# ARIZONA MISSING LINKAGES

## Santa Rita – Tumacacori Linkage Design

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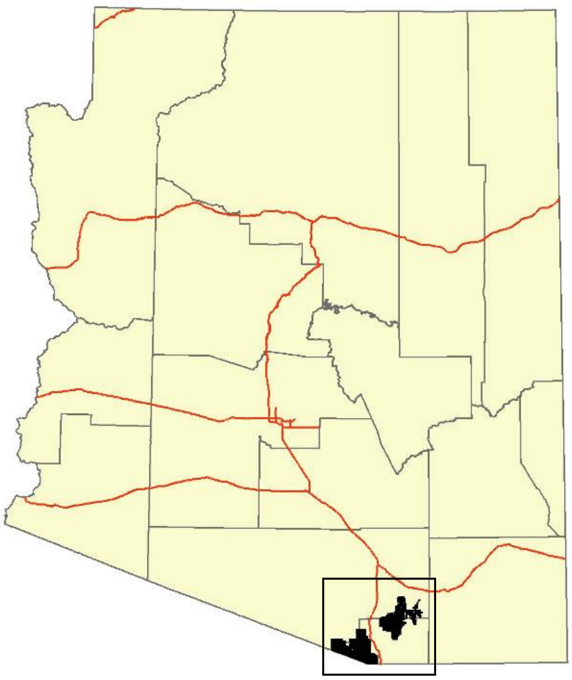
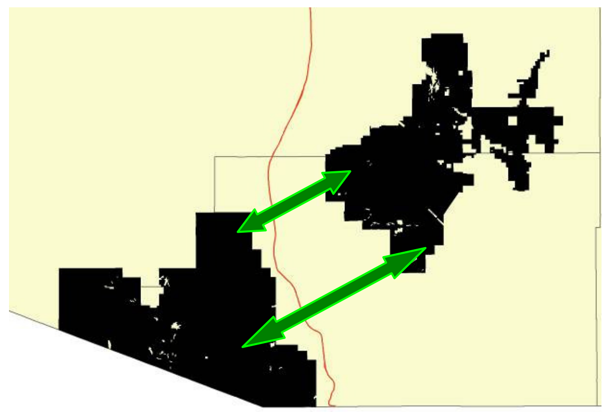
# SANTA RITA – TUMACACORI LINKAGE DESIGN





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This report is one of eight Linkage Designs being developed in 2006.

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# Terminology

*Key terminology used throughout the report includes:*

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

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

**Linkage Design:** A continuous corridor of land which encompasses the biologically best corridors of all focal species and thus should – if conserved – maintain or restore the ability of wildlife to move between the *wildland blocks*.

**Linkage Planning Area:** Includes the protected Wildland blocks and the Potential Linkage Area. If the Linkage Design in this report is implemented, the biological diversity of the entire Linkage Planning Area will be enhanced.

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

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

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

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

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

# Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between two large areas of conserved wildlands, namely the Santa Rita Mountains wildland block and the Tumacacori Mountains wildland block. These two areas represent a massive public investment in biological diversity, and this Linkage Design is a reasonable step to maintain the value of that investment. This report will be followed by Linkage Designs for other areas in Arizona where connectivity is at risk.

To begin the process of designing this linkage, academic scientists, agency biologists, and conservation organizations identified 23 focal species that are sensitive to habitat loss and fragmentation, including 2 fish, 3 amphibians, 5 reptiles, 2 birds and 11 mammals (Table 1). These focal species cover a broad range of habitat and movement requirements. Some require huge tracts of land to support viable populations (e.g., mountain lion, badger, black bear). Some species are habitat specialists (e.g., Arizona gray squirrel, Gila topminnow, longfin dace, yellow-billed flycatcher), and others are reluctant or unable to cross barriers such as freeways (e.g. Coue's white-tailed deer, mule deer, rattlesnakes, desert box turtle, coati). Others species, like the jaguar, need corridors to reoccupy former range. Some species are listed as threatened (Chiricahua leopard frog) or endangered (Gila topminnow), while others like javelina and porcupine 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 and montane Sky Islands. Together, these 23 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas we used GIS methods to identify a biologically best corridor for each focal species to move between the Tumacacori and Santa Rita Mountains. 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. Finally, we visited priority areas in the field to identify and evaluate barriers to wildlife movement. We used these observations to suggest strategies to mitigate those barriers, with special emphasis on opportunities to reduce the adverse effects of Interstate-19 and urbanization.

The final Linkage Design (Figure 1, Figure 5 & Figure 6) is composed of four terrestrial strands, ranging from approximately 13 to 20 km in length, and a longer Z-shaped aquatic strand, which together provide habitat for movement and reproduction of wildlife between the Santa Rita and Tumacacori protected wildland blocks. The Santa Cruz River is the crucial central feature of the linkage design, providing critical riparian habitat running perpendicular to the main direction of movement for terrestrial species. We provide detailed mitigations for barriers to animal movement in the section titled "Linkage Design and Recommendations."

The ecological, educational, recreational, and spiritual values of protected wildlands in the Santa Rita-Tumacacori region are immense. Our Linkage Design represents an opportunity to protect a truly 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 Tumacacori and Santa Rita 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, U.S. Fish and Wildlife Service, Tucson Audubon Society, and other conservancy lands.

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

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

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

**Table 1: Focal species selected for Santa Rita - Tumacacori Linkage**

| MAMMALS | AMPHIBIANS & REPTILES | BIRDS |
|---|---|---|
| Antelope Jackrabbit | Chiricahua Leopard Frog | Southwestern Willow Flycatcher |
| Arizona Gray Squirrel | Lowland Leopard Frog | |
| Badger | Sonoran Desert Toad | |
| Black Bear | Desert Box Turtle | **FISH** |
| Coues' White-tailed Deer | Giant Spotted Whiptail | Gila Topminnow |
| Jaguar | Sonoran Whipsnake | Longfin Dace |
| Javelina | Black-tailed Rattlesnake | |
| Mountain Lion | Tiger Rattlesnake | |
| Mule Deer | | |
| Porcupine | | |
| White-nosed Coati | | |

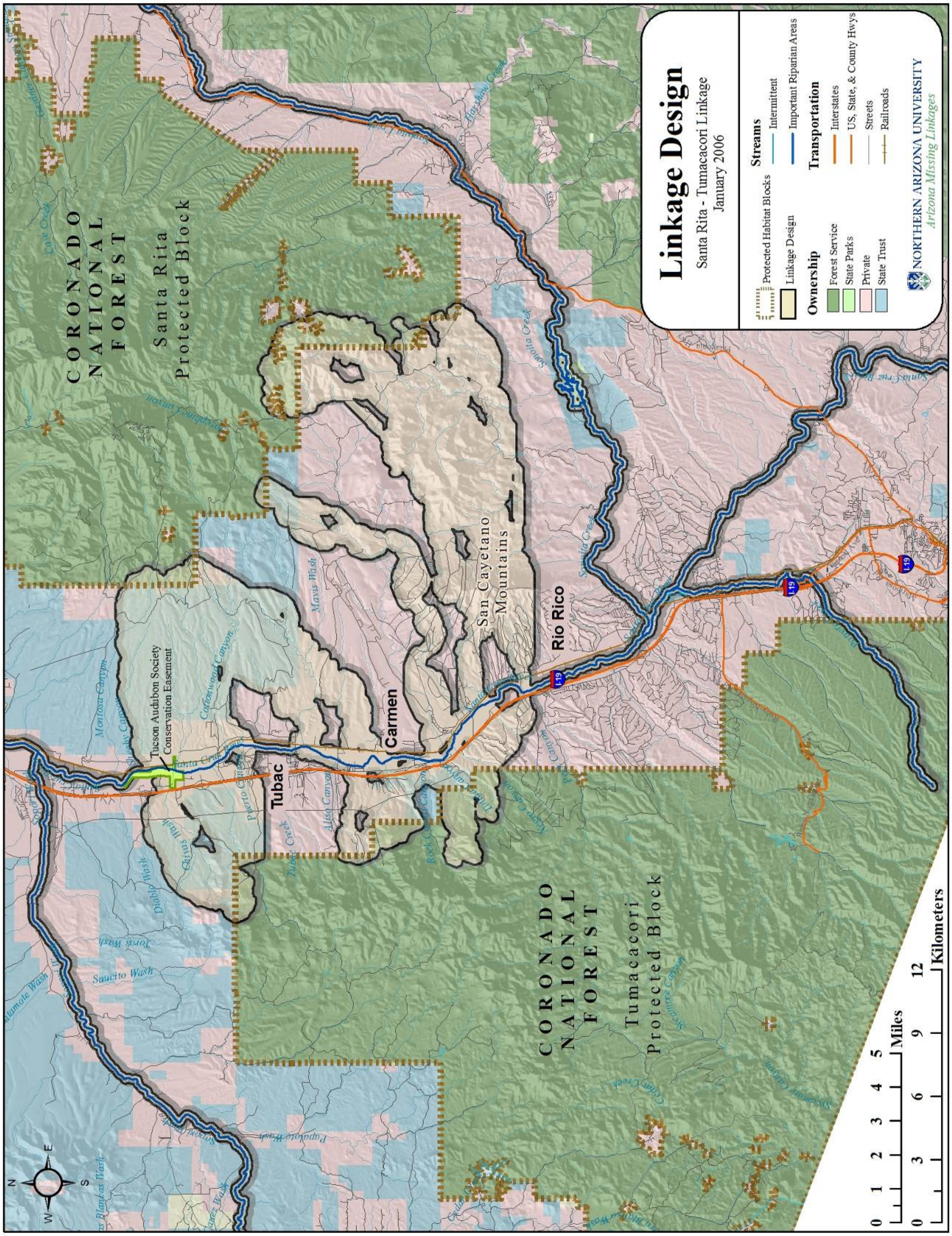


**Figure 1: The Linkage Design between the Santa Rita and Tumacori Mountains includes four terrestrial routes or strands, each of which is important to different species, and a riverine route anchored by the Santa Cruz River, Sonoita Creek, Sopori Wash, and Potero Creek.**

# Introduction

## Nature Needs Room to Move

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

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

Habitat fragmentation is a major reason for regional declines in native species. Species that once moved freely through a mosaic of natural vegetation types are now being confronted with a human-made labyrinth of roads, homes, and agricultural fields. Movement patterns crucial to species survival are being 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 (ADOT 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, 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 (ADOT 2006). Eight potential linkages emerged as priorities for more detailed planning. This Tumacacori-Santa Rita Linkage is one of these first 8 linkages.

## Ecological Significance of the Santa Rita – Tumacacori Linkage

The Santa Rita-Tumacacori Linkage Planning area lies within the Sky Island Ecoregion of southeastern Arizona and southwestern New Mexico. The Sky Islands are a complex of relatively small, isolated mountain ranges surrounded by lower elevation areas of desert scrub and grasslands that provide unique geological and topographic environments. These features make it one of the most biologically diverse landscapes in North America (Turner et al. 1995). The Coronado National Forest, which manages most of the sky island mountain ranges in Arizona, harbors the greatest plant and animal diversity of any National Forest in the United States, totaling more than 2,000 plant species and 576 species of terrestrial vertebrates, including 78 mammals, over 400 birds, and over 60 reptiles (USFS 2005, McLaughlin 1992). Of these species, 175 are considered threatened, endangered or sensitive (USFS 2005).

Within the Sky Island ecosystem, the Linkage Planning Area includes a swath of private and state trust land, 5 to 10 miles wide, separating two protected wildland blocks: the Santa Rita Mountain Complex and the Tumacacori-Atascosa-Pajarito Mountain Complex (Figure 2). Although we use "Tumacacori" as a shorthand label, this southwestern wildland block actually includes 3 major mountain ranges (the Tumacacori Mountains, Atascosa Mountains, and Pajarito Mountains), several smaller mountain ranges, and over 100,000 acres of Sonoran semidesert wildlands. The Tumacacori Mountains are approximately 18 km (11 mi) in length, joining with the 9.6 km (6 mi) long Atascosa range. Further south the Pajarito Mountains stretch across 19 km (12 mi) of the Arizona/Mexico border, and contain the headwaters of the Arivaca and Sopori/Santa Cruz watersheds. The western portion of this wildland block consists of semidesert grasslands within Buenos Aires National Wildlife Refuge.

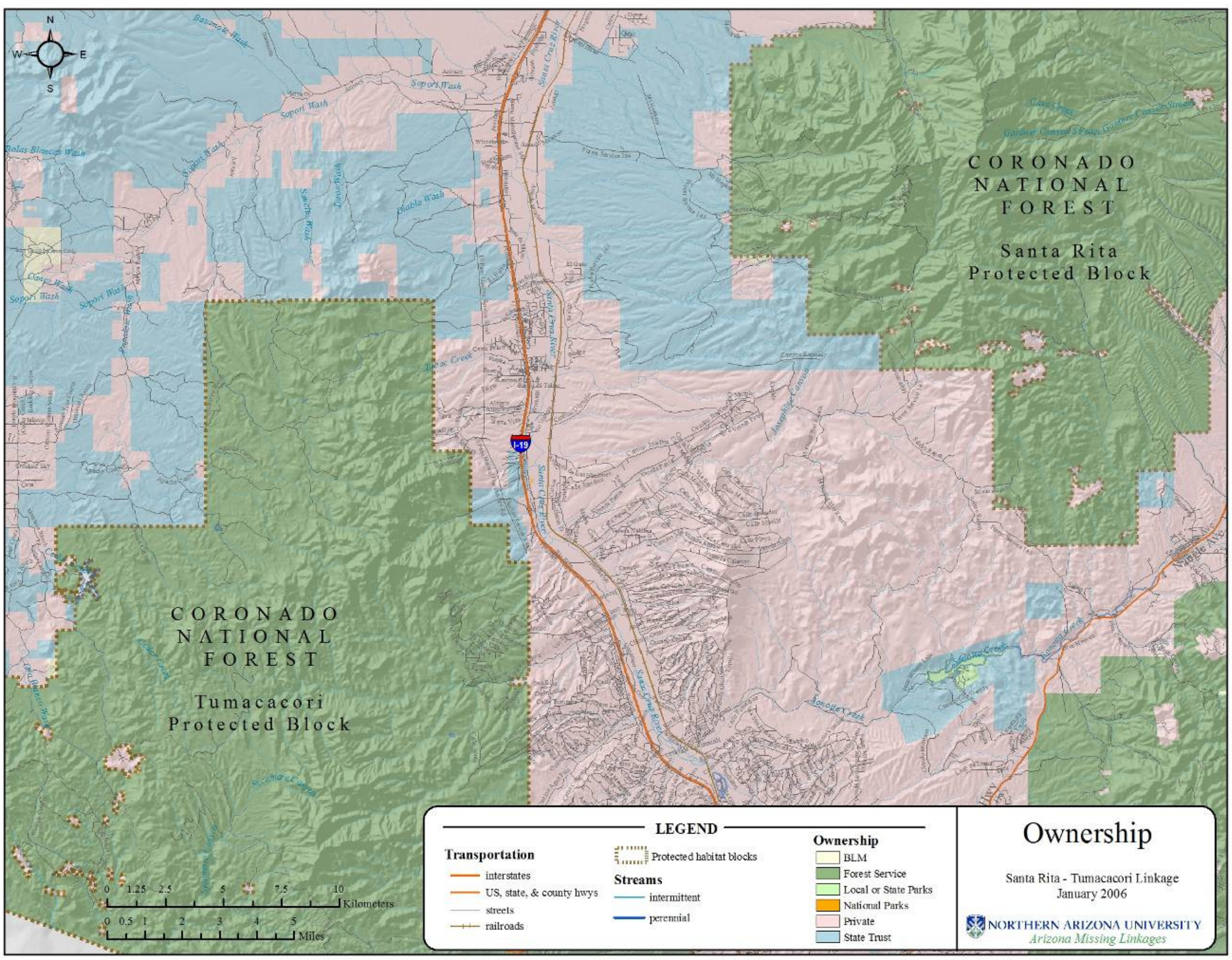


**Figure 2: Land ownership within the Linkage Planning Area.**

The northeastern wildland block includes the Santa Rita Mountains and surrounding areas protected as conservation areas.  The Santa Rita Mountains, extending for 42 km (26 mi), tower to over 9,000 feet, with east-flowing canyons that support the Cienega watershed; the western portion of the wildland block protects desert grasslands and shrublands.

The Linkage Planning Area ranges in elevation from 3000 feet at the Santa Cruz River valley to 9,453 feet at the peak of Mt. Wrightson in the Santa Rita Mountains. Paloverde-mixed cacti desert scrub, semi-desert grassland and steppe, and creosotebush/mixed desert and scrub communities dominate the lower elevations, intergrading upslope with areas of mesquite upland scrub.  Higher elevations support pinyon-juniper and pine-oak woodlands, with conifer-oak and aspen forest types at the highest elevations of the Santa Rita Mountains (Figure 3). Riparian areas in the Linkage Planning Area include the Santa Cruz River, Sonoita Creek, Sopori Wash, Josephine Canyon, Chivas Wash, Madera Canyon, and Tubac Creek.

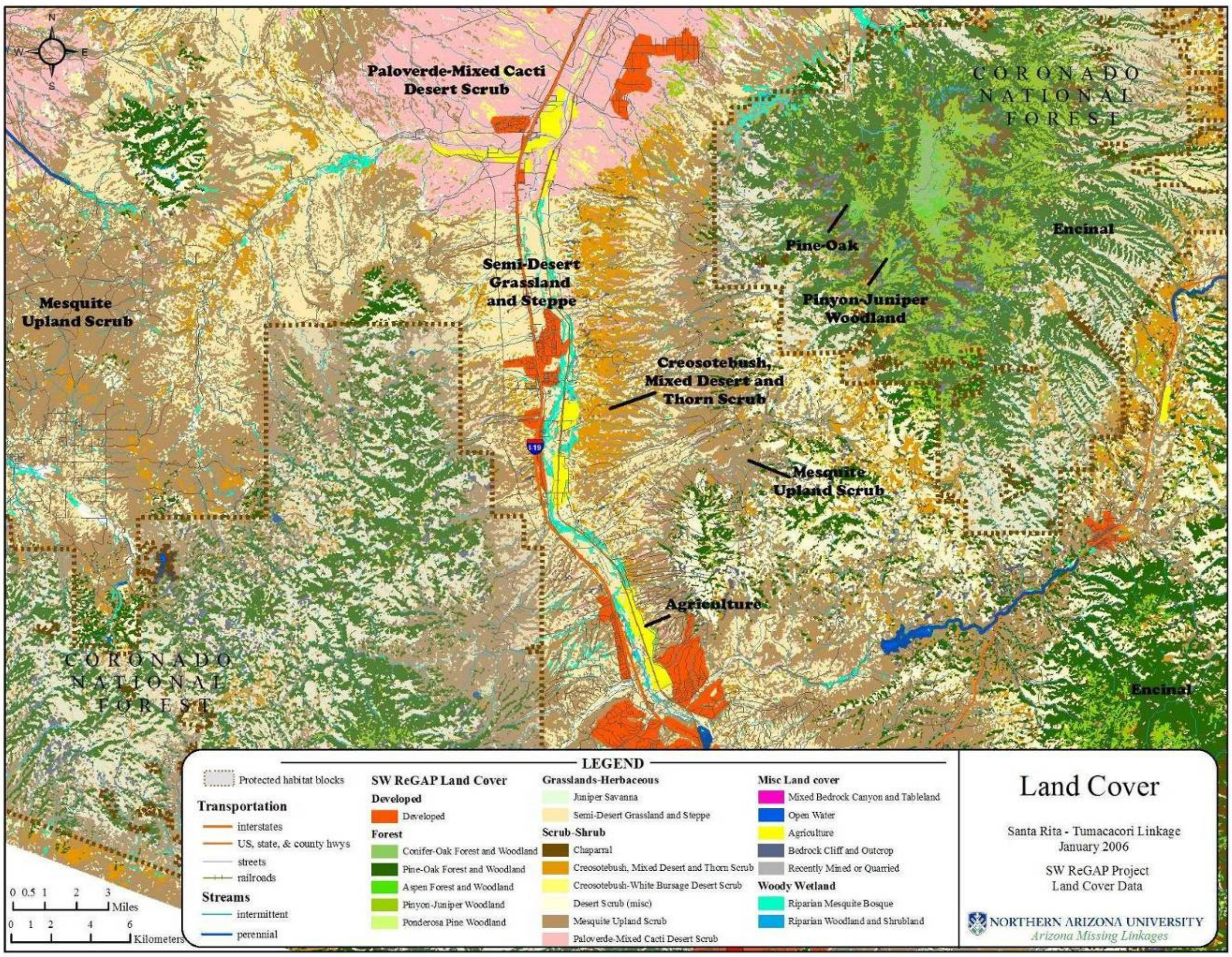


**Figure 3: Land cover within the Linkage Planning Area.**

The varied habitat types in the Linkage Planning Area support a diverse assemblage of animal species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the jaguar, southwestern willow flycatcher, Gould's turkey, Chiricahua leopard frog, lowland leopard frog, giant spotted whiptail lizard, Gila topminnow, and longfin dace, and locally-extirpated species such as desert bighorn sheep (USFWS 2005).  The Linkage Design incorporates and connects critical habitat needed for these species to achieve and sustain viable populations.  The Santa Rita-Tumacacori Linkage Planning Area is also home to far-ranging mammals such as black bear, javelina, Coues' white-tailed deer, mountain lion, and badger. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as bighorn sheep, antelope jackrabbits, white-nosed coati, and porcupines 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 (Gross et al. 2000, Singer et al. 2000, AZGFD 2004, Epps et al. 2004). Corridors in this area are also essential to maintain the potential for jaguars to recolonize Arizona.

## Existing Conservation Investments

The proposed Santa Rita-Tumacacori Linkage is designed to protect and enhance the public investments in conservation in the two wildland blocks it would link. It is therefore important to understand the public investments at stake in each wildland block, and within the Potential Linkage Area.

The **southwestern protected wildland block** (Tumacacori Mountains and adjoining public lands) includes over 200,000 acres within Coronado National Forest, plus the adjoining 118,000-acre Buenos Aires National Wildlife Refuge (Figure 4). Much of the Tumacacori Mountains is a Forest Service designated roadless area, including the 7,420-acre Pajarita Wilderness, which provides an important corridor to Mexico, and 46,988 acres proposed for wilderness designation, in part for its value as habitat for rare Arizona species such as the jaguar, gray hawk, and Chiricahua leopard frog (Sky Islands Wildland Network 2000). The Buenos Aires National Wildlife Refuge protects vast semidesert grasslands and riparian areas in the Altar Valley, and provides habitat to 325 bird species, 53 species of reptiles and amphibians, and 58 mammal species, including mule deer, white-tailed deer, pronghorn, javelina, and mountain lions (US Fish and Wildlife Service 2005). Within the Refuge, Arivaca Cienega and Arivaca Creek have been designated as Important Bird Areas (Tucson Audubon Society 2005).

The **northeastern wildland block** (Santa Rita Mountains) consists of 173,000 acres of land in Coronado National Forest, the 53,000-acre Santa Rita Experimental Range and Wildlife Refuge, the 45,000-acre Las Cienegas Natural Conservation Area, the 5,000-acre Patagonia Lake State Park, and the 1,350-acre Patagonia-Sonoita Creek Preserve (Figure 4). The National Forest land includes the 25,260-acre Mount Wrightson Wilderness and Madera Canyon Recreation Area, which attracts thousands of birders annually from around the world who seek an opportunity to see 240 species of birds in a single canyon (USFS 2005). The Audubon Society has designated the Santa Rita Mountains as an Important Bird Area (Tucson Audubon Society 2005). The Santa Rita Experimental Range is a natural laboratory and preserve owned by the University of Arizona's College of Agriculture, and protects desert grassland communities. The block also contains the proposed 10,703-acre Santa Rita Mountain Park (Pima County 2005). The Las Cienegas Natural Conservation Area, administered by the Bureau of Land Management, includes five of the rarest habitat types in the Southwest: cienegas (marshlands), cottonwood-willow riparian forests, sacaton grasslands, mesquite bosques, and semi-desert grasslands (National Landscape Conservation System Coalition, 2004). Las Cienegas also provides flood prevention for the city of Tucson and surrounding communities (National Landscape Conservation System Coalition, 2004). Patagonia Lake State Park includes a 2.5-mile-long lake and the Sonoita Creek State Natural Area, Arizona's first major state natural area protecting a significant riparian area (Arizona State Parks 2005). The Patagonia-Sonoita Creek Preserve, managed by The Nature Conservancy, protects a magnificent cottonwood-willow riparian forest and endangered fishes and rivals Madera Canyon as a birding area (The Nature Conservancy 2005).

On the northeast edge of this wildland block, Davidson Canyon has been designated as an Important Riparian Area by Pima County's Sonoran Desert Conservation Plan, and has been proposed as a Natural Preserve (Pima County, 2005).

The **Potential Linkage Area** also contains significant existing or proposed conservation investments, including the proposed Santa Cruz Wildlife Corridor, which would protect 11,236 acres of high priority State Trust Lands (Sonoran Institute 2005). Two smaller public lands in the Santa Cruz River valley are the Tubac Presidio State Historical Area, operated by Arizona State Parks, and Tumacacori National Historical Park, a 360 acre area administered by the National Park Service (Arizona State Parks 2005). The Tucson Audubon Society has recently acquired a 300-acre conservation easement along the Santa Cruz River and Chivas Wash in the northern linkage area, and will be intensively restoring habitat within the easement in the next several years. About 12 miles north of the Linkage Planning Area, 111,728 acres of State Trust Land in the Sierrita Mountains, northeast of the Buenos Aires NWR, have been proposed for conservation (Sonoran Institute 2005).

Connectivity between these two valuable and protected wildland blocks would sustain the public's existing investments in these two wildland blocks and within the Potential Linkage Area.

## Threats to Connectivity

Major potential barriers in the Potential Linkage Area include Interstate 19, the Southern Pacific Railroad, and urban development along I-19, which inhibit wildlife movement between the two wildland blocks. Traffic by illegal migrants from Mexico, and border security efforts to control that traffic, also affect animal movement in the Potential Linkage Area. Although the linkage area is not directly affected by border security fencing or stadium lighting, it may increasingly be affected by 24-hour patrols on an expanding network of new roads and by low level overflights (Vacariu 2005).

Connectivity is essential for maintaining this unique area's diverse natural heritage (Warshall 1995). The natural connectivity that has persisted for the last 10,000 years is now at risk. The goal of this plan is to overcome these potential barriers to movement, ensuring that wildlife in both wildland blocks and the potential linkage area will thrive for generations to come.

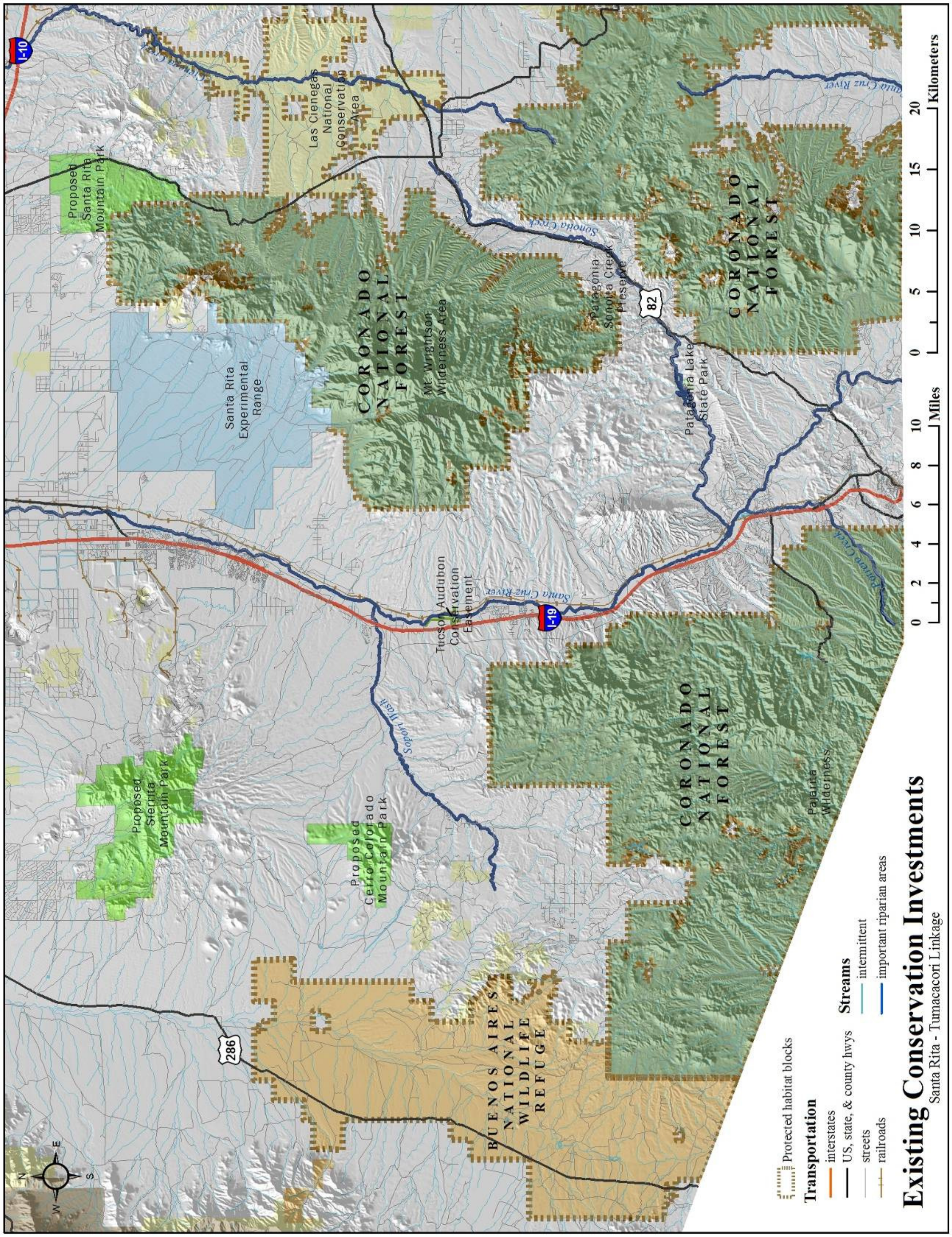


**Figure 4: Existing conservation investments in Linkage Planning Area.**

# Linkage Design & Recommendations

The final Linkage Design (Figure 1, Figure 5 & Figure 6) is composed of four terrestrial strands, ranging from approximately 13 to 20 km in length, and a longer Z-shaped aquatic strand, which together provide habitat for movement and reproduction of wildlife between the Santa Rita and Tumacacori protected wildland blocks. The Santa Cruz River is the crucial central feature of the linkage design, providing critical riparian habitat running perpendicular to the main direction of movement for terrestrial species. In this section, we describe the land cover and ownership patterns in the linkage design, and recommend mitigations for barriers to animal movement. The methods used to develop the Linkage Design are described in Appendix A, Appendix B, and Appendix C.

## Four terrestrial routes and a twisting riparian corridor provide connectivity across a diverse landscape

The linkage design between the Santa Rita and Tumacacori wildland blocks has four terrestrial routes or strands, each of which is important to different species, and a riparian strand anchored by the Santa Cruz River.

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

The northernmost terrestrial strand runs from the northeastern border of the Tumacacori wildland block to the western side of the Santa Rita wildland block. This route is primarily composed of semi-desert grassland, mesquite upland shrub, and creosotebush, providing pass-through and live-in habitat for antelope jackrabbit, badger, javelina, mule deer, Sonoran desert toad, desert box turtle, jaguar, and mountain lion. Between the Santa Rita wildland block and the Santa Cruz River, important topographic and xeroriparian features in the northern route include a 4 km stretch of Montosa Canyon, the entire length of Sheehy Canyon, and portions of Cottonwood Canyon. West of the Santa Cruz River, this route encompasses much of Puerto Canyon and Las Chivas Wash.

The next (2$^{nd}$ most northerly) strand is primarily composed of semi-desert grassland, mesquite upland scrub, creosotebush, and mixed desert scrub, providing potential pass-through and live-in habitat for Coues' white-tailed deer, porcupine, and coati. Important riparian features in this route are portions of Cottonwood Canyon, Mavis Wash, more than 5 km of the Santa Cruz River, and a portion of Aliso Canyon.

The third route (2$^{nd}$ most southerly) serves primarily as a route for saxicolous (rock-loving) species such as the tiger rattlesnake, and species that require rugged topography. This route is primarily composed of mesquite upland scrub, creosotebush, and mixed desert scrub. Important features include a 6 km stretch of upper Josephine Canyon, the northern portions of the San Cayetano Mountains, the San Cayetanos, another 4 km stretch of lower Josephine Canyon, Tinaja Canyon, and Negro Canyon.

The southernmost route serves upslope species such as Arizona gray squirrel and black bear, as well as species that require rugged topography, such as the black-tailed rattlesnake. This route is composed of a mix of vegetation associations, including semi-desert grassland, creosotebush, mixed desert and thorn scrub, riparian mesquite bosque, and encinal. Moving west from the Santa Cruz wildland block, this route captures upper reaches of Alto Gulch and Squaw Gulch, all of Ash and Cieneguita Canyons, portions of Coal Mine Canyon, a 2 km portion of Hangmans Canyon, a portion of Fresno Canyon, and the Grosvenor Hills.

The aquatic strand of the Linkage Design forms a huge jagged "Z" through the potential linkage area, with Sopori Wash forming the upper branch connecting to the Tumacacori wildland block, the Santa Cruz River forming the critical diagonal stroke, and Sonoita Creek forming the lower branch to the Santa Rita wildland block. This aquatic route is critically important for aquatic obligates such as Chiricahua and lowland leopard frogs, giant spotted whiptail, Gila topminnow, longfin dace, yellow-billed cuckoo, and southwestern willow flycatcher. To the south, Potrero Creek forms another aquatic linkage from the Tumacacori Mountains to the Santa Cruz River. The Santa Cruz River also provides the only perennial water along the 4 terrestrial strands of this linkage zone.

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

The Linkage Design encompasses 71,700 acres (29,000 ha) of land, and is composed of 70.6% private land, 29.3% state trust land, and 0.1% Bureau of Land Management land (Figure 5). Seventeen natural vegetation communities account for nearly 98% of the land cover (Figure 6), and developed land accounts for approximately 2% of the land in the Linkage Design (Table 2). Natural vegetation is dominated by scrub-shrub associations, and has less forest vegetation than the vegetation found within the Tumacacori and Santa Rita protected wildland blocks. Riparian vegetation such as mesquite bosque accounts for 2% of the linkage design.

The Linkage Design captured a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, most land is classified as gentle or steep slopes, while approximately 15% of the land is classified as either canyon bottom or ridgetop (Figure 7). A wide range of slopes were captured, with the northern most route composed of gentler slopes, and the southern routes composed of steeper slopes. Every aspect category was represented in approximately equal proportions (Figure 7).

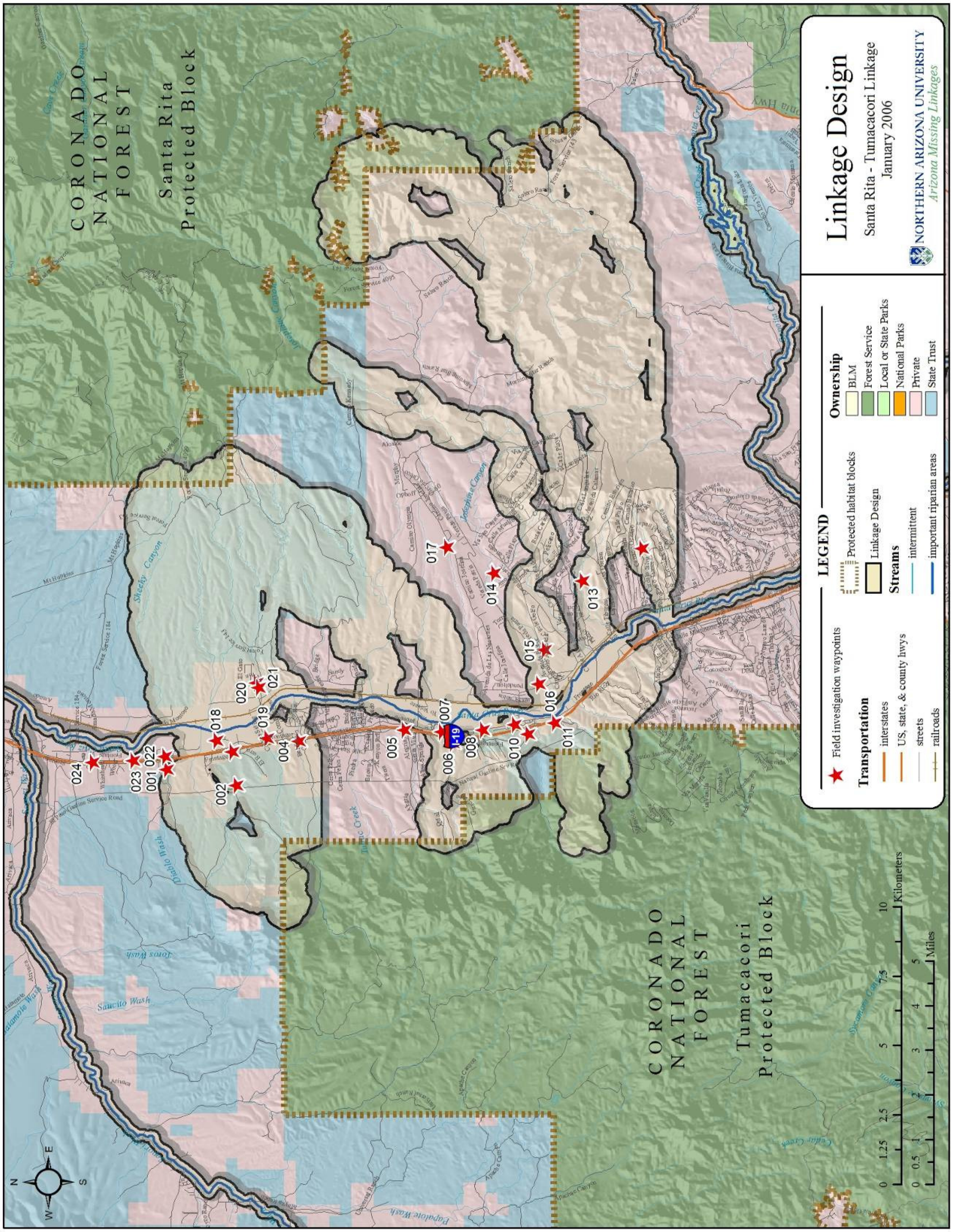


**Figure 5: Property ownership and field investigation waypoints within Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.**

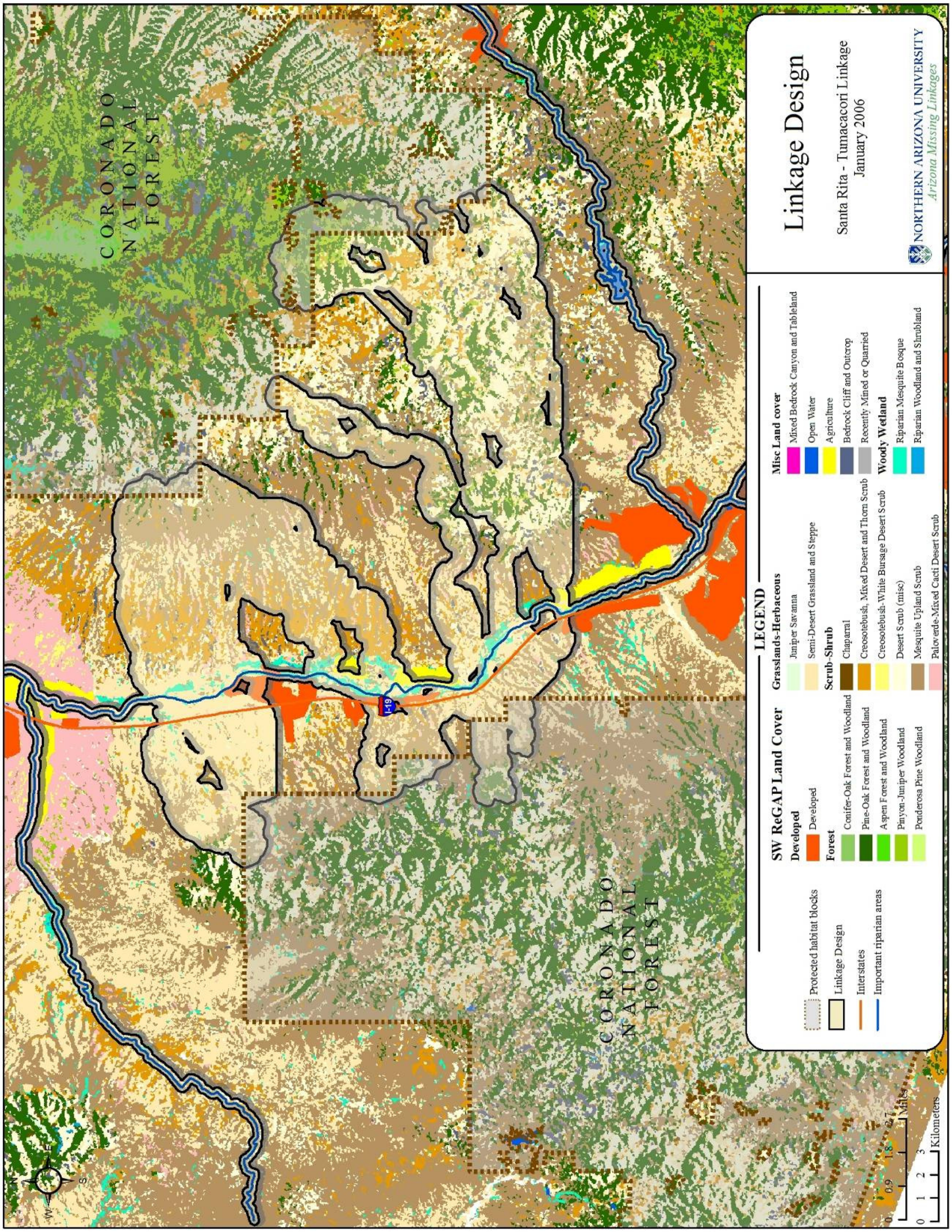


**Figure 6: Land cover within Linkage Design.**

**Table 2: Approximate land cover within Linkage Design.**

| LAND COVER CATEGORY | ACRES | HECTARES | % OF TOTAL AREA |
|---|---|---|---|
| **Evergreen Forest (11.3%)** | | | |
| Encinal (Oak Woodland) | 6446 | 2608 | 9.0% |
| Pine-Oak Forest and Woodland | 308 | 125 | 0.4% |
| Pinyon-Juniper Woodland | 1355 | 548 | 1.9% |
| **Grasslands-Herbaceous (27.9%)** | | | |
| Juniper Savanna | 53 | 31 | 0.1% |
| Semi-Desert Grassland and Steppe | 19917 | 8060 | 27.8% |
| **Scrub-Shrub (54.3%)** | | | |
| Chaparral | 355 | 144 | 0.5% |
| Creosotebush, Mixed Desert and Thorn Scrub | 8126 | 3289 | 11.3% |
| Desert Scrub (misc) | 8894 | 3599 | 12.4% |
| Mesquite Upland Scrub | 20389 | 8251 | 28.4% |
| Paloverde-Mixed Cacti Desert Scrub | 1183 | 479 | 1.6% |
| Stabilized Coppice Dune and Sand Flat Scrub | 105 | 43 | 0.1% |
| **Woody Wetland (2%)** | | | |
| Riparian Mesquite Bosque | 1404 | 538 | 2.0% |
| Riparian Woodland and Shrubland | 32 | 13 | < 0.1% |
| **Emergent Herbaceous Wetland (<0.1%)** | | | |
| Arid West Emergent Marsh | 7 | 3 | < 0.1% |
| **Barren Lands (2.2%)** | | | |
| Bedrock Cliff and Outcrop | 1429 | 578 | 2.0% |
| Volcanic Rock Land and Cinder Land | 149 | 60 | 0.2% |
| Warm Desert Pavement | 1 | 0 | < 0.1% |
| **Developed and Agriculture (2.2%)** | | | |
| Agriculture | 491 | 199 | 0.7% |
| Medium-High Intensity Developed | 644 | 261 | 0.9% |
| Open Space-Low Intensity Developed | 423 | 171 | 0.6% |

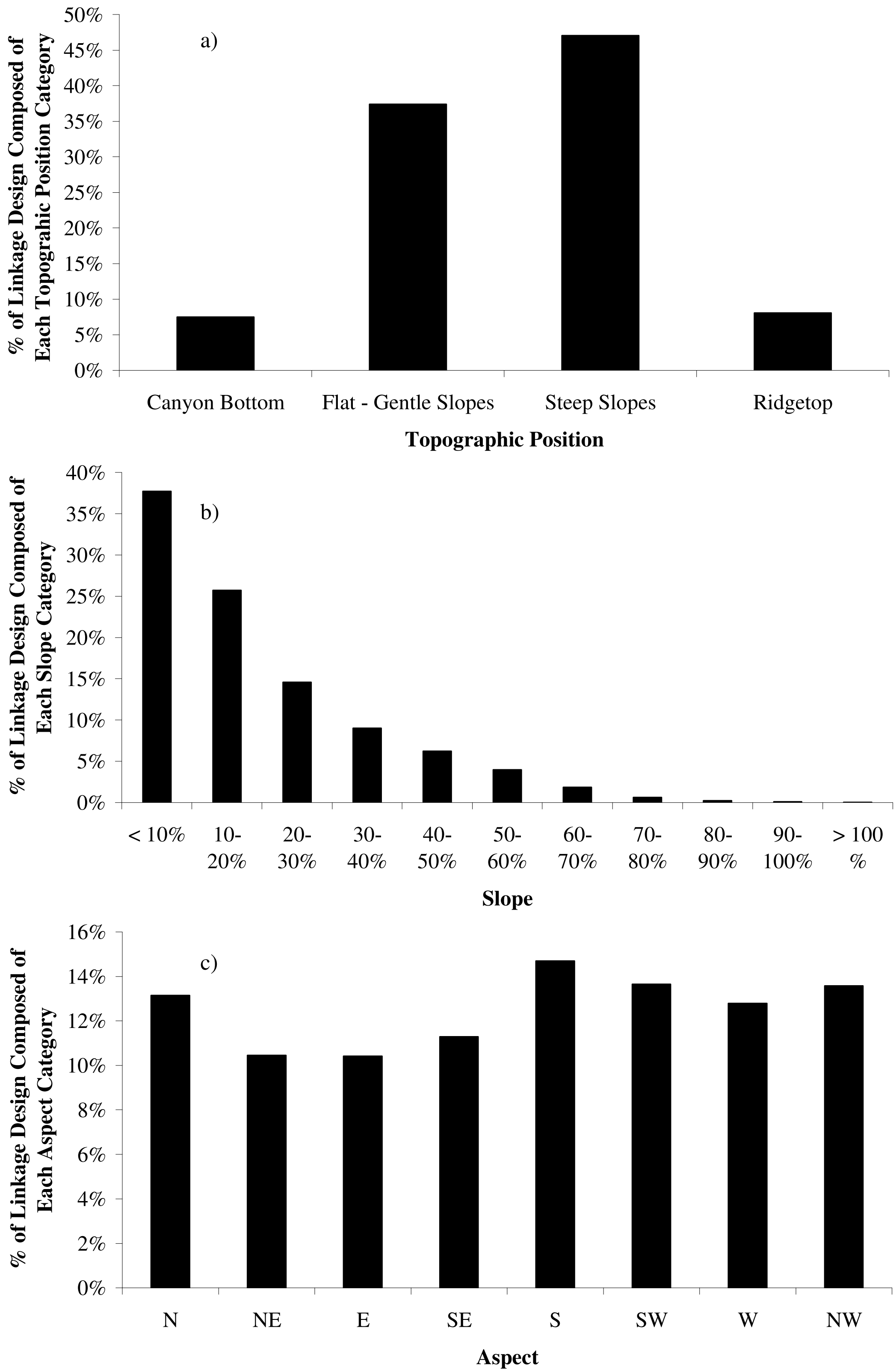


**Figure 7: Diversity of topographic position (a), slope (b), and aspect (c) in the Linkage Design.**

## Removing and Mitigating Barriers to Movement

Although roads, rail lines, residential development, and streamflow impediments 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 mitigation methods for these barriers. The complete database of our field investigations, including UTM coordinates and photographs, is provided in Appendix F and the Microsoft Access database on the CD-ROM accompanying this report.

Although roads, canals, and fences impede animal movement, and the crossing structures we recommend are important, we remind the reader that crossing structures are only part of the overall linkage design. To restore and maintain connectivity between the Santa Rita and Tumacacori wildland blocks, it is essential to consider the *entire* linkage design, including conserving the land in the linkage. Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either 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 (Figure 8). 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 (Rich and Longcore 2006).

### *Mitigation for Roads*

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 9). While many of these structures were not originally constructed with ecological connectivity in mind, research has shown that a wide range of 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 pronghorn.

*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, including 6 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, bighorn sheep, deer, elk, and moose prefer overpasses to underpasses, while species such as mountain lions prefer underpasses (Clevenger & Waltho

2005). Small mammals, such as deer mice and voles, also prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

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

*Drainage culverts* can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species, including mice, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). In south Texas, bobcats most often used 1.85 m x 1.85 m box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

**Figure 8: Characteristics which make species vulnerable to the three major direct effects of roads (from Forman et al. 2003).**

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


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

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

1) **Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area** (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald & St Clair 2004; Clevenger & Waltho 2005; Mata et al. 2005). For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and mountain lions, large box culverts with a natural earthen substrate flooring are optimal (Evink 2002). For small mammals, pipe culverts from 0.3m – 1 m in diameter are preferable (Clevenger et al. 2001; McDonald & St Clair 2004).
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 (Clevenger and Wierzchowski 2006, Mata et al. 2005). 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). Slick walls 1 m high can prevent amphibians and reptiles from entering roadways. One-way ramps over 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 and Rail Lines in the Linkage Design Area

There are approximately 362 km (225 mi) of roads in the Linkage Design. Running parallel to the Santa Cruz River, Interstate 19 runs north-south through every strand of the linkage, and is the single most important threat to connecting the Santa Rita and Tumacacori wildland blocks. Except for I-19, its frontage roads, and Forest Service Rd 143, the other roads in the linkage are local roads with relatively low traffic and traffic speed. Parallel to I-19, about 15.7 km (9.8 mi) of the Union Pacific Railroad runs through the linkage area. We conducted field investigations of many of these roads to document existing crossing structures that could be modified to enhance species movements through the area.

**Table 3: Major transportation routes in the Linkage Design.**

| ROAD NAME | KILOMETERS | MILES |
|---|---|---|
| Interstate 19 | 13.9 | 8.6 |
| East and West Frontage Roads | 20.8 | 12.9 |
| Union Pacific Railroad | 15.7 | 9.8 |
| Forest Service Rd. 143 | 11.2 | 7.0 |
| Via San Cayetano | 9.5 | 5.9 |
| Salero Ranch Rd | 5.8 | 3.6 |
| Avenida Pastor | 4.7 | 2.9 |
| Calle Playa | 4.1 | 2.5 |
| Circulo Silva | 3.9 | 2.4 |
| Avenida Calamar | 3.9 | 2.4 |
| Circulo Tortuga | 3.8 | 2.4 |
| Camino Oceano | 3.7 | 2.3 |
| Rio Rico Rd | 3.7 | 2.3 |
| Pendleton Rd | 3.6 | 2.2 |
| Calle Pulpo | 3.6 | 2.2 |
| Camino Olympia | 3.4 | 2.1 |
| Mt Hopkins Rd | 3.3 | 2.0 |
| Roads < 2 mi long in Linkage Design | 237 | 147 |
| **Total length of transportation routes** | 362 | 225 |

*Existing Crossing Structures on I-19*

Interstate 19 is the most significant road barrier to connectivity within the Linkage Design. NAFTA and the proposed CANAMEX effort to promote commerce among Canada, the United States, and Mexico, will cause large increases in traffic on I-19. The freeway is parallel to and ¼ to 1 mile west of the Santa Cruz River. Because every animal moving between the Santa Rita and Tumacacori wildland blocks must traverse this highway, crossing structures along I-19 are crucial to success of the corridor. Within the linkage design, crossing structures have been built to accommodate stream flow from several canyons draining eastward from the Tumacacoris. Most structures are pipe culverts near the base of fill slopes that are not easily accessed by terrestrial animals. There are only 5 significant crossing structures along I-19, three of which lie in the northernmost strand of the linkage design. We list them from north to south.

- Box culverts (not photographed) where Chivas Wash (Figure 13) crosses I-19. This portion of Chivas Wash lies within the biologically best corridors for mountain lion and jaguar; mule deer and javelina also frequent the area (Ann Philips, Tucson Audubon Society, personal comm.). Thirteen species of amphibians and reptiles, including Sonoran desert toad, were trapped in Chivas Wash in 2005 (Robin Llewellyn, unpublished data). The Tucson Audubon Society recently secured the 300-acre Esperanza Ranch Conservation Easement, which includes 2 miles of the Santa Cruz River Corridor and riparian habitat along ½ mile of Chivas Wash (Figure 13, Figure 14). Tucson Audubon Society will restore vegetation in the Easement.

- A 6 x 8 x 260 ft cement box culvert under I-19 along the northerly strand of the linkage (Figure 10) to accommodate a small un-named wash just south of Chivas Wash. The un-named wash also flows through similar-size culverts under the frontage roads adjacent to this location. Sediments have reduced the height of the culvert to approximately 4.5 ft. This crossing structure lies within the biologically best corridors of antelope jackrabbit, badger, box turtle, jaguar, Sonoran desert toad, and Sonoran whipsnake, and about 700 m north of the best corridors for javelina and mule deer. On January 4, 2006, we found several lizards clinging to the inside wall of the eastern end of the culvert, and javelina tracks outside of the culvert. A conservation easement by the Tucson Audubon Society lies about 700 meters northeast of this crossing structure, and a small residential development (12 buildings) south of the easement area (Figure 10).


**Figure 10: Looking east from waypoint 003 towards the Santa Rita Mountains, a 6 x 8 ft box culvert under I-19 and Frontage Rd. Waypoint 18 is at the southern edge of a Tucson Audubon Society conservation easement; a small rural housing area is south of waypoint 018. See Figure 5 to locate this scene within the linkage design.**

- A large multiple-span cement box culvert where Puerto Canyon crosses I-19, near the southern edge of this same northerly stand of the linkage (Figure 11). This crossing structure lies within the biologically best corridor for mule deer. The village of Tubac and other residential development are within 1 km of this crossing.

- A large bridged underpass where I-19 crosses an unnamed east-flowing wash between Rock Corral Canyon and Tinaja Canyon (Figure 12). This underpass lies in an area where the 3 southern strands of the linkage design merge. It is within the biologically best corridors models of black-tailed rattlesnake, tiger rattlesnake, and Arizona gray squirrel; it would also be useful for wide-ranging species such as mountain lion and jaguar. There is no significant human development west of this crossing structure; large agricultural fields lie about 1 km east of the structure in the Santa Cruz River floodplain, and the foothills of the Santa Rita Mountains further east have a network of dirt roads serving a growing number of residences. This un-named wash from the Tumacacoris flows into the Santa Cruz River near where Josephine Canyon flows into the River from the Santa Rita Mountains.

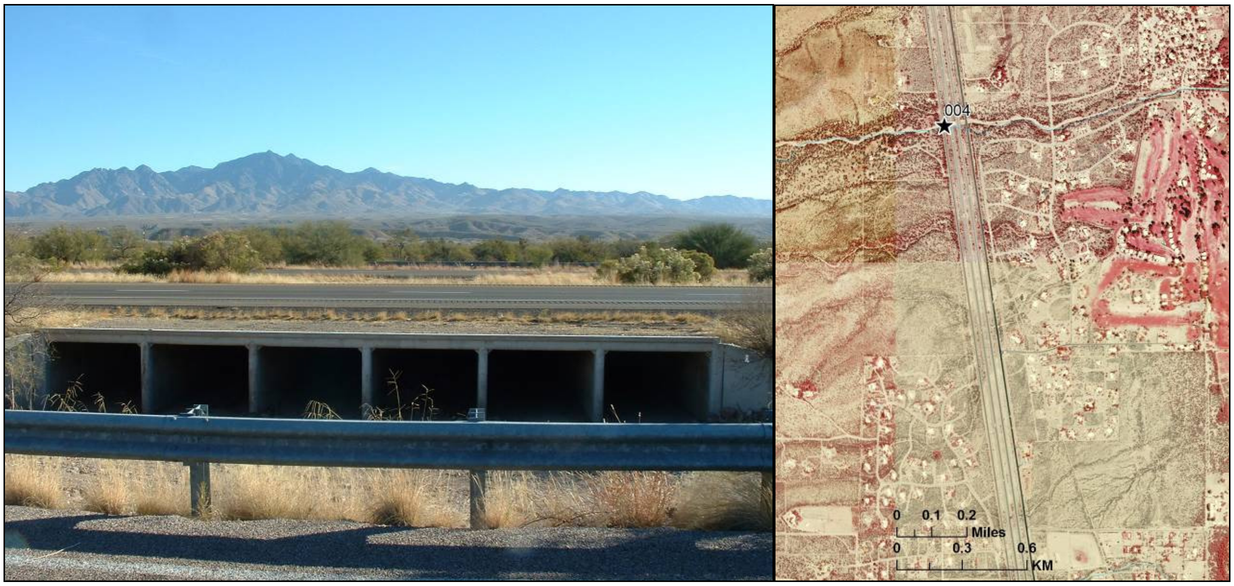


**Figure 11: Looking east from Waypoint 004 towards the Santa Rita Mountains, Puerto Canyon crosses under I-19 via a set of six 7x9 ft box culverts. See Figure 5 to locate this scene within the linkage design.**

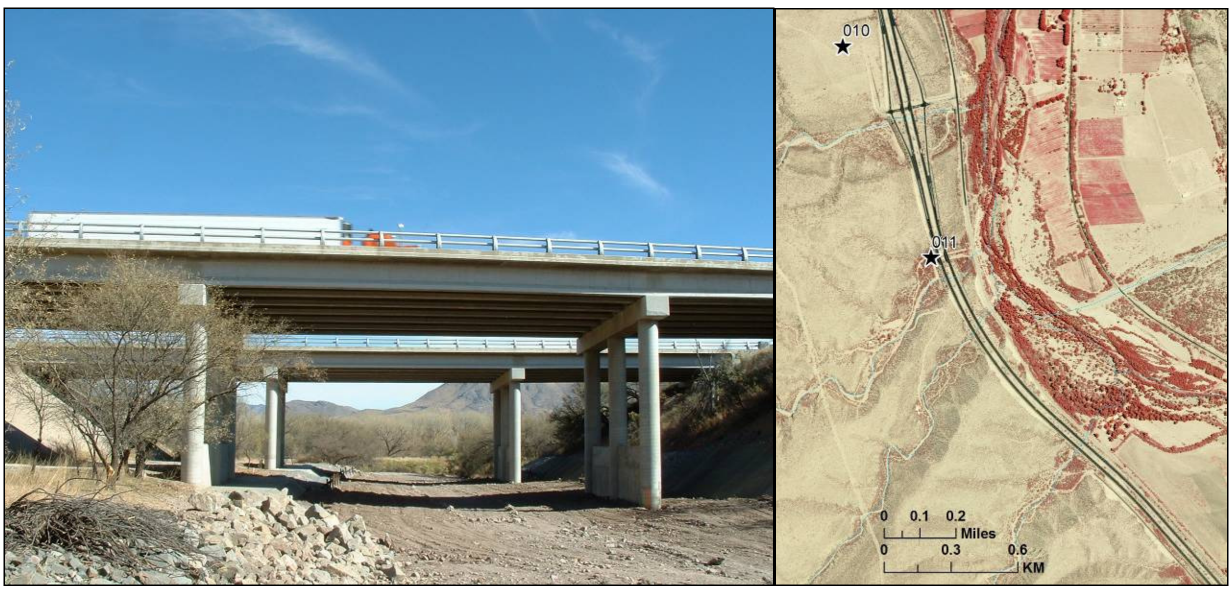


**Figure 12: Looking east from Waypoint 011, a large bridge on I-19 is approximately 38m wide and 10m high. The gravel road serves only Rock Corral Ranch. The un-named canyon flows from the Tumacacori Mountains, joining the Santa Cruz River near the point where Josephine Canyon (lower right edge of air photo) joins from the Santa Rita Mountains. See Figure 5 to locate this scene within the linkage design.**

- The bridge over Peck Canyon at the extreme southern edge of the linkage design (not photographed). The lowermost reaches of Peck Canyon (between I-19 and the Santa Cruz River) probably provide important habitat for Gila topminnow and southwestern willow flycatcher. Suitable cottonwood-willow habitat may continue up Peck Creek for some distance west of the bridge, but suburban development (Rio Rico) along Peck Canyon west of the Freeway limits the utility of this crossing structure for most wildlife needing to move between the Tumacacori Mountains and the Santa Cruz River.

*Recommendations for Interstate 19*

The existing crossing structures are not adequate to serve the movement needs of the full suite of wildlife species that need to move between the Santa Rita and Tumacacori Mountains. We recommend upgrading the crossing structures described above, and new crossing structures at 3 new locations in the central and southern part of the linkage design, as follows:

- Where Chivas Wash (Figure 13, Figure 14) crosses I-19, replace the culverts with a bridge. This is a high priority to take advantage of the ongoing effort by Tucson Audubon Society to restore the vegetation at the recently-acquired Esperanza Ranch Conservation Easement. The existing culvert should be replaced with a larger, open bridge that will allow large carnivores and deer to pass under I-19. Ideally, the bridge should be high enough to allow enough light for vegetation to grow underneath it. If the bridge cannot be built that high, then box and pipe should be added adjacent to the bridge to maintain connectivity for reptiles, amphibians, rodents, and invertebrates, and provision of artificial cover (stumps, brushpiles) under the bridge in an area not subject to scouring floods.

- Replace the crossing structure in the center of the northerly strand of the linkage (Figure 10) with a bridge adequate for use by mountain lion, jaguar, and deer, and meeting the recommendations in the previous paragraph.

- Replace the culvert at Puerto Canyon (Figure 11 with a bridge or larger, more open culvert. If this crossing structure is to remain useful, residential development to the east and southeast must be limited to retain natural habitat along the wash between I-19 and the Santa Cruz River. The existing golf-course should be encouraged to use wildlife-friendly landscaping, and current homeowners and landowners along the linkage should also be provided with information and encouragement to be corridor stewards.

- The existing bridge serving Rock Corral Ranch is excellent, but vegetation should be maintained and restored under and adjacent to the bridge. Efforts should also be made to provide for connectivity across East Frontage Road in this vicinity. Suburban development on the hills east of the Santa Cruz River, especially along Josephine Creek, should be controlled in a way that will be compatible with wildlife movement.

- The existing bridge over Peck Canyon is also permeable for most wildlife species and should be conserved, but most of Peck Canyon west of this area is outside the Linkage Design, and existing urban development limit westward movement or most terrestrial wildlife.

- Create three new bridged crossing structures in the central part of the linkage design, between Tubac and Peck Canyon (Figure 15). In this area, approximately 10 canyons or washes flow eastward from the Tumacacoris. Except for the bridged wash mentioned above (Figure 10) and Peck Canyon, each wash passes under I-19 via small box or pipe culverts under 10-50 ft of fill material (embankments for I-19). Thus this 8-mile (13 km) portion of I-19 currently has only 1 bridged undercrossing within it (plus the Peck Canyon bridged undercrossing at the southern edge of the linkage design) – far below the ideal of 1 bridged structure per 0.93 miles (Clevenger and Wierzchowski 2006). Urban development is proceeding rapidly along the East Frontage Road south of Tubac. However, from the village of Carmen southward, residential development occurs only on the Frontage Road or without about 1 city block of the Frontage Road. Gaps between houses of 100 m or more occur at waypoints 8, 9, Rock Corral Canyon (waypoint 10), Tinaja Canyon, and Negro Canyon where small washes now pass via small pipe culverts under I-19. Three of these areas should be outfitted with bridged crossings, with the choice coordinated with plans to minimize development east of I-19 near the chosen locations.

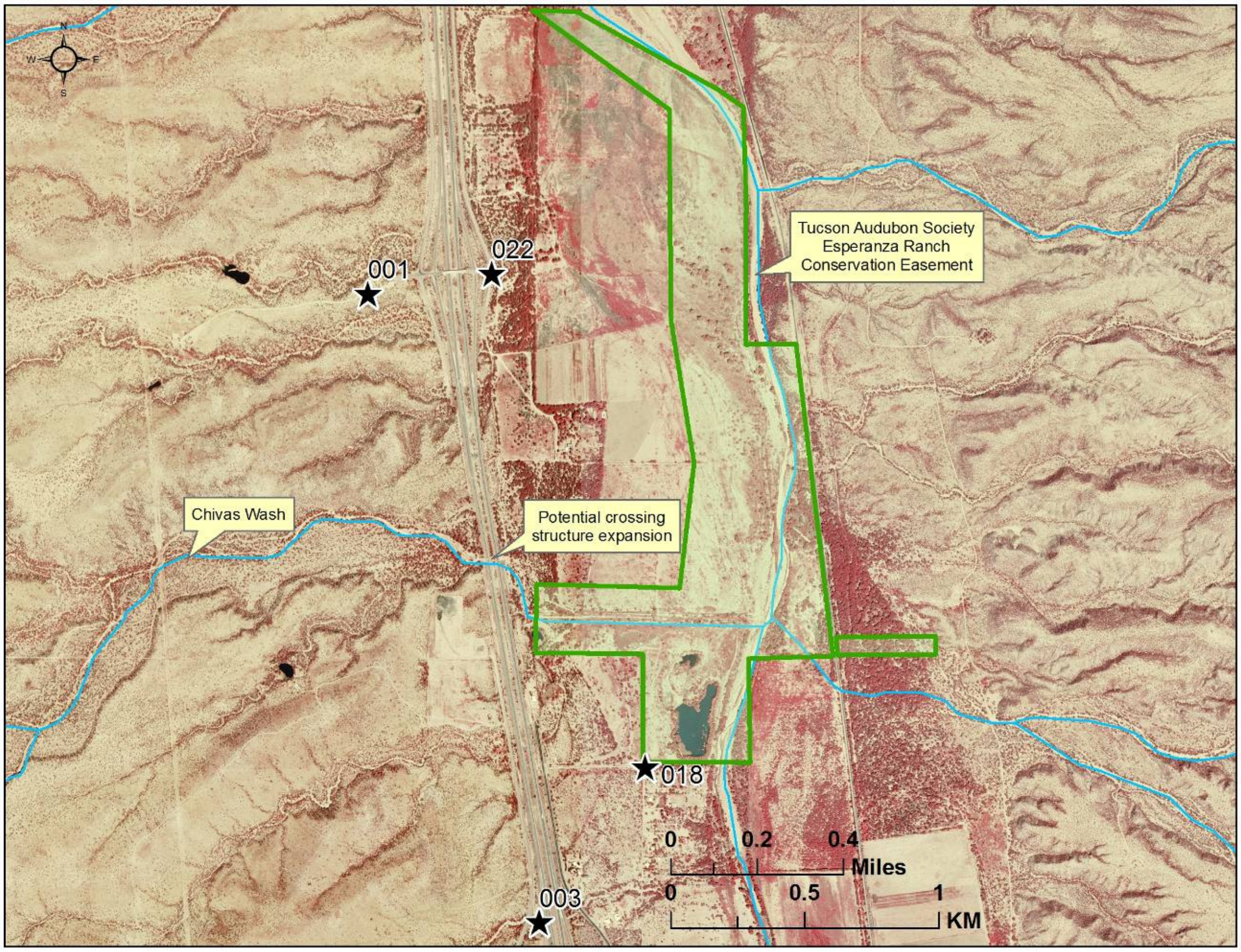


**Figure 13: Potential crossing structure expansion at junction of Chivas Wash & I-19. Tucson Audubon Society Esperanza Ranch Conservation Easement boundary is in green.**

**Figure 14: Chivas Wash, east of I-19 on the Tucson Audubon Society's Esperanza Ranch Conservation Easement. (Photo taken in September 2005 by Kendall Kroes).**

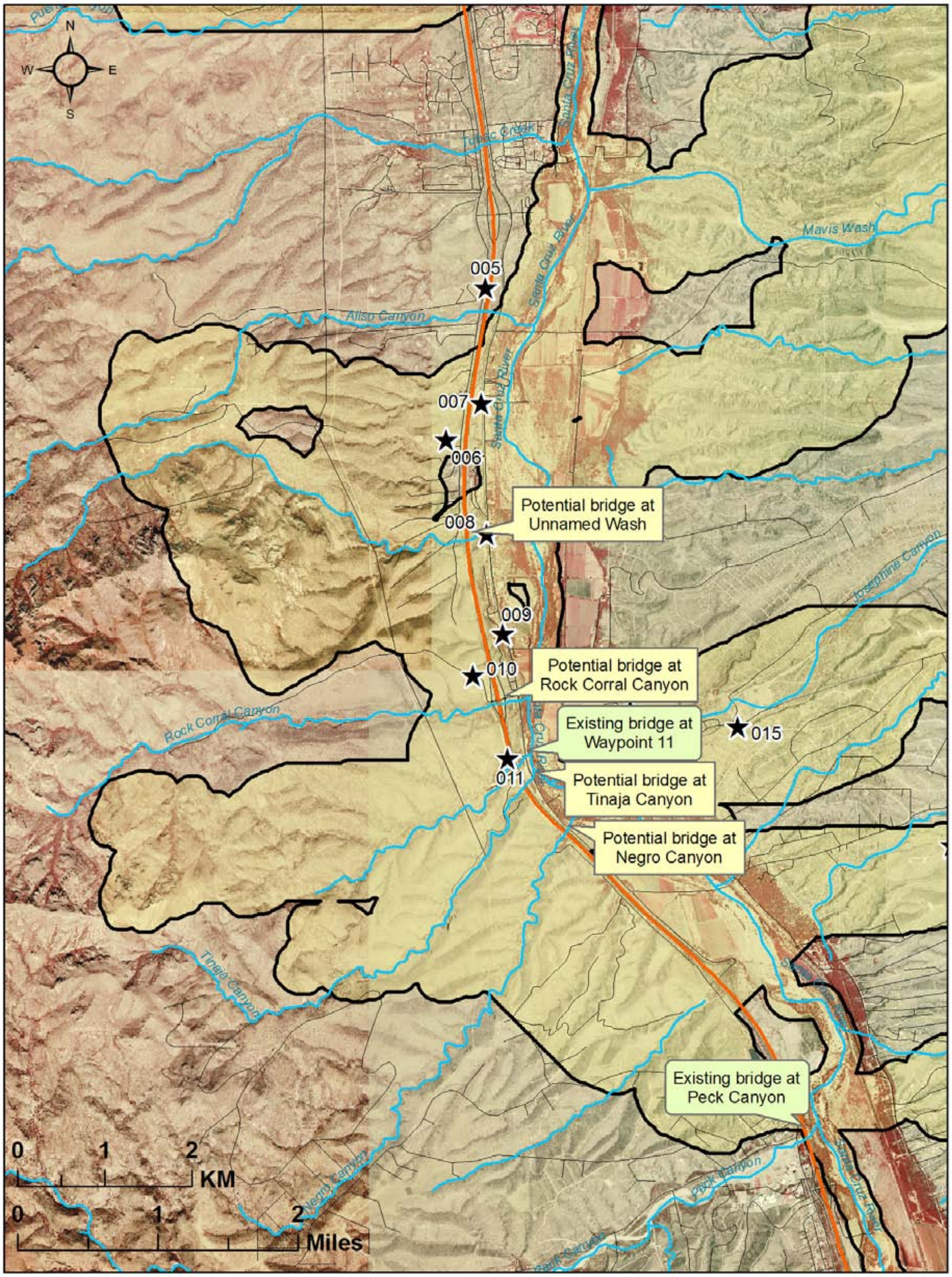


**Figure 15: In addition to the 2 existing bridges, bridged wildlife undercrossings should be built under I-19 at 3 of the 4 labeled Potential Bridge Locations. The choice of crossing structure locations should be coordinated plans to control urban development east of the chosen locations.**

## Impediments to Streams and the Santa Cruz River Corridor

*Stream Impediments in the Linkage Design Area*

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 (Wilbor 2005). The Santa Cruz River and its associated riparian vegetation are preferred habitat for many species in the linkage area, including skunk, gray fox, javelina, jaguar, mountain lion, white-tailed deer, black bear, leopard frogs, giant-spotted whiptail, Mexican garter snake, at least 8 species of rodents, and 22 Birds of Conservation Concern (such as gray hawk, Southwestern Yellow-billed cuckoo, and Southwestern willow flycatcher). The Santa Cruz River also sustains one of on1y 14 viable populations of the Gila topminnow in the Gila River watershed (Wilbor 2005). Unfortunately, connectivity of stream and riparian habitat on the Santa Cruz River has been degraded by many factors, including loss and degradation of habitat from vegetation clearing, tree die-off, cattle grazing in riparian habitat, erosion due to channelization, invasion of non-native plants, accumulation of trash, pollutants in surface water and sediment, and predation and competition by invasive aquatic animals (Wilbor 2005).

*Mitigating Stream Impediments*

Despite these impediments, recovery of a functioning riparian ecosystem is still possible for this portion of the Santa Cruz River. This potential must be seized quickly, before development creates further problems. In a recent extensive study of the upper Santa Cruz River riparian corridor (Wilbor 2005), the Tucson Audubon Society made the following management recommendations which we endorse as crucial steps necessary for riparian connectivity and habitat conservation:

1) **Allow natural flood flows** – Do not harden riverbanks, and do not build developments in floodplain so the Santa Cruz River can maintain natural flooding regimes.
2) **Promote base flows and maintain groundwater levels within the shallow aquifer** – Subsurface water is important for riparian vegetation, and can be sustained more efficiently by reducing ground water pumping near the river and providing municipal water sources to homes.
3) **Maintain or improve native riparian vegetation** – For *cottonwood/willow habitat*, groundwater should be maintained within 9 feet (2.6 m) below ground level. *Large mesquite bosques*, such as those found north of Rio Rico along Pendleton Road, north and south of Clark Crossing east of the river, and at Esperanza Ranch east of the river, should receive the highest priority for conservation protection because of their rarity in the region. Mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut. Mesquite bosques at the confluence of tributaries such as Josephine/Tinaja Canyons and Cottonwood Canyon should also be protected. Livestock should be excluded from cottonwood-willow and mesquite bosque habitats. Pumps within ½ mile of the river or near springs should cease pumping, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May.
4) **Eliminate ATV and OHV use in riparian vegetation in the floodplain** – Off-road vehicles are causing erosion and habitat damage to understory vegetation.
5) **Eradicate non-native invasive plants and animals** – Tamarisk removal should be a top priority, because this invasive plant is not yet dominant along the river. Bullfrogs, crayfish, and mosquitofish populations should be controlled, or if possible, eliminated. For cowbirds, at least a 100 m width of riparian vegetation should be maintained to minimize intrusion into riparian habitat used by nesting native birds.

## Urban Development as Barriers to Movement

Urban and industrial development, unlike roads, creates barriers to movement which cannot easily be removed, restored, or otherwise mitigated. Most large carnivores, small mammals, and reptiles cannot occupy these areas for a significant period of time, although several species of lizards or small mammals may occasionally occupy residential areas. While mapped urban areas only accounted for 2% of the land cover, residential development is increasing rapidly in parts of the Linkage Design.

*Urban Barriers in the Linkage Design Area*

Between I-19 and the Santa Cruz River, there is considerable urban development in and south of Tubac (Figure 16). Biologically best corridor models for Coues' white-tailed deer and porcupine pass through the Santa Cruz riparian area adjacent to this development.

**Figure 16: significant urban development between I-19 and the Santa Cruz River (looking east from waypoint 005).**

Extending from Clark's Crossing to Old Bailey Crossing, the town of Carmen presents a potential urban barrier to connectivity in the Linkage Design (Figure 17). The town is approximately 1 block wide, and is mainly composed of older homes in poor condition. The biologically best corridor for coati passes through Carmen.


**Figure 17: The town of Carmen is a potential urban barrier to connectivity (view east and northeast from waypoint 007).**

Although there are only scattered residences today in the Cayetano Mountain region in the southernmost route of the linkage, an extensive network of roads, powerlines, and utilities suggest that thousands of acres may be converted to residential areas as the town of Rio Rico grows (Figure 18). These areas are currently mapped as natural vegetation, and biologically best corridor models for black bear, Arizona gray squirrel, and black-tailed rattlesnake all passed through this area.

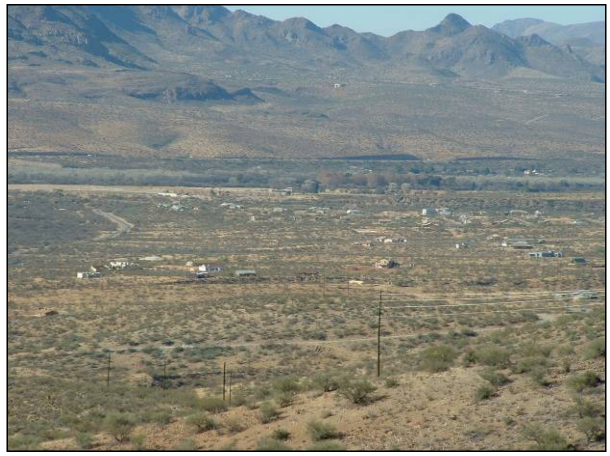

**Figure 18: Significant development is likely in the southernmost strand of the Linkage Design. Note the network of roads and powerlines in areas with only a few scattered residences at present (views south and northwest from waypoint 012).**

In addition to residential development, a gravel mining operation in lower Josephine Canyon, the Sand and Gravel Rio Rico Pit, may adversely affect ecological connectivity between the Santa Rita and Tumacacori wildland blocks (Figure 19). This mining operation falls in the biologically best corridor for Tiger Rattlesnake.

**Figure 19: Gravel mining operation in Josephine Canyon (view northeast from waypoint 015).**

*Mitigation for Urban Barriers*

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

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

# Appendix A: Linkage Design Methods

Our goal was to identify a continuous corridor of land which – if conserved and integrated with underpasses or overpasses across potential barriers – will best maintain or restore the ability of wildlife to move between large protected 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 23 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., some snakes that select small rocks), or if the species probably can travel (e.g., by flying) across unsuitable habitat.

[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.

## 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 20):

- *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 D.
- *Elevation.* We used the USGS National Elevation Dataset digital elevation model.
- *Topographic position.* We characterized each pixel as ridge, canyon bottom, flat to gentle slope, or steep slope.
- *Straight-line distance from the nearest paved road or railroad.* Distance from roads reflects risk of being struck by vehicles as well as noise, light, pets, pollution, and other human-caused disturbances.

To create a habitat suitability map, we assigned each of the 46 vegetation classes (and each of 4 topographic positions, and each of several elevation classes and distance-to-road classes) a score from 1 (best) to 10 (worst), where 1-3 is optimal habitat, 4-5 is suboptimal but usable habitat, 6-7 may be occasionally used but cannot sustain a breeding population, and 8-10 is strongly avoided. Whenever possible we recruited biologists with the greatest expertise in each species to assign these scores (see *Acknowledgements*). When no expert was available for a species, three biologists independently assigned scores and, after discussing differences among their individual scores, were allowed to adjust their scores before the three scores were averaged. Regardless of whether the scores were generated by a species expert or our biologists, the scorer first reviewed the literature on habitat selection by the focal species[2].

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 1 and 10. We then weighted each of the by 4 factors by a weight between 0% and 100%, subject to the constraint that the 4 weights must sum to 100%, and added the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10. We used these habitat suitability scores to create a habitat suitability map that formed the foundation for the later steps.

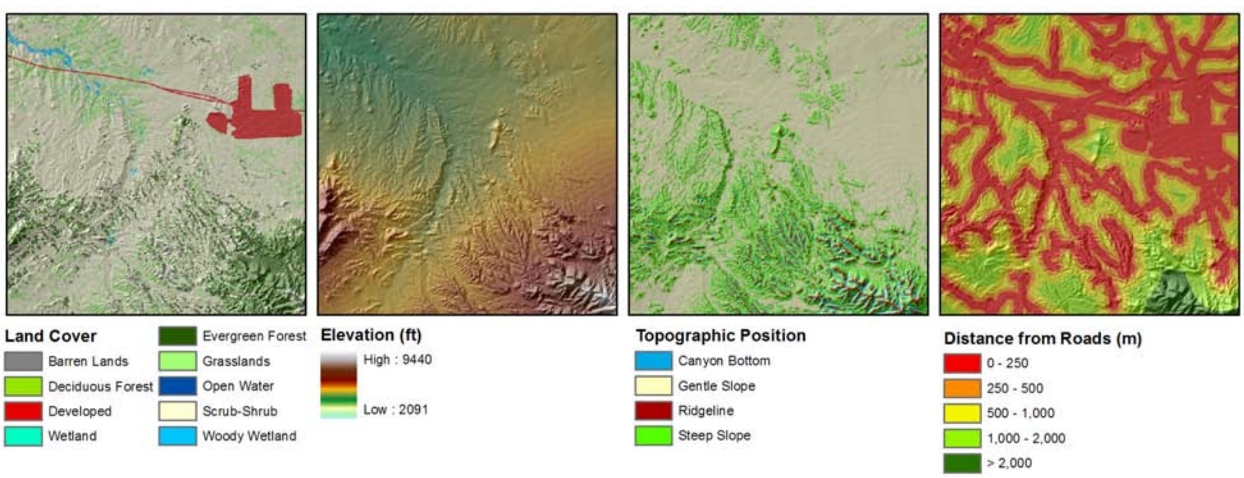


**Figure 20: Four habitat factors used to create habitat suitability models. Inputs included land cover, elevation, topographic position, and distance from roads.**

If necessary, we also used additional factors critical for a particular species, such as a minimum slope needed as escape terrain for bighorn sheep, or proximity to water for frogs. To create a habitat suitability

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

model using critical features, we reclassified any pixel beyond a specified threshold distance from the critical feature as unsuitable for breeding (score > 5). This was accomplished using the equation:

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

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

## Identifying Potential Breeding Patches & Potential Population Cores

The habitat suitability map provides scores for each 30x30-m pixel. For our analyses, we also needed to identify – both in the Protected 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 21). We averaged habitat suitability within a 3x3-pixel neighborhood (0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[3]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) into polygons that represented potential 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.

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

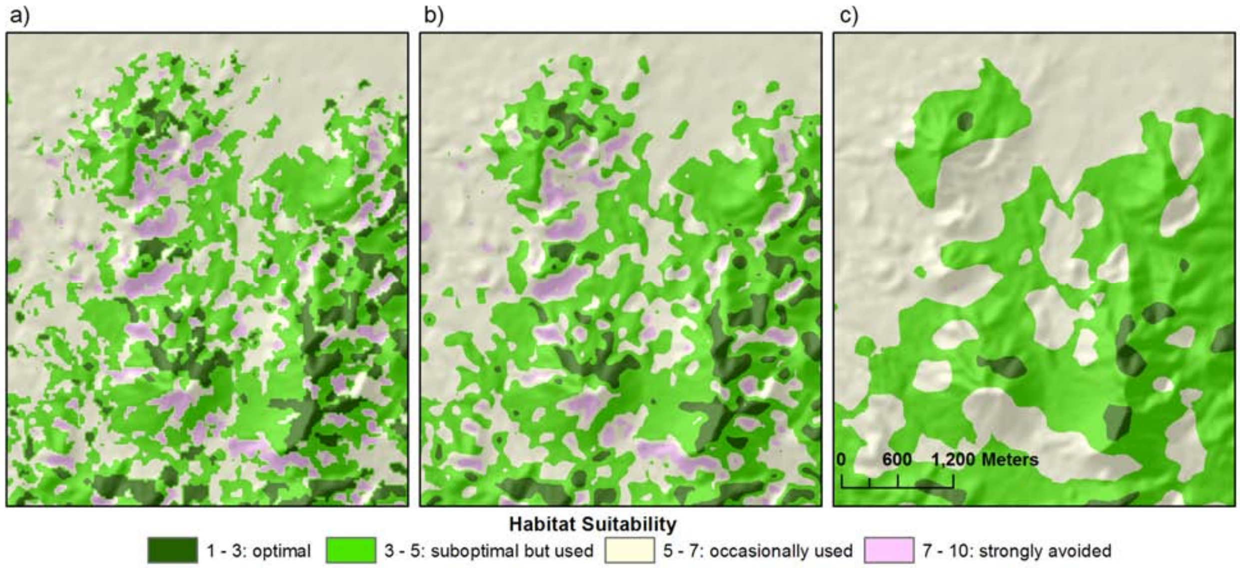


**Figure 21: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.**

## Identifying Biologically Best Corridors

The *biologically best corridor*[4] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one protected wildland block to a potential population core in the other protected wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

We developed BBCs only for some focal species, namely species that (a) exist in both protected 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). For focal species that did not meet these criteria, we conducted patch configuration analysis (next section).

To define the start and end points for a corridor, we identified potential population cores and habitat patches that fell completely within each protected wildland block. If potential population cores existed within each block, we used these potential cores as the starting & ending points for the corridor analysis. Otherwise, the start-end points were potential habitat patches within the protected wildland block or (for a wide-ranging species with no potential habitat patch entirely within a wildland block) any suitable habitat within the 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[5]. We used three rules to transform habitat suitability scores into travel costs,

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[4] 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.
[5] Levey et al. (2005) provide evidence that animals make movement decisions based on habitat suitability.

depending on ecological characteristics of the species:

- For a *locally widespread species* (habitat suitability score < 5 in nearly all of the potential linkage zone, suggesting that breeding populations could occur throughout), we used the raw pixel habitat suitability score as the travel cost score.

Species that were not widespread throughout the potential linkage area were divided into 2 groups:

- For *corridor-dwelling species* (species needing weeks to generations to traverse the potential linkage area – including most reptiles, amphibians, and small mammals)[6], we reassigned a score of 1 to each pixel in a potential habitat patch or potential population core. Our rationale was that these areas provide steppingstones for multi-generational movement. We did not rescore single pixels, or polygons smaller than a potential breeding area, because these are too small to provide meaningful stopover habitat.
- For *passage species* (mobile species that can make the journey between protected wildland blocks in a single movement event of a few hours or days), we assigned each pixel with a pixel habitat suitability score of 1 through 5 a travel cost score of 1. In preliminary models that lacked this rescoring, the biologically best corridor tended to follow an unrealistic straight line rather than best habitat.

For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd protected wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 500 m (Figure 22). 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 protected 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 distance[7] of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between protected wildland blocks, a patch of good 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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[6] Beier & Loe (1992) introduced this distinction between *passage species* and *corridor-dwelling* species.

[7] 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.

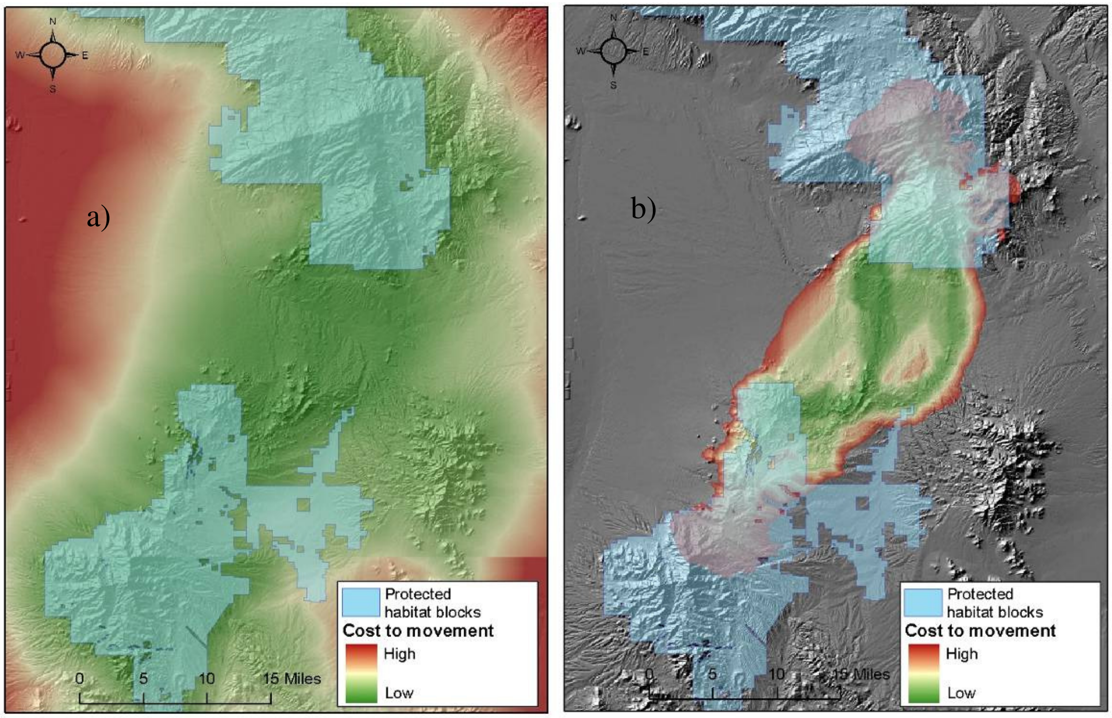



**Figure 22: Landscape permeability layer for a hypothetical species across a) entire landscape, b) most permeable 10% of landscape.**

## 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 1.5 km (0.94 mi) along the length of each terrestrial branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available.

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

We also imposed a 200 meter minimum width on the aquatic strand of the linkage, consisting of the Santa Cruz River and several intermittent streams identified by species experts as crucial resources for amphibians and fish. Because riparian areas are unlikely to change location with climate change, we did not believe that a purely aquatic linkage needed to be 1.5 km wide. A buffer of 100 m on each side of the stream should protect water quality and most ecological functions (Environmental Law Institute 2003). We extended the buffer of the Santa Cruz River to 200 meters on each side because the riparian area of the River is so broad (> 200m in many places) that a 100-m buffer would not protect water quality. The wider width for the Santa Cruz River is also needed because the River presents an obstacle perpendicular to the biologically best corridor for some terrestrial species. These animals would benefit from protected habitat along the river as they attempt to cross. Finally, protecting upland habitat adjacent to the River will benefit terrestrial animals for which the River is the only reliable water within their biologically best corridor.

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 F, as well as in a MS Access database on the CD-ROM accompanying this report.

# Appendix B: Individual Species Analyses

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

| | Antelope Jackrabbit | Arizona Gray Squirrel | Badger | Black Bear | Coues' White-tailed Deer |
|---|---|---|---|---|---|
| **Factor Weights** | | | | | |
| Land Cover | 70 | 70 | 65 | 75 | 65 |
| Elevation | 10 | 10 | 7 | 10 | 5 |
| Topography | 13 | 10 | 15 | 10 | 15 |
| Distance from Roads | 7 | 10 | 13 | 5 | 15 |
| **Land Cover** | | | | | |
| Conifer-Oak Forest and Woodland | 8 | 2 | 6 | 1 | 2 |
| Encinal | 4 | 2 | 6 | 1 | 1 |
| Pine-Oak Forest and Woodland | 9 | 2 | 5 | 1 | 2 |
| Pinyon-Juniper Woodland | 7 | 6 | 4 | 6 | 3 |
| Aspen Forest and Woodland | 10 | 7 | 6 | 5 | 5 |
| Juniper Savanna | 6 | 8 | 2 | 7 | 3 |
| Semi-Desert Grassland and Steppe | 1 | 10 | 1 | 5 | 6 |
| Chaparral | 7 | 6 | 5 | 3 | 3 |
| Creosotebush, Mixed Desert and Thorn Scrub | 2 | 10 | 2 | 6 | 5 |
| Creosotebush-White Bursage Desert Scrub | 2 | 10 | 2 | 9 | 7 |
| Desert Scrub (misc) | 2 | 10 | 3 | 5 | 6 |
| Mesquite Upland Scrub | 3 | 9 | 3 | 6 | 4 |
| Paloverde-Mixed Cacti Desert Scrub | 2 | 10 | 4 | 5 | 8 |
| Stabilized Coppice Dune and Sand Flat Scrub | 6 | 10 | 4 | 10 | 8 |
| Riparian Mesquite Bosque | 3 | 5 | 6 | 5 | 3 |
| Riparian Woodland and Shrubland | 4 | 1 | 6 | 5 | 2 |
| Arid West Emergent Marsh | 9 | 9 | 8 | 5 | 5 |
| Barren Lands, Non-specific | 8 | 10 | 7 | 10 | 10 |
| Bedrock Cliff and Outcrop | 8 | 9 | 9 | 10 | 8 |
| Volcanic Rock Land and Cinder Land | 8 | 10 | 10 | 10 | 10 |
| Warm Desert Pavement | 9 | 10 | 9 | 10 | 10 |
| Recently Mined or Quarried | 10 | 10 | 9 | 10 | 9 |
| Agriculture | 6 | 7 | 6 | 6 | 7 |
| Developed, Medium - High Intensity | 9 | 9 | 10 | 10 | 10 |
| Developed, Open Space - Low Intensity | 6 | 9 | 7 | 10 | 9 |
| Open Water | 9 | 9 | 9 | 10 | 7 |
| **Elevation (ft)** | | | | | |
| Elevation range: cost | 0-500: 3<br>500-1500: 2<br>1500-5000: 1<br>5000-5500: 8<br>5500-11000: 9 | 0-3290: 9<br>3290-5000: 4<br>5000-6600: 1<br>6600-9350: 4<br>9350-11000: 8 | 0-5500: 1<br>5500-8000: 3<br>8000-11000: 6 | 0-2500: 8<br>2500-4000: 6<br>4000-6500: 2<br>6500-8500: 3<br>8500-11000: 4 | 0-2000: 7<br>2000-3000: 6<br>3000-4000: 2<br>4000-6000: 1<br>6000-8000: 3<br>8000-11000: 7 |
| **Topographic Position** | | | | | |
| Canyon Bottom | 5 | 1 | 5 | 3 | 1 |
| Flat - Gentle Slopes | 1 | 4 | 1 | 6 | 5 |
| Steep Slope | 4 | 5 | 8 | 3 | 2 |
| Ridgetop | 4 | 7 | 7 | 4 | 4 |
| **Distance from Roads (m)** | | | | | |
| Distance from Roads range: cost | 0-250: 9<br>250-500: 6<br>500-1000: 3<br>1000-1500: 1 | 0-250: 7<br>250-500: 4<br>500-15000: 1 | 0-250: 6<br>250-1500: 1 | 0-100: 10<br>100-500: 4<br>500-15000: 1 | 0-250: 8<br>250-500: 6<br>500-750: 2<br>750-15000: 1 |

| | Jaguar | Javelina | Mountain Lion | Mule Deer | Porcupine |
|---|---|---|---|---|---|
| **Factor Weights** | | | | | |
| Land Cover | 60 | 50 | 70 | 80 | 87 |
| Elevation | 5 | 30 | 0 | 0 | 0 |
| Topography | 15 | 20 | 10 | 15 | 3 |
| Distance from Roads | 20 | 0 | 20 | 5 | 10 |
| **Land Cover** | | | | | |
| Conifer-Oak Forest and Woodland | 2 | 7 | 1 | 4 | 1 |
| Encinal | 2 | 4 | 1 | 3 | 1 |
| Pine-Oak Forest and Woodland | 3 | 7 | 1 | 3 | 1 |
| Pinyon-Juniper Woodland | 2 | 5 | 1 | 5 | 1 |
| Aspen Forest and Woodland | 6 | 10 | 3 | 1 | 1 |
| Juniper Savanna | 3 | 7 | 4 | 4 | 5 |
| Semi-Desert Grassland and Steppe | 1 | 2 | 5 | 2 | 6 |
| Chaparral | 4 | 3 | 3 | 4 | 4 |
| Creosotebush, Mixed Desert and Thorn Scrub | 2 | 3 | 6 | 6 | 5 |
| Creosotebush-White Bursage Desert Scrub | 4 | 4 | 6 | 6 | 5 |
| Desert Scrub (misc) | 4 | 2 | 6 | 6 | 5 |
| Mesquite Upland Scrub | 4 | 2 | 4 | 3 | 4 |
| Paloverde-Mixed Cacti Desert Scrub | 5 | 1 | 7 | 3 | 5 |
| Stabilized Coppice Dune and Sand Flat Scrub | 6 | 7 | 5 | 6 | 6 |
| Riparian Mesquite Bosque | 1 | 1 | 4 | 3 | 3 |
| Riparian Woodland and Shrubland | 1 | 2 | 2 | 3 | 3 |
| Arid West Emergent Marsh | 2 | 5 | 8 | 5 | 9 |
| Barren Lands, Non-specific | 10 | 9 | 8 | 10 | 9 |
| Bedrock Cliff and Outcrop | 6 | 8 | 6 | 8 | 6 |
| Volcanic Rock Land and Cinder Land | 9 | 9 | 9 | 8 | 9 |
| Warm Desert Pavement | 9 | 8 | 9 | 9 | 10 |
| Recently Mined or Quarried | 10 | 10 | 8 | 6 | 9 |
| Agriculture | 9 | 7 | 10 | 6 | 7 |
| Developed, Medium - High Intensity | 10 | 7 | 10 | 9 | 9 |
| Developed, Open Space - Low Intensity | 10 | 4 | 8 | 5 | 7 |
| Open Water | 7 | 10 | 9 | 10 | 10 |
| **Elevation (ft)** | | | | | |
| Elevation range: cost | 0-2000: 3<br>2000-4000: 3<br>4000-6000: 1<br>6000-8000: 3<br>8000-11000: 4 | 0-5000: 1<br>5000-7000: 3<br>7000-11000: 10 | | | |
| **Topographic Position** | | | | | |
| Canyon Bottom | 1 | 1 | 1 | 2 | 1 |
| Flat - Gentle Slopes | 5 | 1 | 3 | 2 | 2 |
| Steep Slope | 2 | 7 | 3 | 4 | 1 |
| Ridgetop | 4 | 4 | 4 | 6 | 2 |
| **Distance from Roads (m)** | | | | | |
| Distance from Roads range: cost | 0-250: 10<br>250-500: 7<br>500-1000: 5<br>1000-2000: 2<br>2000-15000: 1 | | 0-200: 8<br>200-500: 6<br>600-1000: 5<br>1000-1500: 2<br>1500-15000: 1 | 0-250: 7<br>250-1000: 3<br>1000-15000: 1 | 0-250: 8<br>250-500: 5<br>500-1000: 2<br>1000-15000: 1 |

| | White-nosed Coati | Black-tailed Rattlesnake | Chiricahua Leopard Frog | Desert Box Turtle | Giant Spotted Whiptail |
|---|---|---|---|---|---|
| **Factor Weights** | | | | | |
| Land Cover | 95 | 0 | 55 | 40 | 70 |
| Elevation | 0 | 0 | 25 | 15 | 30 |
| Topography | 0 | 90 | 10 | 20 | 0 |
| Distance from Roads | 5 | 10 | 10 | 25 | 0 |
| **Land Cover** | | | | | |
| Conifer-Oak Forest and Woodland | 2 | | 10 | 10 | 10 |
| Encinal | 1 | | 6 | 6 | 6 |
| Pine-Oak Forest and Woodland | 2 | | 6 | 10 | 10 |
| Pinyon-Juniper Woodland | 2 | | 6 | 10 | 10 |
| Aspen Forest and Woodland | 7 | | 7 | 10 | 10 |
| Juniper Savanna | 5 | | 6 | 7 | 10 |
| Semi-Desert Grassland and Steppe | 7 | | 6 | 2 | 7 |
| Chaparral | 5 | | 6 | 6 | 4 |
| Creosotebush, Mixed Desert and Thorn Scrub | 5 | | 10 | 5 | 4 |
| Creosotebush-White Bursage Desert Scrub | 7 | | 10 | 6 | 10 |
| Desert Scrub (misc) | 8 | | 10 | 5 | 10 |
| Mesquite Upland Scrub | 3 | | 6 | 3 | 7 |
| Paloverde-Mixed Cacti Desert Scrub | 6 | | 10 | 5 | 10 |
| Stabilized Coppice Dune and Sand Flat Scrub | 9 | | 10 | 2 | 10 |
| Riparian Mesquite Bosque | 2 | | 6 | 1 | 4 |
| Riparian Woodland and Shrubland | 1 | | 6 | 1 | 1 |
| Arid West Emergent Marsh | 3 | | 1 | 3 | 2 |
| Barren Lands, Non-specific | 9 | | 10 | 7 | 10 |
| Bedrock Cliff and Outcrop | 7 | | 10 | 10 | 10 |
| Volcanic Rock Land and Cinder Land | 7 | | 10 | 10 | 10 |
| Warm Desert Pavement | 7 | | 10 | 10 | 10 |
| Recently Mined or Quarried | 9 | | 10 | 10 | 10 |
| Agriculture | 5 | | 6 | 5 | 4 |
| Developed, Medium - High Intensity | 9 | | 7 | 10 | 4 |
| Developed, Open Space - Low Intensity | 7 | | 6 | 5 | 3 |
| Open Water | 10 | | 2 | 5 | 2 |
| **Elevation (ft)** | | | | | |
| Elevation range: cost | | | 0-3300: 10<br>3300-6000: 1<br>6000-9000: 2<br>9000-11000: 3 | 0-1900: 10<br>1900-2600: 4<br>2400-5500: 1<br>5500-6500: 5<br>6500-11000: 9 | 0-2000: 10<br>2000-2330: 5<br>2300-4000: 1<br>4000-4600: 4<br>4600-11000: 9 |
| **Topographic Position** | | | | | |
| Canyon Bottom | | 1 | 1 | 3 | |
| Flat - Gentle Slopes | | 9 | 1 | 1 | |
| Steep Slope | | 1 | 6 | 4 | |
| Ridgetop | | 1 | 7 | 4 | |
| **Distance from Roads (m)** | | | | | |
| Distance from Roads range: cost | 0-500: 8<br>500-15000: 3 | 0-35: 10<br>35-500: 5<br>500-15000: 1 | 0-100: 8<br>100-500: 5<br>500-1000: 3<br>1000-15000: 1 | 0-500: 5<br>500-1500: 3<br>1500-15000: 1 | |

| | Lowland Leopard Frog | Sonoran Desert Toad | Sonoran Whipsnake | Tiger Rattlesnake |
|---|---|---|---|---|
| **Factor Weights** | | | | |
| Land Cover | 60 | 5 | 30 | 20 |
| Elevation | 30 | 50 | 10 | 30 |
| Topography | 0 | 25 | 45 | 40 |
| Distance from Roads | 10 | 20 | 15 | 10 |
| **Land Cover** | | | | |
| Conifer-Oak Forest and Woodland | 10 | 10 | 10 | 10 |
| Encinal | 6 | 7 | 1 | 5 |
| Pine-Oak Forest and Woodland | 7 | 10 | 1 | 10 |
| Pinyon-Juniper Woodland | 7 | 10 | 1 | 6 |
| Aspen Forest and Woodland | 10 | 10 | 10 | 10 |
| Juniper Savanna | 7 | 4 | 3 | 10 |
| Semi-Desert Grassland and Steppe | 6 | 2 | 2 | 5 |
| Chaparral | 6 | 4 | 1 | 6 |
| Creosotebush, Mixed Desert and Thorn Scrub | 6 | 2 | 2 | 3 |
| Creosotebush-White Bursage Desert Scrub | 6 | 4 | 7 | 7 |
| Desert Scrub (misc) | 6 | 2 | 3 | 3 |
| Mesquite Upland Scrub | 6 | 1 | 2 | 4 |
| Paloverde-Mixed Cacti Desert Scrub | 6 | 1 | 1 | 1 |
| Stabilized Coppice Dune and Sand Flat Scrub | 10 | 2 | 10 | 10 |
| Riparian Mesquite Bosque | 6 | 1 | 2 | 5 |
| Riparian Woodland and Shrubland | 6 | 2 | 2 | 5 |
| Arid West Emergent Marsh | 1 | 5 | 3 | 10 |
| Barren Lands, Non-specific | 10 | 7 | 10 | 10 |
| Bedrock Cliff and Outcrop | 10 | 5 | 3 | 2 |
| Volcanic Rock Land and Cinder Land | 10 | 10 | 4 | 1 |
| Warm Desert Pavement | 10 | 5 | 10 | 6 |
| Recently Mined or Quarried | 10 | 4 | 10 | 10 |
| Agriculture | 6 | 4 | 10 | 10 |
| Developed, Medium - High Intensity | 7 | 6 | 10 | 9 |
| Developed, Open Space - Low Intensity | 6 | 4 | 5 | 1 |
| Open Water | 2 | 4 | 10 | 10 |
| **Elevation (ft)** | | | | |
| Elevation range: cost | 0-900: 4<br>900-4000: 1<br>4000-5500: 3<br>5500-7000: 6<br>7000-11000: 10 | 0-4600: 1<br>4600-5250: 4<br>5250-5800: 5<br>5800-11000: 7 | 0-1400: 5<br>1400-2000: 3<br>2000-5600: 1<br>5600-7500: 5<br>7500-11000: 10 | 0-4000: 1<br>4000-5100: 5<br>5100-11000: 10 |
| **Topographic Position** | | | | |
| Canyon Bottom | | 1 | 1 | 1 |
| Flat - Gentle Slopes | | 1 | 3 | 6 |
| Steep Slope | | 6 | 1 | 1 |
| Ridgetop | | 6 | 1 | 3 |
| **Distance from Roads (m)** | | | | |
| Distance from Roads range: cost | 0-100: 8<br>100-500: 5<br>500-1000: 3<br>1000-15000: 1 | 0-200: 5<br>200-1000: 4<br>1000-3000: 2<br>3000-15000: 1 | 0-500: 5<br>500-1000: 4<br>1000-2000: 3<br>2000-15000: 1 | 0-35: 10<br>35-1000: 5<br>1000-15000: 1 |

# Antelope Jackrabbit (*Lepus alleni*)

## Justification for Selection
Antelope jackrabbits have a geographic distribution limited to the deserts and grasslands of southern Arizona and northern Mexico, and are threatened with habitat alteration from expanding agriculture and development (Best & Henry 1993).

## Distribution
Within the United States, the antelope jackrabbit is limited to southern Arizona. The species is also found in the northern portion of the Mexican state Nayarit, and on Tiburón Island in the Gulf of California (Best & Henry 1993).

## Habitat Associations
Antelope jackrabbits are primarily associated with grassy slopes on moderate elevations up to 4,900 feet (Best & Henry 1993). In southern Arizona, antelope jackrabbits live on dry valley slopes away from water, and do not drink water if it is available (Best & Henry 1993). Brown & Krausman (2003) identified the species 73% of the time within vegetation associations composed of mesquite and creosote, while others have found stomach content comprised of 45% grass, 35% mesquite, and 7.8% cactus (Vorhies & Taylor 1933).

## Spatial Patterns
The average home range of antelope jackrabbits has been estimated as 642.8 ha (Swihart 1986), and population density has may range from 0.025 ha to 0.5 ha (Best & Henry 1993). Swihart's (1986) estimate of home range for antelope jackrabbits is much larger than the home range for congeners of the species, such as the black-tailed jackrabbit, which have estimated home ranges ranging from 20 to 140 ha (Best 1993). No information was available on dispersal distances for the species.

## Conceptual Basis for Model Development
*Habitat suitability model* – Because Brown & Krausman (2003) censused the species using a roadway survey which identified the species within 100m of the road, we assumed antelope jackrabbits do not show an aversion to roads. However, this non-sensitivity may result in increased roadkill, so we assigned distance from roads a weight of 7%. Vegetation received an importance weight of 70%, while elevation and topography received weights of 10% and 13%, respectively. For specific costs of classes within each of these factors used for the modeling process, see Table 4.

*Patch size & configuration analysis* – We defined minimum potential habitat patch size as 100 ha, based on Best's (1993) estimate of home range size for black-tailed jackrabbits. Minimum potential habitat core size was defined as 500 ha, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – While no information was available on dispersal distance for this species, antelope jackrabbits were considered potential corridor dwellers in this analysis because of their spatial requirements and the high habitat suitability within the linkage area. Nearly all habitat within the linkage zone was calculated as suitable, so the standard habitat suitability model was used in the corridor analysis.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 23). Within the biologically best corridor for this species, the average habitat suitability ranged from 1 to 7.2, with an average suitability of 2.0 (optimal habitat; S.D: 0.9). Nearly 98% of the habitat within this species' biologically best corridor had a habitat suitability in the 'optimal' category (1-3). Due to the high suitability of habitat within this species' corridor, nearly the entire corridor was a potential habitat core, although several impediments to movement such as I-19 still exist (Figure 24).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are part of Cottonwood Canyon and several unnamed washes.

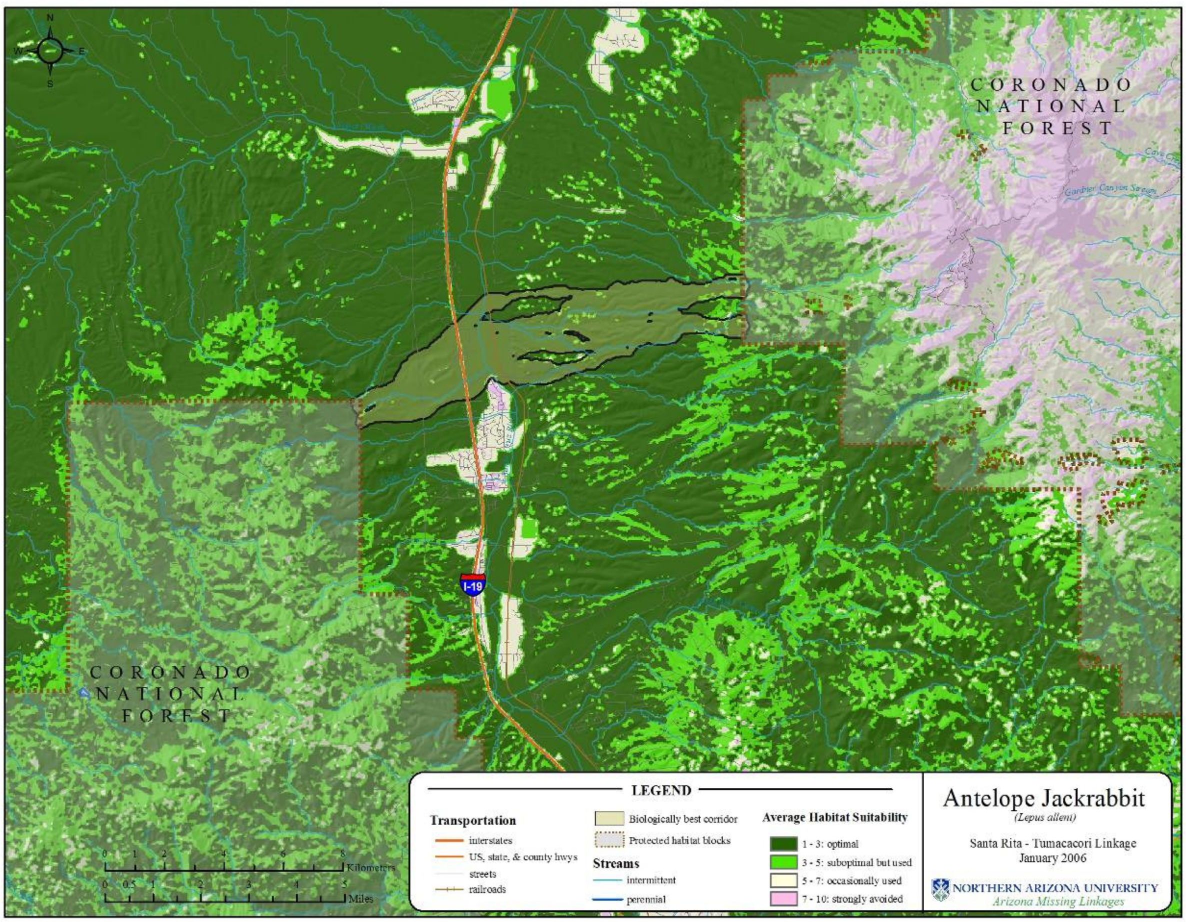



**Figure 23: Modeled habitat suitability of antelope jackrabbit.**

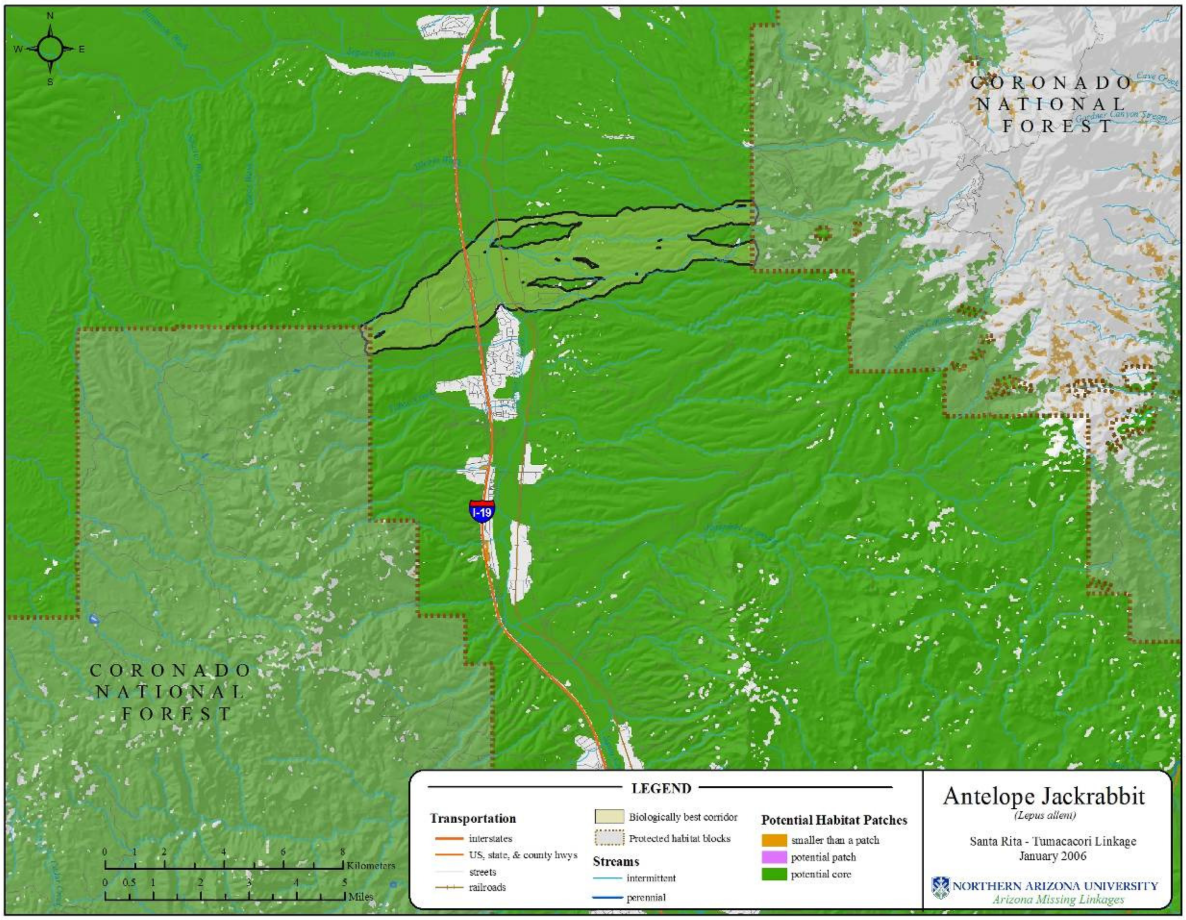



**Figure 24: Potential habitat patches and cores for antelope jackrabbit.**

*Union of biologically best corridors* – The union of biologically best corridors provides ample habitat for the antelope jackrabbit. While the northernmost route of the Linkage Design provides the most high-quality habitat, nearly the entire Linkage Design is a potential habitat patch for this species. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-19, and urban development.

# Arizona Gray Squirrel (*Sciurus arizonensis*)

## Justification for Selection
Arizona gray squirrels have limited geographic distributions and are habitat specialists with strong dependency on montane forest. They are also sensitive to roads (Brown 1984 *in* Best & Riedel 1995), and most likely dispersal limited.

## Distribution
The Arizona gray squirrel is found in Arizona and New Mexico, and to a limited extent in Sonora, Mexico. In Arizona, they occupy a number of mountain ranges in the southern part of the state, as well as the southern and western slopes of the Mogollon Plateau (Best & Riedel 1995).

## Habitat Associations
Arizona gray squirrels are primarily associated with dense, mixed broadleaf forests within deciduous riparian forests (Best & Riedel 1995). They may extend along streams into semi-desert and chaparral areas. Ponderosa pine (*Pinus ponderosa*) and Gambel oak (*Quercus gambeli*) are used extensively when found within riparian communities. Key indicators of Arizona gray squirrel include Arizona walnut (*Juglans major*), Arizona oak (*Quercus arizonica*), and Gambel oak, which provide key nesting & foraging sources (Best & Riedel 1995). While individuals of this species are often killed on roadways, they are not greatly disturbed by dogs and humans. In Arizona, typical elevation range is between 4900 & 6400 feet, although the species can range from approximately 3,600 to 8,900 feet (Best & Riedel 1995).

## Spatial Patterns
No information is known on spatial requirements of the Arizona gray squirrel. Abert's Squirrel (Sciurus aberti), a species within the same genus, has been found to have an average home range of 2.5 to 13 ha (6.2 – 32 acres), with larger home ranges associated with recent timber harvesting (Patton 1977). Average summer home ranges of western gray squirrels in California and Oregon have been found to vary between 2.6 and 4.2 ha (6.4-10.4 acres) (Ryan & Carey 1995). Home ranges of Abert's squirrel have been observed to commonly overlap (Keith 2003), while the home ranges of western gray squirrel displayed little overlap (Vander Haegen et al. 2005) While no dispersal information is available for the Arizona gray squirrel, dispersal distance for tree squirrels is generally not more than several kilometers (NatureServe 2005).

## Conceptual Basis for Model Development
*Habitat suitability model* – Due to this species' strong vegetation preferences, vegetation received an importance weight of 70%, while elevation, topography, and distance from roads each received a 10% weight. For specific scores of classes within each of these factors, see Table 4 for habitat suitability ratings.

*Patch size & configuration analysis* – Based on the range of home ranges for western gray squirrels estimated by Ryan & Carey (1995), we defined minimum patch size for Arizona gray squirrel as 3.4 ha. We assumed the amount of high-quality habitat necessary to support a relatively isolated breeding group of Arizona gray squirrels for approximately 10 years was 17 ha, or five times estimated minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – Other squirrels disperse several kilometers, and potential habitat within the linkage area is patchily distributed, so we considered this species a potential corridor dweller. Because potential habitat was patchily distributed, we re-assigned all 'suitable' habitat (score < 5) a cost of 1, to encourage the biologically best corridor to capture this available habitat.

## Results & Discussion

*Initial biologically best corridor* – The biologically best corridor for this species was comprised of two distinct strands. Although the southern strand generally had more potentially suitable habitat (Figure 25), suitable habitat was patchily distributed in both strands (Figure 26). Within the northern strand, the average habitat suitability ranged from 1.7 to 9.3, with an average suitability of 7.4 (S.D: 1.5). Within the southern strand, the average habitat suitability ranged from 1.0 to 9.3, with an average suitability of 7.6 (S.D: 2.6). The farthest distance between a potential patch and another patch or core within the northern strand was approximately 7.4 km, while this distance was approximately 3.6 km for the southern strand (Figure 27). Because the southern strand was noticeably better than the northern strand, we did not use the northern strand when constructing the final union of biologically best corridors for all species.

The southern strand for this species runs from the eastern side of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Within the corridor near the Santa Rita block are several historical mines, including Royal Blue Mine, Trenton Mine, and Bland Mine. Moving westward from the Santa Ritas, the corridor encompasses Salero Mountain, part of Ash Canyon, Cieneguita Canyon, Grosvenor Hills, and the San Cayetano Mountains, before crossing the Santa Cruz River.

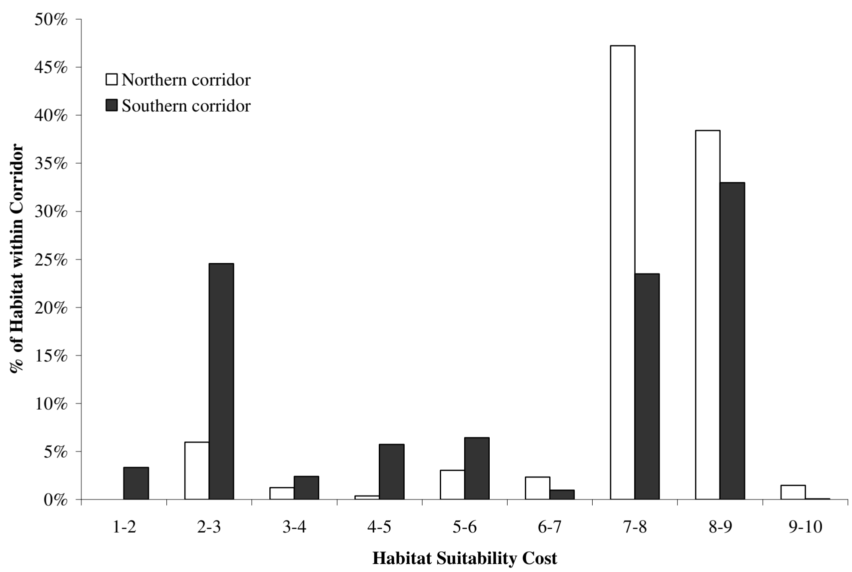



**Figure 25: Percentage of each habitat suitability category in each of the biologically best corridors for Arizona gray squirrel.**

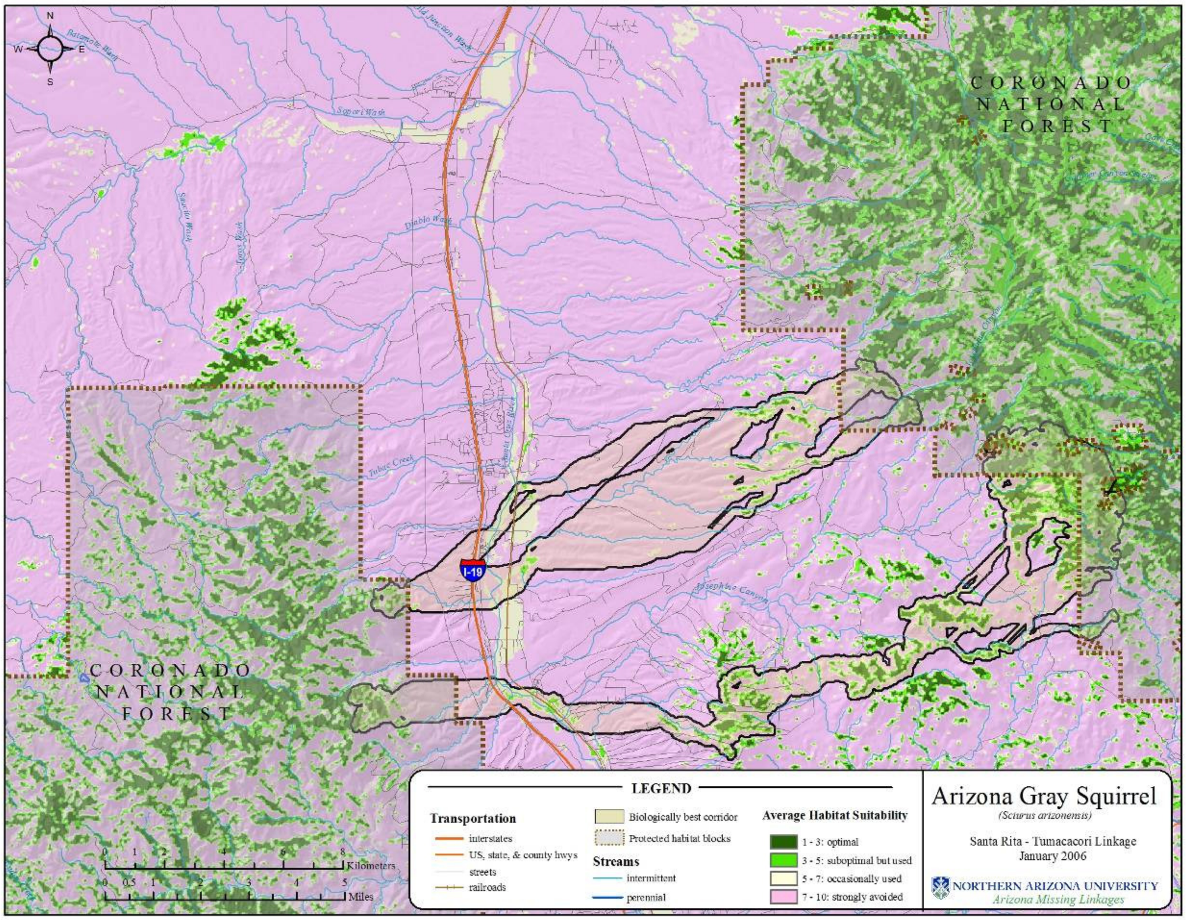



**Figure 26: Modeled habitat suitability of Arizona gray squirrel. Because the southern strand was superior, we used only the southern strand in the Linkage Design.**

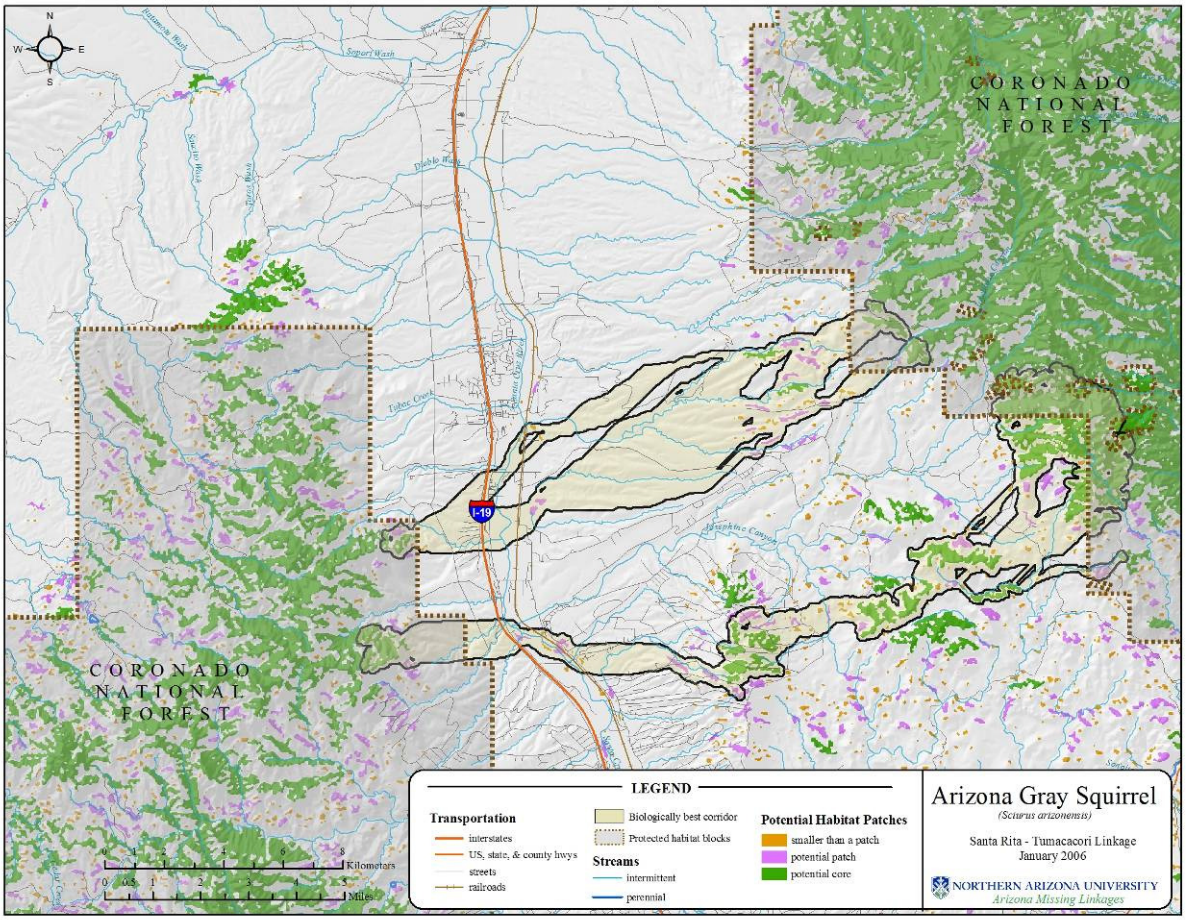



**Figure 27: Potential habitat patches and cores for Arizona gray squirrel. Because the southern strand was superior, we used only the southern strand in the Linkage Design.**

*Union of biologically best corridors* – Because the Arizona gray squirrel is primarily forest-dwelling, the union of biologically best corridors provides little habitat for the species. With the exception of the addition of several potential habitat cores downslope of the Santa Rita wildland block and riparian woodland areas along the Santa Cruz River, the additional area within the union of biologically best corridors is unsuitable habitat for this species. Due to the recent residential development in the San Cayetano Mountains region and this species' limited dispersal capability, it may be difficult to restore ecological connectivity for it.

# Badger (*Taxidea taxus*)

### Justification for Selection

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

### Distribution

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

### Habitat Associations

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

### Spatial Patterns

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

### Conceptual Basis for Model Development

*Habitat suitability model* – Badgers prefer grasslands and other open habitats on flat terrain at lower elevations. They do not show an aversion to roads (Apps et al. 2002), which makes them sensitive to high road mortality. Vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received weights of 7%, 15%, and 13%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

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

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

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 28). Within the biologically best corridor for this species, the average habitat suitability ranged from 1 to 6.9, with an average suitability of 2.1 (S.D: 1.1).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block, bordered on the north by Sheehy Canyon.

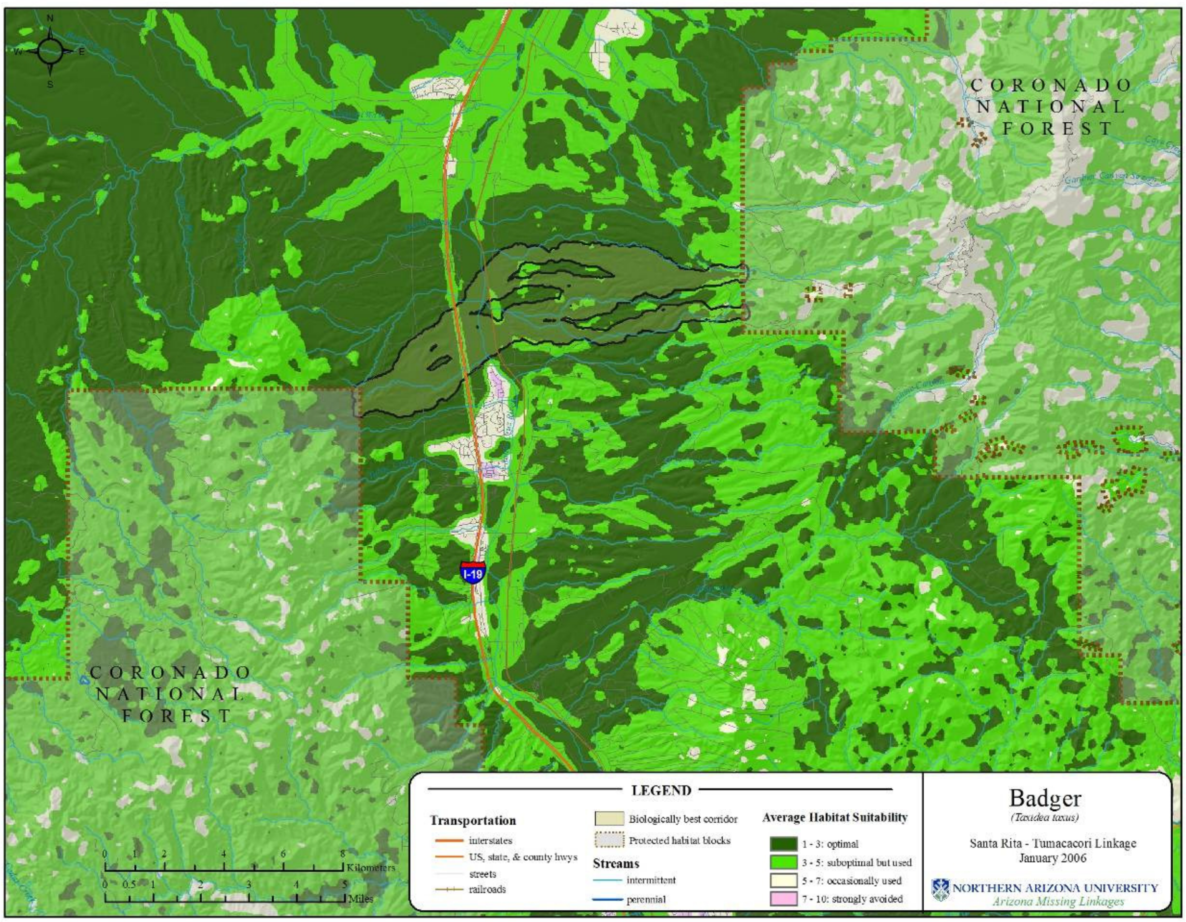



**Figure 28: Modeled habitat suitability of badger.**

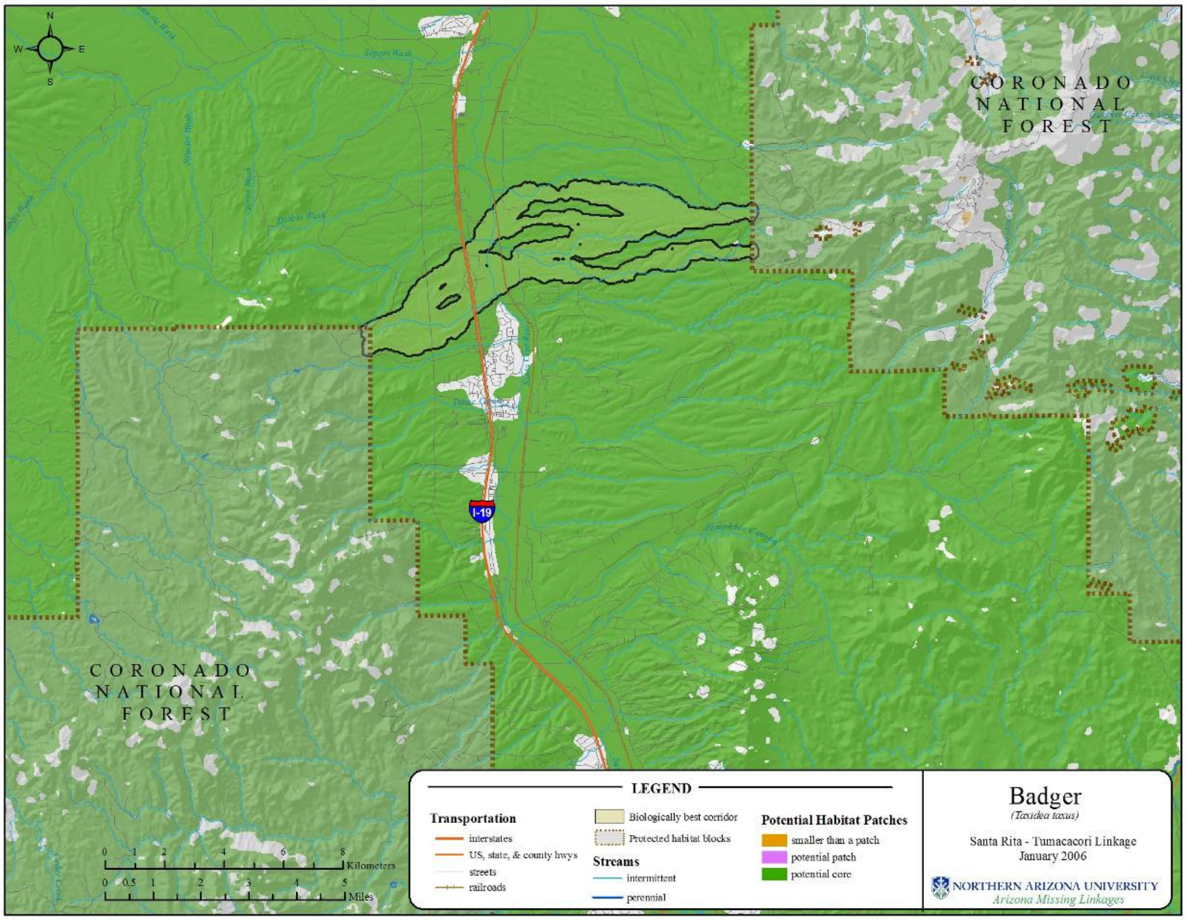



**Figure 29: Potential habitat patches and cores for badger.**

*Union of biologically best corridors* – The union of biologically best corridors provides ample habitat for the badger. While the northernmost route of the Linkage Design provides the most high-quality habitat, nearly the entire Linkage Design is a potential habitat patch for this species. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-19, and urban development.

# Black Bear (*Ursus americanus*)

## Justification for Selection

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

## Distribution

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

## Habitat Associations

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

## Spatial Patterns

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

## Conceptual Basis for Model Development

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

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

*Biologically best corridor analysis* – Because potential habitat was patchily distributed, we re-assigned all 'suitable' habitat (score < 5) a cost of 1, to increase the probability that the biologically best corridor would include this available habitat.

## Results & Discussion

*Initial biologically best corridor* – The biologically best corridor for this species was comprised of two distinct strands. Although the southern strand generally had more potentially suitable habitat (Figure 30, Figure 31), suitable habitat was patchily distributed in both strands (Figure 31). Within the northern strand, the average habitat suitability ranged from 1.3 to 9.2, with an average suitability of 5.1 (S.D: 1.1). Within the southern strand, the average habitat suitability ranged from 1.3 to 9.2, with an average suitability of 4.4 (S.D: 1.5). The farthest distance between a potential patch and another patch or core within the northern strand was approximately 13.7 km, while this distance was approximately 8 km for the southern strand (Figure 32). Because the southern strand was noticeably better than the northern strand, we did not use the northern strand when constructing the final union of biologically best corridors for all species.

The southern strand for this species runs from the eastern side of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Moving westward from the Santa Ritas, the corridor encompasses Cieneguita Canyon, a northern portion of Coal Mine Canyon, a southern portion of Alamo Canyon, and the San Cayetano Mountains before crossing the Santa Cruz River. Between the Santa Cruz River and the Tumacacori wildland block, the corridor encompasses portions of Negro and Tinaja Canyons.

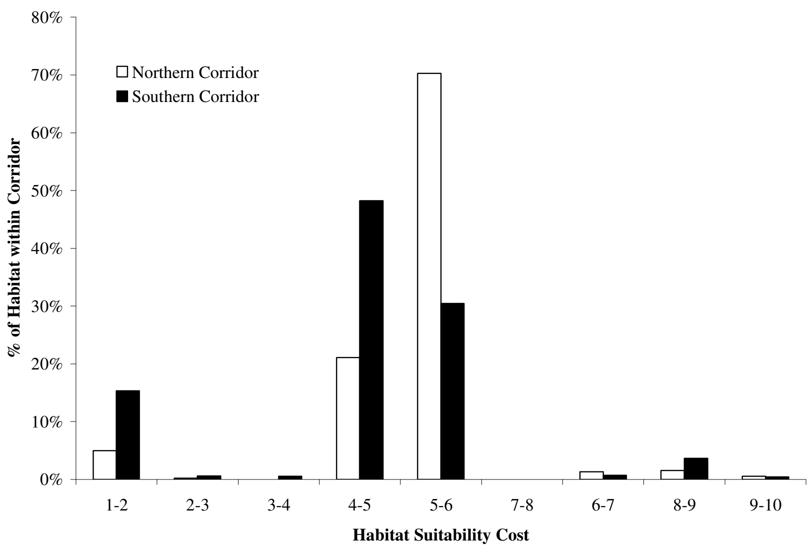



**Figure 30: Percentage of each habitat suitability category in each of the biologically best corridors for black bear.**

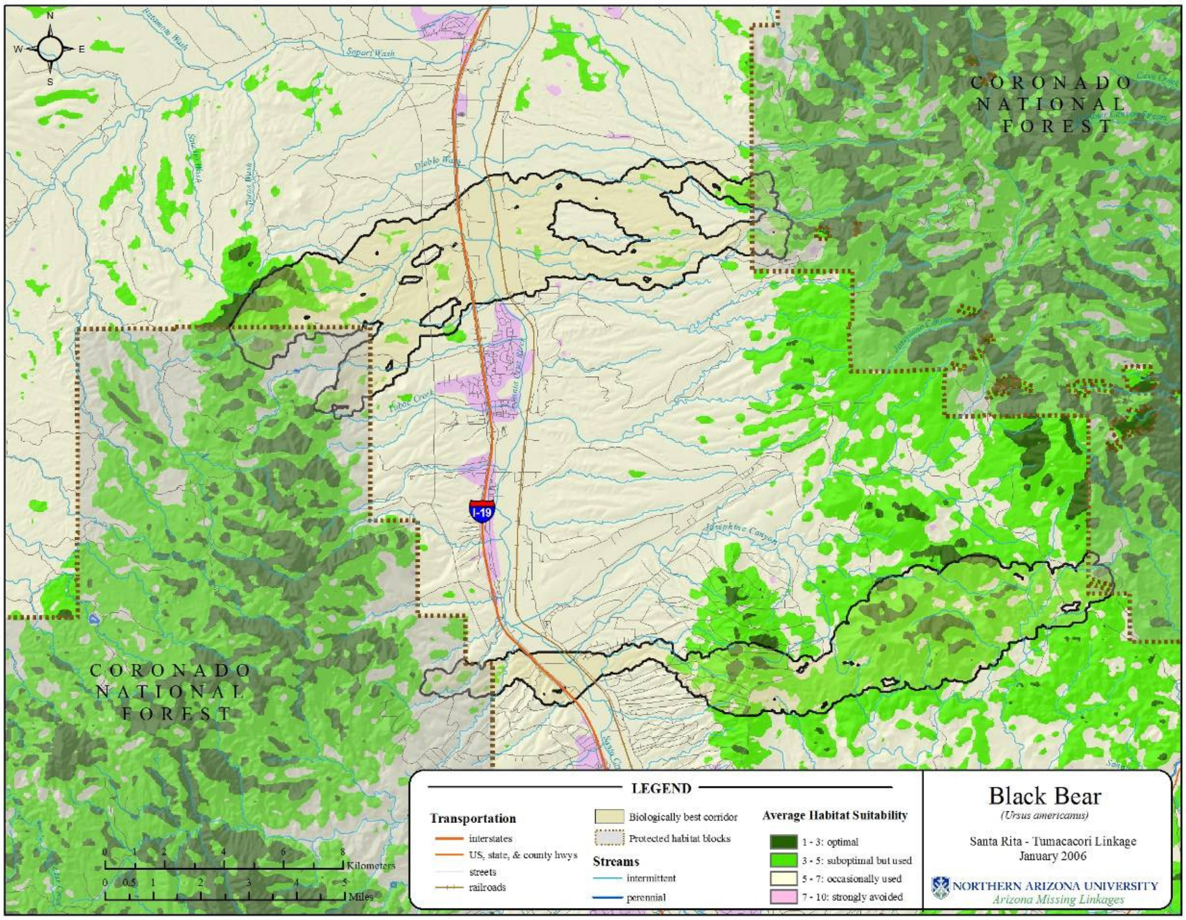



**Figure 31: Modeled habitat suitability of black bear. Because the southern strand was superior, we used only the southern strand in the Linkage Design.**

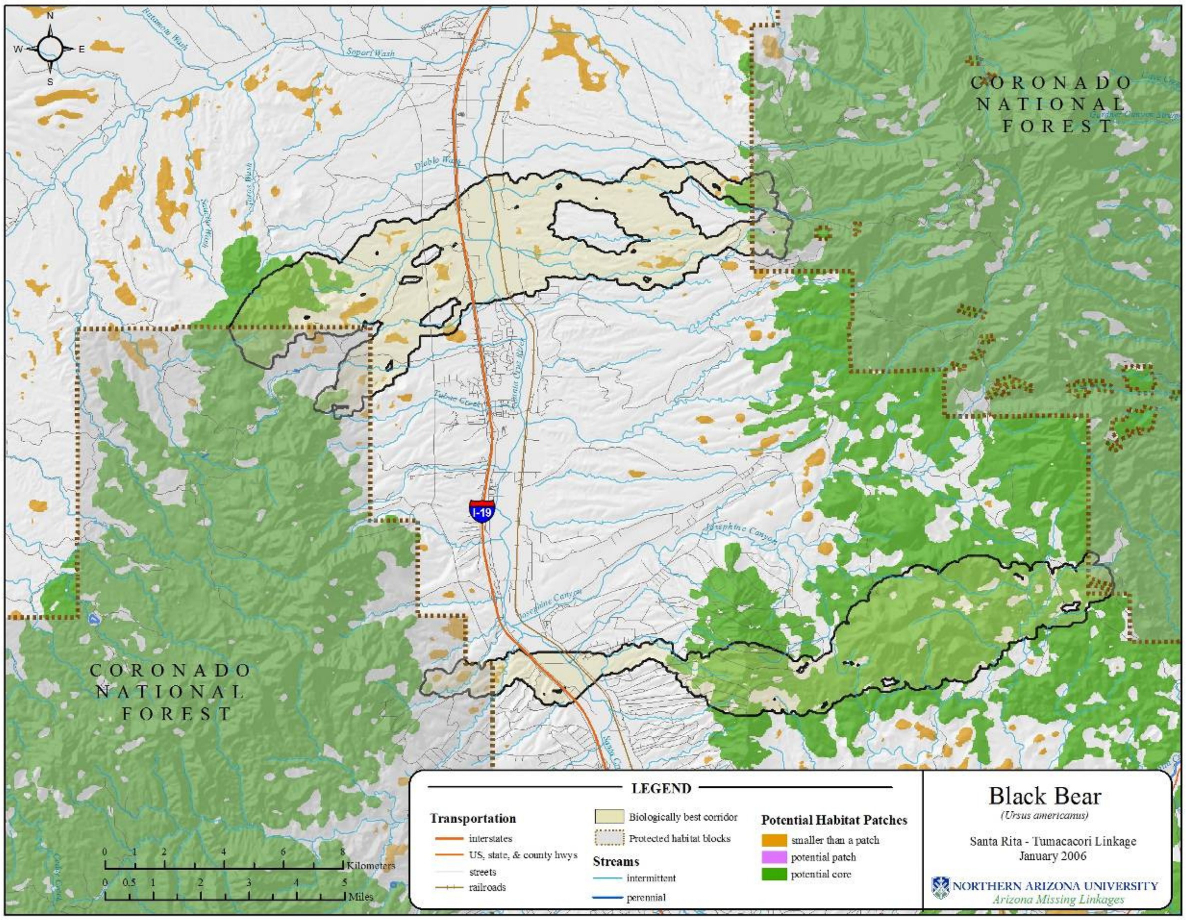



**Figure 32: Potential habitat patches and cores for black bear. Because the southern strand was superior, we used only the southern strand in the Linkage Design.**

*Union of biologically best corridors* – Because the black bear is primarily associated with mountainous areas, the union of biologically best corridors provides only marginal bear habitat. The southernmost route provides the best habitat for this species within between the Tumacacori and Santa Rita wildland blocks; however, in light of the significant development in the San Cayetano Mountains, the northernmost may also serve as a potential viable linkage. Because this species has a long dispersal distance, connectivity can likely be restored if adequate crossing structures and installed along I-19, and existing habitat within the Linkage Design is protected.

# Coues' White-tailed Deer (*Odocoileus virginianus couesi*)

## Justification for Selection
Coues' white-tailed deer are sensitive to human disturbance (Galindo et al. 1993; Ockenfels et al. 1991) and are prey for mountain lions, jaguars, coyotes, bobcats, black bears, and eagles (Knipe 1977; Leopold 1959; Ligon 1927; Ockenfels et al. 1991). They are also important game species. Local populations of these deer have become extinct (apparently due to natural causes) in some small Arizona mountain ranges and connectivity is necessary for natural recolonization to occur.

## Distribution
White-tailed deer range throughout most of the coterminous United States, into southern Canada (Smith 1991). As a small-sized, long-eared subspecies of white-tailed deer, Coues' white-tailed deer are found primarily in the mountain ranges of southeastern Arizona, southwestern New Mexico, and northern Mexico (Knipe 1977).

## Habitat Associations
The chief habitat association of Coues' white-tailed deer is oak or oak-pinyon-juniper woodlands (Hoffmeister 1986; Knipe 1977). They also use chaparral, desert scrub, and mesquite habitats, and forage primarily on shrubs and trees (Gallina et al. 1981). Cacti and grasses are generally not used, and are of little importance to foraging (Gallina et al. 1981; Henry & Sowls 1980; Ockenfels et al. 1991). Coues' white-tailed deer favor canyons and moderately steep slopes, and are usually found within several kilometers of water (Evans 1984; Ligon 1951; Ockenfels et al. 1991). Elevation does not appear to constrain the species; however, vegetation associated with elevation does. Coues' white-tailed deer are susceptible to human disturbance – particularly hunting, dogs, cattle grazing, and roads (Galindo et al. 1993; Ockenfels et al. 1993).

## Spatial Patterns
White-tailed deer are not territorial, and may have large overlap of home ranges (Smith 1991). Female home ranges in the Santa Rita Mountains were found to average 5.18 $km^2$, while male home ranges averaged 10.57 $km^2$ (Ockenfels et al. 1991). Knipe (1977) speculated that Coues' white-tailed deer have a home range from 5-16 $km^2$. Galindo-Leal (1992) estimated the density of Coues' white-tailed deer to range from 0.82-14.21 deer/$km^2$ in the Michilia Biosphere Reserve of Mexico, while Leopold (1959) estimated a density of 12-15 deer/$km^2$ in an undisturbed area of the Sierra Madre Occidental mountain area of Mexico. While this species does not migrate, it does shift habitat use seasonally, eating fruits (nuts, beans, berries) in summer, forbs and browse in fall, and evergreen browse in winter (McCulloch 1973; Welch 1960). Dispersal distance for young males at two areas in southern Texas established new areas of use 4.4±1.0 km and 8.2±4.3 km, respectively, from the center of their autumn home range (McCoy et al. 2005).

## Conceptual Basis for Model Development
*Habitat suitability model* – Due to this species' strong preferences for woodlands and shrubs, vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received a

weight of 5%, 15%, and 15%, respectively. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – We defined minimum patch size for Coues' white-tailed deer as 5.2 $km^2$, the average home range for females in the Santa Rita Mountains (Ockenfels 1991). While this species exhibits high home range overlap, we defined minimum core size as 26 $km^2$, or five times minimum patch size, to ensure potential cores could account for seasonal movements and use of different habitats. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

*Biologically best corridor analysis* – Because potential habitat was patchily distributed surrounding the Santa Cruz River, and most available habitat between wildland blocks had similar costs (mostly 3-5: suboptimal but usable), we re-assigned all 'suitable' habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid urbanized land.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 33). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.2 to 7.4, with an average suitability of 4.5 (S.D: 1.0). Approximately 74% of the habitat within the corridor had a suitability of between 3 and 5, indicating that this habitat was suitable for breeding, but perhaps optimal. Optimal habitat (cost: 1-3) was generally restricted to areas within the wildland blocks.

The corridor for this species runs in a NE-SW direction between the Tumacacori and Santa Rita wildland blocks (Figure 33). Moving southwestward from the Santa Ritas, the corridor encompasses portions of Cottonwood Canyon and Mavis Wash before reaching the Santa Cruz River. The corridor then runs through the area surrounding the town of Carmen, before ending near Tumacacori Peak within the Tumacacori wildland block.

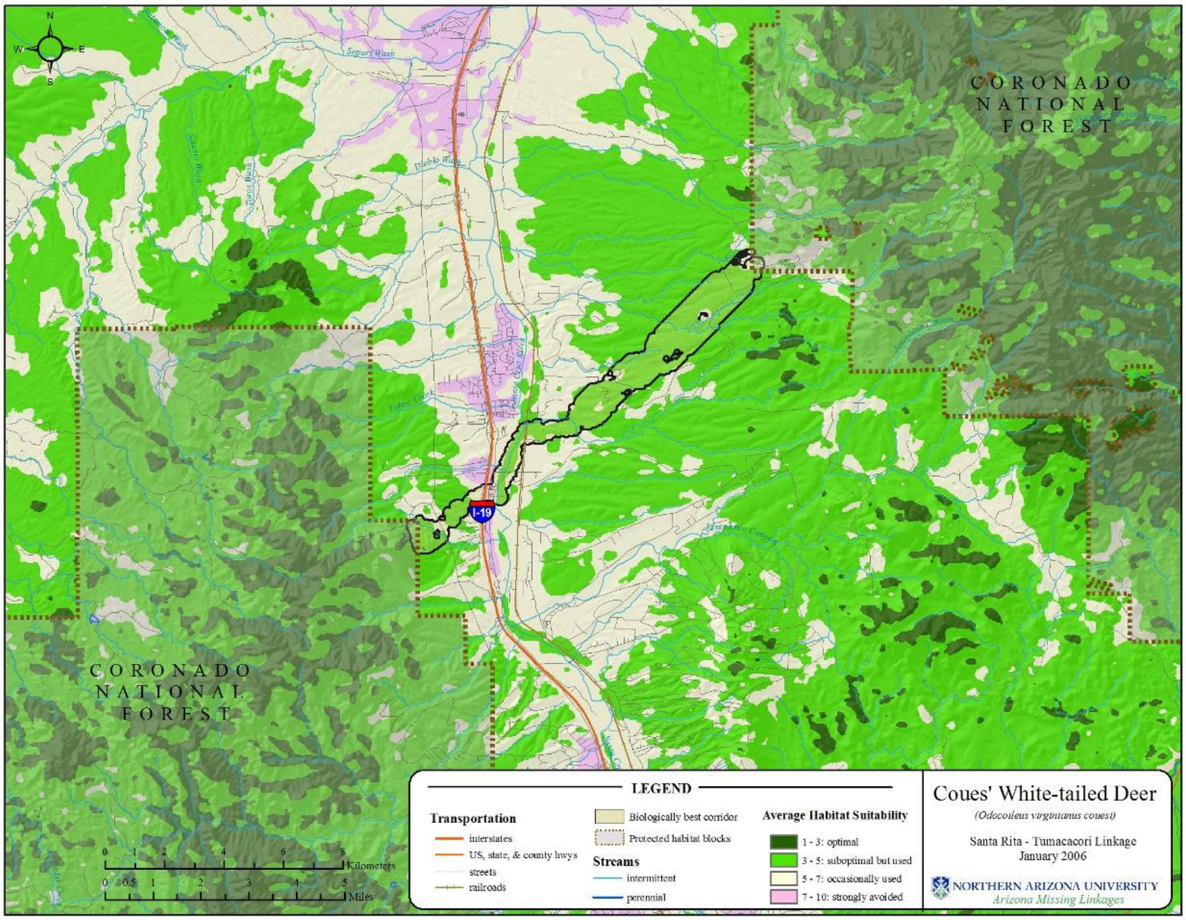



**Figure 33: Modeled habitat suitability of Coues' white-tailed deer.**

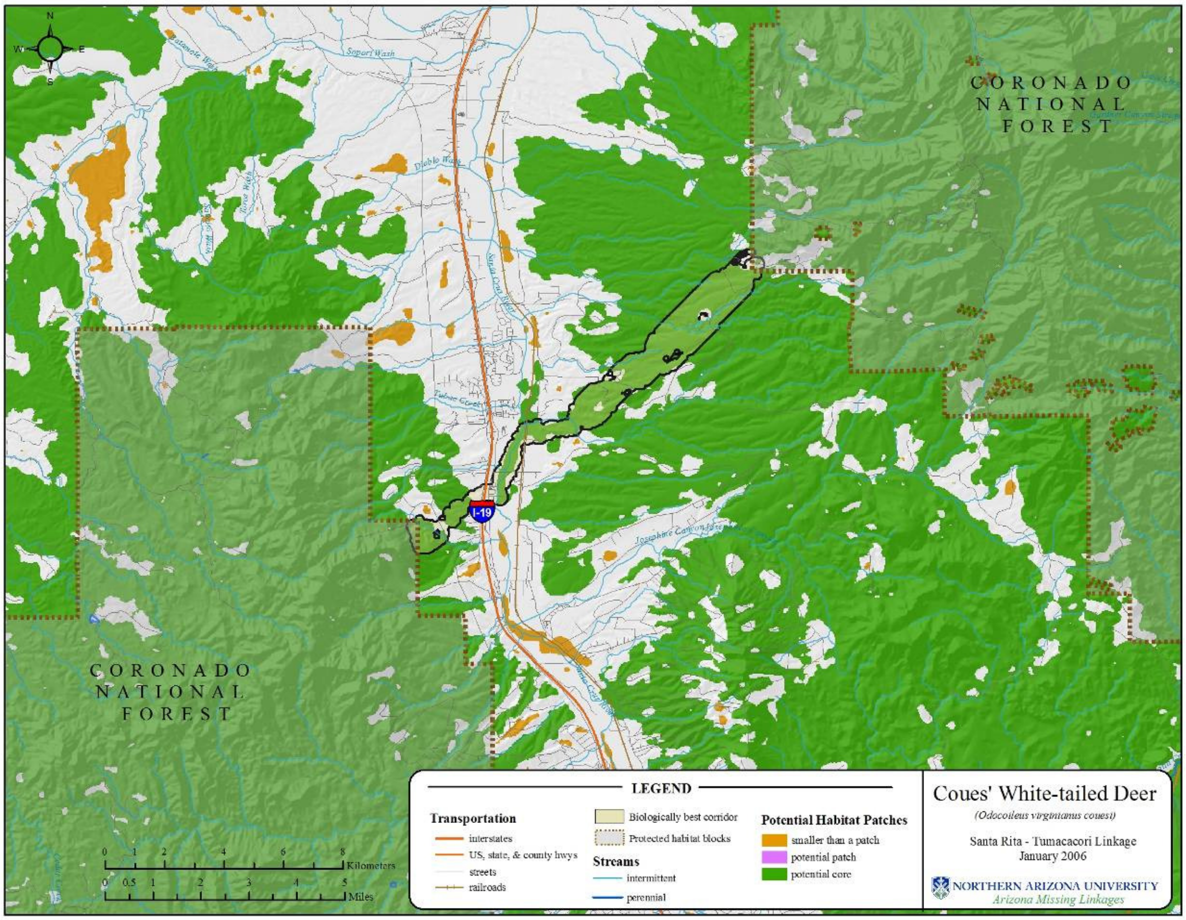



**Figure 34: Potential habitat patches and cores for Coues' white-tailed deer.**

*Union of biologically best corridors* – The union of biologically best corridors provides significant amount of suitable habitat for Coues' white-tailed deer, although the majority of suitable habitat is only classified as "suboptimal but usable." The southernmost route of the union of biologically best corridors provides a large amount of additional potential habitat, including several patches of optimal habitat quality. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-19, and urban development.

## Jaguar (*Panthera onca*)

### Justification for Selection

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

### Distribution

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

### Habitat Associations

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

### Spatial Patterns

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

### Conceptual Basis for Model Development

*Habitat suitability model* –Vegetation received an importance weight of 60%, while elevation, topography, and distance from roads received weights of 5%, 15%, and 20%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

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

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 35). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.1 to 8.9, with an average suitability of 3.3 (S.D: 1.1). 39.5% of the habitat within the jaguar's corridor has a suitability less than 3, indicating optimal habitat, while an additional 53% of the habitat within the corridor has a suitability between 3 and 5.

The corridor for this species begins in the Santa Rita wildland block where Montosa Canyon meets the boundaries of the Coronado National Forest. The corridor encompasses several unnamed washes, and joins the Tumacacori wildland block at the northeast corner of the Coronado National Forest boundary, close to the Tumacacori Mountains.

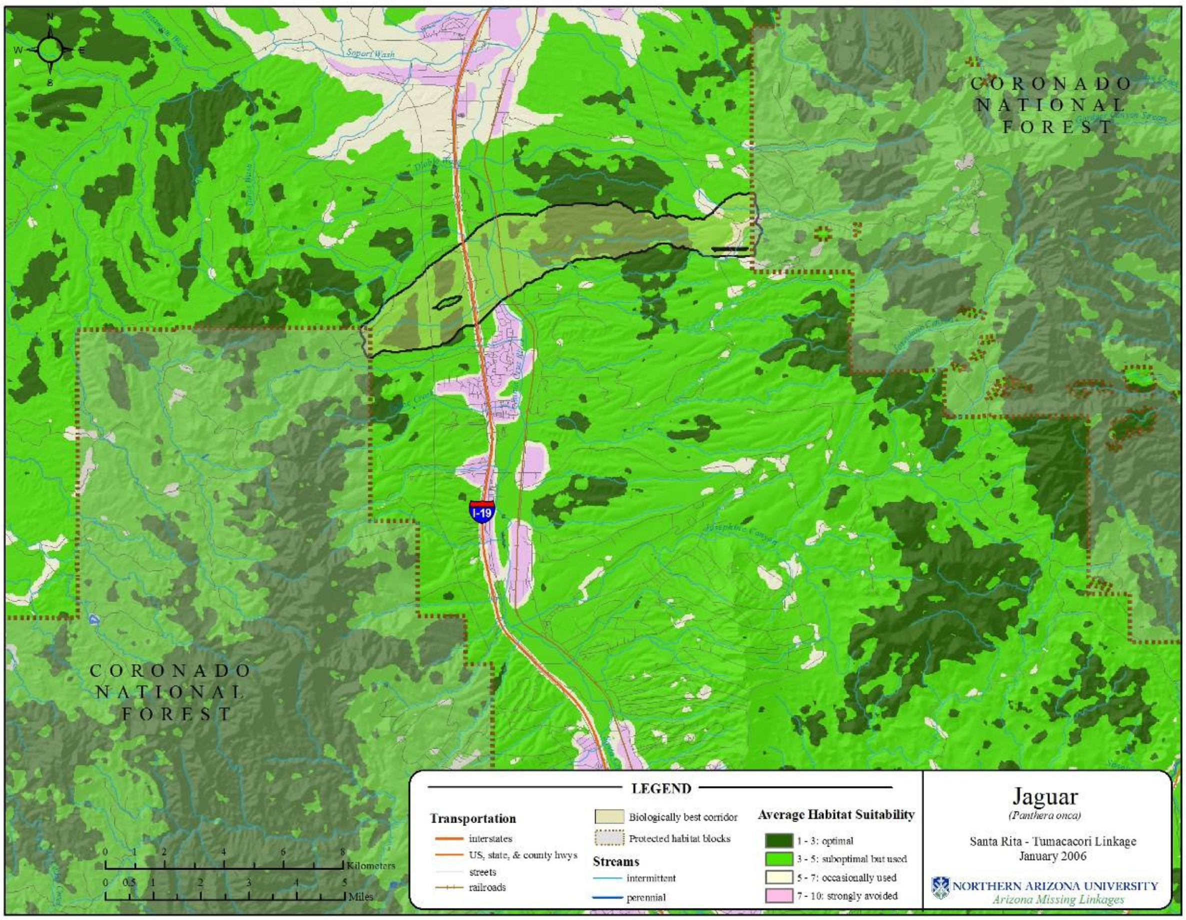



**Figure 35: Modeled habitat suitability of jaguar.**

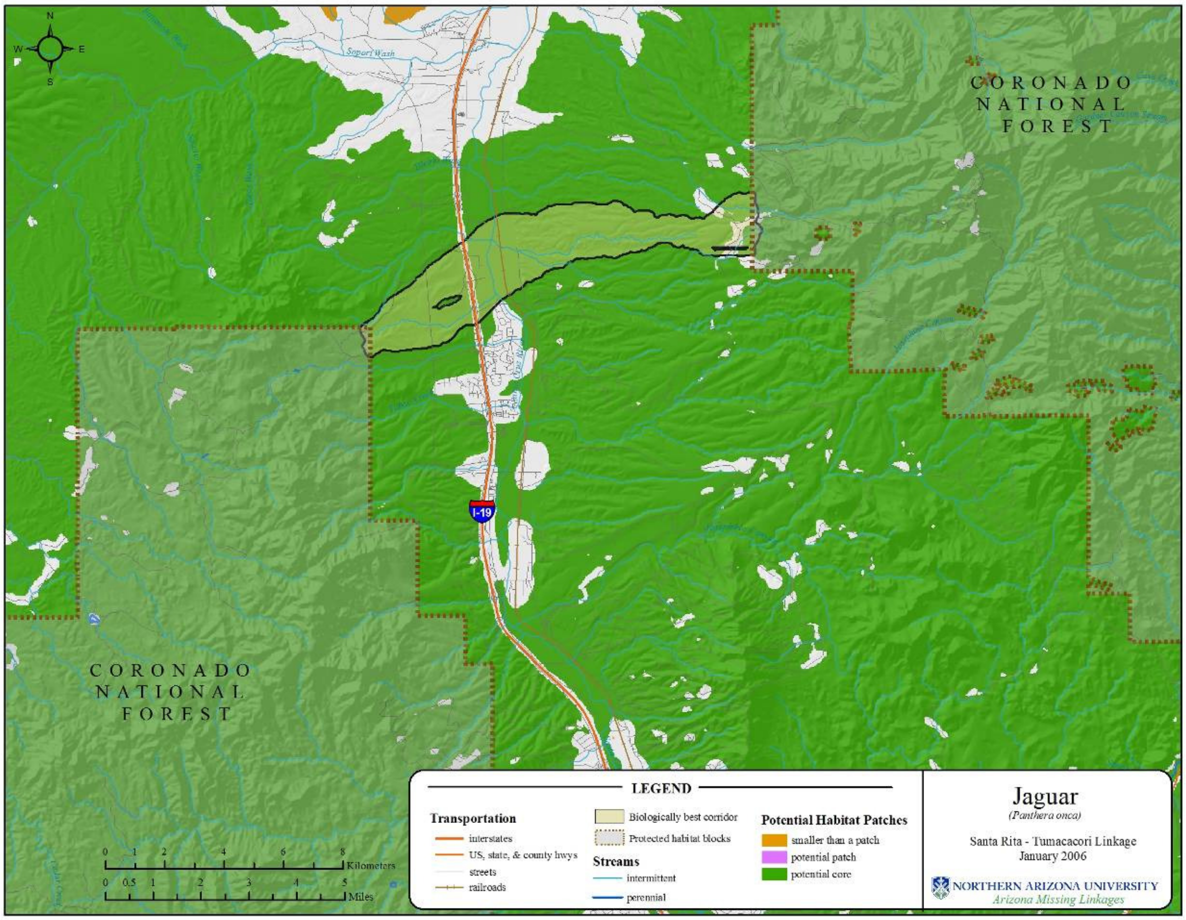



**Figure 36: Potential habitat patches and cores for jaguar.**

*Union of biologically best corridors* – The union of biologically best corridors provides ample habitat for jaguar. While the northernmost route of the Linkage Design provides the most high-quality habitat, nearly the entire Linkage Design is a potential habitat patch for this species, and the southernmost route adds a large patch of optimal habitat. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence in this linkage zone is most likely high-traffic roads such as I-19, and urban development.

# 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). They probably play an important role in seed dispersal and as part of the natural disturbance regime.

## 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 4.

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

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

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 37). Within the biologically best corridor for this species, the average habitat suitability ranged from 1 to 5.7, with an average suitability of 2.0 (S.D: 0.7). Nearly 98% of habitat within the corridor was calculated as optimal (< 3). The entire corridor is a potential habitat core (Figure 38).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are part of Cottonwood Canyon and several unnamed washes.

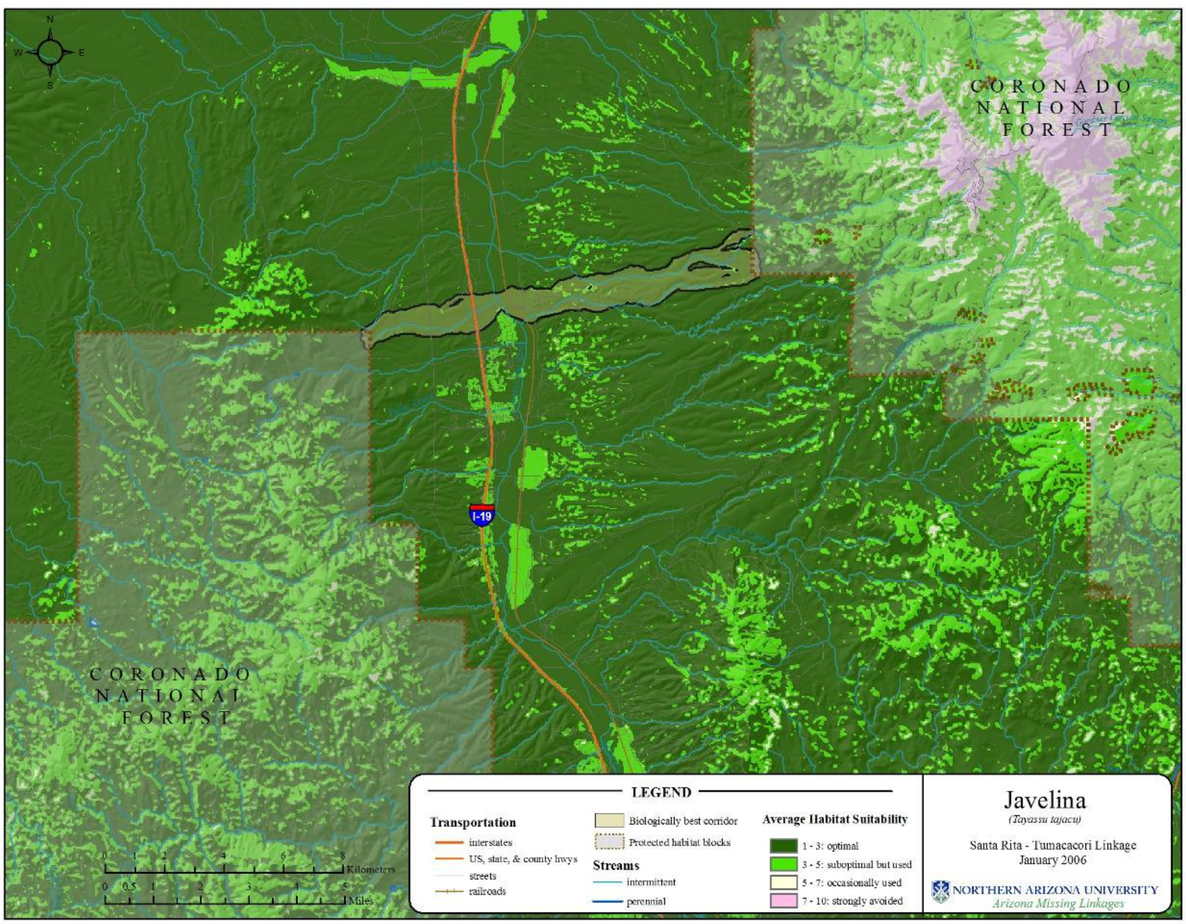



**Figure 37: Modeled habitat suitability of javelina.**

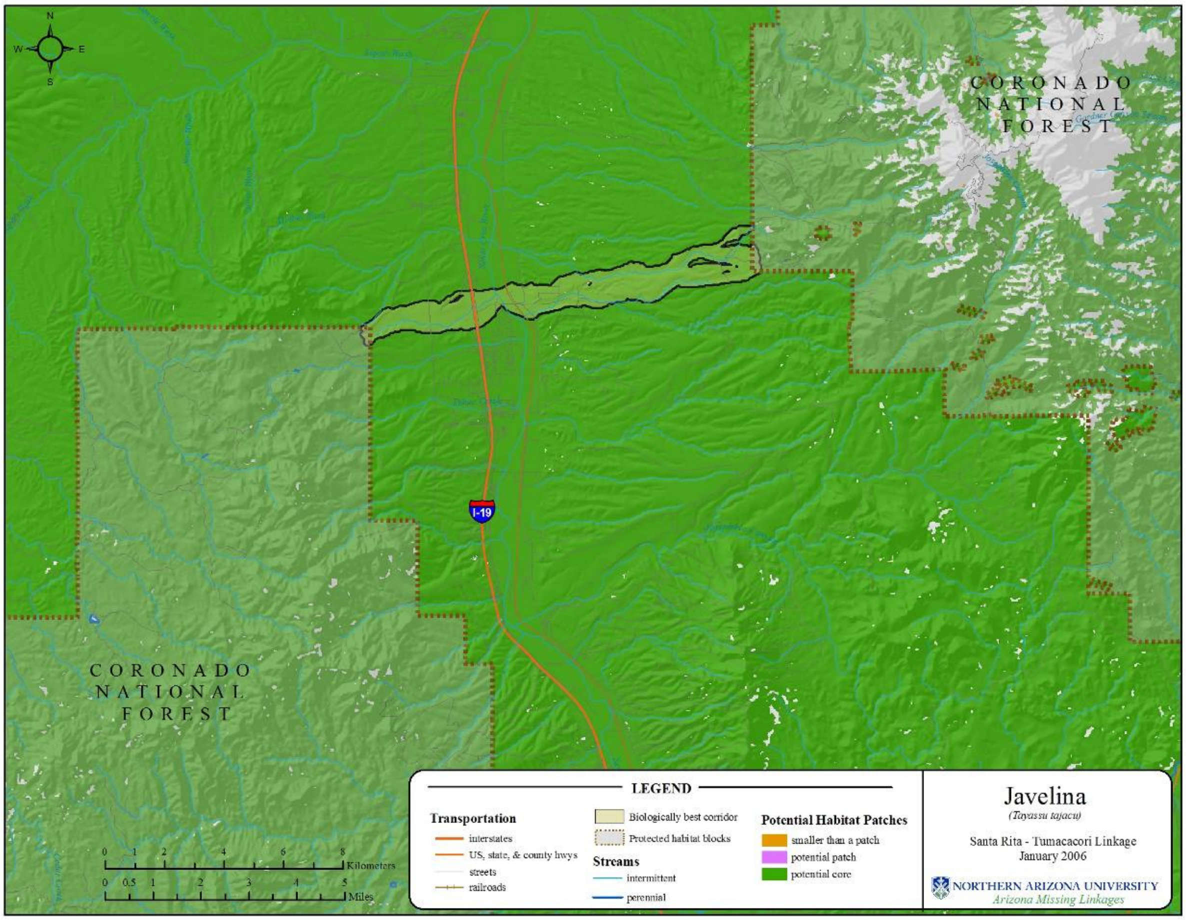



**Figure 38: Potential habitat patches and cores for javelina.**

*Union of biologically best corridors* – The union of biologically best corridors provides ample habitat for the javelina. While the northernmost route of the Linkage Design provides the most high-quality habitat, nearly the entire Linkage Design is a potential habitat patch for this species, and every other route of the Linkage Design is composed primarily of optimal habitat. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-19, and urban development.

# Mountain Lion (*Puma concolor*)

## Justification for Selection

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

## Distribution

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

## Habitat Associations

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

## Spatial Patterns

Home range sizes of mountain lions vary depending on sex, age, and the distribution of prey. One study in New Mexico reported annual home range size averaged 193.4 $km^2$ for males and 69.9 $km^2$ for females (Logan and Sweanor 2001). This study also reported daily movements averaging 4.1 km for males and 1.5 km for females (Logan and Sweanor 2001). Dispersal rates for juvenile mountain lions also vary between males and females. Logan and Sweanor's study found males dispersed an average of 102.6 km from their natal sites, and females dispersed an average of 34.6 km. A mountain lion population requires 1000 - 2200 $km^2$ of available habitat in order to persist for 100 years (Beier 1993). These minimum areas would support about 15-20 adult cougars (Beier 1993).

## Conceptual Basis for Model Development

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

*Patch size & configuration analysis* – Minimum patch size for mountain lions was defined as 79 $km^2$, 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 $km^2$, 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* – Because potential habitat was patchily distributed surrounding the Santa Cruz River, and most available habitat between wildland blocks had similar costs (mostly 3-5: suboptimal but usable), we re-assigned all 'suitable' habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid unsuitable (urbanized) land.

## Results & Discussion

*Initial biologically best corridor* – The biologically best corridor for this species was comprised of three distinct strands which all had similar habitat quality within them (Figure 39, Figure 40). Within the northern strand, the average habitat suitability ranged from 1.0 to 9.0, with an average suitability of 4.7 (S.D: 0.8). Within the central strand, the average habitat suitability ranged from 2.2 to 9.0, with an average suitability of 4.7 (S.D: 0.7). Within the southern strand, the average habitat suitability ranged from 1.0 to 8.9, with an average suitability of 4.8 (S.D: 0.8). The farthest distance between a potential patch and another patch or core within the northern strand was approximately 3.7 km, while this distance was approximately 4.7 km for the central strand, and 3.2 km for the southern strand (Figure 41). Because no strand was noticeably better than the rest, we maintained all strands when constructing the initial union of biologically best corridors for all species.

The northern strand for this species runs from the northern side of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Moving westward from the Santa Ritas, the strand encompasses a portion of Montosa Canyon and Sheehy Canyon. After crossing the Santa Cruz River, it encompasses a portion of Las Chivas Wash before joining the Tumacacori wildland block via the Tumacacori Mountains. The central strand encompasses portions of Cottonwood Canyon and Mavis Wash, before crossing the Santa Cruz River south of Tubac. The southern strand runs NE-SW, encompassing portions of Mavis Wash and Josephine Canyon east of the Santa Cruz River, and portions of Negro Canyon adjacent to the Tumacacori wildland block.

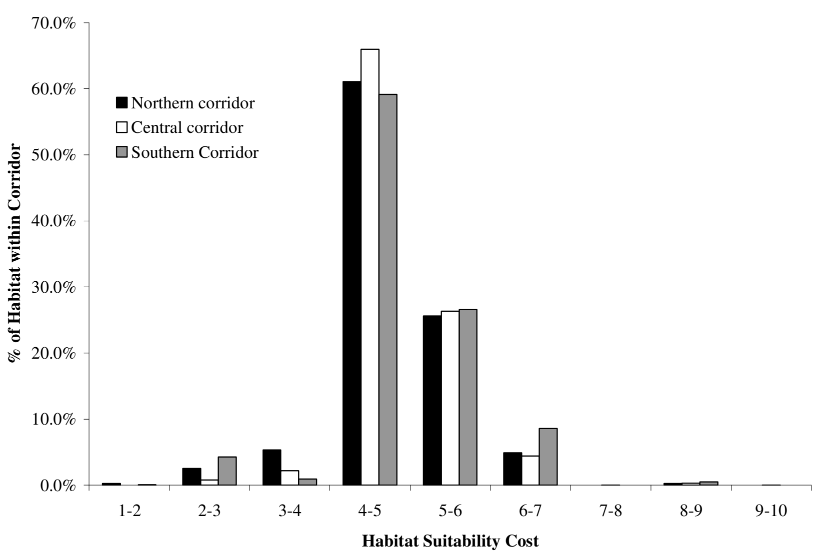



**Figure 39: Percentage of each habitat suitability category in each strand of the biologically best corridor for mountain lion**

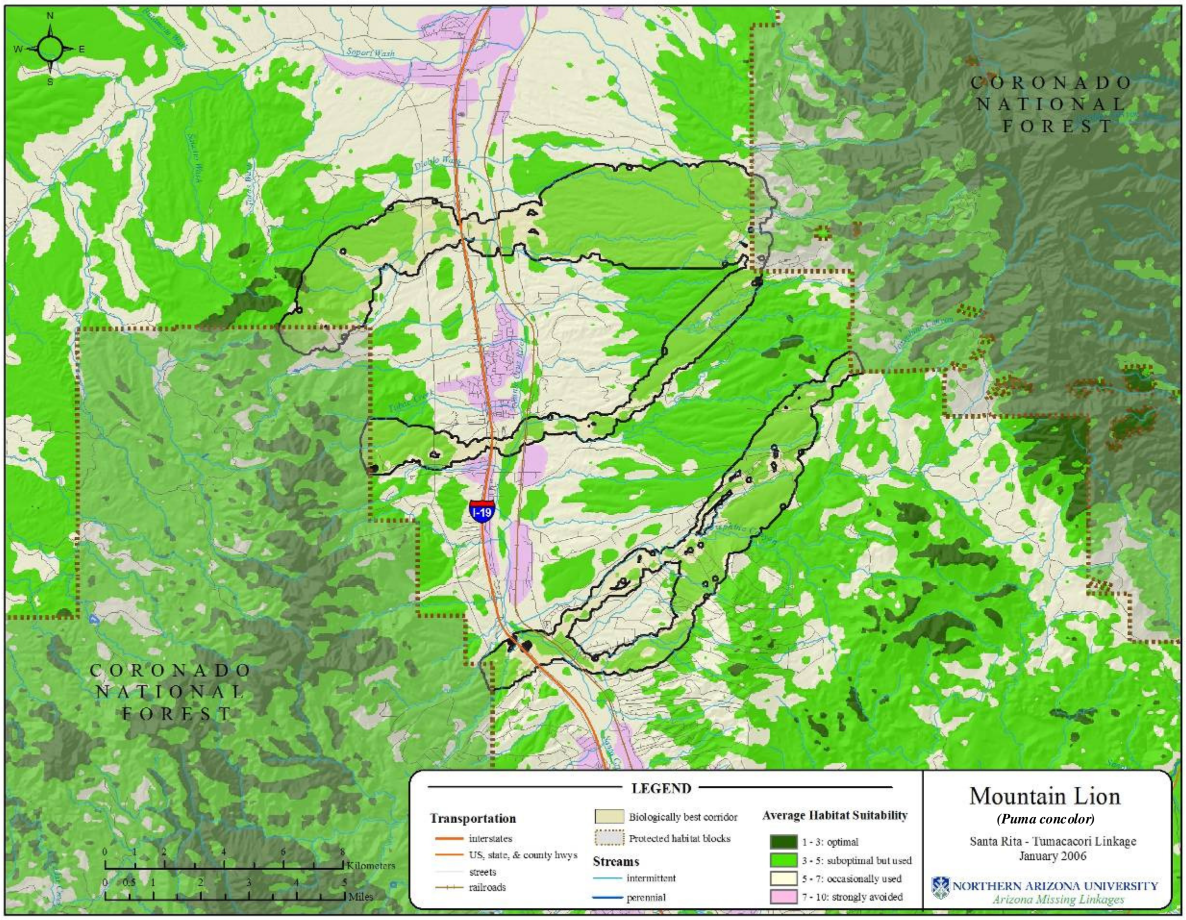



**Figure 40: Modeled habitat suitability of mountain lion**

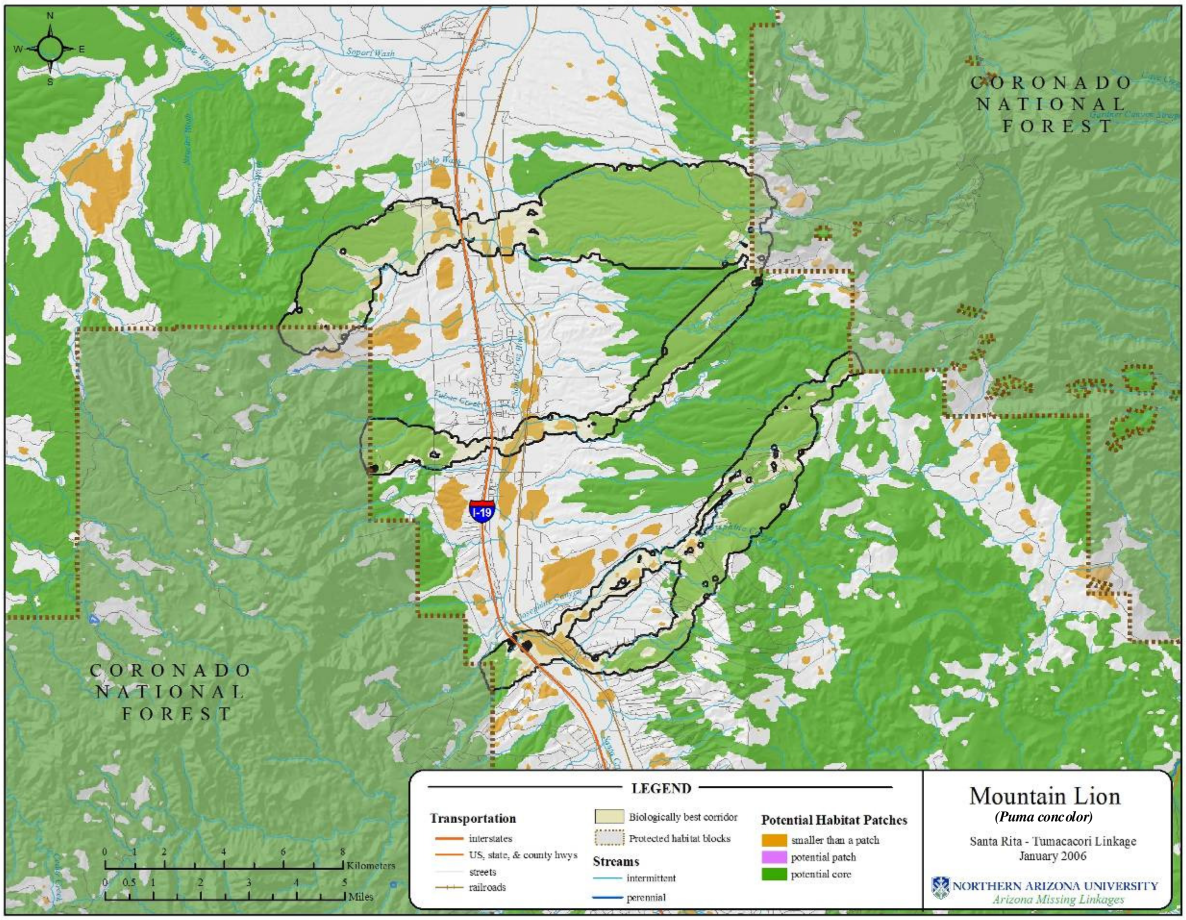



**Figure 41: Potential habitat patches and cores for mountain lion**

*Union of biologically best corridors* – The union of biologically best corridors provides significant amount of suitable habitat for mountain lion, although most suitable habitat is "suboptimal but usable." The southernmost route of the union of biologically best corridors provides a large amount of additional potential habitat, including several patches of optimal habitat quality. Because there is ample habitat for this species, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-19, and urban development.

# Mule Deer (*Odocoileus hemionus*)

## Justification for Selection

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

## Distribution

Mule deer are found throughout most of western North America, extending as far east as Nebraska, Kansas, and western Texas. In Arizona, mule deer are found throughout the state, except for the Sonoran desert in the southwestern part of the state (Anderson & Wallmo 1984).

## Habitat Associations

Mule deer in Arizona are categorized into two groups based on the habitat they occupy. In northern Arizona mule deer inhabit yellow pine, spruce-fir, buckbrush, snowberry, and aspen habitats (Hoffmeister 1986). The mule deer found in the yellow pine and spruce-fir live there from April to the beginning of winter, when they move down to the pinyon-juniper zone (Hoffmeister 1986). Elsewhere in the state, mule deer live in desert shrub, chaparral or even more xeric habitats, which include scrub oak, mountain mahogany, sumac, skunk bush, buckthorn, and manzanita (Wallmo 1981; Hoffmeister 1986).

## Spatial Patterns

The home ranges of mule deer vary depending upon the availability of food and cover (Hoffmeister 1986). Swank (1958) reports that home ranges of mule deer vary from 2.6 to 5.8 km$^2$, with bucks' home ranges averaging 5.2 km$^2$ and does slightly smaller (Hoffmeister 1986). Deer that require seasonal migration movements use approximately the same winter and summer home ranges in consecutive years (Anderson & Wallmo 1984). Desert mule deer home ranges are larger, varying from 5.2 to 13 km$^2$, with bucks having larger home ranges than does. Desert mule deer are generally not considered migratory, although they may make transient movements of several miles. Dispersal distances for male mule deer have been recorded from 97 to 217 km, and females have moved 180 km (Anderson & Wallmo 1984). Two desert mule deer yearlings were found to disperse 18.8 and 44.4 km (Scarbrough & Krausman 1988).

## Conceptual Basis for Model Development

*Habitat suitability model* – Vegetation has the greatest role in determining deer distributions in desert systems, followed by topography (Jason Marshal, personal comm.). For this reason, vegetation received an importance weight of 80%, while topography and distance from roads received weights of 15% and 5%, respectively. For specific scores of classes within each of these factors, Table 4.

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

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

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 42). Within the biologically best corridor for this species, the average habitat suitability ranged from 2.0 to 7.9, with an average suitability of 3.1 (S.D: 1.3). The entire corridor is a potential habitat core (Figure 43).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are part of Cottonwood Canyon, Puerto Canyon, and several unnamed washes.

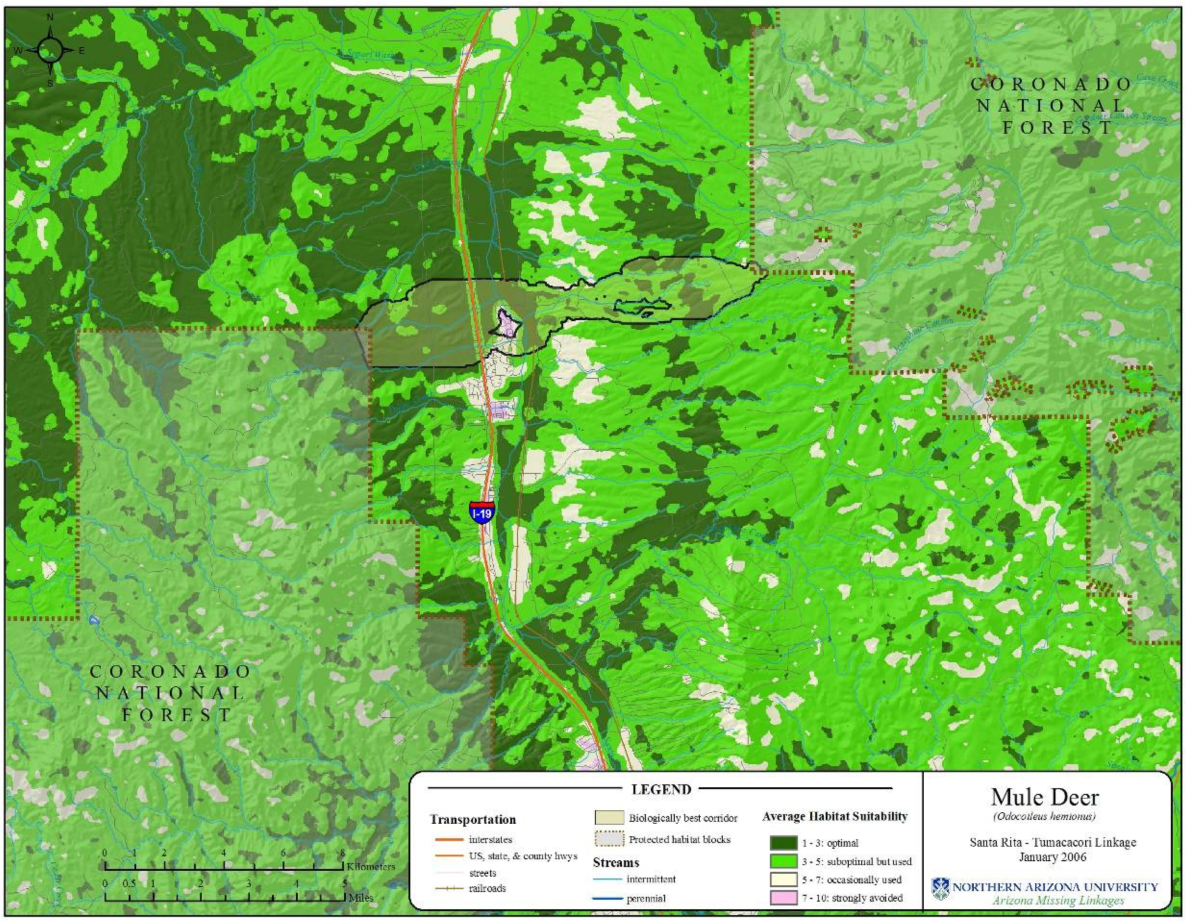



**Figure 42: Modeled habitat suitability of mule deer**

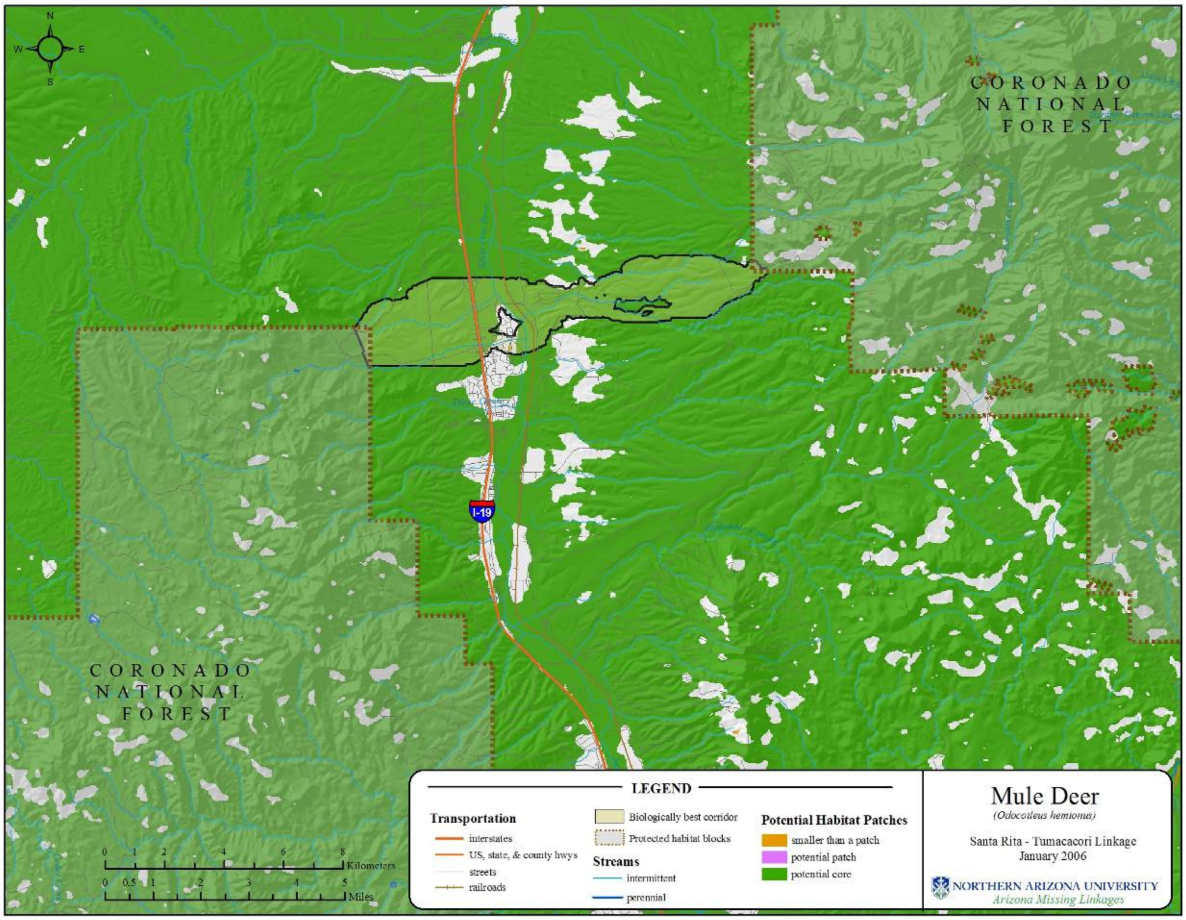



**Figure 43: Potential habitat patches and cores for mule deer**

*Union of biologically best corridors* – The union of biologically best corridors provides significant amount of suitable habitat for mule deer. The northernmost route of the union of biologically best corridors provides extended habitat for the species, including large areas which could serve as potential population cores. The southern routes of the Linkage Design provide substantial amounts of suboptimal but usable habitat.

# Porcupine (*Erethizon dorsatum*)

## Justification for Selection
The porcupine's range has been reduced in some areas due to changes in human distribution and land use (Woods 1973). Porcupines are frequently killed by automobiles while crossing roads (Woods 1973).

## Distribution
Porcupines are widespread in much of North America, from Alaska and northern Canada to parts of northern Mexico (Woods 1973). The porcupine's range includes most of Arizona in forested, mountainous regions of the state as well as riparian areas in lower elevations; they are considered absent or rare in desert areas (Hoffmeister 1986).

## Habitat Associations
Porcupines inhabit montane and subalpine forests that include ponderosa pine, spruce-fir, aspen, pinyon, juniper, and oak in higher elevations. They also live in cottonwood-willow forests of riparian areas and mesquite thickets of semidesert shrublands (New Mexico Department of Game and Fish 2004). In Arizona, they also occur in grassland, chaparral or desert scrub (Hoffmeister 1986). Porcupines consume bark from trees in these areas, as well as mistletoe, pine needles, oak leaves, acorns, fungi, buckbrush, and the fruit of prickly pear cactus (New Mexico Department of Game and Fish 2004). Porcupines seek out rock piles, rocky slopes, mine shafts, and caves for shelter (Hoffmeister 1986).

## Spatial Patterns
Home ranges of porcupines are restricted, with summer range larger than winter range (Woods 1973). Average summer home range is 14 hectares (Marshall et al. 1962), while winter home range is up to 5 hectares (Smith 1979). Average yearly home range has been estimated as 70 ha (Roze 1989). They will occupy the same dens for many years and even generations (Hoffmeister 1986). Individuals move an average of 1.5 kilometers to and from their winter den (Woods 1973). Dispersal among porcupines is female-biased, with juvenile female porcupines dispersing an average of 3.7km while juvenile males generally remain within their natal ranges (Sweitzer and Berger 1998).

## Conceptual Basis for Model Development
*Habitat suitability model* – Vegetation received an importance weight of 87%, while topography and distance from roads received weights of 3% and 10%, respectively. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – Minimum patch size for mule deer was defined as 70 ha and minimum core size as 250 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – Because potential habitat was patchily distributed surrounding the Santa Cruz River, and most available habitat between wildland blocks had similar costs (mostly 3-5: suboptimal but usable), we re-assigned all 'suitable' habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid unsuitable (urbanized) land.

## Results & Discussion

*Initial biologically best corridor* – The biologically best corridor for this species was comprised of two distinct strands. Modeling results indicate significant suitable habitat within both strands for the species, although most suitable habitat within the linkage zone is classified as ‘suboptimal but usable.’ (Figure 44). Suitable habitat was mostly contiguous within both strands (Figure 45). Within the northern strand, the average habitat suitability ranged from 1.0 to 8.7, with an average habitat suitability of 4.5 (S.D: 1.0). Within the southern strand, the average habitat suitability ranged from 1.0 to 8.7, with an average suitability of 4.3 (S.D: 1.0). The farthest distance between a potential patch and another patch or core within the northern strand was approximately 600 m, while this distance was approximately 240 m for the southern strand (Figure 46). Because neither strand was obviously best, we maintained both strands when constructing the initial union of biologically best corridors for all species.

Both strands run in a NE-SW direction between the Santa Rita and Tumacacori wildland blocks. Moving west from the Santa Rita wildland block, the northern strand encompasses Cottonwood Canyon and Mavis Wash, travels approximately 3 km south down the Santa Cruz River, and continues westward to join the Tumacacori block at Tumacacori Peak. The southern strand encompasses a western portion of Mavis Wash, cuts through Josephine Canyon and several unnamed washes, travels north near the riparian areas of the Santa Cruz River approximately 2 km, and joins the Tumacacori wildland block near Negro and Tinaja Canyons.

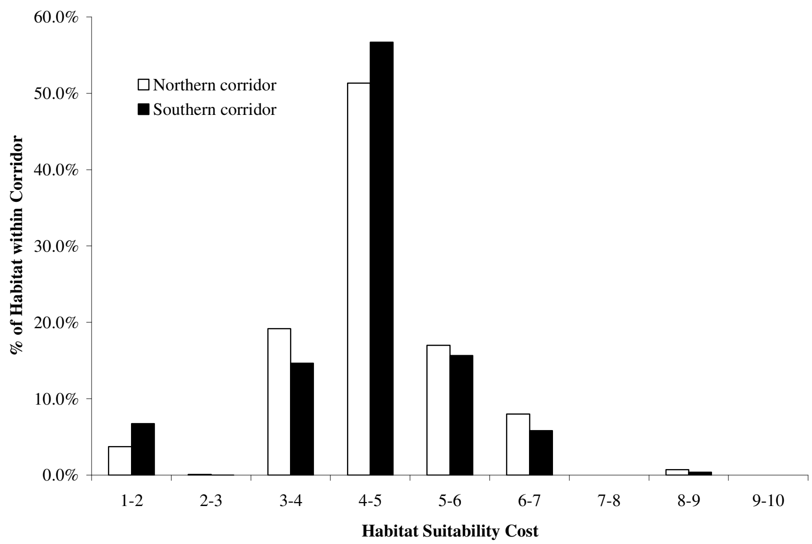



**Figure 44: Percentage of each habitat suitability category in each strand of the biologically best corridor for porcupine**

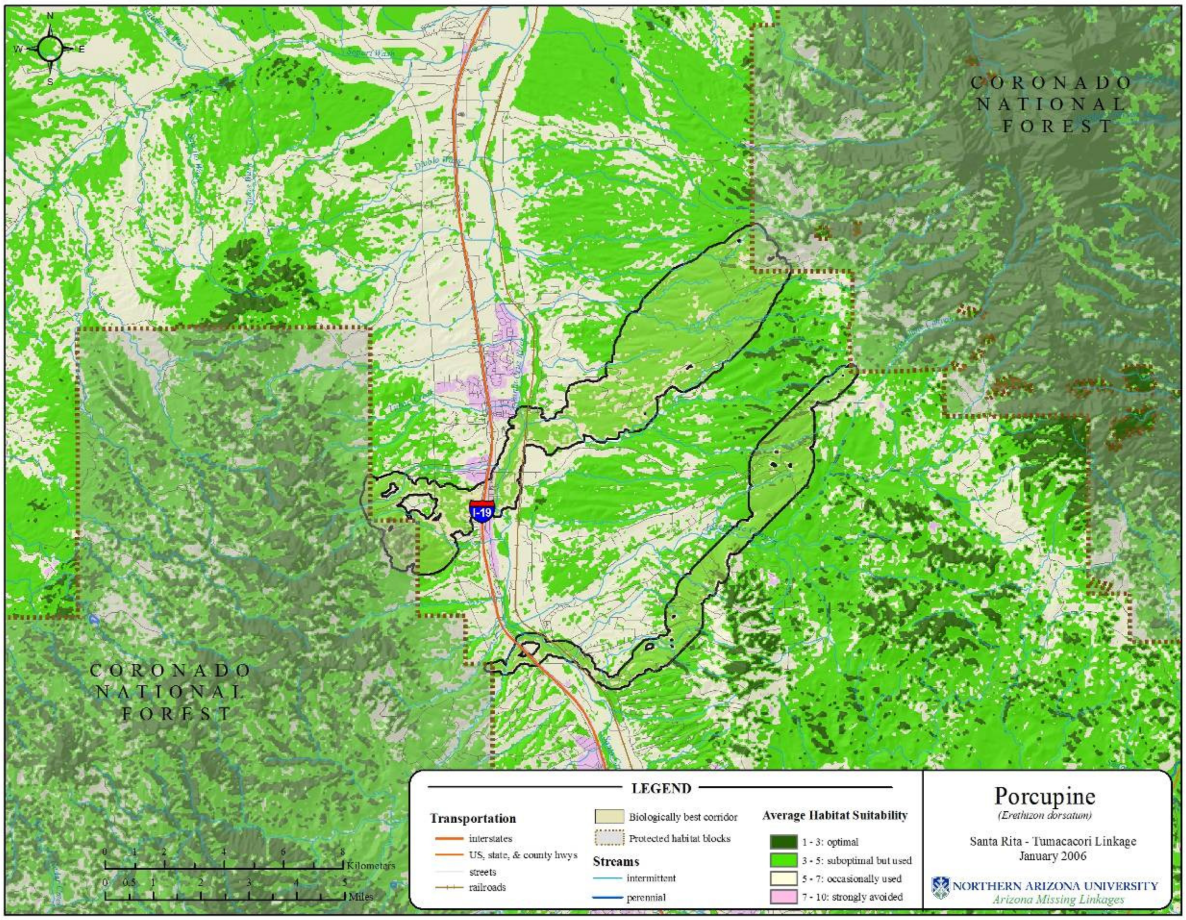



**Figure 45: Modeled habitat suitability of porcupine**

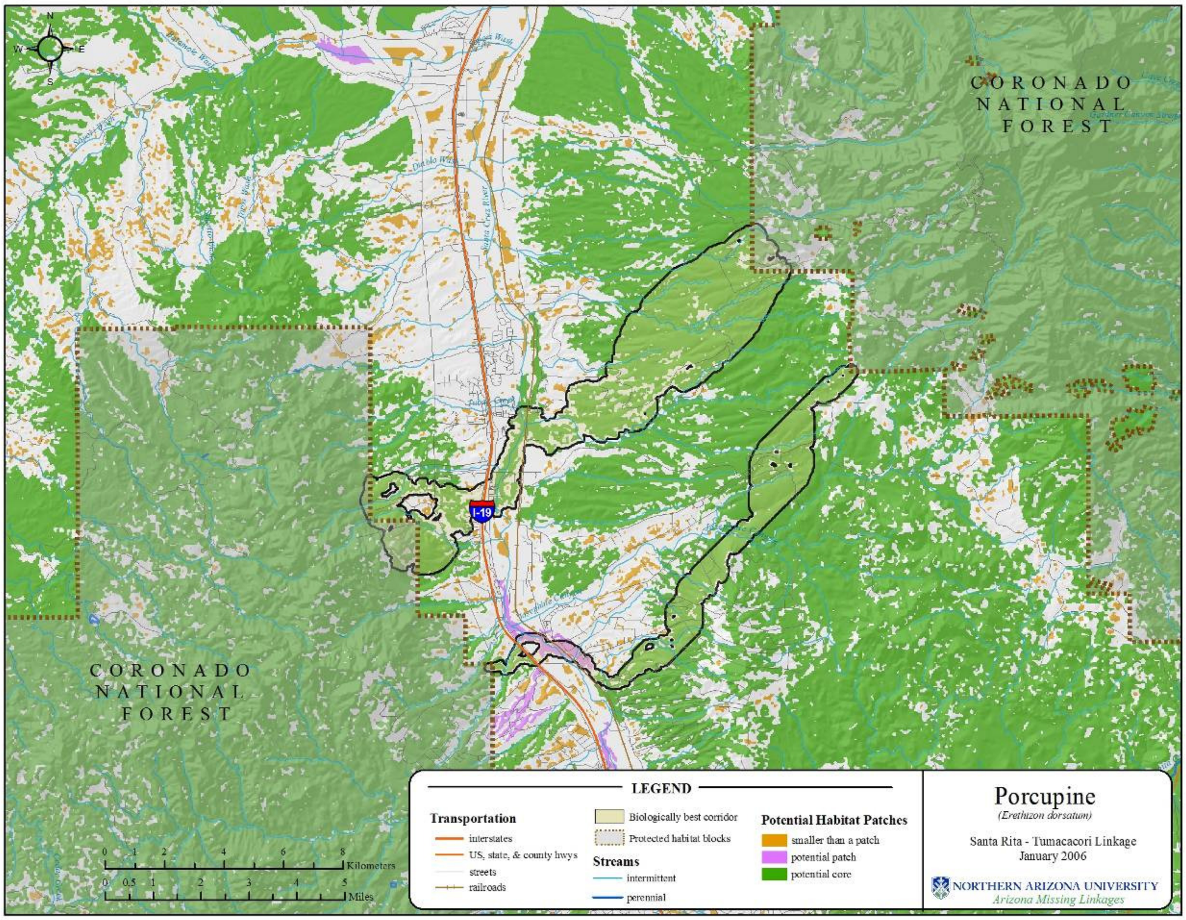



**Figure 46: Potential habitat patches and cores for porcupine**

*Union of biologically best corridors* – The union of biologically best corridors provides significant amount of suitable habitat for porcupine, although the majority of suitable habitat is only classified as "suboptimal but usable." The southernmost route of the Linkage Design contributes a large amount of suitable habitat.

# White-nosed Coati (*Nasua narica*)

## Justification for Selection
White-nosed coatis are primarily forest species, and may serve as prey for top carnivores such as mountain lion (NMDGF 2004). They also appear to be dispersal-limited, and sensitive to roads and habitat fragmentation.

## Distribution
White-nosed coatis are found in southern Arizona and New Mexico, and Texas, and throughout Mexico and Central America (Gompper 1995). In Arizona, coatis are found as far north as the Gila River, and throughout southeastern Arizonan forests.

## Habitat Associations
Coatis are primarily a forest species, preferring shrubby and woodland habitats with good horizontal cover (Gompper 1995; C. Hass, personal comm.). While they do not have strong topographic preferences, they are generally found within several miles of water, and prefer riparian habitats if available (Gompper 1995). In Arizona, elevation places no constraints on habitat use, as this species are found from sea level to mountains exceeding 10,000 feet. While they are not a desert species, coatis will move through desert scrub and shrublands when moving between forested areas (Hoffmeister 1986).

## Spatial Patterns
Female coatis and their yearlings (both sexes) live in groups of up 25 individuals, while males are solitary most of the year (Hoffmeister 1986). In southeastern Arizona, average home range of coati troops was calculated as 13.57 $km^2$ (Hass 2002). Home ranges of males overlapped other males up to 61% and overlapped troops up to 67%, while home ranges of troops overlapped each other up to 80% (Hass 2002). Virtually nothing is known about dispersal distance in coatis, and radioed animals have not dispersed more than a few kilometers (Christine Hass, personal comm.). Females are philopatric, but males have been observed at large distances from known coati habitat, and tend to get hit by cars. While successful dispersal of any distance is unknown, it is thought that males may disperse up to 5 km (Christine Hass, personal comm.)

## Conceptual Basis for Model Development
*Habitat suitability model* – Due to this species' strong vegetation preferences, vegetation received an importance weight of 95%, while distance from roads received a weight of 5%. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – Minimum potential habitat patch size was defined as 13.6 $km^2$, the average home range observed in southeastern Arizona by Hass (2002). Minimum potential habitat core size was defined as 68 $km^2$, 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 large spatial requirements for coati groups.

*Biologically best corridor analysis* – Because potential habitat was patchily distributed in the linkage area, and most available habitat between wildland blocks had similar costs (mostly 3-5: suboptimal but usable), we re-assigned all ‘suitable’ habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid unsuitable (urbanized) land.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate a fair amount of suitable habitat within the linkage area (Figure 47). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.1 to 9.0, with an average suitability of 4.3 (S.D: 1.7). The farthest distance between a potential patch and another patch or core within the corridor was approximately 1.1 km.

The corridor runs in a NE-SW direction between the Santa Rita and Tumacacori wildland blocks. Moving west from the Santa Rita wildland block, the corridor encompasses portions of Cottonwood Canyon and Mavis Wash, passes between the town of Carmen and Tumacacori National Monument near the Santa Cruz River, and joins the Tumacacori wildland block near Tumacacori Peak.

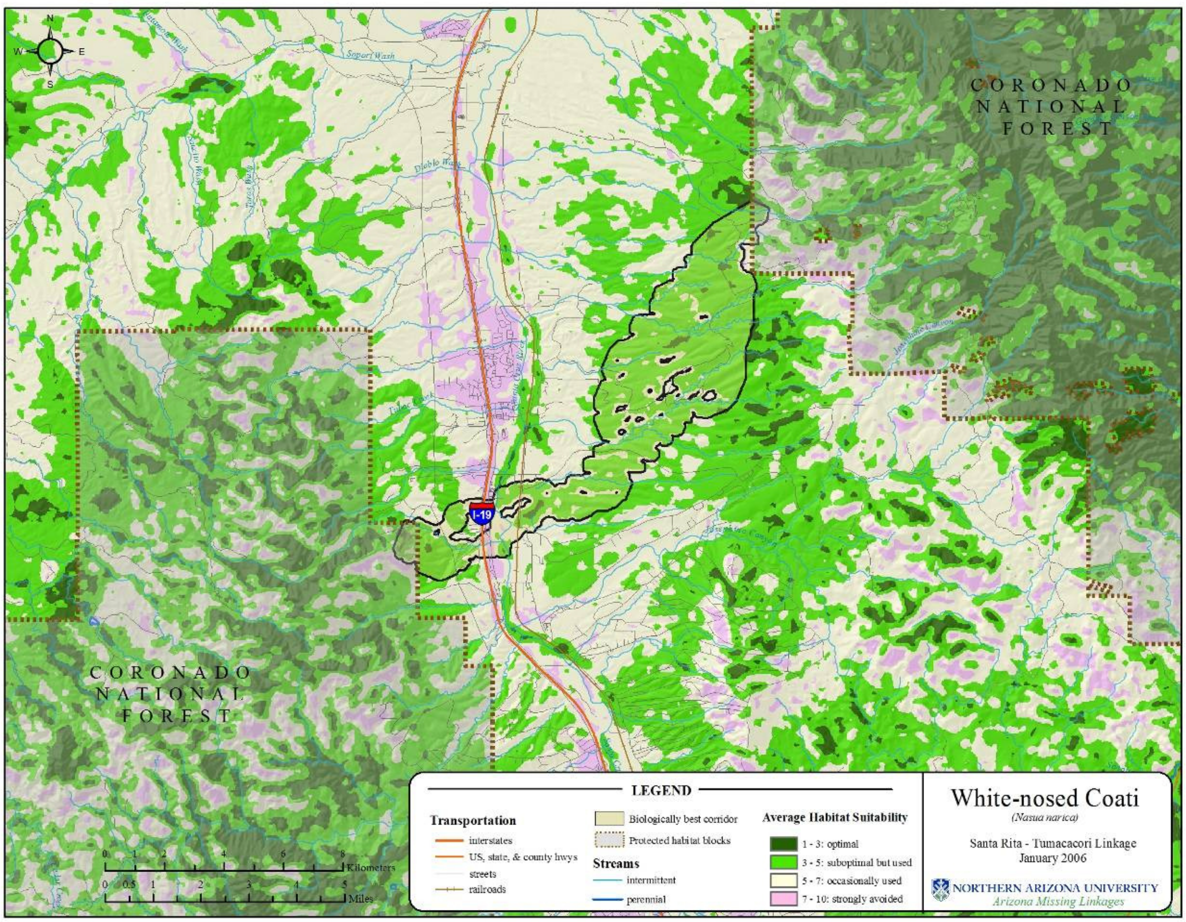



**Figure 47: Modeled habitat suitability of white-nosed coati**

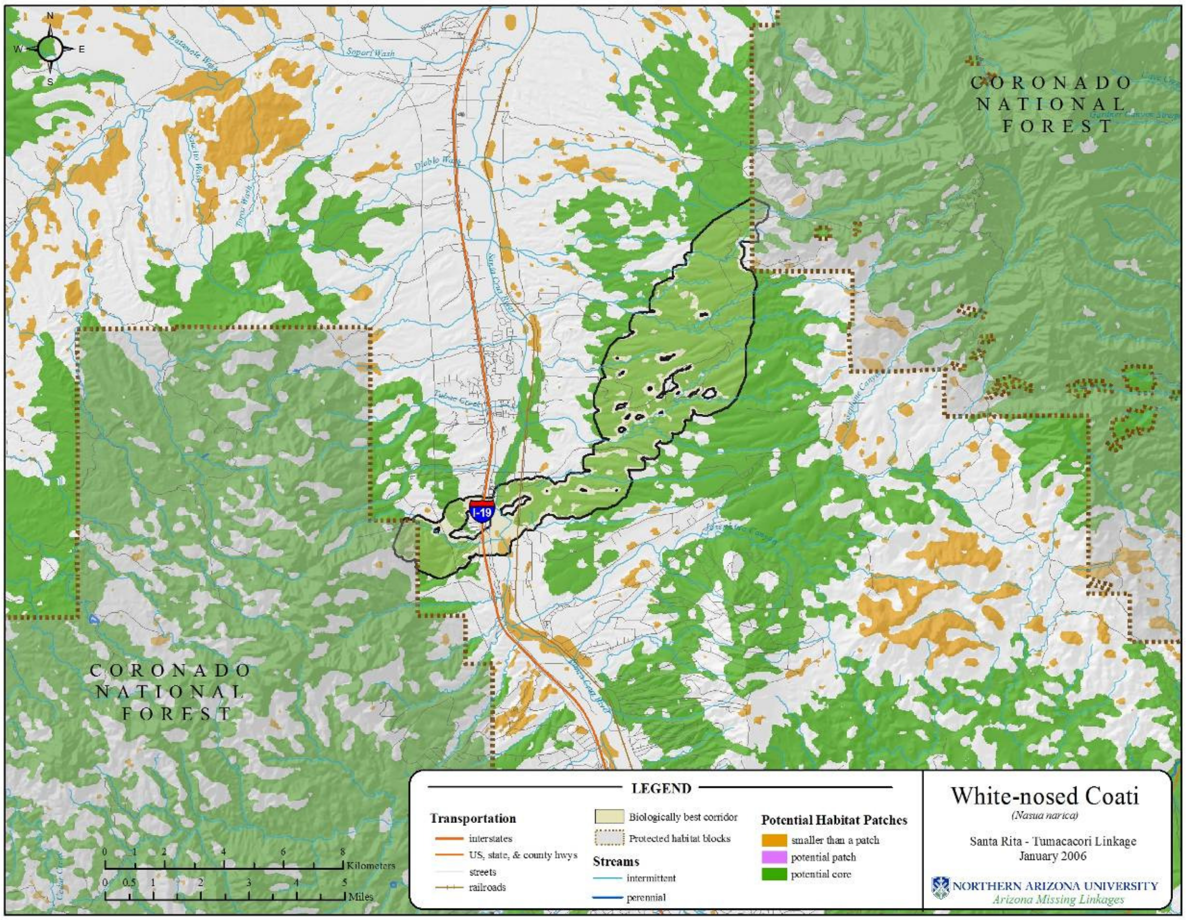



**Figure 48: Potential habitat patches and cores for white-nosed coati**

*Union of biologically best corridors* – The union of biologically best corridors does not provide a significant amount of suitable habitat beyond the initial biologically best corridor model for coati. While coatis tend to be close to water, and a riparian area would provide a better movement corridor for this species than a dry wash (Christine Hass, personal comm.), the only significant riparian area between the Santa Rita and Tumacacori wildland blocks for this species is the Santa Cruz River.

# Black-tailed Rattlesnake (*Crotalus molossuss*)


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

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

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

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

### Conceptual Basis for Model Development
*Habitat suitability model* – While this species is a vegetation generalist, it is strongly associated with rocks and outcrops on mountain slopes, and rarely seen at any distance from these environments (Matt Goode & Phil Rosen, personal comm.). Because of this strong topographic association, topography received an importance weight of 90%, while distance from roads received a weight of 10%. For specific scores of classes within each of these factors, see Table 4. To ensure that suitable habitat was restrained to locations close to rocky areas, habitat suitability beyond 500 meters from rocky areas mapped in the ReGAP vegetation layer were reclassified to suitability scores between 5 and 10.

*Patch size & configuration analysis* – Beck (1995) found home ranges from 3-4 ha in size; however, it is thought that home ranges for most black-tailed rattlesnakes are slightly larger (Phil Rosen, personal comm.), so minimum patch size was defined as 10 ha. Minimum core size was defined as 100 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – Because potential habitat was patchily distributed, and most available habitat between wildland blocks had similar costs (mostly 1-3: optimal), we re-assigned all 'suitable' habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid unsuitable land.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate a fair amount of suitable habitat within the linkage area, due to the topography of the linkage area (Figure 49). Within the biologically best corridor for this species, the average habitat suitability ranged from 1 to 9.6, with an average suitability of 2.4 (S.D: 2.5). The farthest distance between a potential patch and another patch or core within the corridor was approximately 1.6 km (Figure 50), which should be short enough to allow this species to traverse between wildland blocks.

The corridor for this species runs the eastern side of the Tumacacori wildland block to the southwestern corner of the Santa Rita wildland block. Moving westward from the Santa Ritas, the corridor encompasses portions of Hangmans Canyon, Ash Canyon, Coal Mine Canyon, Grosvenor Hills, Fresno Canyon, and the San Cayetano Mountains, before crossing the Santa Cruz River. After crossing the river, the corridor runs northwest, encompassing portions of Negro, Tinaja, and Rock Corral Canyons, before joining the Tumacacori wildland block near Tumacacori Peak.

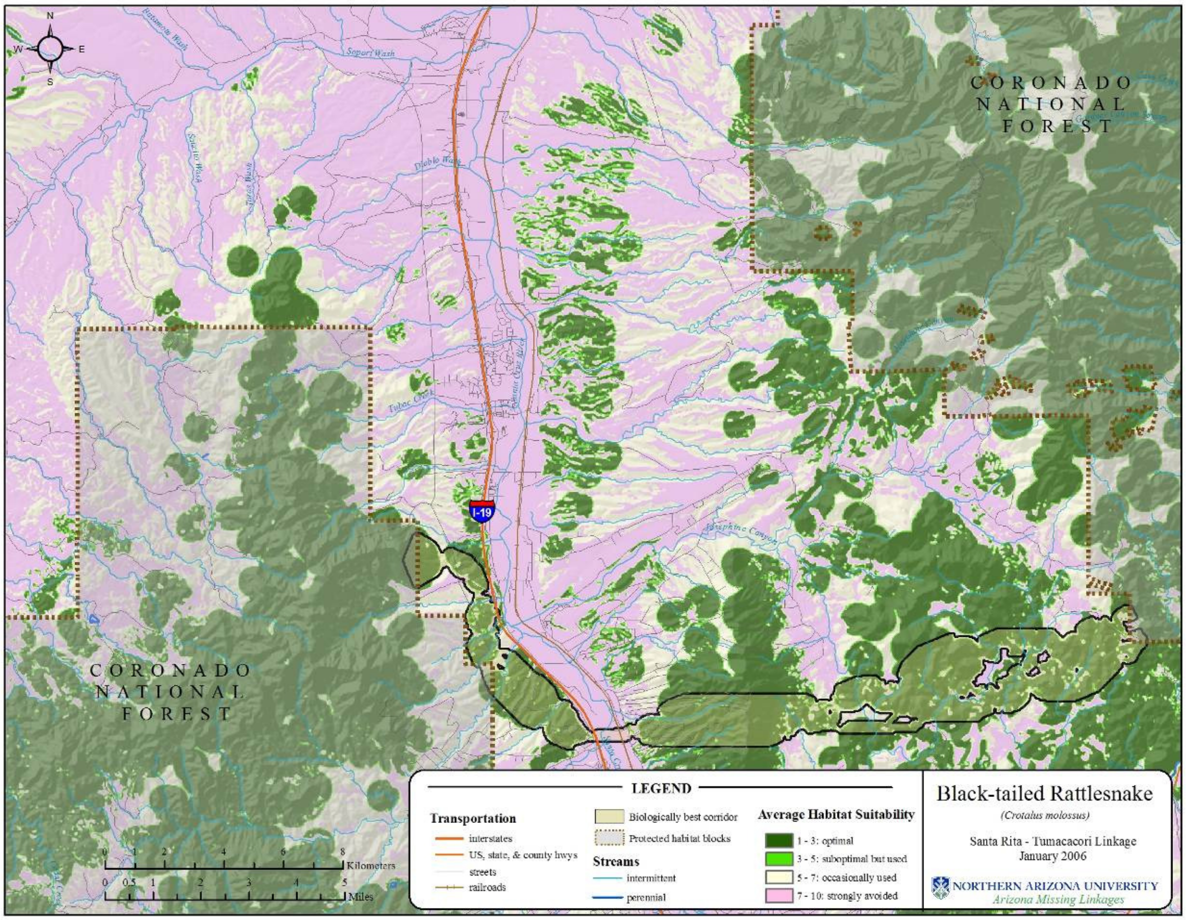



**Figure 49: Modeled habitat suitability of black-tailed rattlesnake**

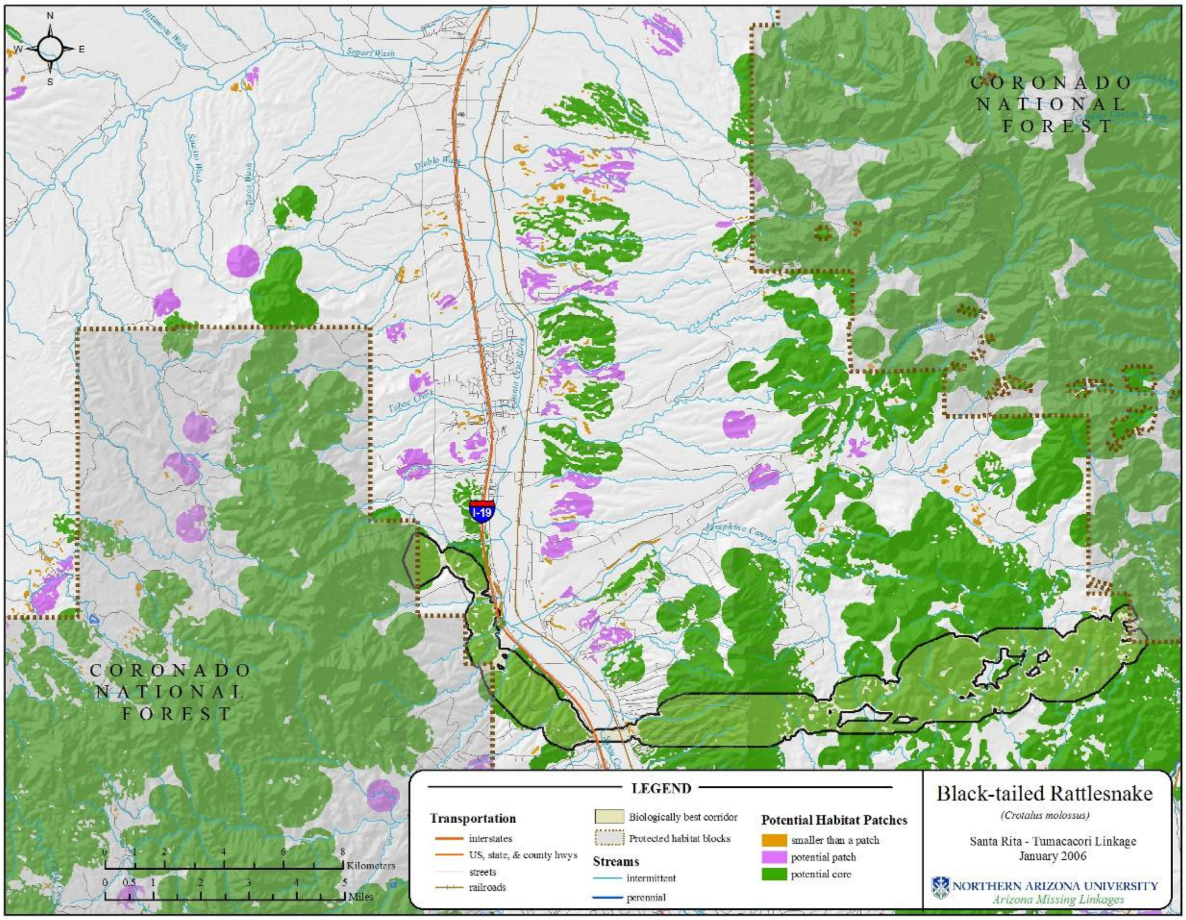



**Figure 50: Potential habitat patches and cores for black-tailed rattlesnake**

*Union of biologically best corridors* – The union of biologically best corridors provides the black-tailed rattlesnake with an expanded amount of optimal habitat adjacent to the habitat contained in its individual corridor. Due to the recent residential development in the San Cayetano Mountains region and this species' limited dispersal capability, ecological connectivity for this species may be difficult to maintain.

# Chiricahua Leopard Frog (*Rana chiricahuensis*)


## Justification for Selection

The Chiricahua leopard frog's population is declining in Arizona, and has been extirpated from about 75 percent of its historic range in Arizona and New Mexico (U.S. Fish and Wildlife Service 2002). Reasons for decline include habitat fragmentation, major water manipulations, water pollution, and heavy grazing (Arizona Game and Fish Department 2001). The Chiricahua leopard frog has been listed as a threatened species by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2002), and is also Forest Service Sensitive and a Species of Special Concern in Arizona (Arizona Game and Fish Department 2001). This frog has a metapopulation structure and requires dispersal corridors to include a buffer and riparian and stream corridors (Pima Co., Arizona 2001). Human activities have eliminated natural dispersal corridors in Arizona (Pima Co., Arizona 2001).

## Distribution

The range of the Chiricahua leopard frog includes the montane regions of central and southern Arizona, southwestern New Mexico south into the Sierra Madre Occidental to western Jalisco, Mexico (Pima Co., Arizona 2001). Within Arizona, this species' range is divided into two portions: one extending from montane central Arizona east and south along the Mogollon Rim to montane parts of southwestern New Mexico; the other extends through the southeastern montane sector of Arizona and into Sonora, Mexico (Degenhardt 1996; Arizona Game and Fish Department 2001).

## Habitat Associations

The Chiricahua leopard frog's primary habitat is oak, mixed oak, and pine woodlands, but also is found in areas of chaparral, grassland, and even desert (Arizona Game and Fish Department 2001). Within these habitats, this frog is an aquatic species that uses a variety of water sources including thermal springs and seeps, stock tanks, wells, intermittent rocky creeks, and main-stream river reaches (Degenhardt 1996). Other aquatic systems include deep rock-bound pools and beaver ponds (Arizona Game and Fish Department 2001). The elevation range for this species is 1,000 – 2,600m (New Mexico Department of Game and Fish 2004).

## Spatial Patterns

Home range requirements of Chiricahua leopard frogs are not known. Available information on movements of Chiricahua leopard frogs indicates that most individuals stay within a few kilometers of their breeding sites, though occasionally individuals will move distances of several kilometers (NatureServe 2005). Chiricahua leopard frogs have been observed dispersing up to 1.5 miles from their home ponds (Pima Co., Arizona 2001).

## Conceptual Basis for Model Development

*Habitat suitability model* – Vegetation received an importance weight of 55%, while elevation, topography, and distance from roads received weights of 25%, 10%, and 10%, respectively. This species is an aquatic obligate, so we restricted its habitat suitability model to only those riparian areas likely to be important for this species. According to Phil Rosen, the linkage for Chircahua leopard frogs would most likely be down historic habitat in Sonoita Creek, to the Santa Cruz River, up the Santa Cruz to Sopori Wash, then up the Sopori bottom to Arivaca Cienega; or it could cross the bajada in the south end of the Santa Cruz Valley using stock ponds.

*Patch size & configuration analysis* – Minimum patch size was defined as 0.05 ha, while minimum core size was defined as 0.1 ha (Phil Rosen, personal comm.). Because distinctions between these two habitat thresholds cannot be made using the GIS data layers available to us, we did not map potential habitat patches.

*Biologically best corridor analysis* – Because this species lives primarily between the protected Tumacacori and Santa Rita blocks, we did not perform a biologically best corridor analysis.

## Results & Discussion

*Habitat suitability model* – The habitat model for this species shows a fair amount of suitable habitat along the Santa Cruz River and Sopori Wash. However, connectivity can only be restored for this species based on a conceivable future in which the species was undergoing recovery through active management (Phil Rosen, personal comm.).

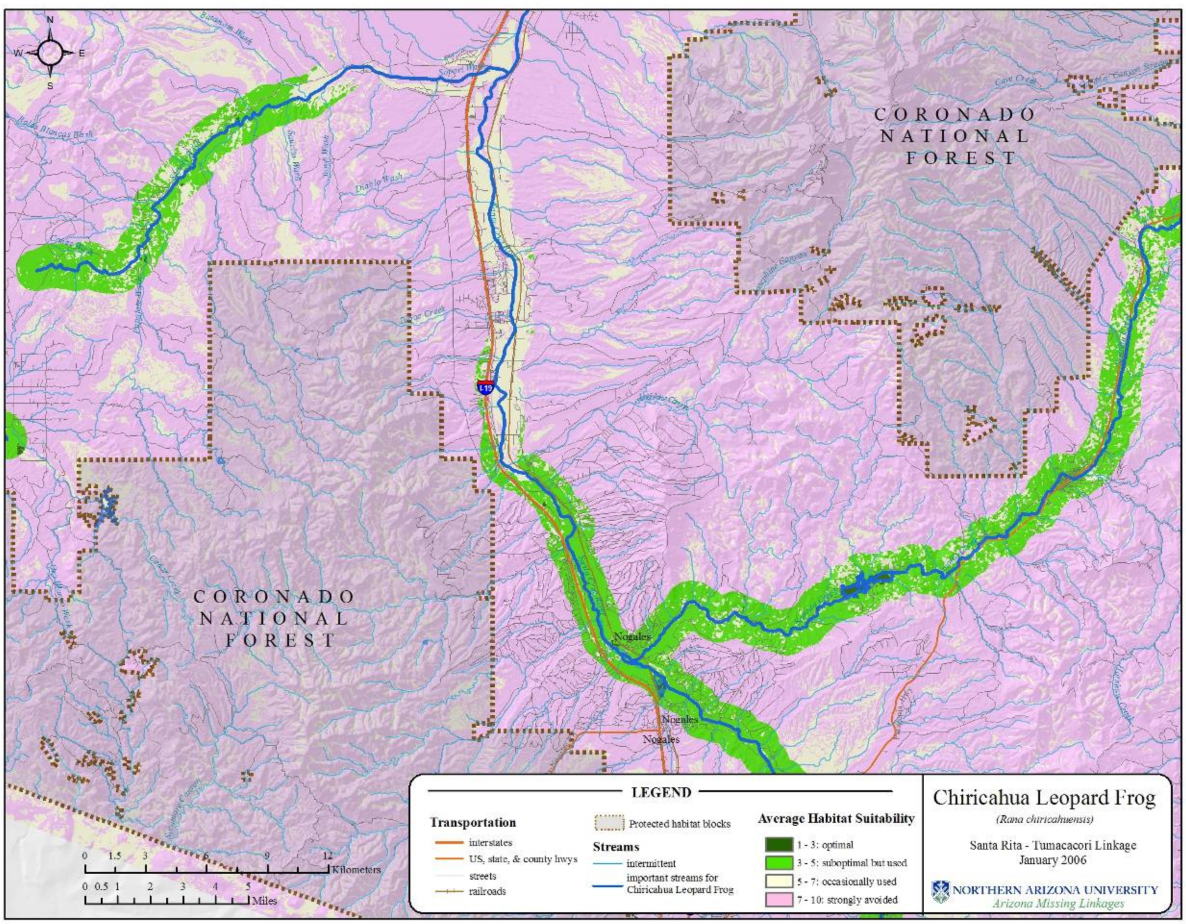



**Figure 51: Modeled habitat suitability of Chiricahua leopard frog**

# Desert Box Turtle (*Terrapene ornate luteola*)

## Justification for Selection

The desert grassland box turtle is uncommon in Arizona, and its habitat continues to be limited by recent residential developments (Pima Co., Arizona 2001). Habitat alterations from agriculture also may be eliminating populations in some areas of its range (New Mexico Department of Game and Fish 2004). This turtle is sensitive to highway traffic, and automobiles are considered a significant cause of mortality (Pima Co., Arizona 2001).

## Distribution

The desert box turtle's range encompasses south-central New Mexico south to central Chihuahua and Sonora, Mexico, and from west Texas across southern New Mexico to the eastern base of the Baboquivari Mountains (Pima Co., Arizona 2001). In Arizona, the desert box turtle occurs in Pima and Santa Cruz counties (New Mexico Department of Game and Fish 2004). This species has historically occured in the Santa Cruz Valley, but may have been extirpated (Phil Rosen, personal comm.).

## Habitat Associations

This species is associated with arid and semiarid regions, and is found in grasslands, plains, and pastures (New Mexico Department of Game and Fish 2004). It prefers open prairies with herbaceous vegetation and sandy soil (New Mexico Department of Game and Fish 2004). This turtle also occurs in rolling grass and shrub land, as well as open woodlands with herbaceous understory (Pima Co., Arizona 2001). Specifically, it is common to mesquite-dominated bajada and abundant in bajada grasslands, grassland flats, and mesquite-dominated flats, but uncommon in rocky slopes and bajada desertscrub (New Mexico Department of Game and Fish 2004). This turtle has been observed taking refuge in subterranean mammal burrows, especially those of the kangaroo rat (Plummer 2004). Elevation range for this species is 0 to 2000 meters, but elevations of 1,200 to 1,600 meters are most suitable (Pima Co., Arizona 2001). In arid regions such as the linkage planning area, this species is dependent on inhabitable sections of riparian bottoms (Phil Rosen, personal comm.)

## Spatial Patterns

Due to extended periods of unfavorable weather conditions within its range, the desert box turtle is active only a few weeks out of the year (Plummer 2004). During activity, it requires up to 12 ha for its home range, including land with moist soil that is not compacted (Pima Co., Arizona 2001). One study in Cochise County, Arizona reported average home ranges of 1.1 ha in a dry year and 2.5 ha in a wet year (Pima Co., Arizona 2001). Another study at Fort Huachuca found home ranges that varied from 1.6 ha to 12.4 ha, with an average of 8.5 ha (Pima Co., Arizona 2001). Daily movements include early morning and late afternoon excursions to flat water sites, including cattle tanks (New Mexico Department of Game and Fish 2004; Plummer 2004).

## Conceptual Basis for Model Development

*Habitat suitability model* – Vegetation received an importance weight of 40%, while elevation, topography, and distance from roads received weights of 15%, 20%, and 25%, respectively. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – Minimum potential habitat patch size was defined as 5 ha, and minimum potential core size was defined as 50 ha (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* – Nearly all habitat within the linkage zone was calculated as suitable (cost < 5), so the standard habitat suitability model was used in the corridor analysis.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 52). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.0 to 6.2, with an average suitability of 2.6 (S.D: 0.7). The entire corridor is a potential habitat core (Figure 53).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are part of Montosa Canyon and several unnamed washes.

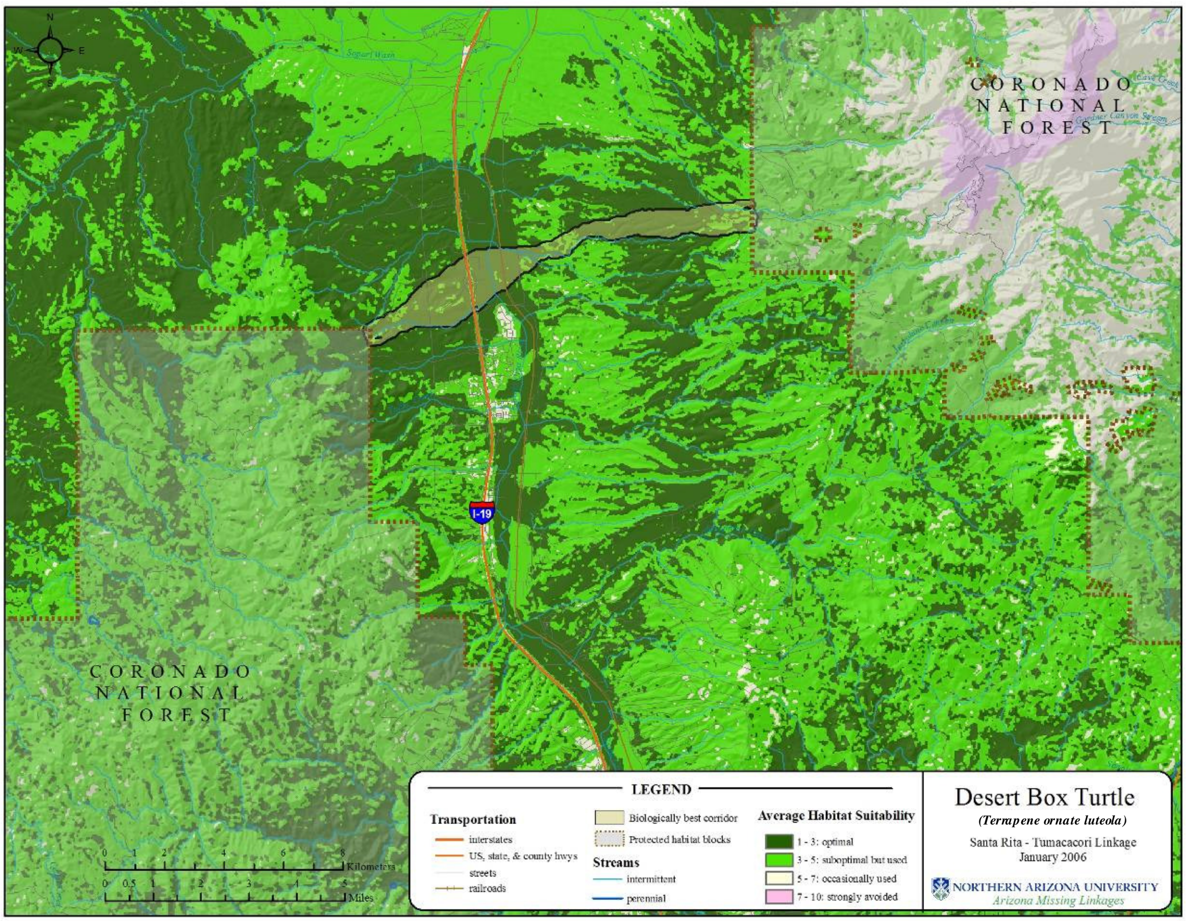



**Figure 52: Modeled habitat suitability of desert box turtle**

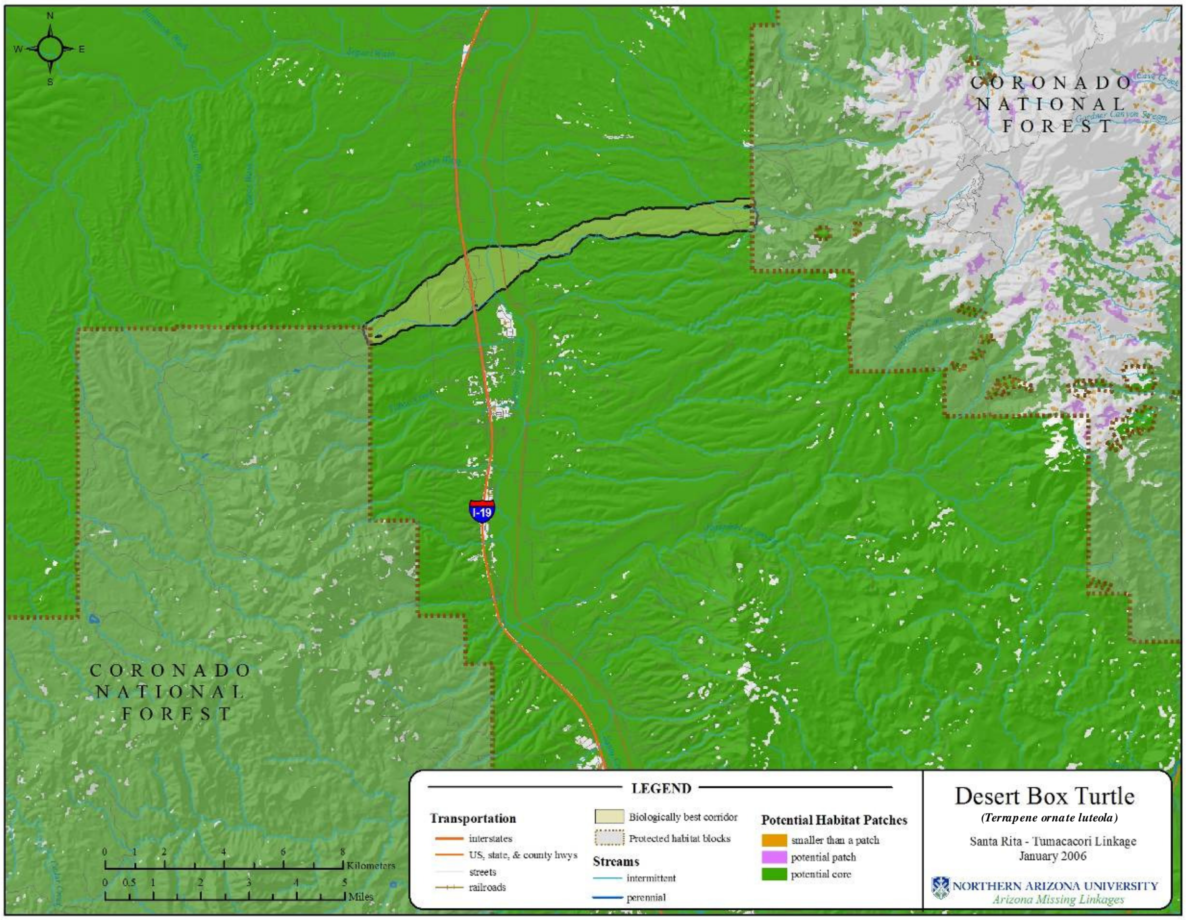



**Figure 53: Potential habitat patches and cores for desert box turtle**

*Union of biologically best corridors* - The union of biologically best corridors provides a significant increase in potential habitat for the desert box turtle. Despite the apparent ample amount of suitable habitat, desert box turtles are still rare in the linkage area, likely due to a lack of riparian habitats. Riparian habitats are optimal for this species, and linkages between wildland blocks should include inhabitable chunks of the riparian bottoms if they are to provide any likelihood of supporting connectivity for this species (Phil Rosen, personal comm.).

# Giant Spotted Whiptail (*Aspidoscelis burti stictogrammus*)


Jim Rorabaugh, US Fish & Wildlife Service

## Justification for Selection

The giant spotted whiptail is thought to be stable; however, little is known of its population trends (Arizona Game and Fish Department 2001). This species has a limited distribution, and is listed as Forest Service Sensitive (1999) and Bureau of Land Management Sensitive (2000; Arizona Game and Fish Department 2001). Although the giant spotted whiptail is not considered to be migratory, corridors are needed to connect disjunct populations (Pima Co., Arizona 2001). They are adversely impacted by habitat alteration due to overgrazing of riparian vegetation (Pima Co., Arizona 2001).

## Distribution

This lizard's range is limited to southeastern Arizona including the Santa Catalina, Santa Rita, Pajarito, and Baboquivari Mountains. It is also known to exist in the vicinity of Oracle, Pinal County, and Mineral Hot Springs, Cochise County. Outside of Arizona, the giant spotted whiptail is found in Guadalupe Canyon in extreme southwest New Mexico and northern Sonora, Mexico (Arizona Game and Fish Department 2001).

## Habitat Associations

Giant spotted whiptails are found in the riparian areas of lower Sonoran life zones, as well as mountain canyons, arroyos, and mesas in arid and semi-arid regions (Pima Co., Arizona 2001). These lizards inhabit dense shrubby vegetation, often among rocks near permanent and intermittent streams, as well as open areas of bunch grass within these riparian habitats (Arizona Game and Fish Department 2001). They are able to access lowland desert along stream courses (Pima Co., Arizona 2001). Elevation ranges of suitable habitat are from 2,200 to 5,000 feet (670 to 1,500m) (Pima Co., Arizona 2001).

## Spatial Patterns

Giant spotted whiptails require only 2-4 ha for their home range (Rosen et al. 2002). Within this area, they rely on a mosaic of open spaces and cover of dense thickets of thorny scrub while foraging (Pima Co., Arizona 2001). These lizards are not migratory, and hibernate in winter.

## Conceptual Basis for Model Development

*Habitat suitability model* – Vegetation received an importance weight of 70%, while elevation received a weight of 30%.

*Patch size & configuration analysis* – Minimum patch size was defined as 4 ha, while minimum core size was defined as 25 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – Because this species lives primarily between the protected Tumacacori and Santa Rita blocks, we did not perform the typical biologically best corridor analysis. Instead we relied on expert opinion (Phil Rosen, University of Arizona) to determine the most probably corridor for this species.

## Results & Discussion

*Habitat suitability model* – The habitat suitability model may not accurately reflect the Giant Spotted Whiptail's habitat, because thornscrub, as mapped by the ReGAP project, includes much more arid aspects of vegetation than can be utilized by this species, and the thornscrub which can be occupied by this species is typically localized near major drainages (Phil Rosen, personal comm.)

*Initial biologically best corridor* – According to Phil Rosen, the likely linkage for this species between the Santa Rita to Tumacacori wildland blocks would not be direct across the Santa Rita bajada (as that is probably, but not absolutely known to be, unoccupied), but rather from the Santa Ritas and upper Cienega Creek, and the northern Patagonia Mountains, down Sonoita Creek to the Santa Cruz River and Potrero Creek near Nogales, and thence into the Atascosa Mountain complex, which includes the Tumacacori and Pajarito Mountains.

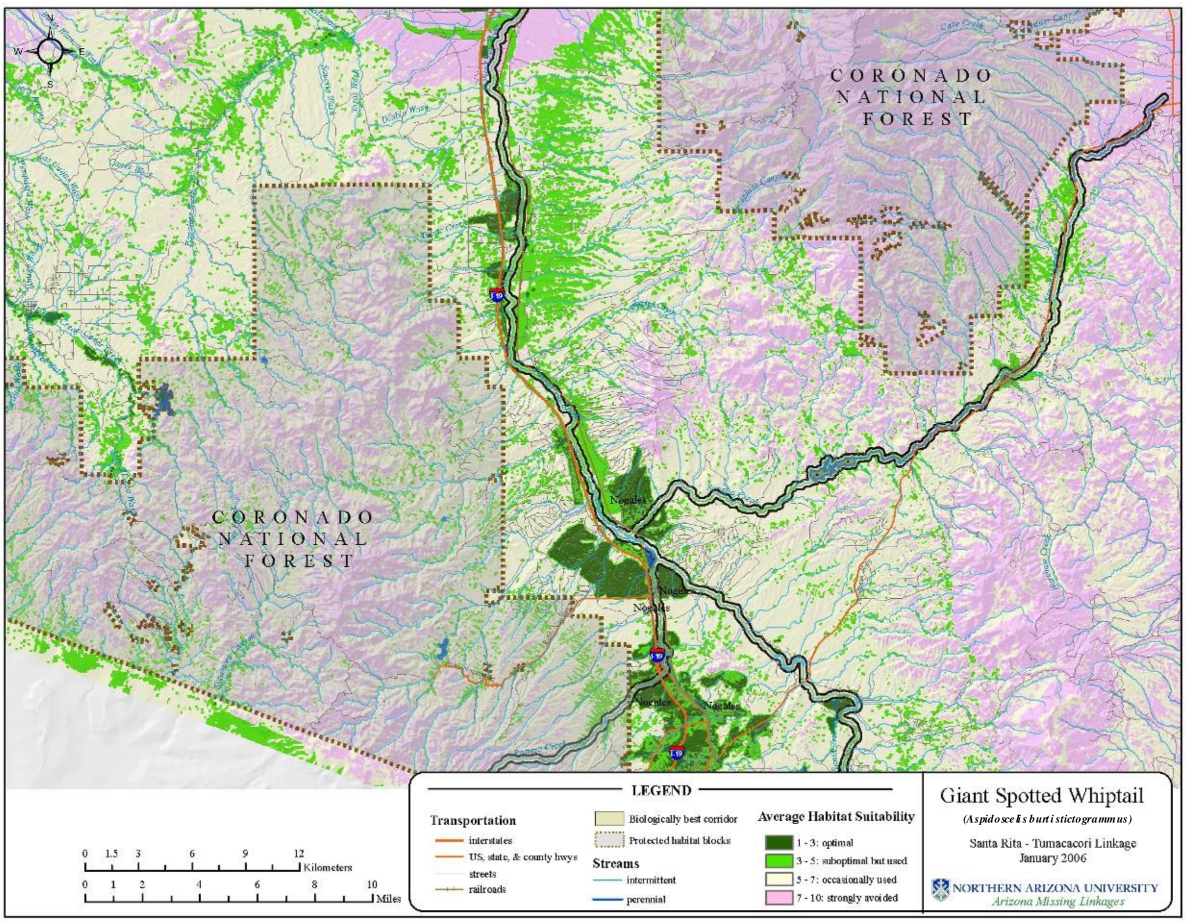



**Figure 54: Modeled habitat suitability of giant spotted whiptail**

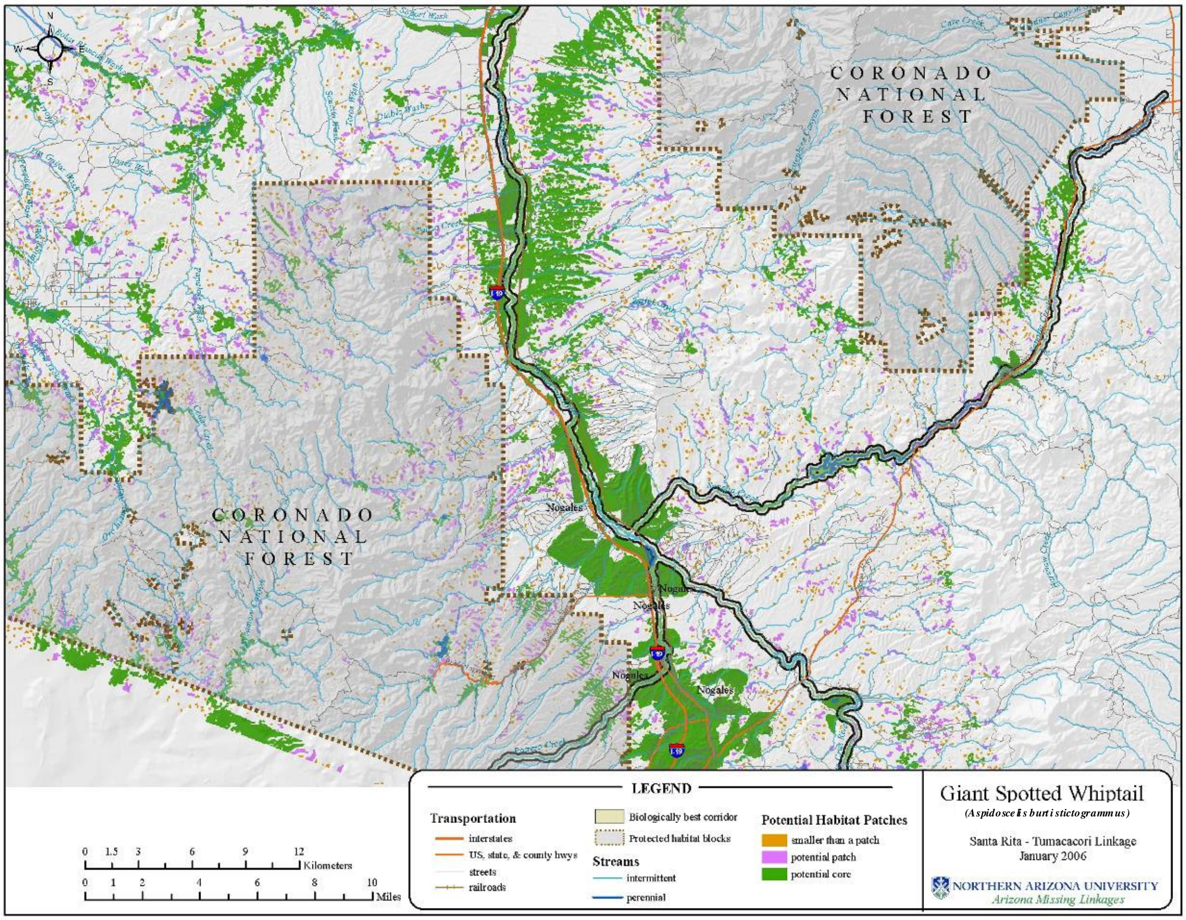



**Figure 55: Potential habitat patches and cores for giant spotted whiptail**

*Union of biologically best corridors* – The union of biologically best corridors encompasses riparian woodland and shrubland along the Santa Cruz River which is important habitat for this species. The UBBC also encompasses other important riparian areas which could be valuable in maintaining connectivity for this species, such as Sonoita and Potrero Creeks.

***Aspidoscelis***

# Lowland Leopard Frog (*Rana yavapaiensis*)


## Justification for Selection

This species has a limited distribution and is susceptible to road mortality. They have lost much of their habitat due to development, fragmentation, and water manipulation, and have been negatively impacted by bullfrogs, crayfish, and chytrid fungus (Arizona Game and Fish Department 2001).

## Distribution

The lowland leopard frog historically ranged throughout low elevation sites in the lower Colorado River and its tributaries in Arizona, New Mexico, California, Nevada, and northern Mexico. Within Arizona, the species is found in the Colorado River near Yuma, and south of the Mogollon Rim (AZGFD 2001).

## Habitat Associations

This species is 100% dependent on aquatic habitat. They can occur in aquatic systems ranging from desert grasslands to pinyon-juniper. Generally, effective corridors would tend to be in stream bottoms (like Cienega Creek, where it still occurs) and connecting to stock ponds and mountain springs or tinajas via major washes, especially those with intermittent, rather than ephemeral flow (Phil Rosen, personal comm.). Optimal elevation for this species is from 900 to 4,000 ft, although it can be found at higher elevations (Lannoo 2005; P. Rosen, personal comm.)

## Spatial Patterns

Very small but suitable sites as small as 0.05 ha, such as stock tanks, exceptional springs, or maintained frog pools, can sustain populations of leopard frogs (Fernandez 1996; P. Rosen, personal comm.). The longest recorded movement from a known population of leopard frogs is 5km, although the species could potentially disperse up to 16 km from a huge, burgeoning population (Platz 1990; Rosen & Schwalbe 1997, 1998).

## Conceptual Basis for Model Development

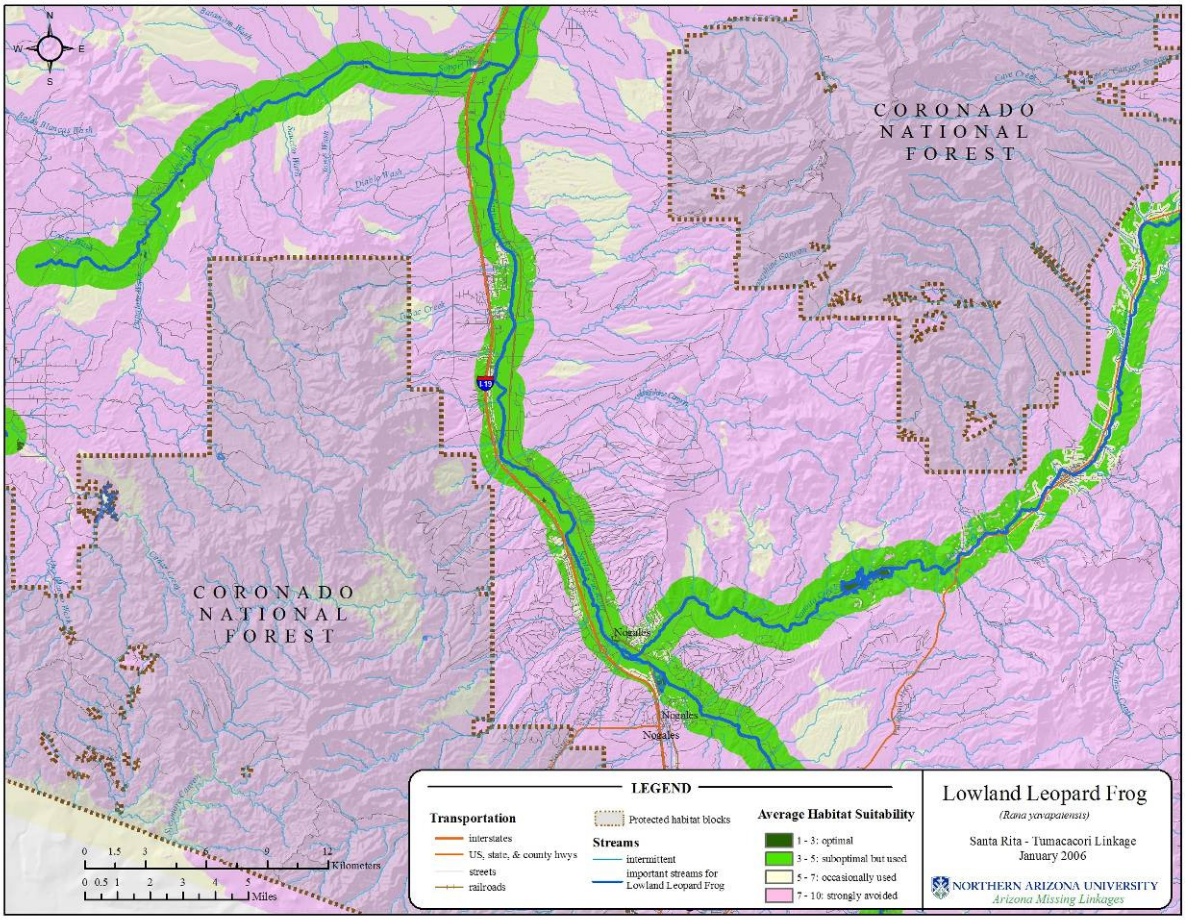
*Habitat suitability model* – Vegetation received an importance weight of 60%, while elevation and distance from roads received weights of 30% and 10%, respectively. This species is an aquatic obligate, so we restricted its habitat suitability model to only those riparian areas likely to be important for this species. According to Phil Rosen, the linkage for lowland leopard frogs would tend to be in stream bottoms (like Cienega Creek, where it still occurs) and connecting to stock ponds and mountain springs or tinajas via major washes, especially those with intermittent, rather than ephemeral flow.

*Patch size & configuration analysis* – Minimum patch size was defined as 0.05 ha, while minimum core size was defined as 0.1 ha (Phil Rosen, personal comm.). Because distinctions between these two habitat thresholds cannot be made using the GIS data layers available to us, we did not map potential habitat patches.

*Biologically best corridor analysis* – Because this species lives primarily in aquatic areas between the protected Tumacacori and Santa Rita blocks, we did not perform a biologically best corridor analysis.

## Results & Discussion

*Habitat suitability model* – The habitat model for this species shows a fair amount of suitable habitat along important riparian areas in the linkage area; however, specific sites in these areas would need to be considered for there to be any real chance of establishing connectivity without large scale management action like that needed for connectivity to be conceivable for the Chiricahua Leopard Frog (P. Rosen, personal comm.).



# Sonoran Desert Toad (*Bufo alvarius*)

### Justification for Selection


This species is thought to be potentially susceptible to extirpation or demographic impact from road mortality due to its large size, conspicuous activity, numerous observations of road-killed adults, presumed long natural lifespan, and apparent declines in road-rich urban zones. However, in at least one place, a population is thriving in central Tucson (Rosen and Mauz (2001).

### Distribution

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

### Habitat Associations

Breeding is naturally concentrated in canyons and upper bajada intermittant streams, and on valley floors in major pools, but not naturally frequent on intervening bajadas. With stock ponds, breeding can occur anywhere on the landscape, but valley centers and canyons likely remain as the core areas (Phil Rosen, personal comm.).

### Spatial Patterns

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

### Conceptual Basis for Model Development

*Habitat suitability model* – Sonoran desert toads appear capable of occupying any vegetation type, from urbanized park to their maximum elevation. Roads can have a massive mortality impact and presumed population impact, but some populations live near roads that may be peripheral or marginal to the core habitat (Phil Rosen, personal comm.). Vegetation received an importance weight of 5%, while elevation, topography, and distance from roads received weights of 50%, 25%, and 20%, respectively. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha (Rosen & Mauz 2001; Phil Rosen, personal comm.). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

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

### Results & Discussion

*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 56). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.2 to 3.4, with an average suitability of 2.2 (S.D: 0.6). The entire corridor is a potential habitat core (Figure 57).

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are part of Montosa Canyon and several unnamed washes.

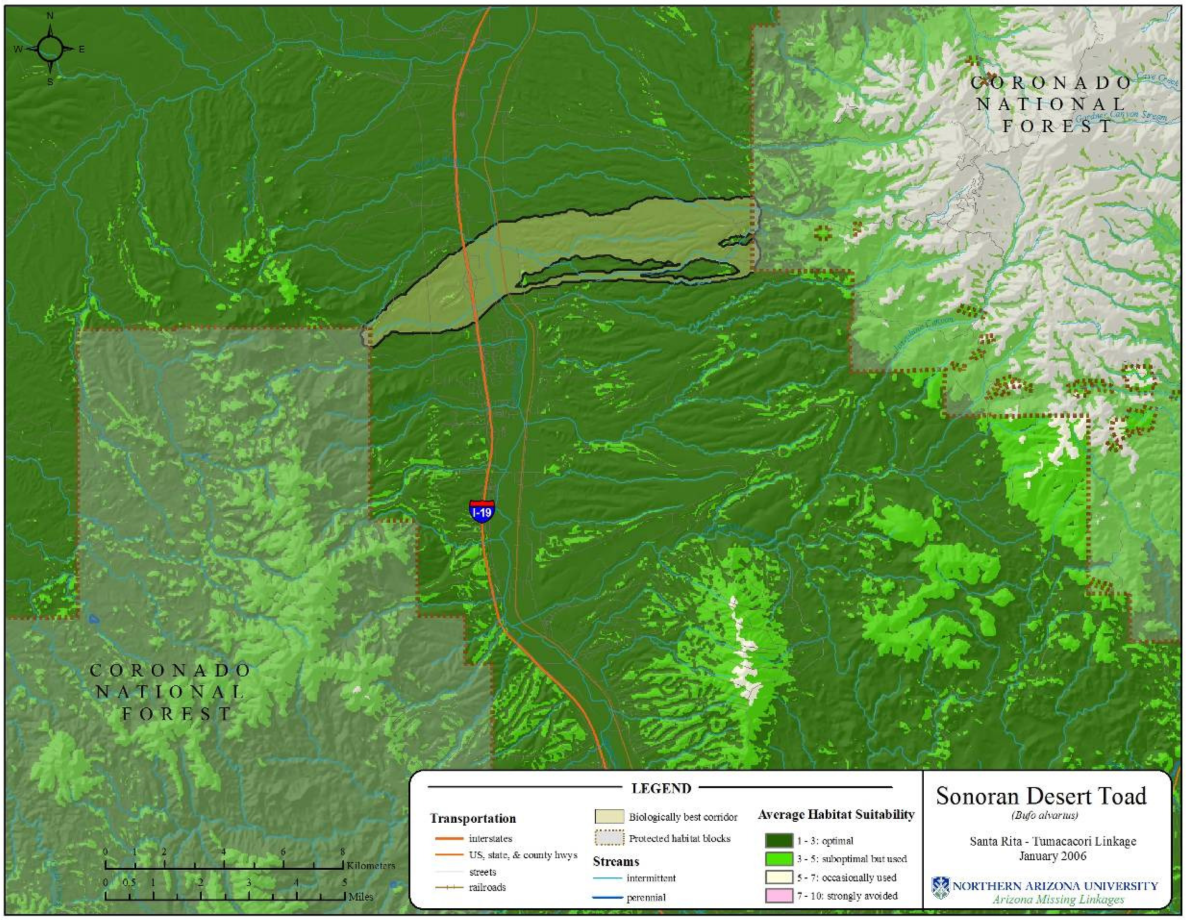



**Figure 56: Modeled habitat suitability of Sonoran desert toad**

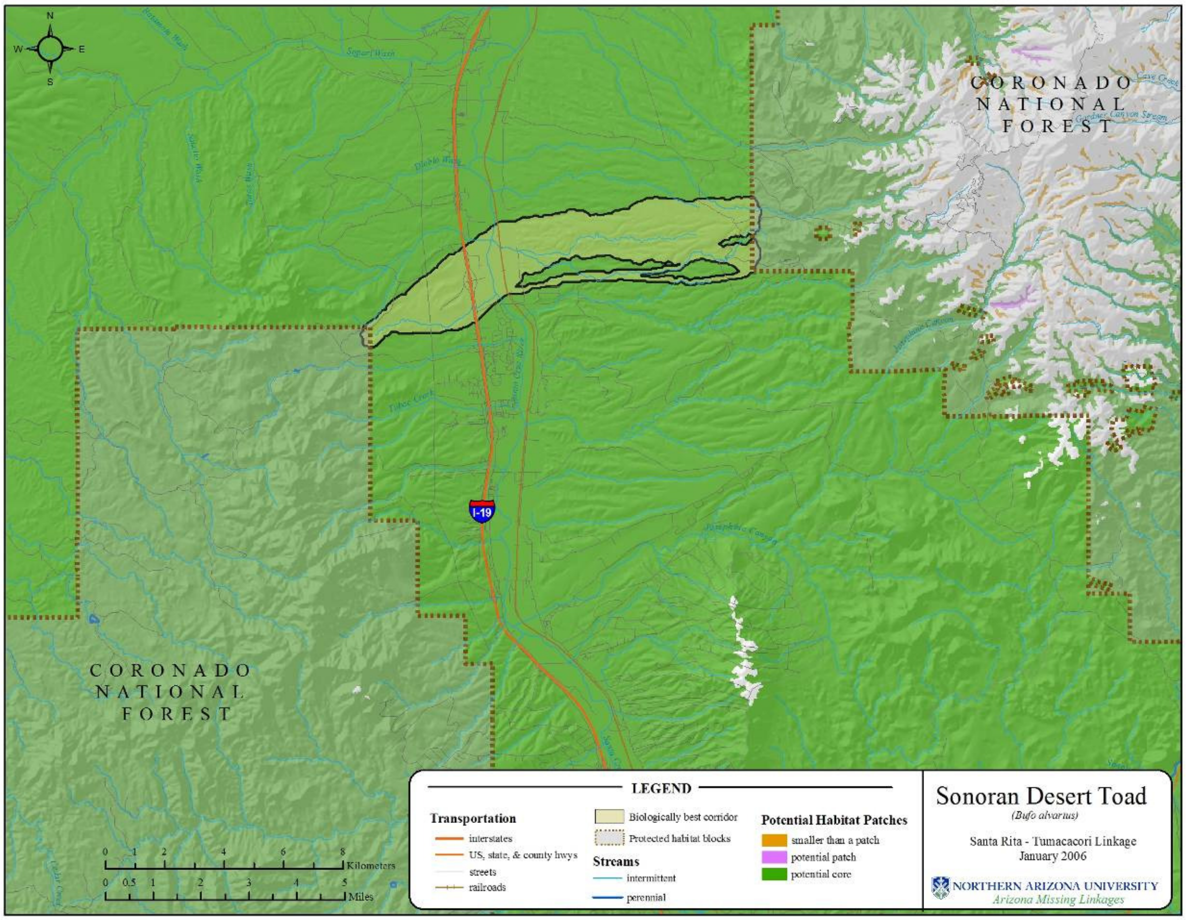



**Figure 57: Potential habitat patches and cores for Sonoran desert toad**

*Union of biologically best corridors* – The union of biologically best corridors adds additional optimal habitat to the biologically best corridor for the Sonoran desert toad. While the entire linkage area was modeled as a potential habitat core, it is important to note that because breeding is naturally concentrated in canyons and upper bajada intermittent streams and on valley floors in major pools, but not naturally frequent on intervening bajadas, these areas are particularly important for this species. With stock ponds, breeding can occur anywhere on the landscape, but valley centers and canyons likely remain as the core areas.

# Sonoran Whipsnake (*Masticophis bilineatus*)

### Justification for Selection
Wide-ranging, active, diurnal snakes including whipsnakes and racers are usually observed to disappear when urban road networks become dense, and the assumption is that road mortality plays a large roll. However, coachwhips are still found on the Tucson Fotthills bajada, suggesting a small tolerance for roads (Phil Rosen, personal comm.).

### Distribution
The Sonoran whipsnake is mainly found in the Sonoran desert of Mexico, but also occurs within southern Arizona and New Mexico.

### Habitat Associations
This species tends to prefer areas with rugged topography, and will also use mid-to-high elevation riparian flats. This species is mobile, may occur along or move along desert and grassland washes, and thus might occasionally traverse areas of flat non-habitat between mountains, like some other larger reptiles. Preferred land cover types include Encinal, Pine-Oak Forest, Pinyon-Juniper Woodland, Chaparral, Creosotebush - Mixed Desert and Thorn Scrub, and Paloverde-Mixed-Cacti Desert Scrub.

### Spatial Patterns
Home range has been estimated as 50 ha for this species (Parizek et al. 1995). Little is know about dispersal distance, but a telemetry study found one large male to move up to 1 km per day (Parizek et al. 1995). Based on observations of other whipsnakes, movement events of up to 4.5 km may be feasible (Phil Rosen, 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 10%, 45%, and 15%, respectively. For specific scores of classes within each of these factors, see Table 4.

*Patch size & configuration analysis* – Minimum potential habitat patch size was defined as 50 ha, and minimum potential core size was defined as 250 ha (Parizek et al. 1995; 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* – Nearly all habitat within the linkage zone was calculated as suitable (cost < 5), so the standard habitat suitability model was used in the corridor analysis.

### Results & Discussion
*Initial biologically best corridor* – Modeling results indicate ample suitable habitat for this species within the potential linkage area (Figure 58). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.0 to 5.2, with an average suitability of 2.3 (S.D: 0.6). The entire corridor is a potential habitat core, so Sonoran whipsnake should be able to disperse through this corridor (Figure 59). While there seems to be a lot of potential habitat for this species, our model may have overestimated

the amount of suitable habitat, because the species only likes flat areas in mid-high elevation riparian flats.

The corridor for this species runs the northeastern corner of the Tumacacori wildland block to the western edge of the Santa Rita wildland block. Found within the corridor are several unnamed washes.

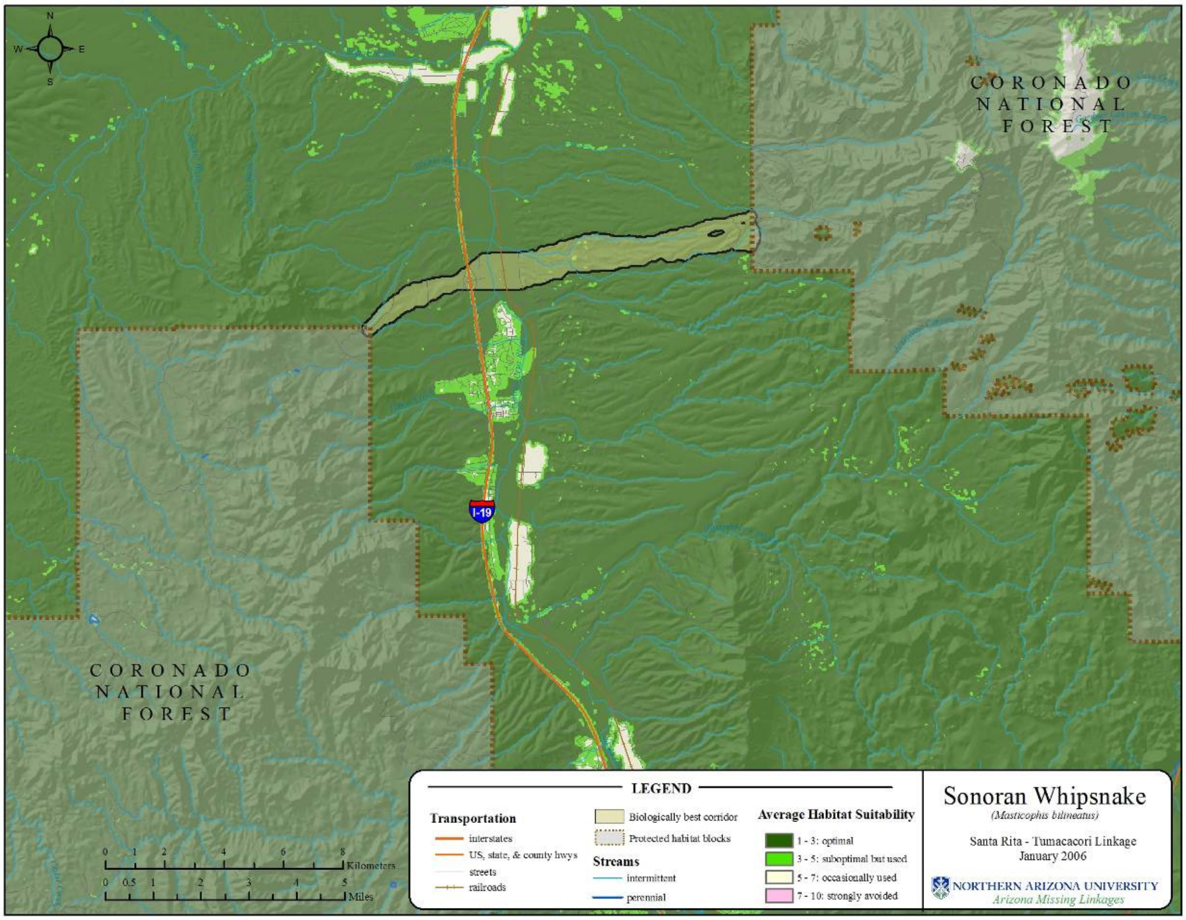



**Figure 58: Modeled habitat suitability of Sonoran whipsnake**

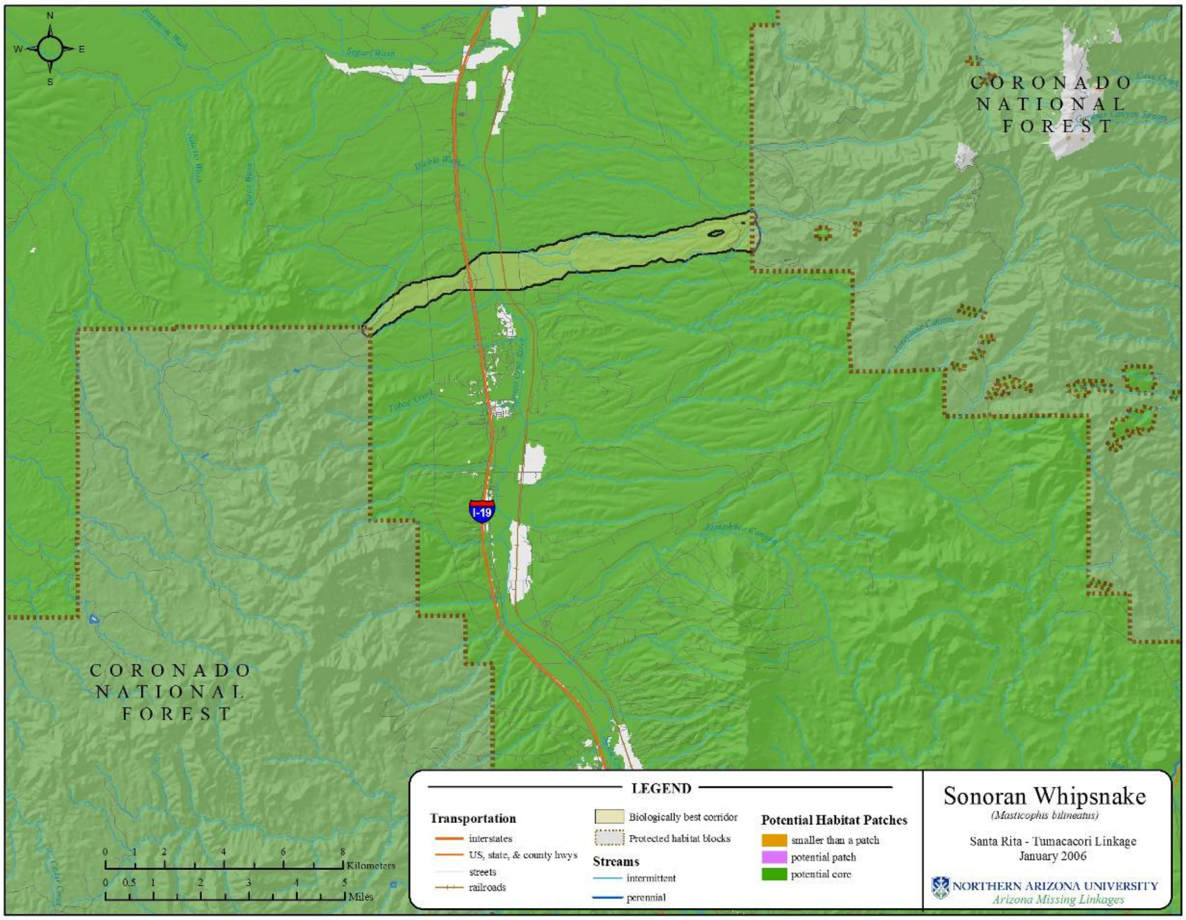



**Figure 59: Potential habitat patches and cores for Sonoran whipsnake**

*Union of biologically best corridors* – While the amount of suitable habitat may have been overestimated for this species due to the classification of lower-elevation flats as suitable, the union of biologically best corridors provides expanded areas of rugged topography which could be used by this species. The Santa Cruz River found within the UBBC also provides potential habitat for this species.

# Tiger Rattlesnake (*Crotalus tigris*)

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

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

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

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

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

*Patch size & configuration analysis* – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

*Biologically best corridor analysis* – Because potential habitat was patchily distributed, we re-assigned all 'suitable' habitat (cost < 5) a cost of 1 to encourage the biologically best corridor to capture this available habitat and avoid unsuitable land.

## Results & Discussion

*Initial biologically best corridor* – Modeling results indicate a fair amount of suitable habitat within the linkage area, due to the topography of the linkage area (Figure 60). Within the biologically best corridor for this species, the average habitat suitability ranged from 1.2 to 7.9, with an average suitability of 3.7 (S.D: 1.5). The farthest distance between a potential patch and another patch or core within the corridor was approximately 500 m (Figure 61), which should be short enough to allow this species to traverse between wildland blocks.

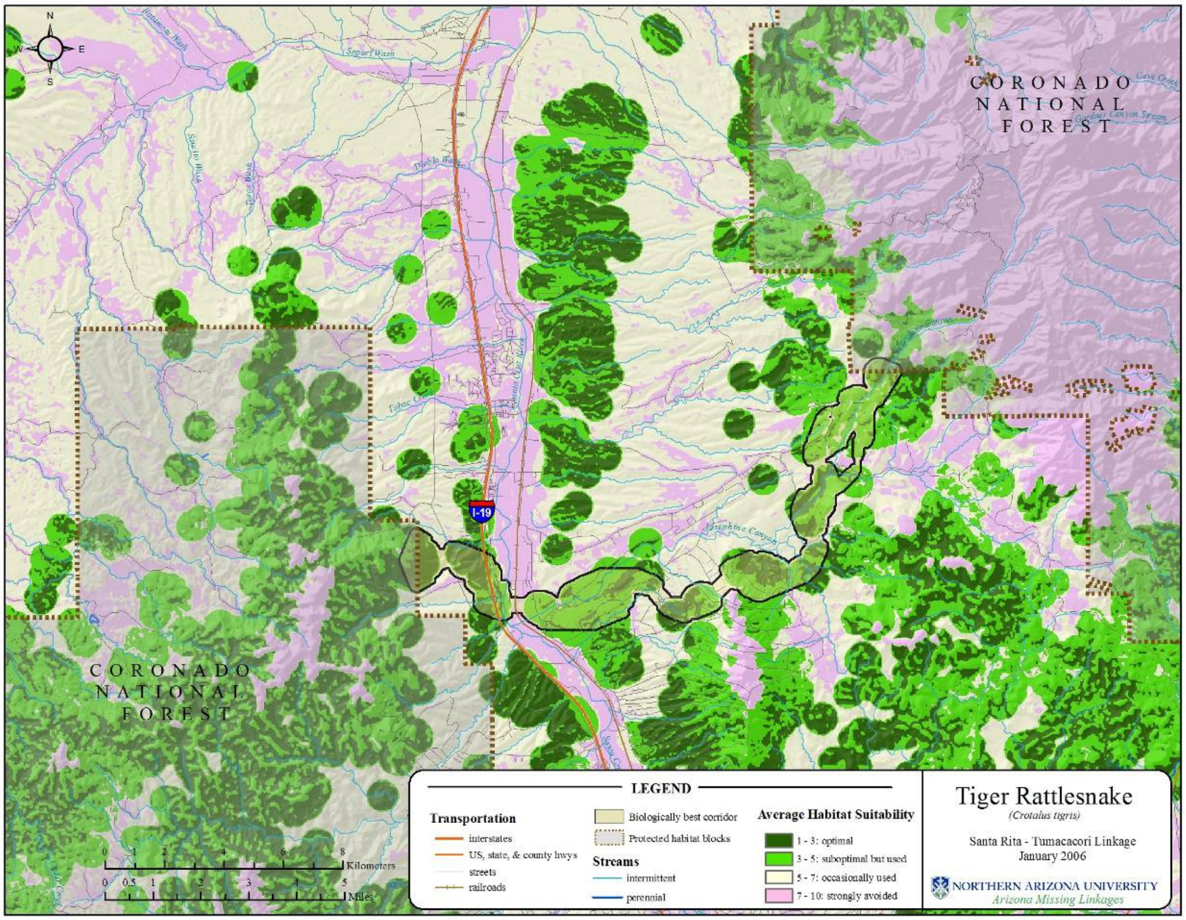



**Figure 60: Modeled habitat suitability of tiger rattlesnake**

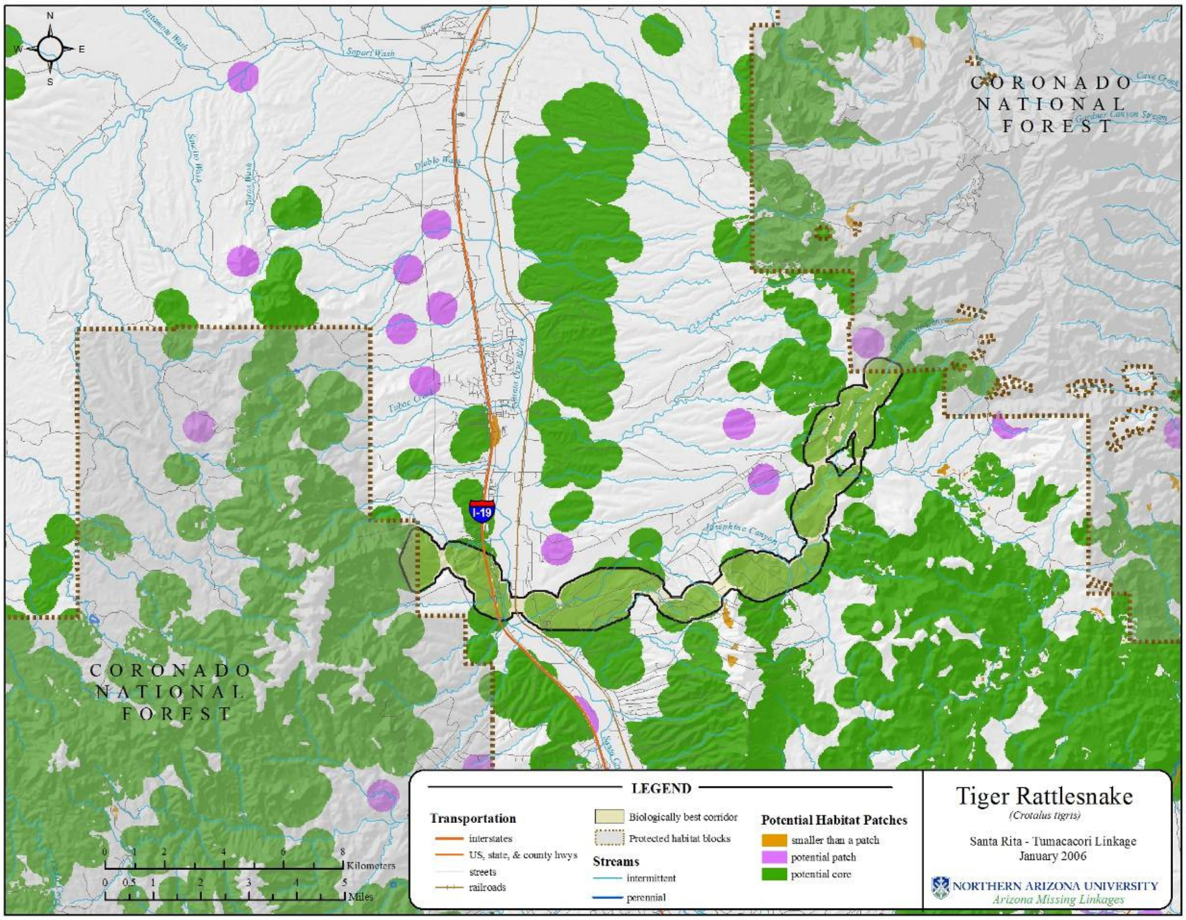



**Figure 61: Potential habitat patches and cores for tiger rattlesnake**

*Union of biologically best corridors* – The union of biologically best corridors provides the tiger rattlesnake with an expanded amount of optimal habitat, particularly in the southernmost strand of the Linkage Design. Due to the recent residential development in the San Cayetano Mountains region and this species' limited dispersal capability, ecological connectivity for this species may be difficult to maintain.

# Gila topminnow (*Poeciliopsis occidentalis occidentalis*)


## Justification for Selection

The Gila topminnow is listed as endangered by the U.S. Fish and Wildlife Service, and is a Wildlife of Special Concern in Arizona (U.S. Fish and Wildlife Service 2001; Arizona Game and Fish Department 2001). Gila topminnow has gone from being one of the most common fishes of the Gila basin to one that exists at not more than 30 localities (12 natural and 18 stocked). Many of these localities are small and highly threatened.

Threats to this species include habitat modification, habitat destruction from groundwater pumping, water impoundment and diversion, water pollution, and stream channelization (U.S. Fish and Wildlife Service 2001; Arizona Game and Fish Department 2001). Another threat to this fish is introduction and spread of non-native species such as the largemouth bass, bullfrog, western mosquitofish, bullhead catfish, bluegill, and black crappie (U.S. Fish and Wildlife Service 2001, NatureServe 2005). Also, grazing pressures in the Gila topminnow's habitat leads to incision of stream channels, which reduces the quantity and quality of natural stream waters (NatureServe 2005).

## Distribution

The Gila topminnow historically was one of the most common fish in the Gila River drainage of Arizona and New Mexico, and its range also extended into Sonora, Mexico (U.S. Fish and Wildlife Service 2001, Arizona Game and Fish Department 2001). Currently, this species only occurs only in Arizona and Mexico in isolated populations (U.S. Fish and Wildlife Service 2001). Specifically, occurrences include one locality in the Bill Williams River drainage, and several localities in the Gila River drainage, some of which are re-introduced populations (U.S. Fish and Wildlife Service 2001, Arizona Game and Fish Department 2001). Most of the remaining native populations in Arizona exist in the Santa Cruz River system (U.S. Fish and Wildlife Service 2001).

## Habitat Associations

Gila topminnows live in shallow, warm water areas of small streams, cienegas, and springs that have aquatic vegetation and debris for cover (U.S. Fish and Wildlife Service 2001). They are also able to exist in backwater areas of intermittent streams and marshes (Arizona Game and Fish Department 2001, NatureServe 2005). Associated plant communities include cottonwood, willow, and burrobrush riparian areas of deserts and grasslands (Arizona Game and Fish Department 2001; NatureServe 2005). The Gila topminnow occurs at elevations from 1,320 – 7,510 feet (403-2,291 m), but prefers elevations below 5,000 feet (Arizona Game and Fish Department 2001).

## Spatial Patterns

Distinct occurrences are grouped by spring systems that are undivided by barriers, or a separation distance of 10 aquatic km. for individual populations, regardless of habitat quality (NatureServe 2005).

## Results & Discussion

Because this species is 100% dependent on aquatic habitat, we did not perform habitat or corridor modeling. All locations of perennial water along the Santa Cruz River must be conserved for persistence of this species.

# Longfin Dace (*Agosia chrysogaster*)

## Justification for Selection

The longfin dace is vulnerable to human activities that alter the quality or flow of water, especially flood control and irrigation practices (Arizona Game and Fish Department 2002). Changes in water flow can cause massive mortalities amongst individual populations (Arizona Game and Fish Department 2002). They are also threatened by interactions with non-native fish species and habitat alterations caused by dewatering, stream diversion, dam construction, groundwater pumping, and channel and watershed erosion (NatureServe 2005). The longfin dace is listed as BLM Sensitive, and is threatened in Mexico (Arizona Game and Fish Department 2002).

## Distribution

The Longfin dace is found in southern New Mexico and Arizona, and is native to the Gila, Bill Williams, Yaqui, Magdalena, and Sonoyta drainages (Arizona Game and Fish Department 2002). This species has been introduced into the Virgin River basin, Arizona and the Zuni, Mimbres, and Rio Grande Rivers in New Mexico (Arizona Game and Fish Department 2002).

## Habitat Associations

Longfin daces live in varied habitats, from intermittent hot low-desert streams to clear, cool brooks at higher elevations (Arizona Game and Fish Department 2002). They tend to occupy small streams with gravelly or sandy bottoms (Arizona Game and Fish Department 2002). Adjacent plant communities to streams occupied by longfin dace are varied, from desert scrub to the lower end of conifer woodlands (Arizona Game and Fish Department 2002). Elevation ranges are 1,360 – 6,740 ft. (415 – 2,056m) in Arizona, with most occurrences less than 4,900 ft. (1,500m) (Arizona Game and Fish Department 2002).

## Spatial Patterns

Data on dispersal and other movements are not available, but a separation distance of 10 aquatic kilometers, regardless of habitat quality, is used to identify independent population occurrences (NatureServe 2005).

## Results & Discussion

Because this species is 100% dependent on aquatic habitat, we did not perform habitat or corridor modeling. All locations of perennial water along the Santa Cruz River must be conserved for persistence of this species.

# Southwestern Willow Flycatcher (*Empidonax traillii extimus*)


## Justification for Selection

Southwestern willow flycatchers have been listed as endangered by the U.S. Fish and Wildlife Service since 1995, with critical habitat designated in 1997 (Arizona Game and Fish Department 2002; U.S. Fish and Wildlife Service 2004). Southwestern willow flycatchers are also designated Forest Service Sensitive, and are listed as a Species of Special Concern in Arizona (Arizona Game and Fish Department 2002). Major causes of decline include loss and modification of riparian habitat as a result of agricultural and urban development, river and stream impoundments, ground water pumping, and flood control projects (U.S. Fish and Wildlife Service 2004). The southwestern willow flycatcher's habitat is also threatened by diversion of water from streams, draining of wetlands, canal construction, livestock grazing, off-road vehicle use, and invasion of exotic tamarisk (Arizona Game and Fish Department 2002).

## Distribution

The southwestern willow flycatcher's historical range includes southern California east to western Texas, and from southern Nevada and southern Utah south through Arizona to extreme northwestern Mexico (U.S. Fish and Wildlife Service 2004). This species has been extirpated throughout much of its historic range, with only remnant populations remaining in historic locations. In Arizona, southwestern willow flycatchers are found locally near the mouth of the Little Colorado River in the Grand Canyon, the Colorado River south of Yuma, the headwaters of the Little Colorado River, and very locally along the middle Gila, Salt, and Verde Rivers. (Arizona Game and Fish Department 2002). Local populations also exist on the middle to lower San Pedro River, Cienega Creek, Pinal Creek, Tonto Creek, and the upper San Francisco River (Arizona Game and Fish Department 2002; U.S. Fish and Wildlife Service 2004). This bird winters in the rain forests of Mexico, Central America, and northern South America (U.S. Fish and Wildlife Service 2004).

## Habitat Associations

Southwestern willow flycatchers are riparian obligate, and occur in dense riparian habitats along rivers, streams, and wetlands where cottonwood, willow, boxelder, tamarisk, Russian olive, arrowweed, and buttonbrush are present (U.S. Fish and Wildlife Service 2004). They prefer dense canopy cover, a large volume of foliage, and surface water during midsummer, but avoid steep, closed canyons (Arizona Game and Fish Department 2002). Southwestern willow flycatchers are found at elevations up to 9,180 feet in Arizona (Arizona Game and Fish Department 2002).

## Spatial Patterns

Southwestern willow flycatchers are known to move between patches of habitat in their breeding range from year to year. One Arizona Game and Fish study of a southeastern Arizona population reported an average movement distance for individuals of 18.2 km (range: 0.55 – 57.67 km) (Munzer et al. 2005).

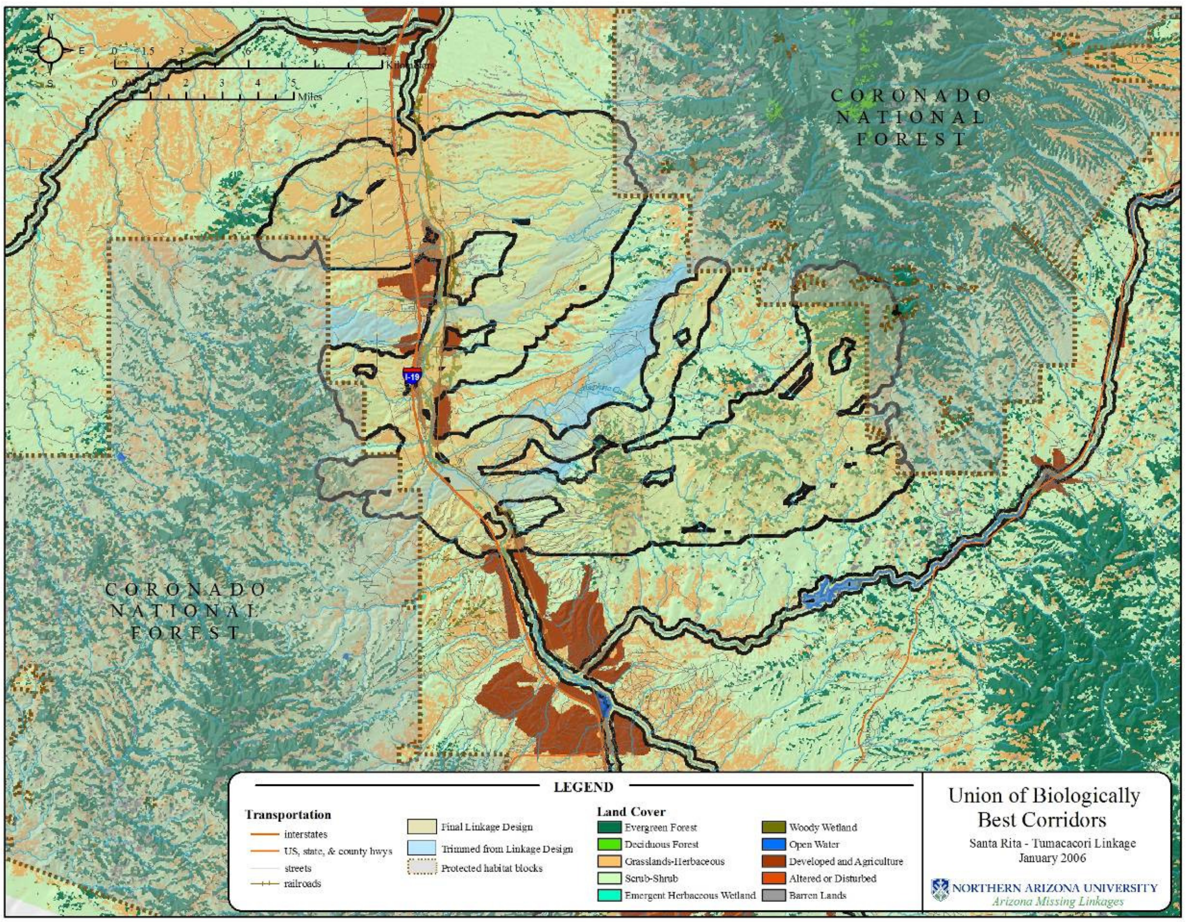
## Conceptual Basis for Model Development

Because this species is dependent on riparian vegetation, we did not perform habitat or corridor modeling. To maintain habitat connectivity for this species, it is crucial to follow the riparian recommendations outlined in the Linkage Design chapter.

# Appendix C: Creation of Final Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, with several modifications:

- For Arizona gray squirrel, we used only the southern strand, because it was significantly better than the northern strand for the species.
- We used only the southern strand of the biologically best corridor for black bear, because the southern strand was noticeably better than the northern strand.
- We used only the northern strand of the biologically best corridor for mountain lion, because all three corridors for this species were similar in habitat composition, and the northernmost strand was most unfettered by development.
- We used only the northern strand of the biologically best corridor for porcupine.



# Appendix D: 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, taken largely from the document, Landcover Descriptions for the Southwest Regional GAP Analysis Project (Available from http://earth.gis.usu.edu/swgap)*

**EVERGREEN FOREST (4 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.

Conifer-Oak Forest and Woodland – This system occurs at the upper elevations in the Sierra Madre Occidentale and Sierra Madre Orientale. In the U.S., it is restricted to north and east aspects at high elevations (1980-2440 m) in the Sky Islands (Chiricahua, Huachuca, Pinaleno, Santa Catalina, and Santa Rita mountains) and along the Nantanes Rim. The vegetation is characterized by large- and small-patch forests and woodlands dominated by *Pseudotsuga menziesii, Abies coahuilensis*, or *Abies concolor* and Madrean oaks such as *Quercus hypoleucoides* and *Quercus rugosa*. It is similar to Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland

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

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

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

**DECIDUOUS FOREST (1 CLASS) –** 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 shed foliage simultaneously in response to seasonal change.

Aspen Forest and Woodland – Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions. Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand, and secondarily is limited by the length of the growing season or low temperatures. These are upland forests and woodlands dominated by *Populus tremuloides* without a significant conifer component (<25% relative tree cover).

**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.

<u>Juniper Savanna</u> – 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.

<u>Semi-Desert Grassland and Shrub Steppe</u> – 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 (7 CLASSES)** – Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

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

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

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

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.

Stabilized Coppice Dune and Sand Flat Scrub – This ecological system includes the open shrublands of vegetated coppice dunes and sandsheets found in the Chihuahuan Desert. Usually dominated by *Prosopis glandulosa* but includes *Atriplex canescens, Ephedra torreyana, Ephedra trifurca, Poliomintha incana*, and *Rhus microphylla* coppice sand scrub with 10-30% total vegetation cover. *Yucca elata, Gutierrezia sarothrae*, and *Sporobolus flexuosus* are commonly 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.

**EMERGENT HERBACEOUS WETLAND (1 CLASS)** – Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Arid West Emergent Marsh – This widespread ecological system occurs throughout much of the arid and semi-arid regions of western North America. Natural marshes may occur in depressions in the landscape (ponds, kettle ponds), as fringes around lakes, and along slow-flowing streams and rivers (such riparian marshes are also referred to as sloughs). Marshes are frequently or continually inundated, with water depths up to 2 m.

**BARREN LANDS (4 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.

Bedrock Cliff and Outcrop – This ecological system is found from subalpine to foothill elevations and includes barren and sparsely vegetated landscapes (generally <10% plant cover) of steep cliff faces, narrow canyons, and smaller rock outcrops of various igneous, sedimentary, and metamorphic bedrock types. Also included are unstable scree and talus slopes that typically occur bellow cliff faces. Species present are diverse and may include *Bursera microphylla, Fouquieria splendens, Nolina bigelovii, Opuntia bigelovii*, and other desert species, especially succulents. Lichens are predominant lifeforms in some areas. May include a variety of desert shrublands less than 2 ha (5 acres) in size from adjacent areas.

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.

Warm Desert Pavement – This ecological system occurs throughout much of the warm deserts of North America and is composed of unvegetated to very sparsely vegetated (<2% plant cover) landscapes, typically flat basins where extreme temperature and wind develop ground surfaces of fine to medium gravel coated with "desert varnish." Very low cover of desert scrub species such as *Larrea tridentata* or *Eriogonum fasciculatum* is usually present. However, ephemeral herbaceous species may have high cover in response to seasonal precipitation, including *Chorizanthe rigida, Eriogonum inflatum*, and *Geraea canescens*.

**ALTERED OR DISTURBED (1 CLASSES) –**

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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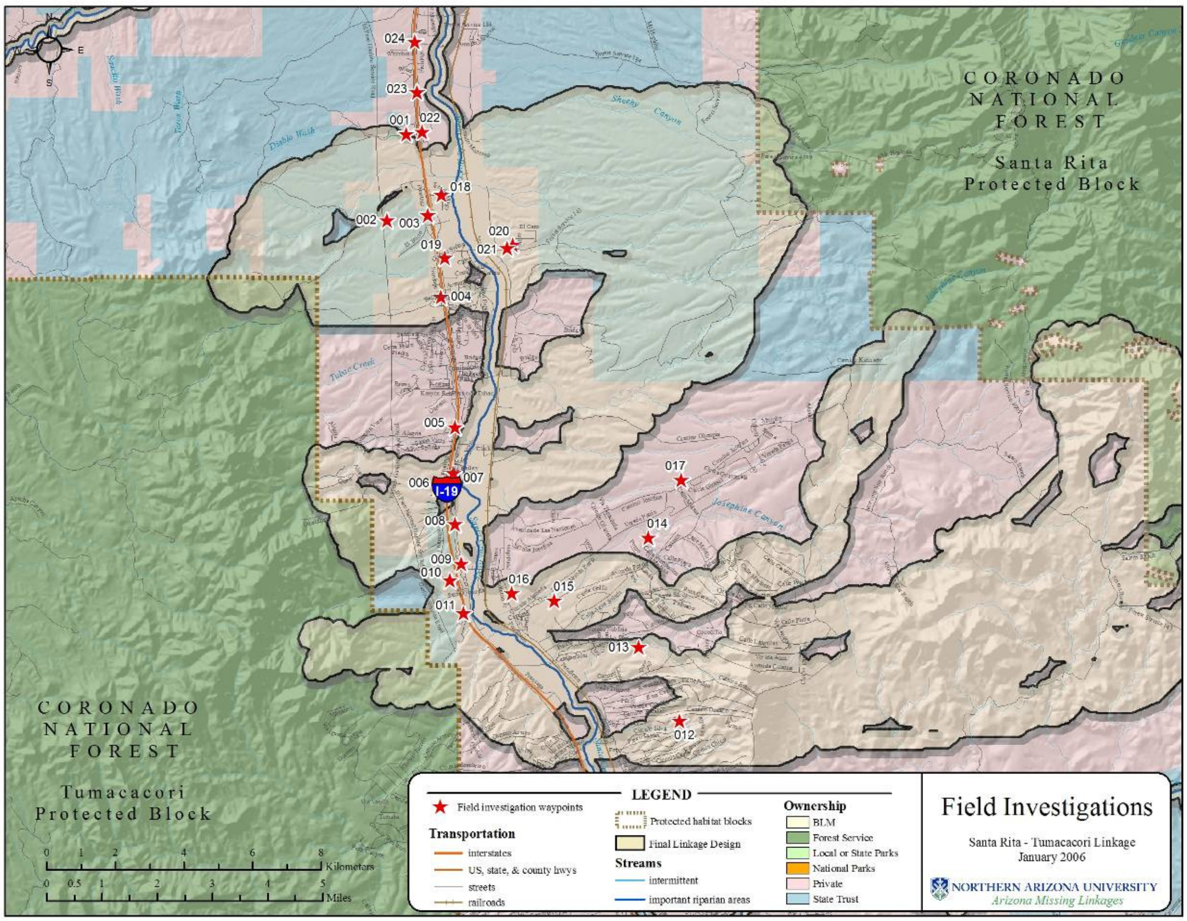
## Appendix F: Database of Field Investigations

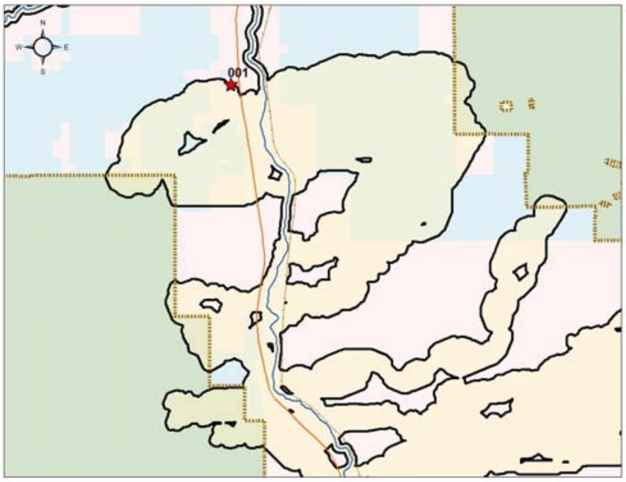
Attached is a database of field notes, GPS coordinates, and photos collected as part of our field investigations of this linkage zone. The database is found as an MS Access database on the CD-ROM accompanying this report. This database is also an ArcGIS 9.1 Geodatabase which contains all waypoints within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



# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 001 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.67645604 | **Longitude:** | -111.067466 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 493605.2126 | **UTM Y:** | 3504576.177 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

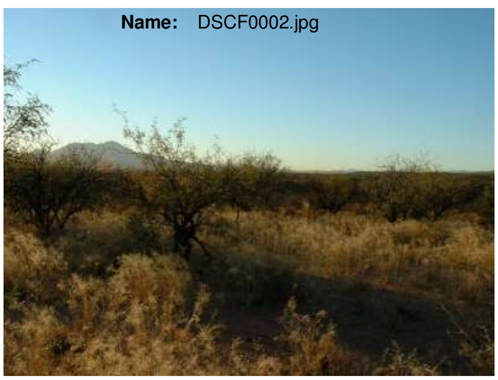
## Waypoint Map




## Waypoint Notes

This point shows Mesquite/grass vegetation associations.

## Site Photographs



**Name:** DSCF0002.jpg

**Zoom:** 1x

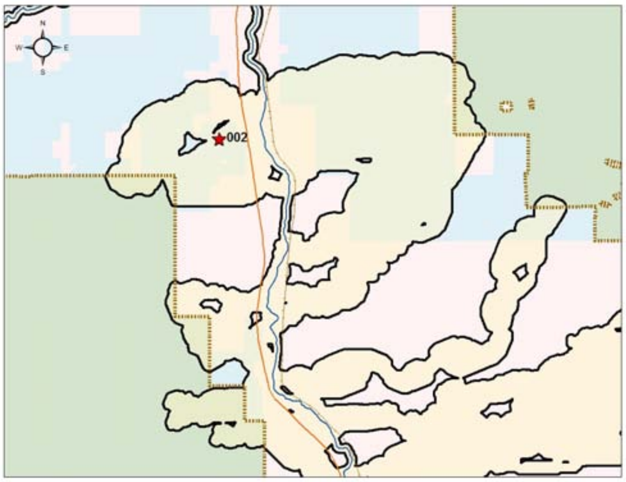
**Name:** DSCF0003.jpg

**Zoom:** 1x

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 002 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.65391107 | **Longitude:** | -111.073383 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 493042.6428 | **UTM Y:** | 3502077.730 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

## Site Photographs

**Name:** DSCF0004.jpg

**Azimuth:** 215 **Zoom:** 1x

**Notes:** This image shows the major peak in the Tumacacori Mountains

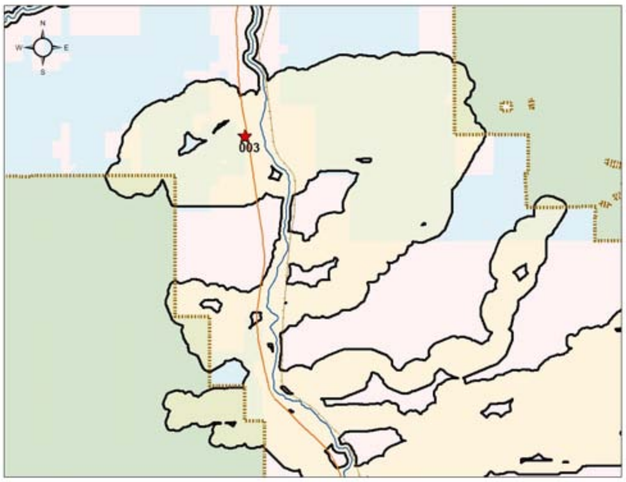
**Name:** DSCF0005.jpg

**Azimuth:** 76 **Zoom:** 1x

**Notes:** This image shows the tallest visible peak in the Santa Ritas.

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 003 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.65525025 | **Longitude:** | -111.060696 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494245.6018 | **UTM Y:** | 3502225.422 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Two box culverts - approx. 6x8 ft each. Concrete bottom. Height of culverts has been decreased to approx. 4.5 ft due to sediment. Approx. 80 m long. Some animal tracks lead in and out of culverts, possibly javelina. Lizards spotted along east end of culvert walls. A similar culvert to this is also placed on the Frontage road.

## Site Photographs

**Name:** DSCF0006.jpg

**Azimuth:** 78 **Zoom:** 1x

**Notes:** Culvert under I-19, Santa Rita Mtns pictured in background

**Name:** DSCF0007.jpg

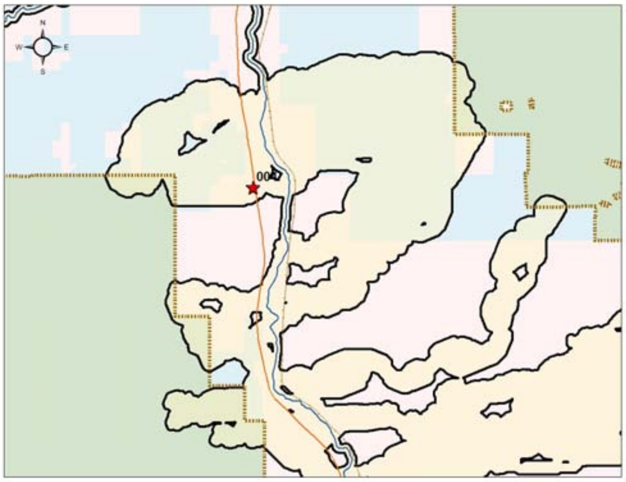
**Azimuth:** 260 **Zoom:** 1x

**Notes:** Culvert, on opposite side of road as image DSCF0007; looking west from east end of culvert

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 004 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.63366978 | **Longitude:** | -111.056694 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494623.7325 | **UTM Y:** | 3499833.319 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

6 box culverts under I-19, each approx. 7x9 ft, Length measured approx. 60 m using rangefinder.

## Site Photographs

**Name:** DSCF0008.jpg

**Azimuth:** 90 **Zoom:** 1x

**Notes:** Box culverts, Santa Rita peak in background.

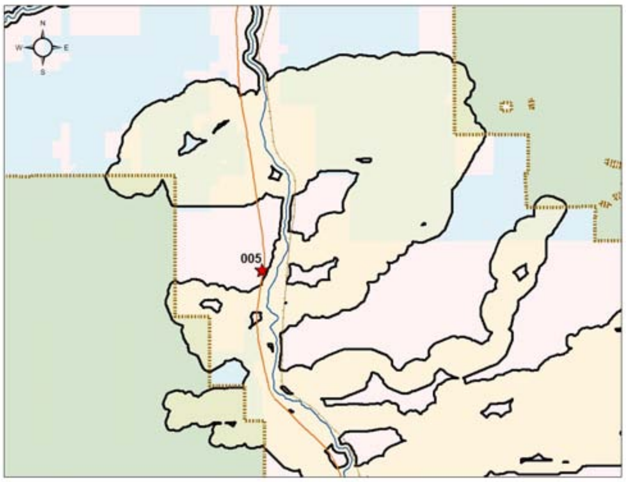
**Name:** DSCF0009.jpg

**Azimuth:** 244 **Zoom:** 1x

**Notes:** Looking upstream from box culverts

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 005 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.59947379 | **Longitude:** | -111.052465 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 495023.0008 | **UTM Y:** | 3496042.979 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Recent development on east side of I-19, through potential linkage area.

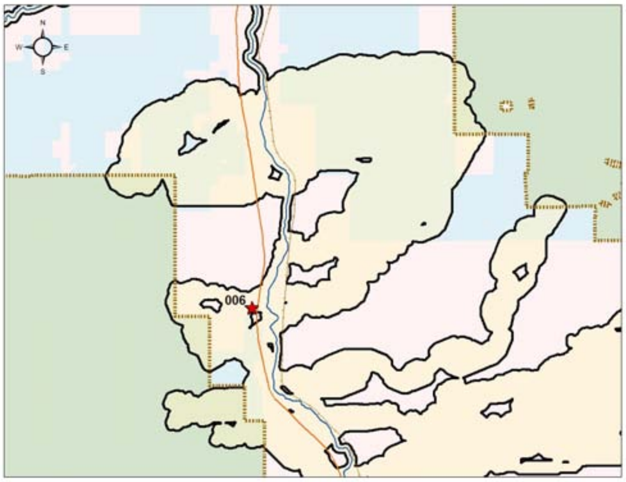
## Site Photographs

**Name:** DSCF0012.jpg

**Azimuth:** 62 **Zoom:** 1x

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 006 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.58370174 | **Longitude:** | -111.057247 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494568.3966 | **UTM Y:** | 3494295.106 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Mapped roads off of W. Frontage Rd. are all driveways, each serving 1 home, and occasionally 2 homes. Each wash in this area is a steep-sloped draw, and seems to cross I-19 via a pipe culvert in fill slope. Photos taken from small rise on paved driveway.

## Site Photographs

**Name:** DSCF0013.jpg

**Azimuth:** 325 **Zoom:** 1x

**Notes:** Low-density upscale homes, apparently on parcels of 5-10+ acres.

**Name:** DSCF0014.jpg

**Azimuth:** 67 **Zoom:** 1x

**Notes:** Across I-19 to Santa Ritas. Several homes are found on E. Frontage Rd.

**Name:** DSCF0015.jpg

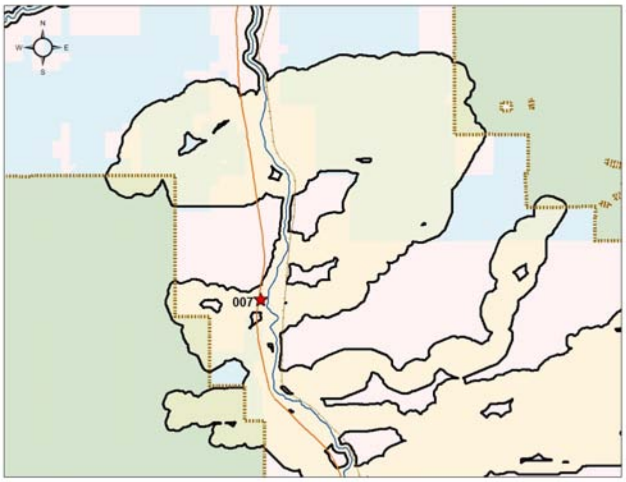
**Azimuth:** 225 **Zoom:** 1x

**Notes:** No obstructions west to Tumacacoris

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 007 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.58747099 | **Longitude:** | -111.052982 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494973.3042 | **UTM Y:** | 3494712.667 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

From Clark's crossing to Old Baiiley Crossing, the village of Carmen AZ extends about 1 block deep towards the Santa Cruz River. All homes are small and old, and many are in poor condition. Santa Cruz River lying behind town was flowing on field survey date.

## Site Photographs

**Name:** DSCF0016.jpg

**Azimuth:** 80 **Zoom:** 1x
**Notes:** View of Carmen

**Name:** DSCF0017.jpg

**Azimuth:** 154 **Zoom:** 1x
**Notes:** View of Carmen

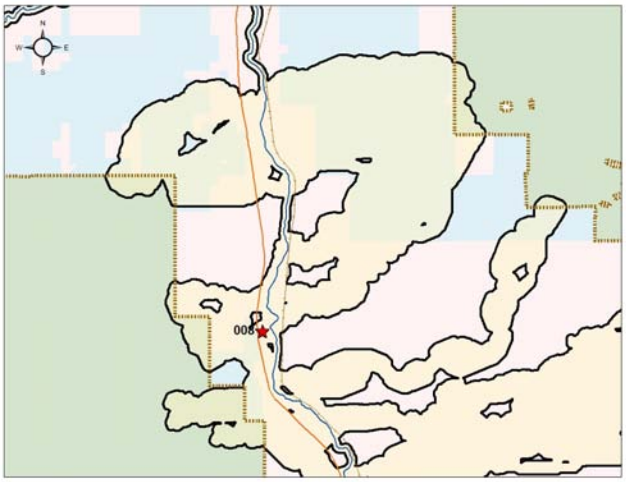
**Name:** DSCF0018.jpg

**Azimuth:** 50 **Zoom:** 1x
**Notes:** Trailer park in Carmen

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 008 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.57394084 | **Longitude:** | -111.052358 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 495031.8081 | **UTM Y:** | 3493213.023 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

North from here, a solid row of small old homes along Frontage Rd. This small wash provides one of the biggest gaps in houses moving South from Carmen

## Site Photographs

**Name:** DSCF0019.jpg

**Azimuth:** 268 **Zoom:** 1x

**Notes:** Taken from south edge of Carmen; North edge of Tumacacori on E. Frontage Rd.

**Name:** DSCF0020.jpg

**Azimuth:** 80 **Zoom:** 1x

**Notes:** Image facing Santa Ritas

**Name:** DSCF0021.jpg

**Azimuth:** 86 **Zoom:** 1x

**Notes:** View of wash. There is a house on either side, about 50m from either side of wash

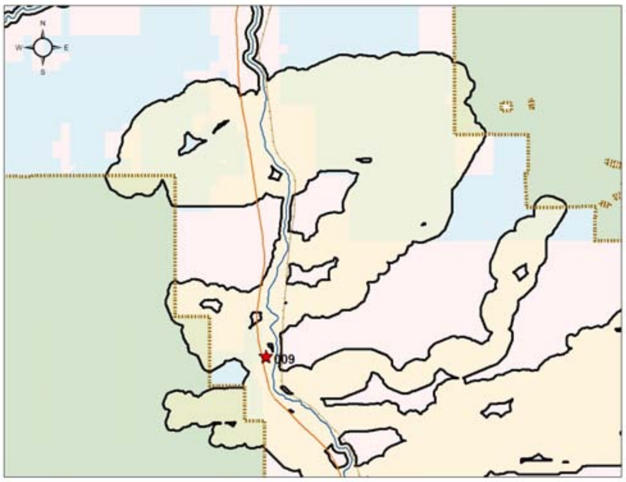
**Name:** DSCF0022.jpg

**Azimuth:** 246 **Zoom:** 1x

**Notes:** Photo shows wash to I-19 & westbound.

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 009 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.5635653 | **Longitude:** | -111.050395 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 495217.5268 | **UTM Y:** | 3492062.963 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

This is apparently the largest gap in homes. Only a couple homes here to I-19 underpass.

## Site Photographs

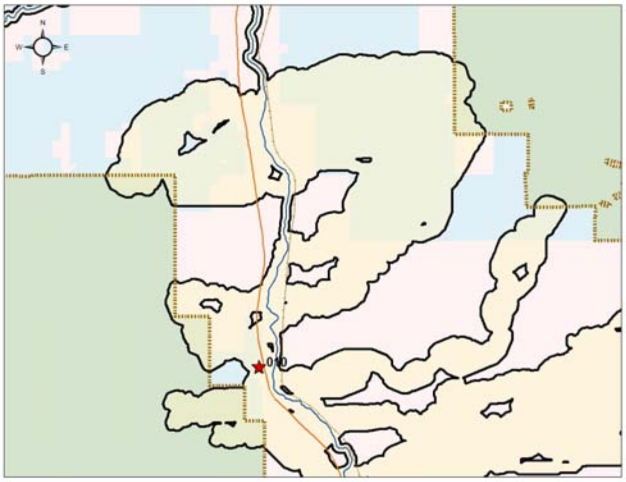
**Name:** DSCF0023.jpg

**Azimuth:** 154 **Zoom:** 1x

**Notes:** Photo was taken a few feet south of Santa Cruz Gift Shop, driving to 1854 Frontage Rd.

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 010 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.5592425 | **Longitude:** | -111.053997 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494875.4728 | **UTM Y:** | 3491584.009 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map



## Waypoint Notes

## Site Photographs

**Name:** DSCF0024.jpg

**Azimuth:** 108 **Zoom:** 1x

**Notes:** Ranchette/rural homes to SE.

**Name:** DSCF0025.jpg

**Azimuth:** 108 **Zoom:** 6x

**Notes:** Zoom photo of DSCF0024

**Name:** DSCF0026.jpg

**Azimuth:** 46 **Zoom:** 1x

**Notes:** Santa Cruz River riparian area. Ranchette development

**Name:** DSCF0027.jpg

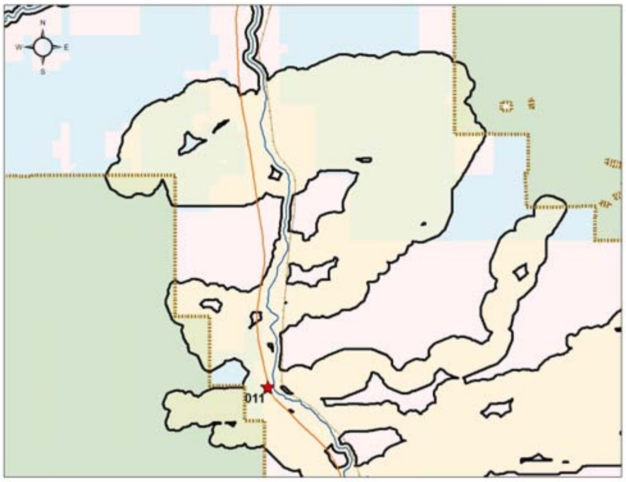
**Azimuth:** 46 **Zoom:** 3x

**Notes:** Zoom photo of DSCF0026.jpg

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 011 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.55066974 | **Longitude:** | -111.04981 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 495272.4224 | **UTM Y:** | 3490633.661 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Large bridged underpass on I-19. 38m wide, approx. 10m in height

## Site Photographs

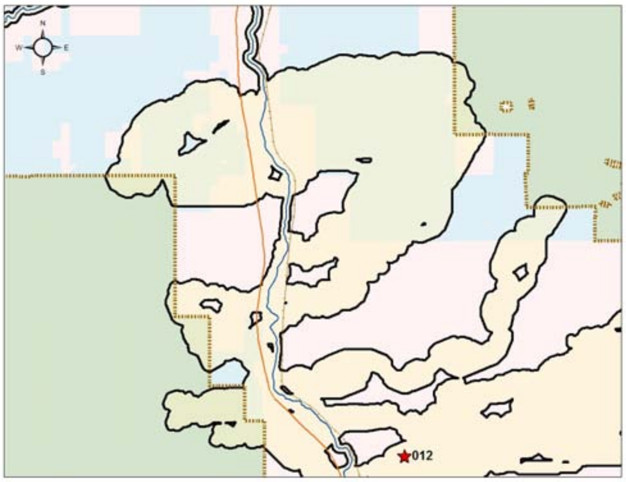
**Name:** DSCF0029.jpg

**Azimuth:** 85 **Zoom:** 1x

**Notes:** Photo taken on Ranch Rd, under I-19.

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 012 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.52226632 | **Longitude:** | -110.983518 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 501564.8309 | **UTM Y:** | 3487484.628 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Low-density housing

## Site Photographs

**Name:** DSCF0030.jpg

**Azimuth:** 300 **Zoom:** 1x

**Notes:** Photo taken in soon-to-be neighborhood off Camino Oceano (Mar) St.

**Name:** DSCF0031.jpg

**Azimuth:** 310 **Zoom:** 6x

**Notes:** Zoom photo of houses in DSCF0030

**Name:** DSCF0032.jpg

**Azimuth:** 188 **Zoom:** 1x

**Notes:** New roads for future development.

**Name:** DSCF0033.jpg

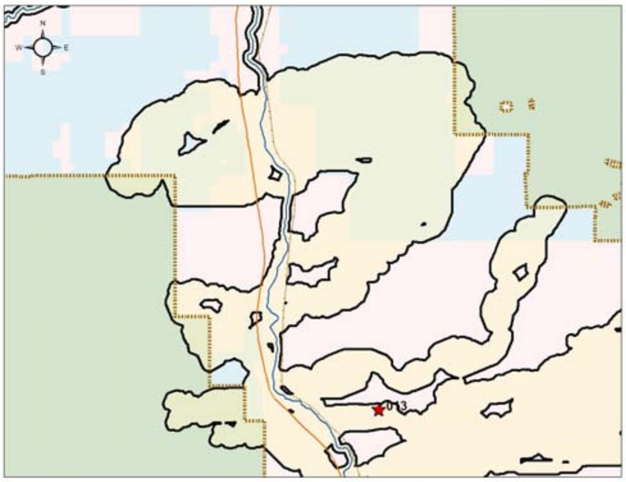
**Azimuth:** 144 **Zoom:** 1x

**Notes:** New roads for future development.

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 013 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.54165861 | **Longitude:** | -110.995974 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 500382.1235 | **UTM Y:** | 3489633.848 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map



## Waypoint Notes

Southern braid of potential linkage

## Site Photographs

**Name:** DSCF0034.jpg

**Azimuth:** 296 **Zoom:** 3x

**Notes:** In flatter areas, parcels are about 0.25 acre. Most lots are note developed yet, but power lines & water lines have been installed along

**Name:** DSCF0035.jpg

**Azimuth:** 38 **Zoom:** 3x

**Notes:** Branch of potential linkage facing towards NE

**Name:** DSCF0036.jpg

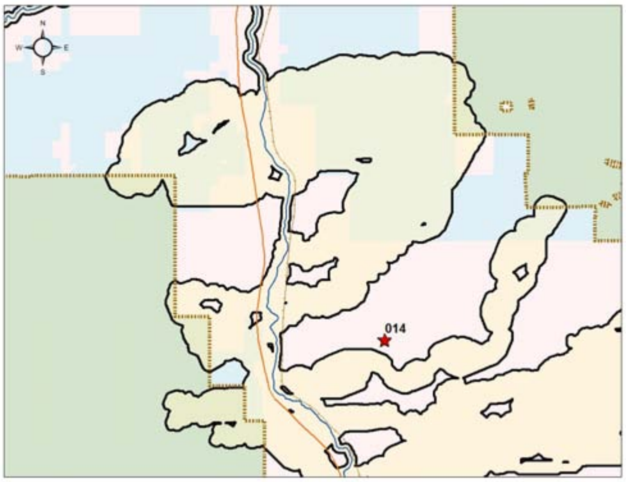
**Azimuth:** 92 **Zoom:** 1x

**Notes:** Facing east along potential linkage zone.

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 014 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.57044651 | **Longitude:** | -110.993002 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 500664.0340 | **UTM Y:** | 3492824.561 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Crossing structure over wash

## Site Photographs

**Name:** DSCF0047.jpg

**Azimuth:** 310 **Zoom:** 1x

**Notes:** Crossing structure over wash - similar crossing structure exists over same wash on Pendleton St.

**Name:** DSCF0048.jpg

**Azimuth:** 322 **Zoom:** 1x

**Notes:** Photo taken standing under bridge, showing NW side of wash

**Name:** DSCF0049.jpg

**Azimuth:** 222 **Zoom:** 1x

**Notes:** Gabions lining area under bridge

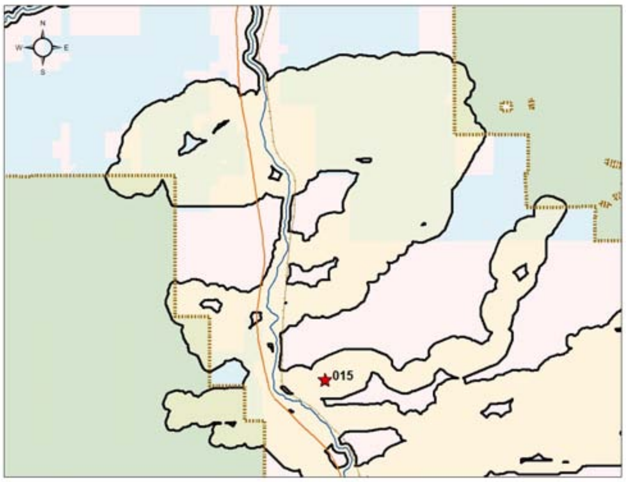
**Name:** DSCF0050.jpg

**Azimuth:** 74 **Zoom:** 1x

**Notes:** Photo taken standing on bridge, showing east side of wash

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 015 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.55396341 | **Longitude:** | -111.021921 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 497919.4732 | **UTM Y:** | 3490997.847 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Gravel mining operation near Josefina Canyon. Company is 'Sand and Gravel Rio Rico Pit,'

## Site Photographs

**Name:** DSCF0051.jpg

**Azimuth:** 48 **Zoom:** 1x

**Linkage #:** 93

**Linkage Zone:** Tumacacori - Santa Rita

**Observers:** Paul Beier, Dan Majka

**Field Study Date:** 1/4/2006

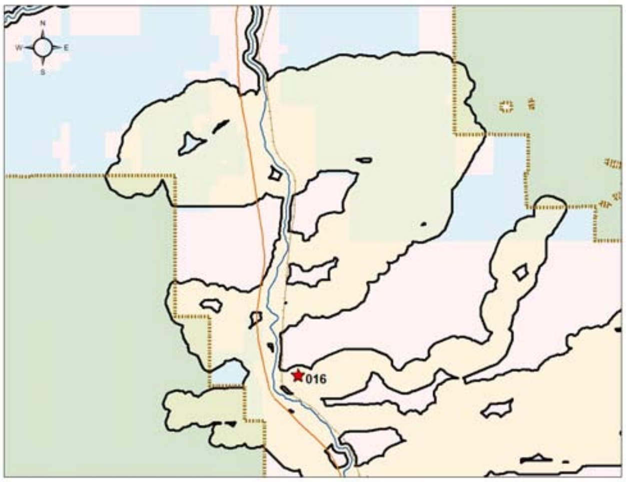
**Waypoint #:** 016

**Latitude:** 31.55576879 **Longitude:** -111.034889

**UTM X:** 496688.7807 **UTM Y:** 3491198.265

**Last Printed:** 5/24/2007

## Waypoint Map




## Waypoint Notes

## Site Photographs

**Name:** DSCF0052.jpg

**Azimuth:** 224 **Zoom:** 1x

**Notes:** Large ranch house north of mouth of Josefina Canyon

**Name:** DSCF0053.jpg

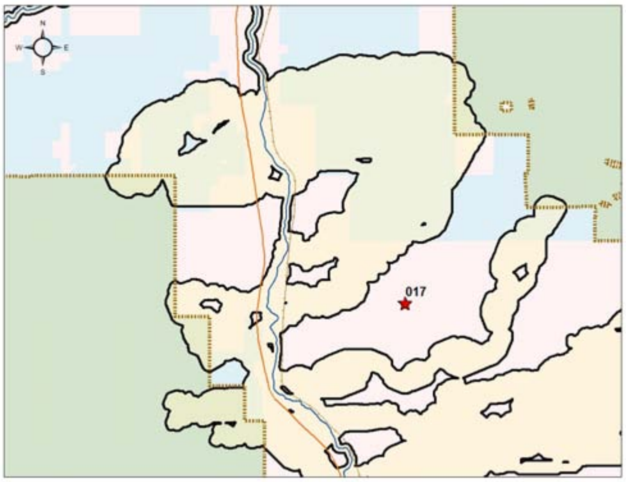
**Azimuth:** 276 **Zoom:** 1x

**Notes:** Overpass on I-19

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 017 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.58563963 | **Longitude:** | -110.983022 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 501610.7968 | **UTM Y:** | 3494508.596 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

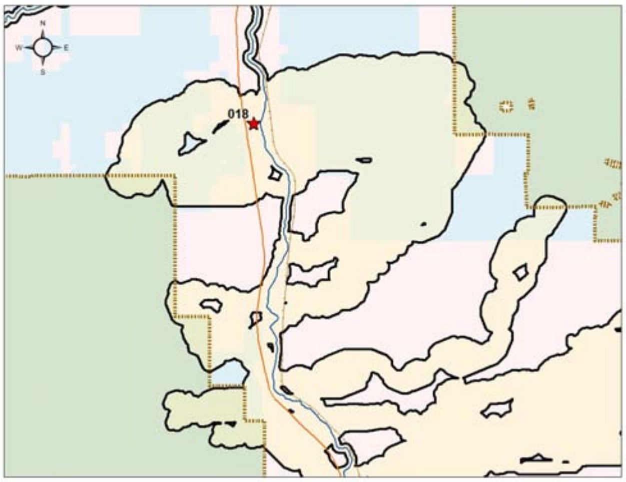
Corner of Josefina & Murphy: Power lines end here. There is a side street approx. every 100 m. west of this point, but only 1 more side street to the east. Power lines and side roads begin again at Morning Star Ranch Rd. to the South. A huge area of power lines extends all the way to Camino Kennedy; also for at least 2 miles along Morning Star Rd. The only access road is Camino de P__(Exit 25 Rd) that has undguarded railroad crossing. All vehicles must ford Santa Cruz River to access these new developments. At least ~5000 lots, but less than 500 built homes in this area. To better understand this development, examination of parcel maps is necessary. NO PHOTOS WERE TAKEN WITH THIS WAYPOINT - SEE PREVIOUS WAYPOINTS DOCUMENTING AREA.

## Site Photographs

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 018 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.66048466 | **Longitude:** | -111.056534 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494640.5083 | **UTM Y:** | 3502805.374 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map



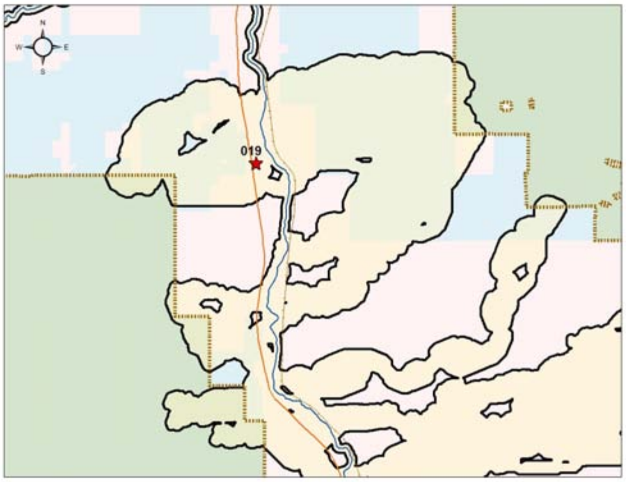

## Waypoint Notes

Property north of this East-West dirt road posted, "Conservation Easment - Tucson Audubon Society." Road then turns south for 1/4 mile. There are about 12 buildings there - most double-wides, small trailers, and converted farm buildings. There are 5 residences , spaced ~ 100m apart. No development on East Frontage Rd. from Chaves Siding Exit 17 to Chaves Siding Rd (1 km). A sign at the junction of Frontage Rd & Chaves Siding Rd says "4.1 acre homesites". NO PHOTOS WERE TAKEN WITH THIS WAYPOINT.

## Site Photographs

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 019 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.64396879 | **Longitude:** | -111.055528 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494734.9081 | **UTM Y:** | 3500974.765 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Junction of E. Circulo Bautista & Chaves Siding Rd. 21 parcels available - 6 sold, none built. No sign of development to north.

## Site Photographs

**Name:** DSCF0054.jpg

**Azimuth:** 324 **Zoom:** 1x

**Notes:** Image taken from junction of E. Circulo Bautista & Chaves Siding Rd.

**Name:** DSCF0055.jpg

**Azimuth:** 16 **Zoom:** 1x

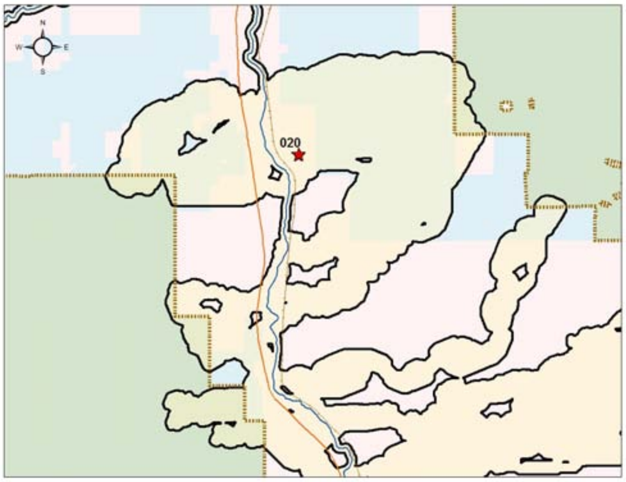
**Name:** DSCF0056.jpg


**Azimuth:** 120 **Zoom:** 1x

**Notes:** Lots for sale - to be a gated community w/ walled yards.

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 020 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.64751115 | **Longitude:** | -111.034666 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 496713.1812 | **UTM Y:** | 3501366.570 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Facing towards Tumacacori Mtns, there are about 12 large lot homes on 10-20 acre parcels on this mesa. Probably permeable to animals. A jackrabbit was seen in this area.

## Site Photographs

**Name:** DSCF0057.jpg

**Azimuth:** 290 **Zoom:** 1x

**Notes:** Taken from SW edge of small mesa with homes

**Name:** DSCF0058.jpg

**Azimuth:** 40 **Zoom:** 1x

**Notes:** House

**Name:** DSCF0059.jpg

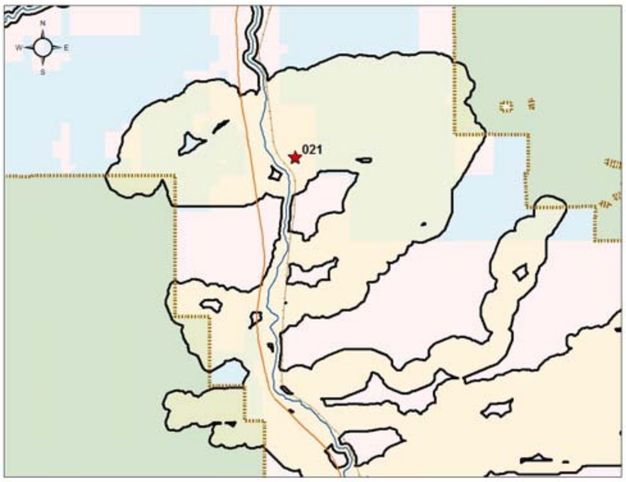
**Azimuth:** 70 **Zoom:** 1x

**Notes:** Santa Ritas across from houses on mesa.

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 021 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.64661898 | **Longitude:** | -111.036381 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 496550.4677 | **UTM Y:** | 3501267.738 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

View NW of Linkage area

## Site Photographs

**Name:** DSCF0060.jpg

**Azimuth:** 268 **Zoom:** 1x
**Notes:** Taken from bend on Cuiton Rd.

**Name:** DSCF0061.jpg

**Azimuth:** 294 **Zoom:** 3x
**Notes:** Lots for sale

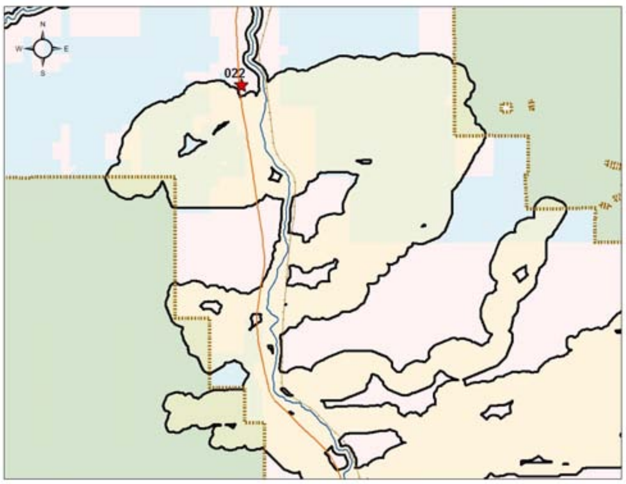
**Name:** DSCF0062.jpg

**Azimuth:** 228 **Zoom:** 3x
**Notes:** Taken from road, east of river

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 022 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.67713339 | **Longitude:** | -111.062588 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 494067.6528 | **UTM Y:** | 3504650.977 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

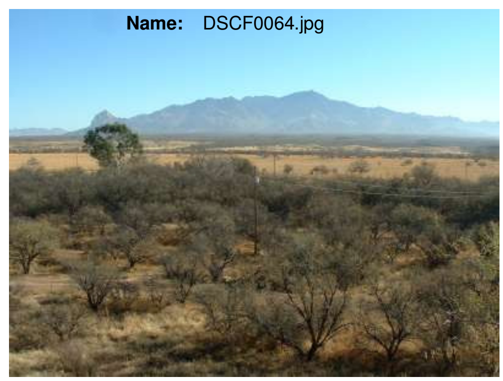
East Frontage Road has 2 abandoned houses and only 1 occupied building - a large rance house at the south end of the road.

## Site Photographs

**Name:** DSCF0063.jpg

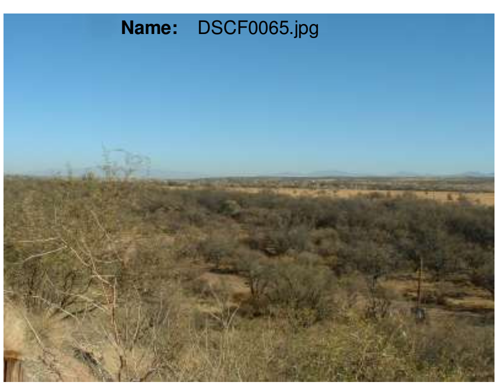
**Azimuth:** 138 **Zoom:** 1x
**Notes:** Linkage area

**Name:** DSCF0064.jpg



**Azimuth:** 80 **Zoom:** 1x
**Notes:** Linkage area

**Name:** DSCF0065.jpg

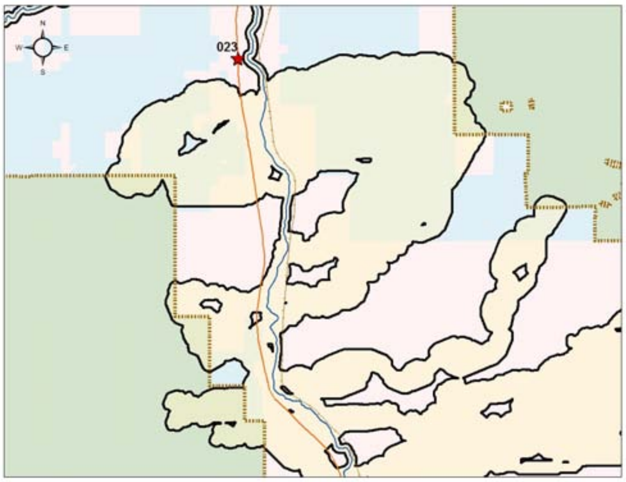


**Azimuth:** 30 **Zoom:** 1x
**Notes:** Linkage area

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 023 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.68745712 | **Longitude:** | -111.064083 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 493926.5666 | **UTM Y:** | 3505795.310 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

Diablo Wash, Santa Rita Mountains. Linkage could expand north to include this. No development to SE of here; one house 150 m NE

## Site Photographs

**Name:** DSCF0066.jpg

**Azimuth:** 106 **Zoom:** 1x

**Notes:** Photo taken from East Frontage Rd. at Diablo Wash, I-19.

**Name:** DSCF0067.jpg

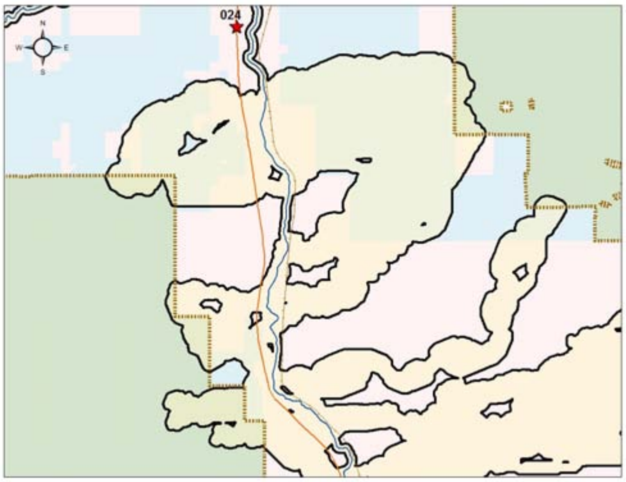
**Azimuth:** 290 **Zoom:** 1x

**Notes:** Five box culverts, approx. 5x10 ft, each cross I-19 and both Frontage Roads. Very long.

# Appendix F: Database of Field Investigations

| | | | | | |
|---|---|---|---|---|---|
| **Linkage #:** | 93 | **Waypoint #:** | 024 | | |
| **Linkage Zone:** | Tumacacori - Santa Rita | **Latitude:** | 31.70073347 | **Longitude:** | -111.064854 |
| **Observers:** | Paul Beier, Dan Majka | **UTM X:** | 493854.4133 | **UTM Y:** | 3507266.866 |
| **Field Study Date:** | 1/4/2006 | **Last Printed:** | 5/24/2007 | | |

## Waypoint Map




## Waypoint Notes

There were a few (approx. 6) small homes spaced on E. Frontage Rd. between waypoints 23 and 24, as well as a few on W. Frontage Rd. More housing & a large RV park are located to the north.

## Site Photographs

**Name:** DSCF0068.jpg

**Azimuth:** 100 **Zoom:** 1x

**Notes:** Photo taken at east Frontage Rd Jct Wash at Amador. Photo shows wash leading to Santa Cruz River.

**Name:** DSCF0069.jpg

**Azimuth:** 266 **Zoom:** 1x

**Notes:** Photo shows culvert under I-19 from East Frontage Road.