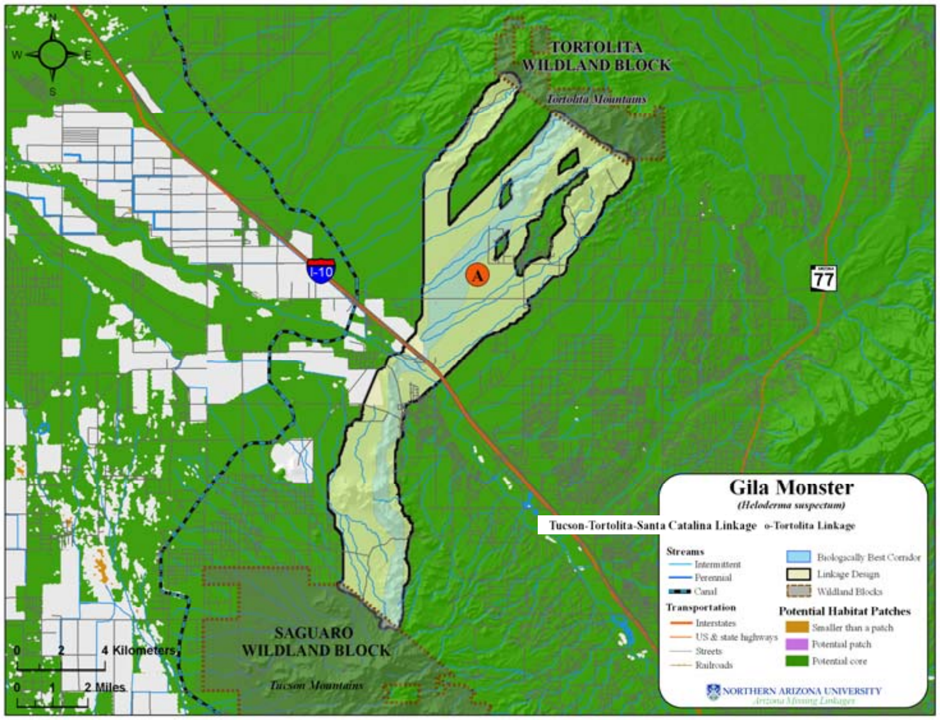

Figure 47: Potential habitat patches and cores for gila monster in Strand A.

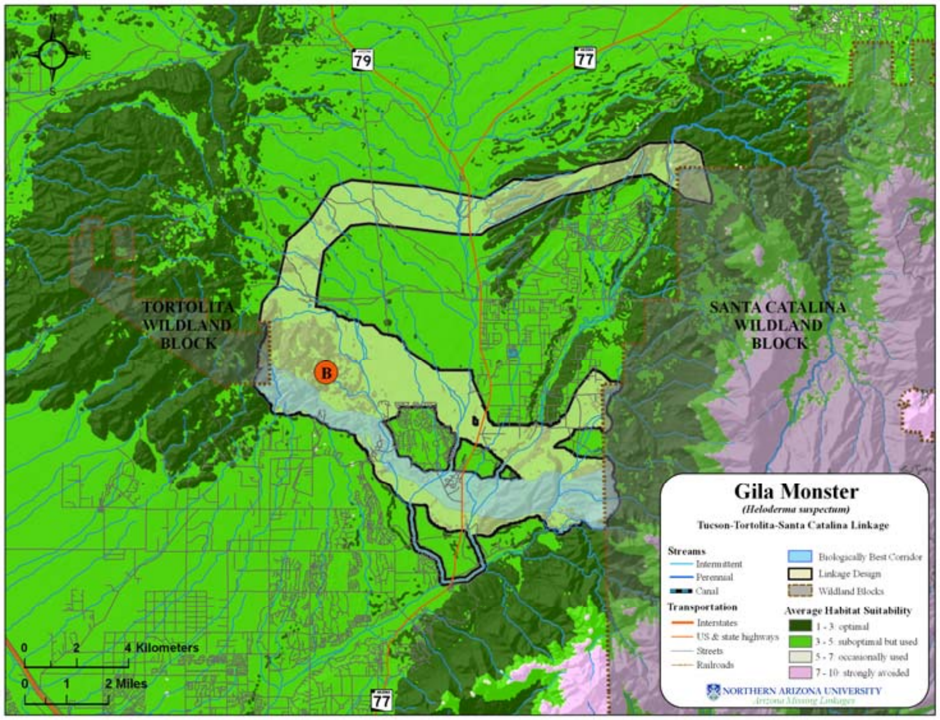

Figure 48: Modeled habitat suitability for gila monster in Strand B.

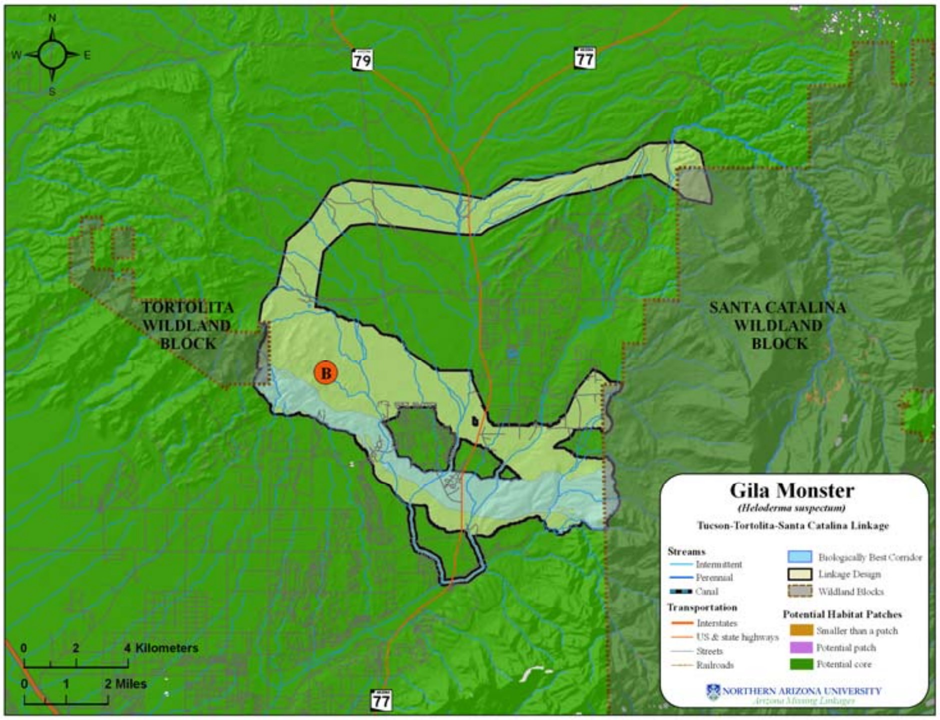

Figure 49: Potential habitat patches and cores for gila monster in Strand B.

Javelina (*Tayassu tajacu*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

Javelina live in stable herds, though occasionally some individuals may move out of the herd to join another or establish their own (Hoffmeister 1986). Home ranges for herds have been reported as 4.7 km² in the Tortolita Mountains (Bigler 1974), 4.93 km² near Prescott (Ticer et al. 1998), and between 1.9 and 5.5 ha in the Tonto Basin (Ockenfels and Day 1990). Dispersal of javelina has not been adequately studied, but they are known to be capable of extensive movements of up to several kilometers (NatureServe 2005).

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate ample optimal habitat for javelina within the potential linkage area, with suitable habitat occurring along major roads and in developed areas (Figure 50 and Figure 52). Most of the potential linkage area serves as a potential population core for javelina (Figure 51 and Figure 53). Within the BBC in Strand A, habitat suitability scores ranged from 1.0 to 4.8, with an average suitability cost of 1.3 (S.D:0.5). Within the BBC in Strand B, habitat suitability scores ranged from 1.0 to 5.0, with an average of 1.7 (S.D:0.8).

Union of biologically best corridors – The area encompassed by the Linkage Design is almost entirely made up of optimal habitat for javelina. The greatest threats to their connectivity and persistence are most likely high-traffic roads such as Interstate 10 and SR-77, urbanization, and habitat fragmentation.

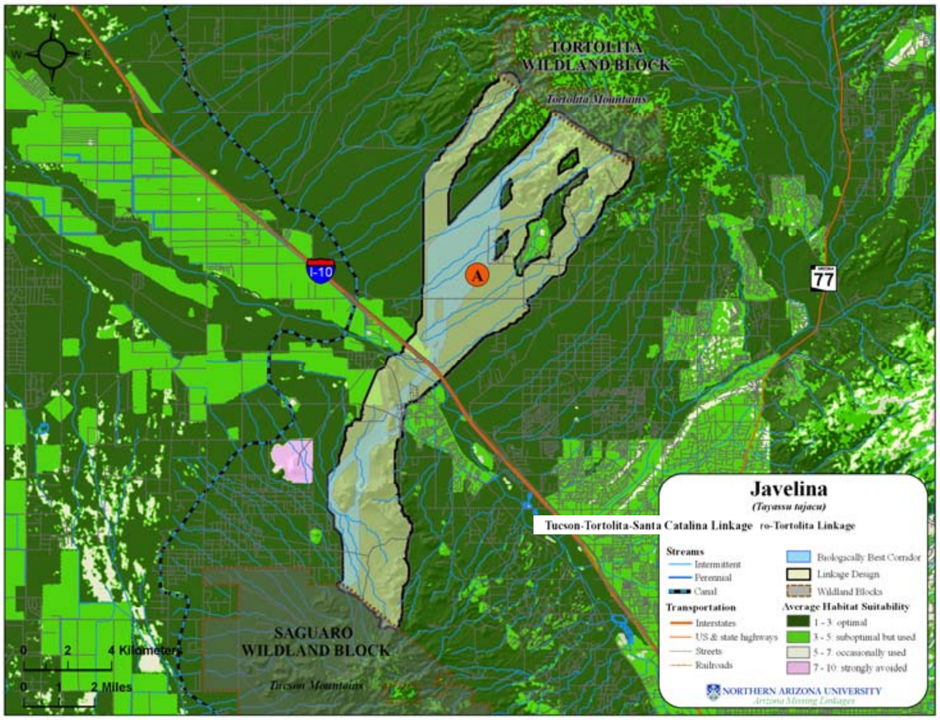

Figure 50: Modeled habitat suitability for javelina in Strand A.

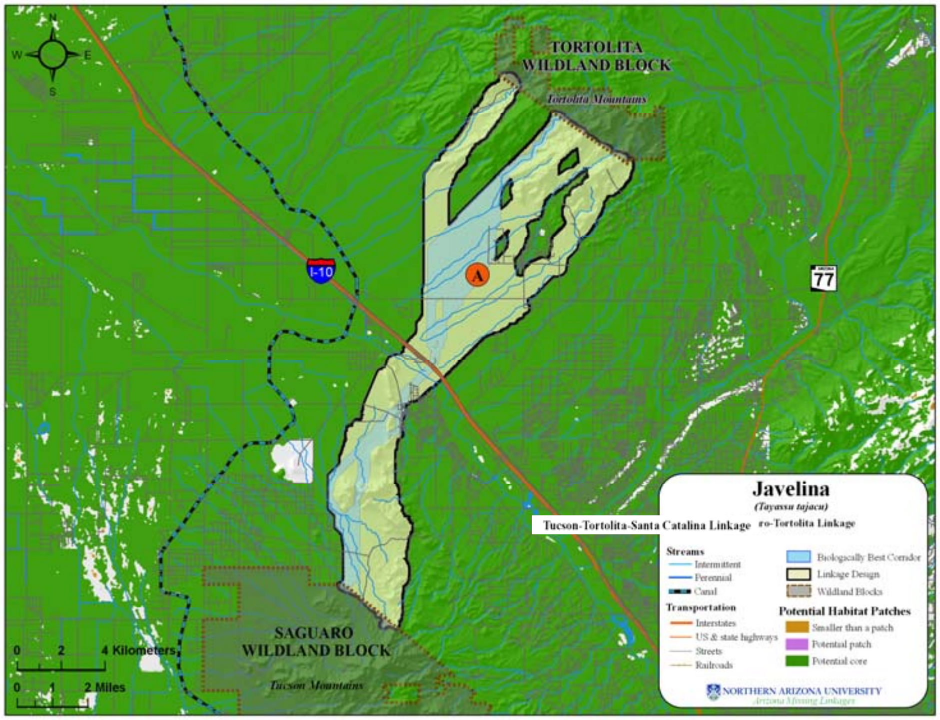

Figure 51: Potential habitat patches and cores for javelina in Strand A.

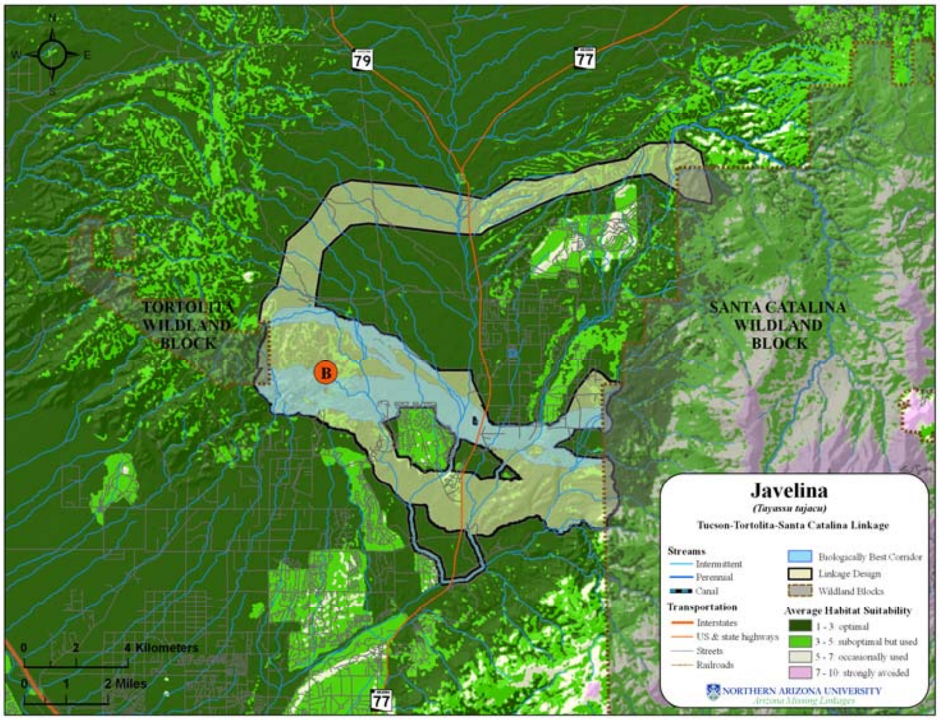

Figure 52: Modeled habitat suitability for javelina in Strand B.

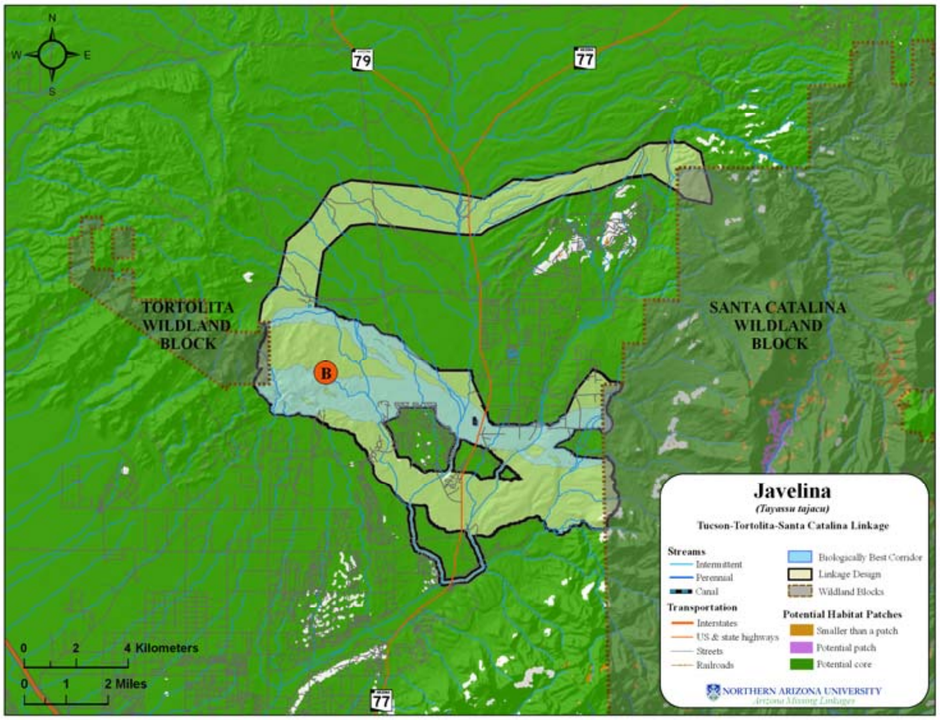

Figure 53: Potential habitat patches and cores for javelina in Strand B.

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.

Results & Discussion
Initial biologically best corridor – Modeling results indicate significant amounts of optimal habitat for kit fox within the potential linkage area, interspersed with smaller patches of suitable habitat and occasionally used or avoided habitat occurring adjacent to major roads or urban areas (Figure 54 and

Figure 56). Within the BBC in Strand A, habitat suitability scores ranged from 1.0 to 6.9, with an average suitability cost of 2.6 (S.D: 0.7). Within the BBC in Strand B, habitat suitability scores ranged from 1.0 to 6.8, with an average of 2.7 (S.D:0.9).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures a mixture of suitable and optimal, and small patches of avoided habitat for kit fox. With the exception of areas adjacent to major roads, most of the Linkage serves as a potential population core (Figure 55 and Figure 57). 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 SR-77, urbanization, and habitat fragmentation.

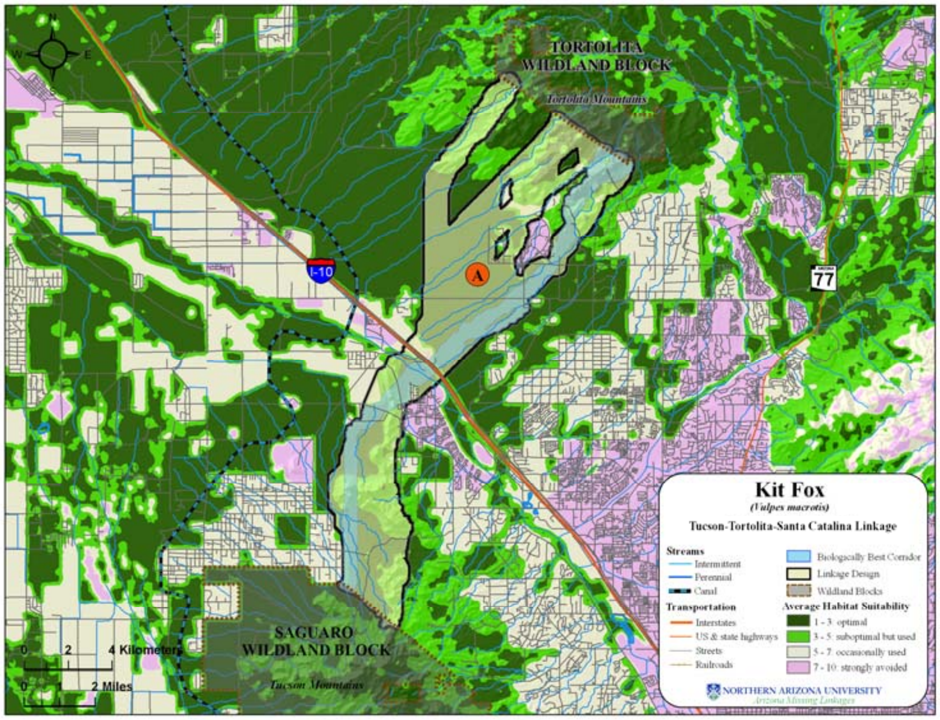

Figure 54: Modeled habitat suitability for kit fox in Strand A.

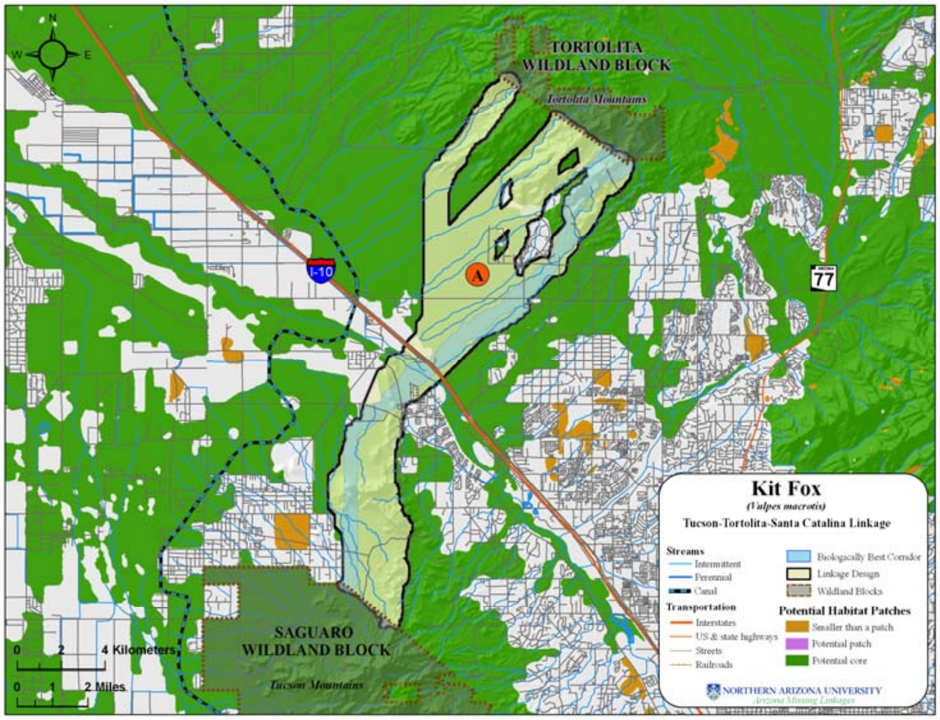

Figure 55: Potential habitat patches and cores for kit fox in Strand A.

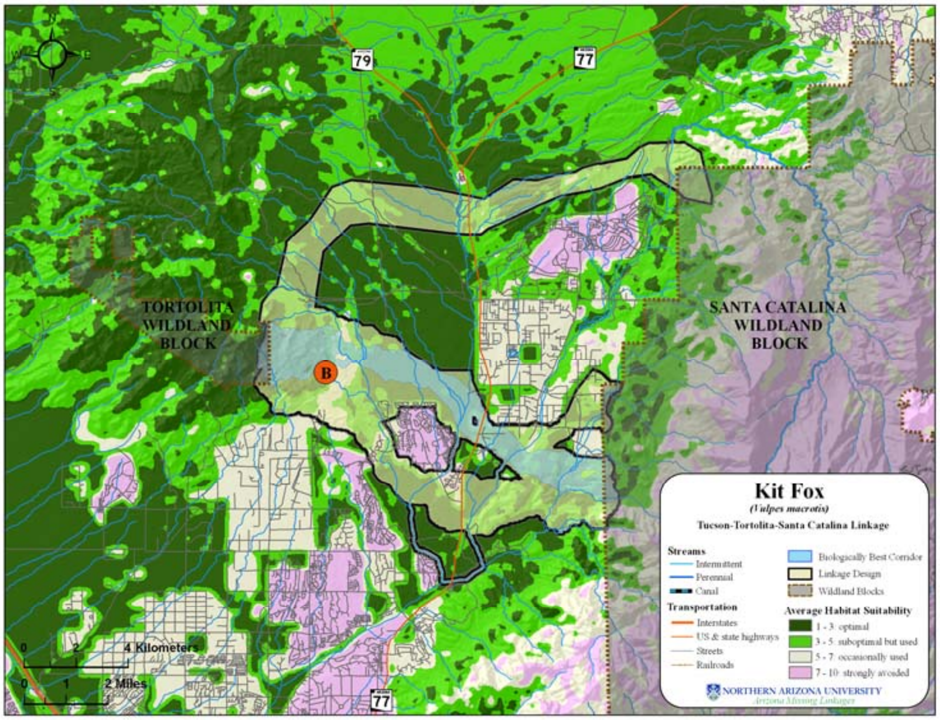

Figure 56: Modeled habitat suitability for kit fox in Strand B.

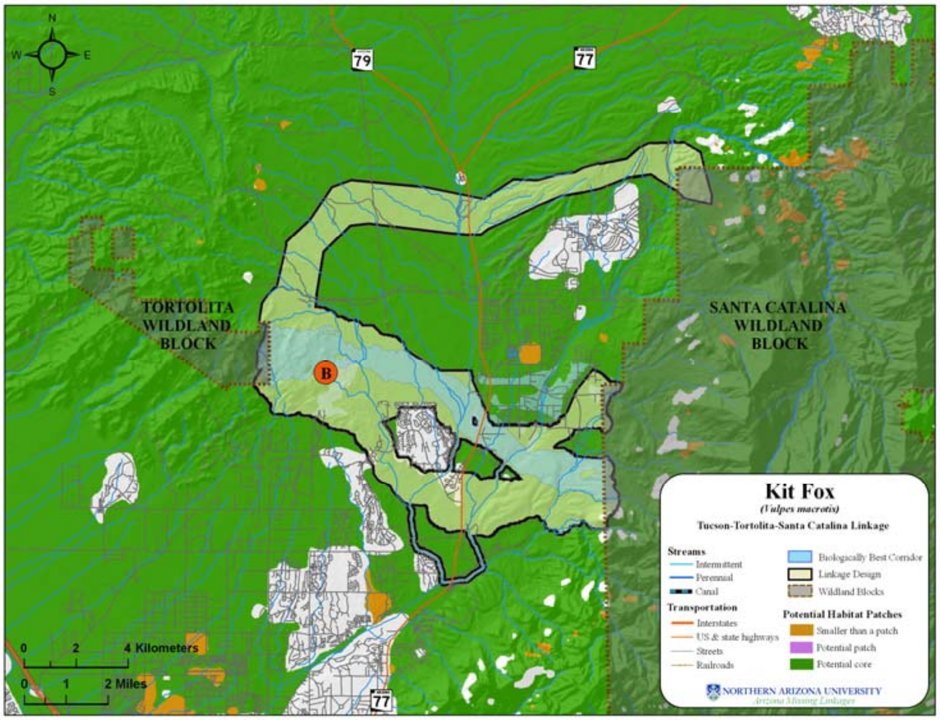

Figure 57: Potential habitat patches and cores for kit fox in Strand B.

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.

Results & Discussion

Initial biologically best corridor – Modeling identified a large potential population core for mountain lions in the Santa Catalina Mountains (Figure 59 and Figure 61) where the only significant amount of optimal habitat is located. A small patch of suitable habitat occurs in and around the Tortolita wildland block (Figure 58 and Figure 60) while the Tucson Mountains offers the least amount of suitable habitat for mountain lion (Figure 58), and occasionally used or avoided habitat comprises the remainder of the linkage planning area except for some patches of suitable habitat near the junction of SR 77 and SR 79, north of the Oro Valley. We created Strand B based on actual movements of one collared lion (Figure 62) between the Tortolita and Santa Catalina mountains, and deleted a portion of the original BBC that was deemed to developed to be permeable during the creation of the Linkage Design (Appendix F, Figure 68 and Figure 69). Within the BBC in Strand A, habitat suitability scores ranged from 2.1 to 9.6, with an average suitability cost of 6.3 (S.D: 0.9). Within the BBC in Strand B, habitat suitability scores ranged from 1.3 to 8.9, with an average of 5.3 (S.D:1.3).

Union of biologically best corridors – The additional area encompassed by the Linkage Design captures a few small patches of suitable mountain lion habitat between the Tortolita and Santa Catalina mountains. Because there is very little remaining suitable or optimal habitat for mountain lion within the linkage planning area, habitat conservation and linkages are integral to its connectivity and persistence.

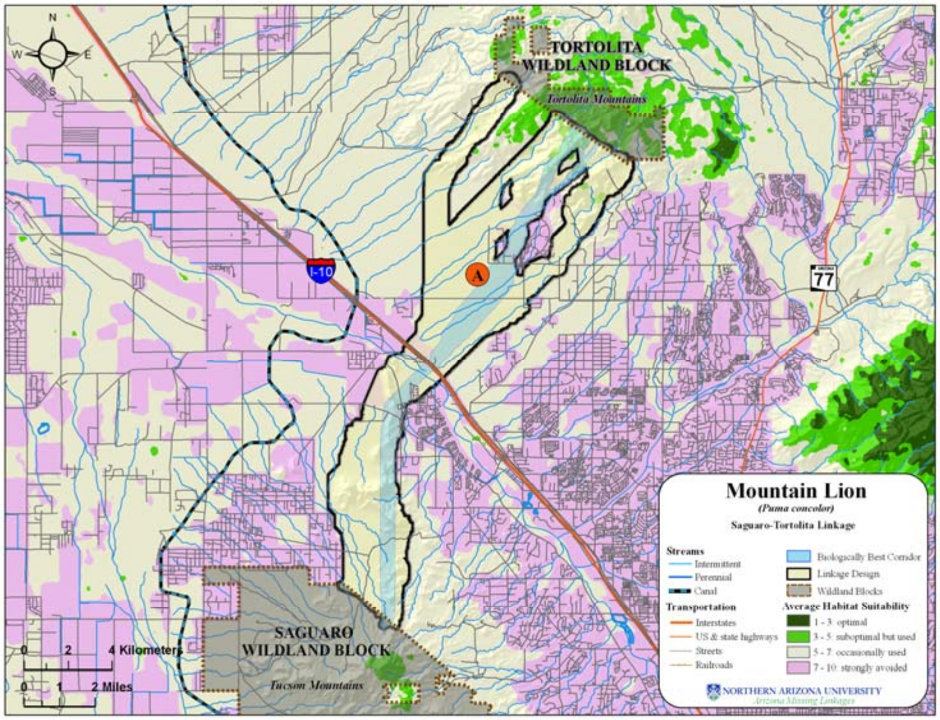

Figure 58: Modeled habitat suitability of mountain lion in Strand A.

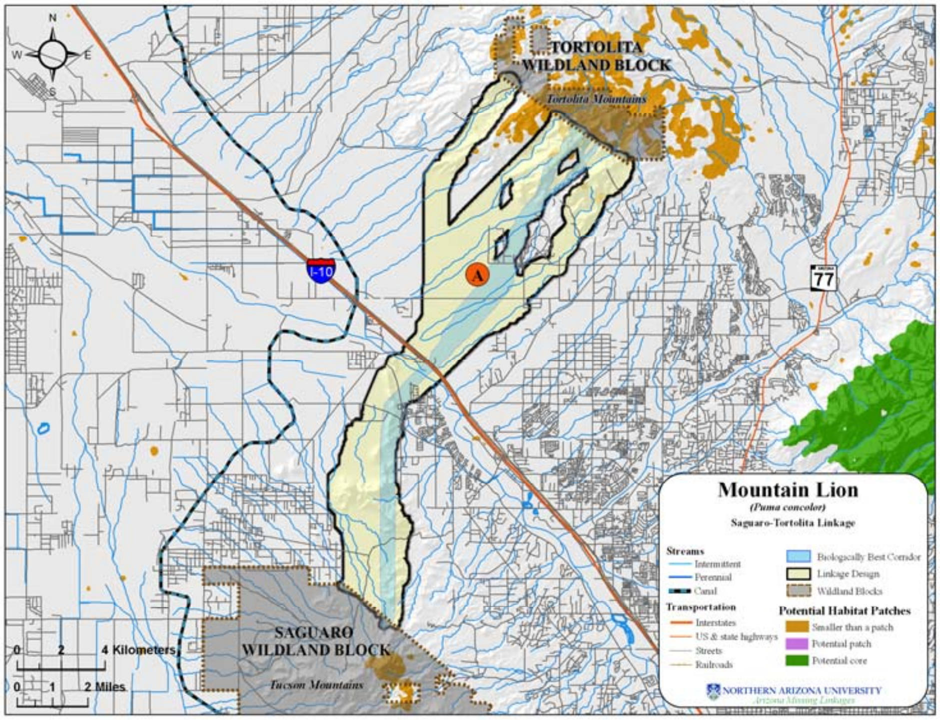

Figure 59: Potential habitat patches and cores for mountain lion in Strand A.

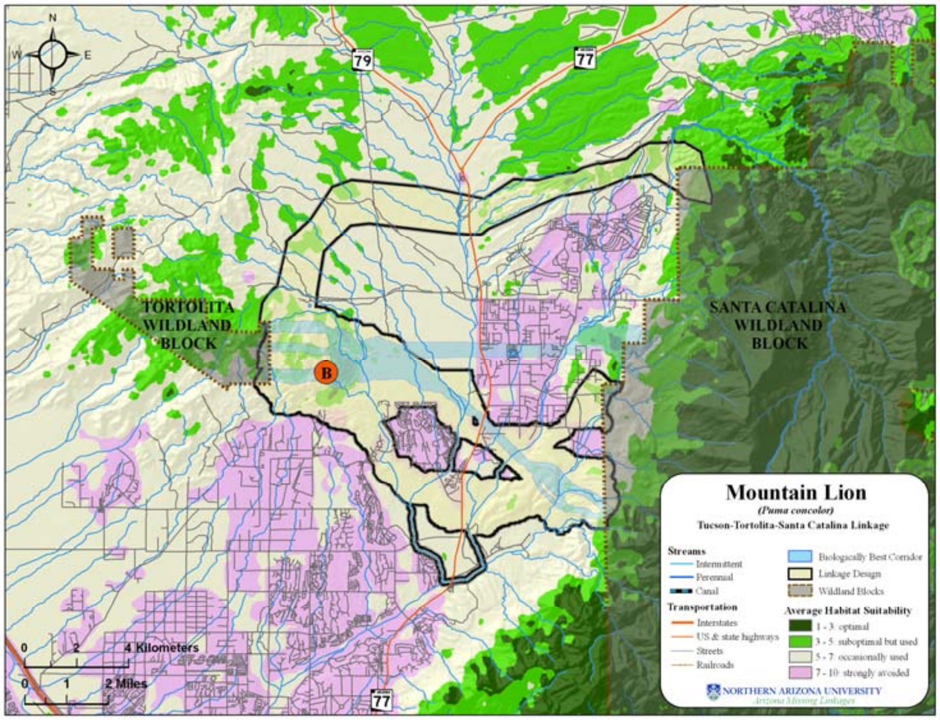

Figure 60: Modeled habitat suitability of mountain lion in Strand B.

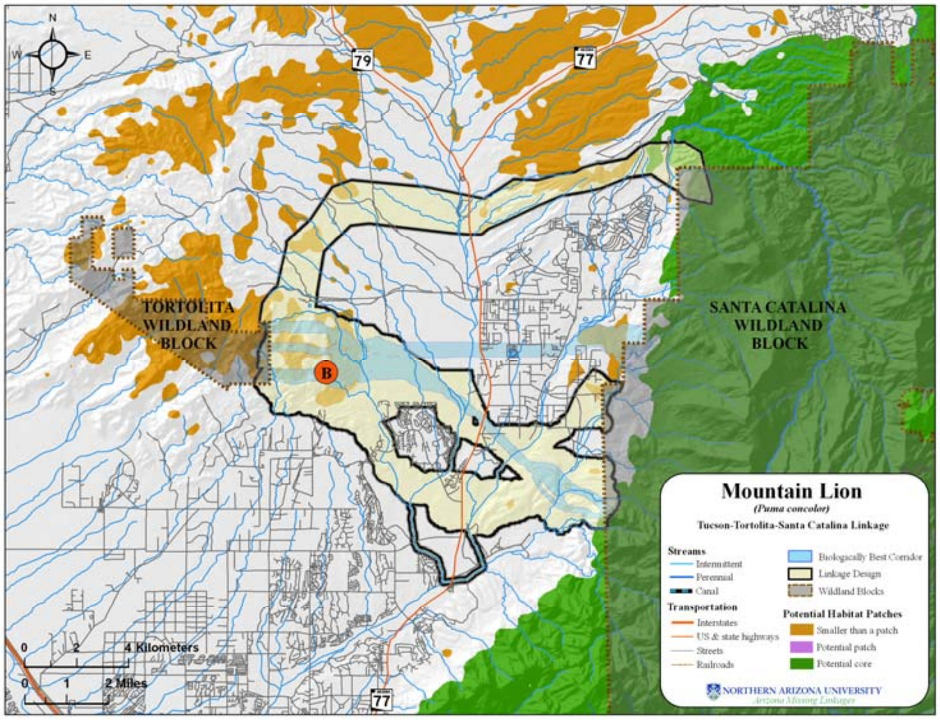

Figure 61: Potential habitat patches and cores for mountain lion in Strand B.

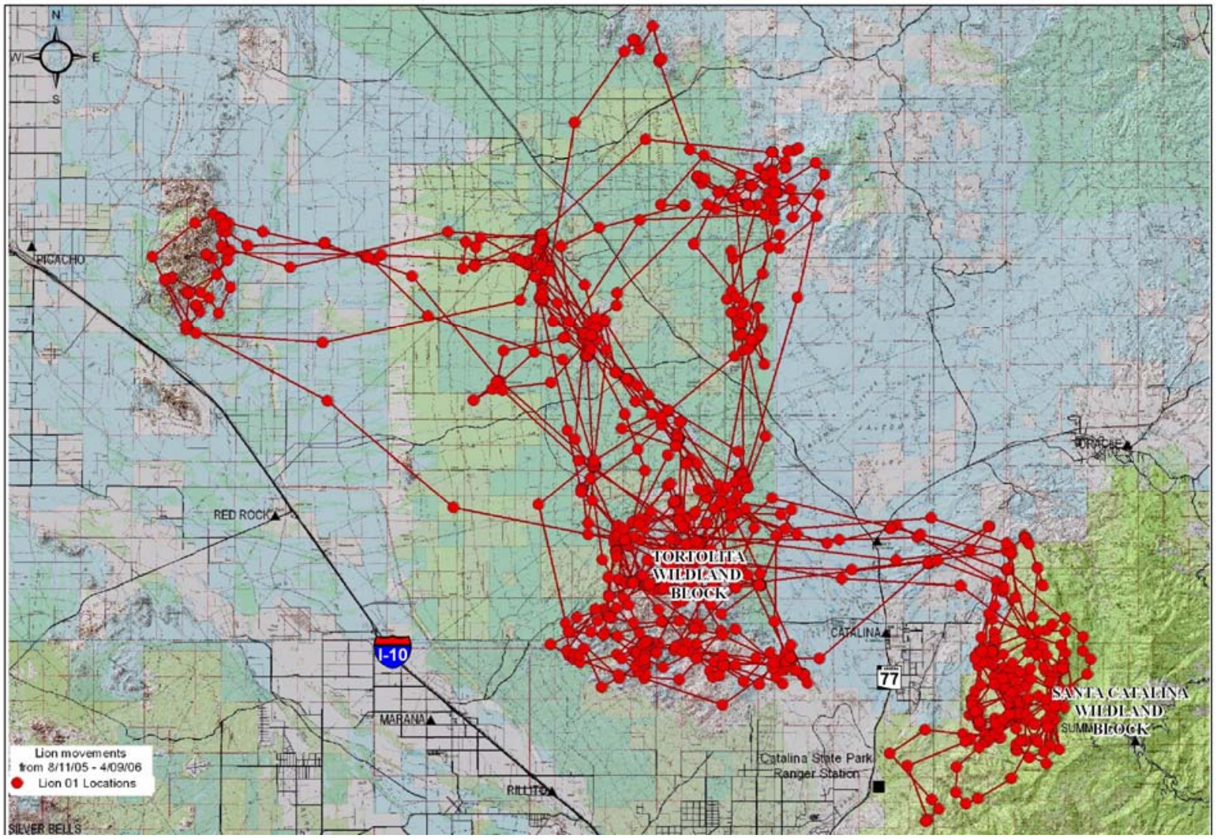

Figure 62: GPS locations of Lion 01 in 2005 and 2006, which provided additional information for the development of the lion BBC between the Tortolita and Santa Catalina Mountains (data provided by AGFD).

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 Table 5.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for mule deer within the potential linkage area, interspersed with smaller patches of optimal habitat and occasionally used or avoided habitat occurring adjacent to major roads or in high-density urban areas (Figure 63 and Figure 65). Within the BBC in Strand A, habitat suitability scores ranged from 2.1 to 9.6, with an average suitability cost of 6.3 (S.D: 0.9). Within the BBC in Strand B, habitat suitability scores ranged from 2.7 to 7.5, with an average of 3.8 (S.D: 0.7).

Union of biologically best corridors – The area encompassed by the Linkage Design captures a mixture of suitable and optimal mule deer habitat. With the exception of areas adjacent to major roads, and high-density urban areas most of the Linkage serves as a potential population core (Figure 64 and Figure 66). 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 SR-77, urbanization, and habitat fragmentation.

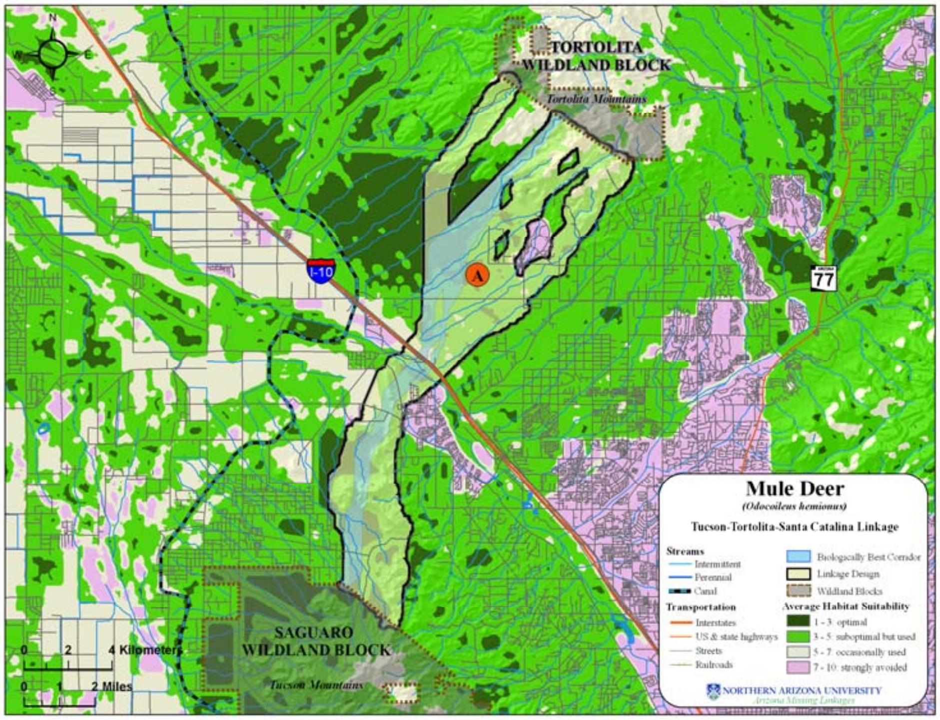

Figure 63: Modeled habitat suitability for mule deer in Strand A.

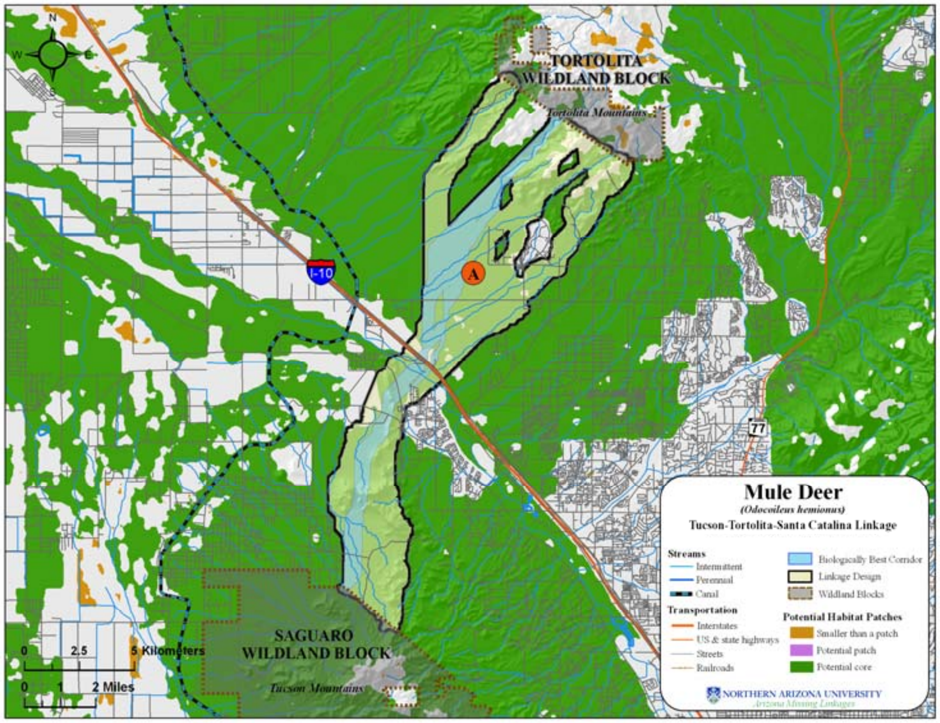

Figure 64: Potential habitat patches and cores for mule deer in Strand A.

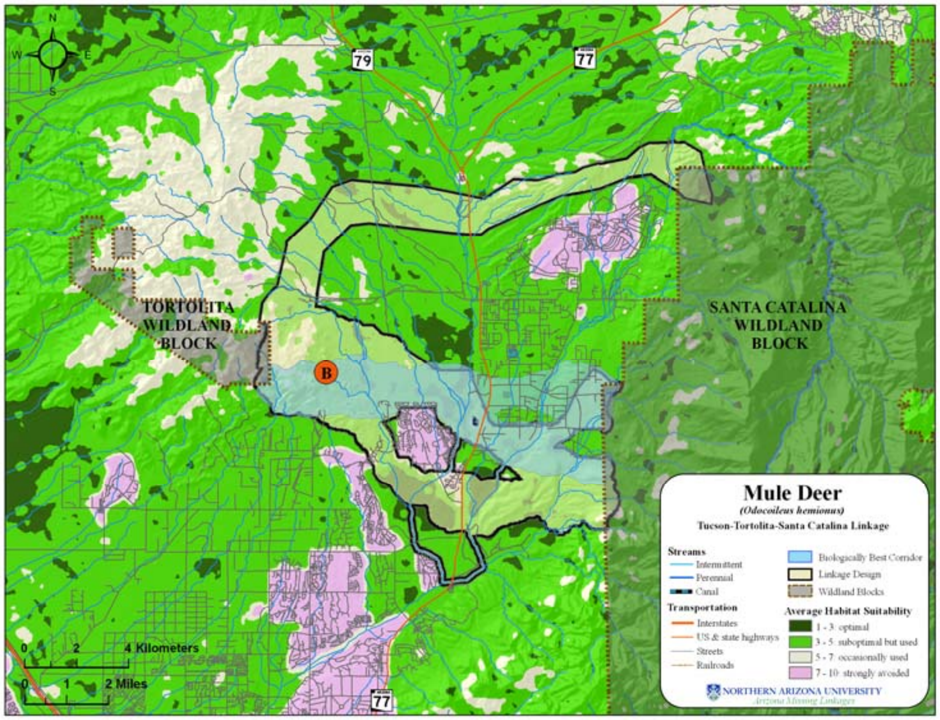

Figure 65: Modeled habitat suitability for mule deer in Strand B.

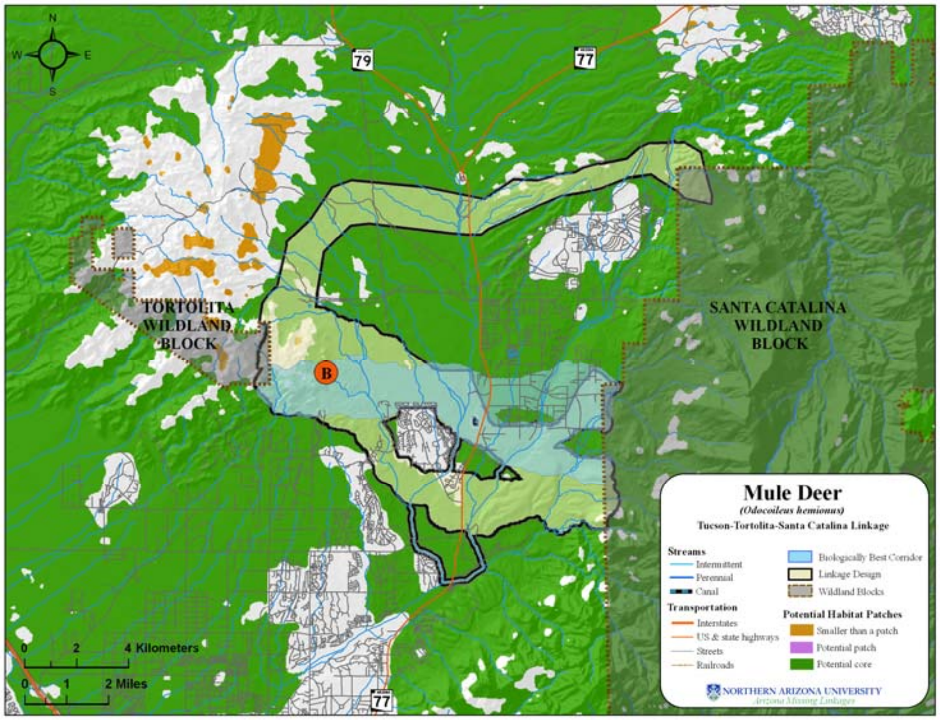

Figure 66: Potential habitat patches and cores for mule deer in Strand B.

Appendix C: Suggested Focal Species not Modeled

The habitat requirements and connectivity needs of several other suggested focal species could not be adequately modeled in this study. A list of these species follows:

Mammals

- Bats – ‘Bats’ were suggested as a focal taxon; however, their habitat preferences cannot be easily modeled using standard GIS layers, and they are highly mobile.

Birds

- Cactus Ferruginous Pygmy Owl (Glaucicium brasilianum cactorum) – This species was removed from the federal list of endangered and threatened wildlife in 2006. Pygmy-owls are associated with desert riparian woodlands, mesquite (Prosopis velutina and P. glandulosa) bosques (woodlands), Sonoran desertscrub, semidesert grassland, and Sonoran savanna grassland communities. The main characteristics in common include the presence of fairly dense thickets or woodlands, and the presence of trees, saguaros (Carnegiea giganteus), or other columnar cacti large enough to support cavities for nesting, and (3) elevations below 1,200 meters (various sources cited by USFWS Federal Register 71:19452-19458). In its delisting decision, FWS recognized that the Arizona population remains a conservation concern, and stressed the importance of local government in conserving the bird.

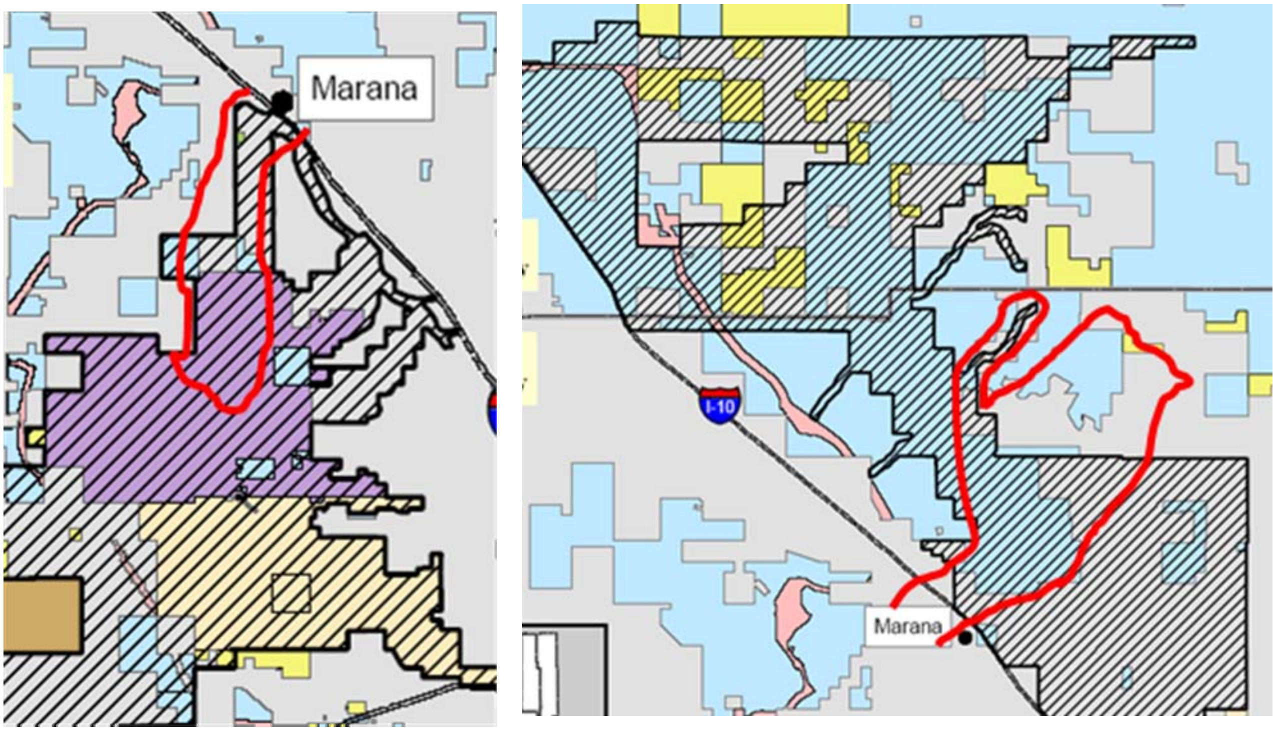

Figure 67. Unit 2 (left) and Unit 3 (right) of Proposed Critical Habitat (crosshatched area) for cactus ferruginous pygmy owl (US FWS 2002). Red polygon illustrates how Strand A of the Linkage Design overlaps the proposed critical habitat.

In mapping biologically best corridors, our approach models pixel-to-pixel movement, which is not appropriate for species that can fly. Thus we did not build a model. Nonetheless, we did examined how our Linkage Design overlaps Critical Habitat, with an eye to modifying the Linkage design if such modification would improve apparent connectivity. The Linkage Design contributes significantly to connectivity between Unit 2 and Unit 3 of proposed Critical Habitat (Figure 67). The Linkage Design also would include Cochie Canyon, and important finger of Unit 2. In light of these relationships, we did not feel the need to modify the Linkage Design.

Reptiles and Amphibians

- Arizona Striped Whipsnake (*Aspidoscelis arizonae)* – found in southeastern Arizona in low valleys and sandy flats within semidesert grasslands (AGFD 2007).

- Coachwhip *(Masticophis flagellum)* – Occurs in creosotebush desert, shortgrass prairie, shrub-covered flats and hills at lowest elevations are preferred, although sagebrush desert and pinyon-juniper woodlands to near 2200 m are also occupied. Coachwhips are common to mesquite-dominated bajada and bajada grassland, uncommon to grassland flats, abundant in mesquite-dominated flats, and common to agricultural edge of the Sulphur Springs Valley in Arizona (Rosen & et al, 1996).

- Red-backed Whiptail (*Cnemidophorus burti xanthonotus*) – The red-backed whiptail is found on desert mountains from Organ Pipe Cactus National Monument east across the Tohono O'odham reservation to at least Martina Mountain near Robles Junction (west of Tucson), and northward to the Sierra Estrella south of Phoenix (Rosen et al. 2002b). It occupies "juniper-oak, desert edge habitats" on desert mountains (Stebbins 1985).

- Gopher Snake (*Pituophis cantifer affinis*) – Gopher snakes are uncommon to rock slopes, common to bajada desertscrub, abundant in mesquite-dominated bajada and bajada grassland, uncommon in grassland flats, abundant in mesquite-dominated flats, and common to agricultural edge of the Sulphur Springs Valley in Arizona (Rosen & et al, 1996).

- Lowland Leopard Frog – *(Rana yavapaiensis*) – This species range historically extended throughout low elevation sites in the drainage of the lower Colorado River and its tributaries. It inhabits aquatic systems in desert grasslands to pinyon-juniper. The species is declining in southeast Arizona and has been extirpated from southwest Arizona. It is threatened by introduced predators, a chytrid fungus, habitat fragmentation, water pollution, and heavy grazing (AGFD 2001).

- Mohave Rattlesnake (*Crotalus scutulatus scutulatus*) – This species is found in deserts, mesquite-grasslands, and in the southern part of its range, pine-oak forests (Campbell and Lamar, 1989).
- Sonoran Desert Toad (*Bufo alvarius*) – Also known as the Colorado River Toad, this species is thought to be widespread across the Sonoran Desert, this species has been located in desert scrub, semidesert grassland, and riparian areas at Saguaro National Park (Lowe and Holm 1991).

- Sonoyta Mud Turtle (*Kinosternon sonoriense longifemorale)* – occurs only in Pima County where it may be seriously threatened by the crayfish as the latter spreads throughout Arizona's waters (Fernandez and Rosen, 1996).

- Tiger Rattlesnake (*Crotalus tigris*) –Tiger rattlesnake have a known elevational range in Arizona (300-1700 m), and are never found far from rock outcrops. Although mostly in Arizona Upland (saguaro/palo verde/mixed cactus), they can be found at the lower elevations of oak grassland and out into creosote flats on the lower bajada if rocky washes are present. As for roads, detailed radiotelemetry work suggests that they may actively avoid busy roads, but readily cross roads with low traffic volume (Goode, pers. comm.).

- Western Diamondback Rattlesnake (*Crotalus atrox*) – This snake may be found in terrain ranging from flat coastal plains to steep rocky hillsides and canyons and in a variety of vegetation types including mesquite-grassland, desert, and pine-oak forests; along the southern part of its range it occurs in tropical deciduous forest and thorn forest. It is most abundant in lowland regions that xeric or seasonally dry (Campbell and Lamar, 1989).

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 adjustments to the union of biologically best corridors (Figure 68):

- We removed two substrands of Linkage B that ran through urban areas. These two strands served species (mountain lion, blackbear, badger, bobcat, and mule deer) that find good habitat in other strands of this linkage.
- We widened part of the main southern arm of Linkage B, south of Rancho Vistoso, to meet minimum width requirements, and filled in a few minor holes that were artifacts of the modeling process.
- We added a northern strand to Linkage B to capture suitable habitat that mountain lions have been documented to use to cross between the Tortolita and Santa Catalina mountains (Figure 62).
- We widened the Linkage Design in several locations in Strand A to ensure all arms were at least 1 km wide, and filled in holes that were a result of the modeling process.

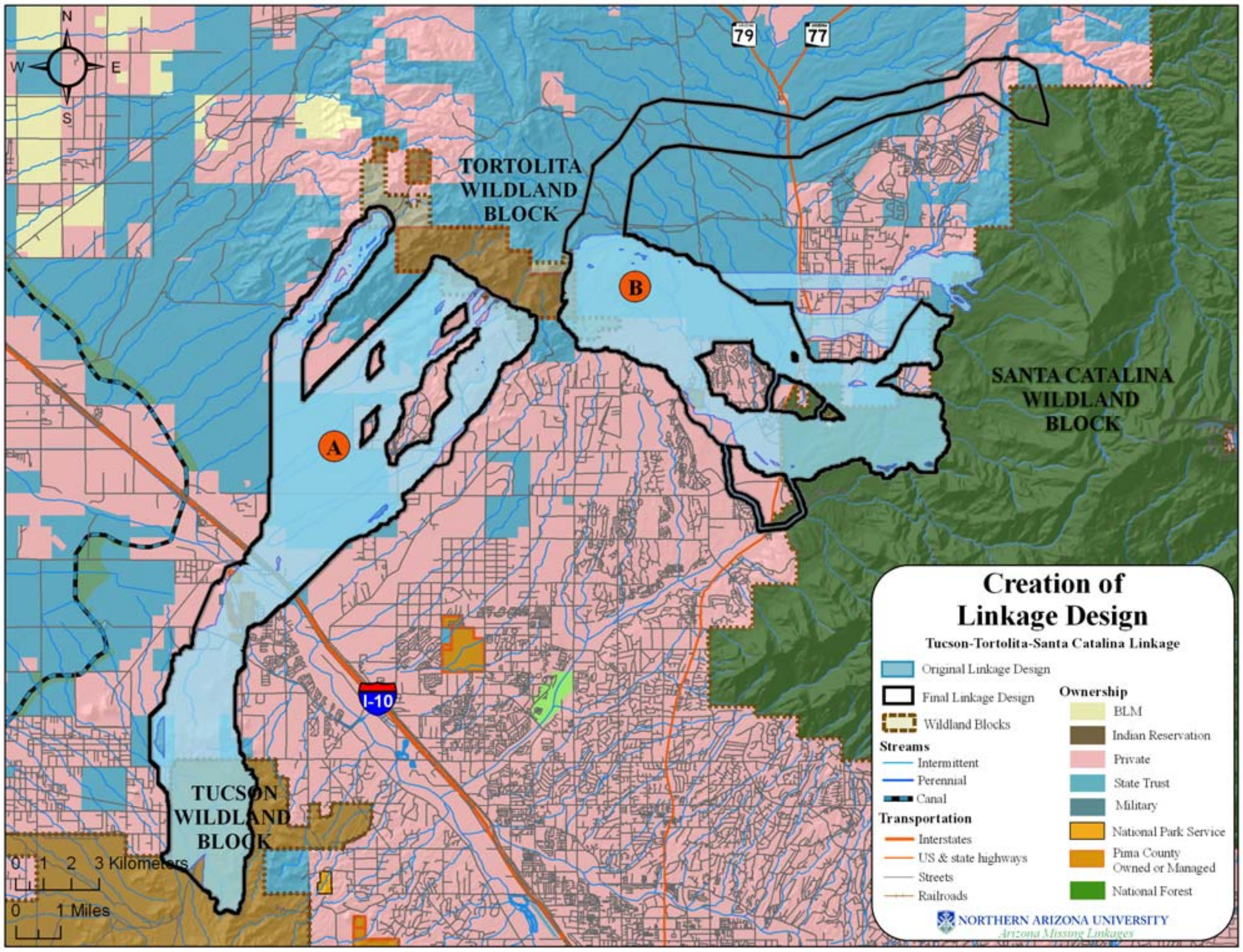

Figure 68: Adjustments made to union of biologically best corridors to create the Linkage Design.

Figure 69: The original linkage included too much development in the two northernmost strands to be permeable for wildlife. We removed portions of these arms and added a new arm through less development to the north (map produced in Google Earth).

Appendix E: Description of Land Cover Classes

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

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

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

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

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

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

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

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

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

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

Chaparral – This ecological system occurs across central Arizona (Mogollon Rim), western New Mexico and southwestern Utah and southeast Nevada. It often dominants along the mid-elevation transition from the Mojave, Sonoran, and northern Chihuahuan deserts into mountains (1000-2200 m). It occurs on foothills, mountain slopes and canyons in dryer habitats below the encinal and *Pinus ponderosa* woodlands. Stands are often associated with more xeric and coarse-textured substrates such as limestone, basalt or alluvium, especially in transition areas with more mesic woodlands.

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

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

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

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

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

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

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

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

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

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Appendix G: Database of Field Investigations

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

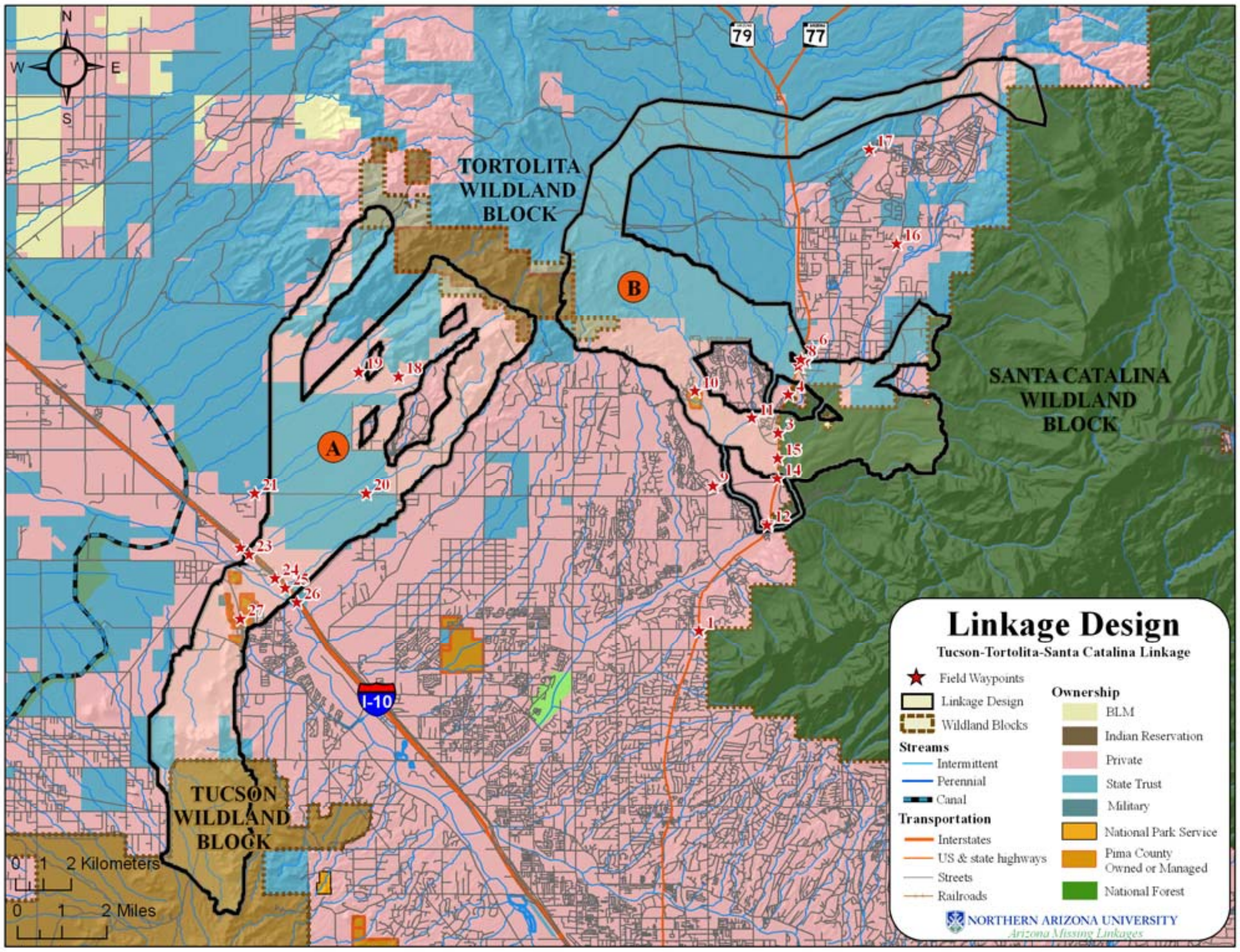

Figure 70: Waypoints marking field investigation sites within the Linkage Planning Area.