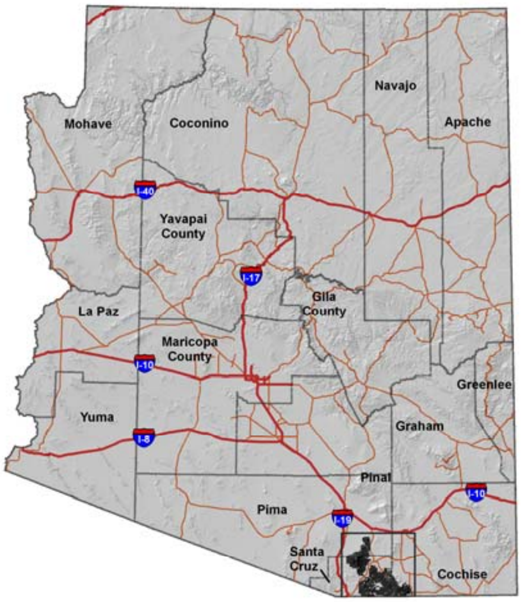
ARIZONA MISSING LINKAGES

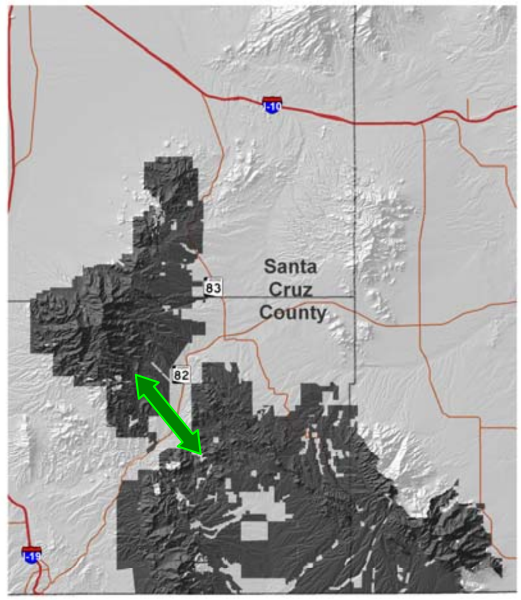
Patagonia – Santa Rita Linkage Design

Paul Beier, Emily Garding, Daniel Majka

2008

PATAGONIA – SANTA RITA LINKAGE DESIGN





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Terminology

Key terminology used throughout the report includes:

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

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

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

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

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

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

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

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

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between two large wildlands administered by the U.S. Forest Service in southeastern Arizona. Arizona State Route 82 (SR-82) Arizona State Route 83 (SR-83), and residential development may impede animal movement between the Santa Rita Mountains and the Patagonia Mountains. These areas represent a large public investment in biological diversity, and this Linkage Design is a reasonable science-based approach to maintain the value of that investment.

To begin the process of designing this linkage, we asked academic scientists, agency biologists, and conservation organizations to identify species sensitive to habitat loss and fragmentation. They identified 22 focal species, including 1 amphibian, 2 reptiles, 6 birds, 4 fish, and 9 mammals (Table 1). These focal species cover a broad range of habitat and movement requirements. Some require huge tracts of land to support viable populations (e.g. mountain lion, jaguar). Some species are habitat specialists (e.g ocelot, longfin dace), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer). Some species are rare and/or endangered (ie. Gila topminnow), while others like mule deer are common but still need gene flow among populations. Others species, like the jaguar, need corridors to reoccupy former range. All the focal species are part of the natural heritage of this mosaic of montane Sky Islands and Sonoran Desert. Together, these 22 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 wildland blocks we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the Linkage Design (Figure 1) provides live-in or move-through habitat for each focal species. The Linkage Design is composed of three strands between the Santa Rita and Patagonia Mountains, plus a riparian strand along Sonoita Creek, which runs northeast to southwest through the linkage planning area. Together, these strands provide habitat for movement and reproduction of wildlife between the Santa Rita and Patagonia wildland blocks. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

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

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

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

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

Table 1: Focal species selected for Patagonia – Santa Rita Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	Chiricahua Leopard Frog	Black-bellied Whistling Duck
*Black Bear	Northern Mexican Gartersnake	Cactus Ferruginous Pygmy-owl
*Coues' White-tailed Deer	Red-backed Whiptail	Common Black Hawk
*Jaguar		Mexican Spotted Owl
*Mexican Gray Wolf		Northern Gray Hawk
*Mountain Lion		Rose Throated Becard
*Mule Deer		**FISH**
Ocelot		Desert Sucker
Yellow-nosed Cotton Rat		Gila Topminnow
		Longfin Dace
		Razorback Sucker

* Species modeled in this report. The other species were not modeled because there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), because the species does not occur in both wildland blocks, or because the species probably can travel (e.g., by flying) across unsuitable habitat.

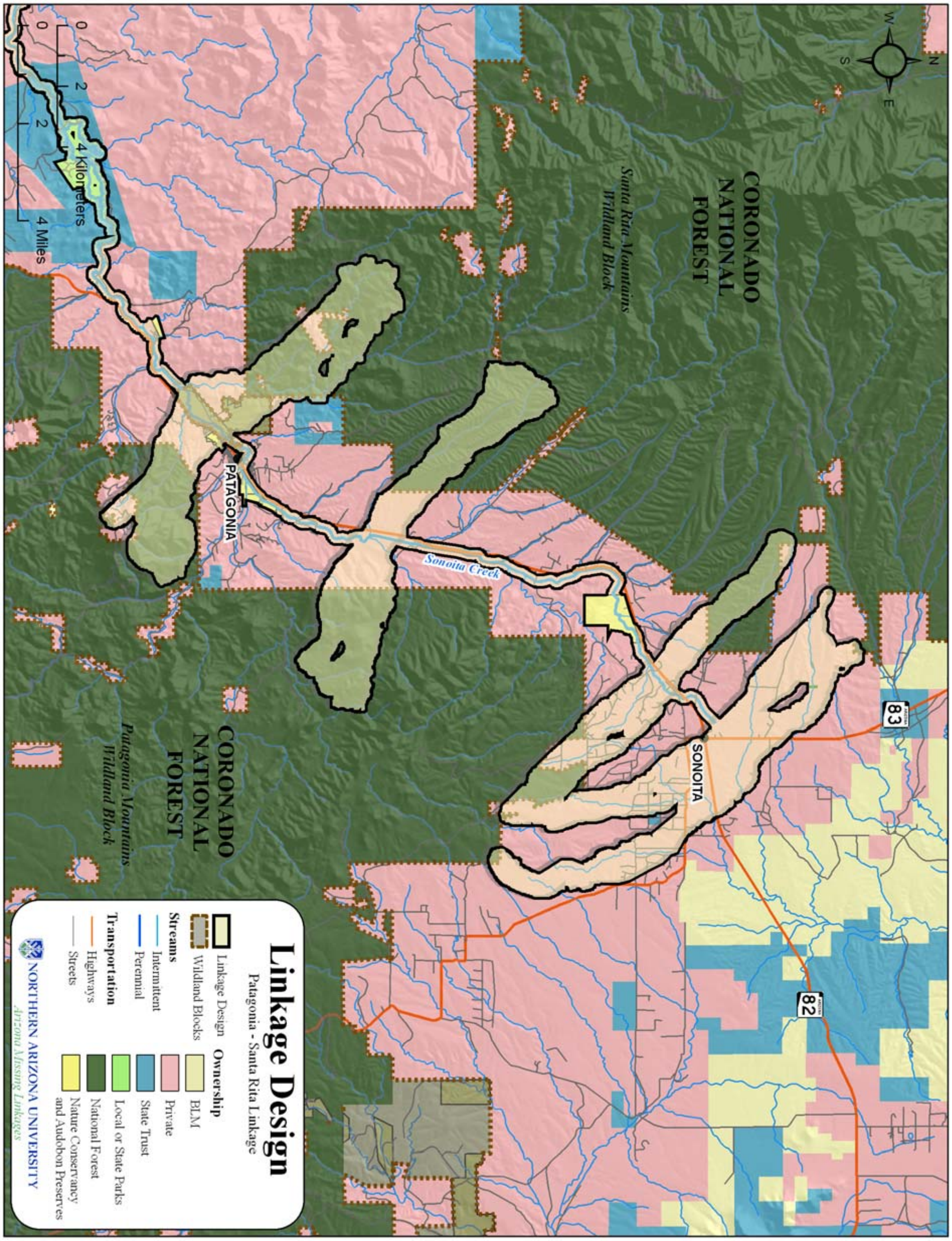


Figure 1: The Linkage Design between the Santa Rita and Patagonia wildland blocks includes 4 strands, each of which is important to different species.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

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

Ecological Significance of the Santa Rita-Patagonia Wildland Blocks and Linkage Area

The Santa Rita and Patagonia linkage planning area lies within 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 2000 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 Sky Island Ecosystem, the Linkage Planning Area includes a swath of private land and state trust land 2 to 4 miles wide, with SR-82 running roughly southwest-northeast through it, that separates two USFS administered wildland blocks: the Santa Rita Mountains wildland block and the Patagonia Mountains wildland block.

The **Santa Rita Mountains wildland block** encompasses 138,000 acres in Coronado National Forest and the Santa Rita Experimental Range. The Santa Rita Mountains extend 42 km (26 miles) from northwest to southeast and tower to over 9,000 feet, with east-flowing canyons that support the Cienega watershed. The varied terrain supports Sonoran desert, grasslands, shrublands, chaparral, pine forests, and riparian areas. It includes the 25,260-acre Mount Wrightson Wilderness Area where Old Baldy rises to 9,000 feet. The desert flats and steep canyons comprise diverse habitat for a variety of wildlife including mule deer, white-tailed deer, and black bear. The headwaters of Madera Canyon, a popular birdwatching site, are located in the Wilderness.

The **Patagonia Mountains wildland block** encompasses 272,000 acres in Coronado National Forest, including the Patagonia Mountains, the Canelo Hills, the western Huachuca Mountains, Lone Mountain, the San Rafael Valley, and the headwaters of the Santa Cruz River. Terrain is characterized by the gentle slopes in the Canelo Hills, rolling hills in the San Rafael Valley, and rocky mountains cut by steep canyons throughout the Patagonia range. Elevations range from approximately 4,200' to 7,220' on Mt. Washington in the Patagonia Mountains. Vegetation is characterized by oak-juniper woodlands at the higher elevations, bordered by rolling plains grasslands in the San Raphael Valley, and upper Sonoran desert along the western slopes of the Patagonia Mountains. The 20,190-acre Miller Peak Wilderness lies in the southeastern corner of the block. Smaller conservation areas include the San Rafael Ranch Natural Area, Las Cienegas National Conservation Area, and Appleton-Whittle Audubon Research Ranch (Figure 3).

The **Linkage Planning Area** ranges from 3000 feet at the Santa Cruz River valley to 9,453 feet at the peak of Mt. Wrightson in the Santa Rita Mountains. Semi-desert grassland and steppe 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.

Sonoita Creek flows through the floodplain separating the wildland blocks. This permanent stream provides the richest riparian habitat in the region. It flows steadily for the first fifteen miles of its westward course past Patagonia, its bird sanctuary and Patagonia Lake, but sinks beneath the sand seven to eight miles before joining the Santa Cruz River a few miles north of Nogales. Harshaw Creek flows into Sonoita Creek in the town of Patagonia. Sonoita Creek is the central feature of the Patagonia-Sonoita Creek Preserve, managed by The Nature Conservancy to protect rare riparian resources, cienegas and rare cottonwood-willow forests that support more than 280 species of birds. Patagonia Lake State Park and the Sonoita Creek State Natural Area encompass important riparian habitat along Sonoita Creek and reservoir in the southwestern corner of 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, Chiricahua leopard frog, Gila top minnow, and longfin dace, and locally-extirpated species such as the Mexican gray wolf and ocelot (USFWS 2005). The Linkage Design incorporates and connects critical habitat needed for these species to achieve and sustain viable populations. The Linkage Planning Area is also home to far-ranging mammals such as black bear, and mountain lion. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists 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.

Threats to Connectivity

Major potential barriers in the linkage planning area include SR-82, SR-83, border security, and expanding urban development in and near Patagonia and Sonoita. Over 58% of the land within the linkage design is privately owned (Figure 5). These barriers may inhibit wildlife movement between the Patagonia Mountain and Santa Rita Mountain wildland blocks. Fortunately, current urban development is limited, and most of it is compact. Avoiding leapfrog sprawl is key to maintaining connectivity.

Illegal immigration and border enforcement activities can damage protected lands and sensitive habitats. Impacts are brought on by countless border crossers, vehicle patrols, fences, litter, roads, vehicular traffic, and low-level aircraft overflights. These activites threaten to impede wildlife movement across the United States-Mexico borderlands region in southeastern Arizona's Sky Islands and elsewhere (Wildlands Project 2005).

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

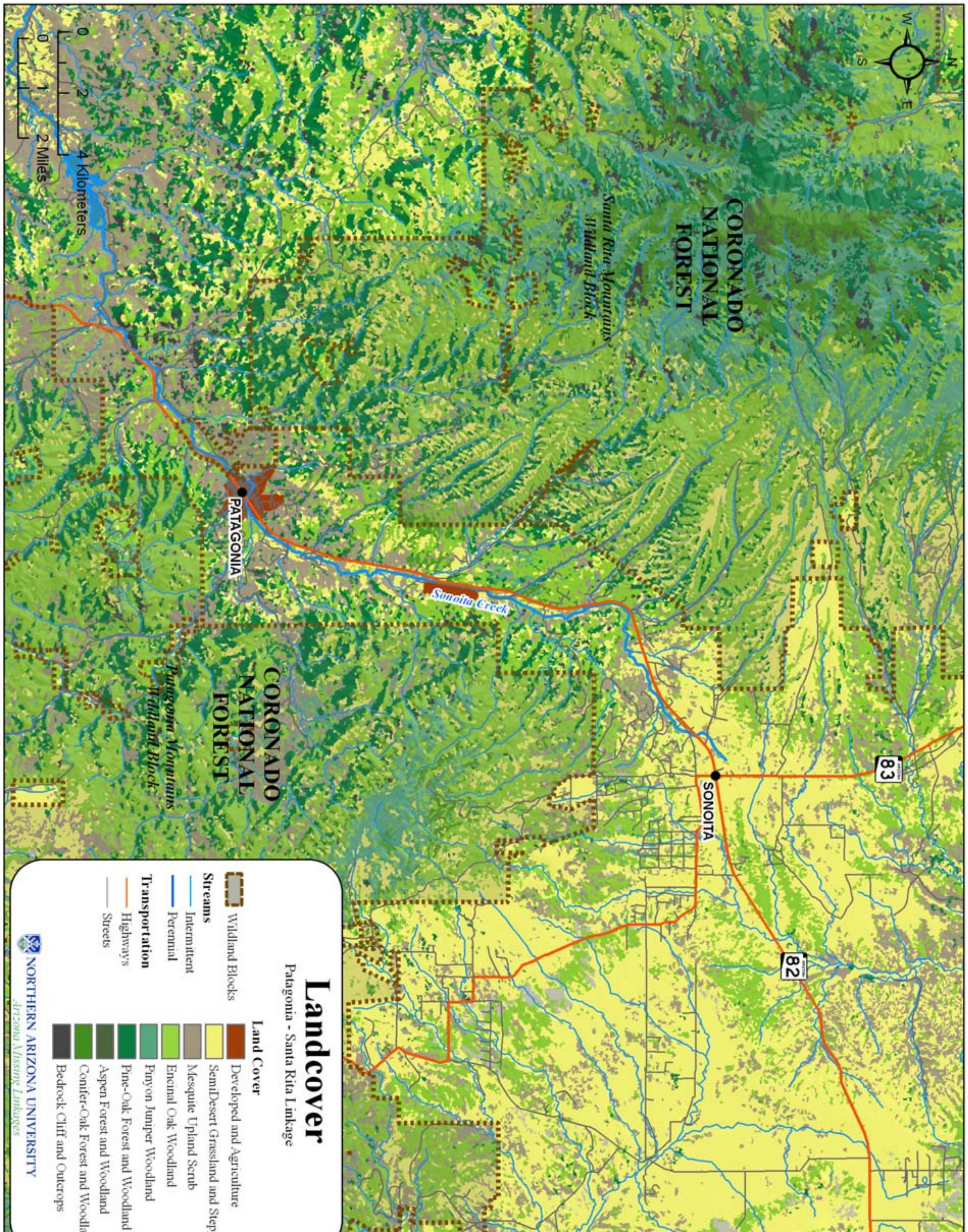


Figure 2: Land cover within the linkage planning area

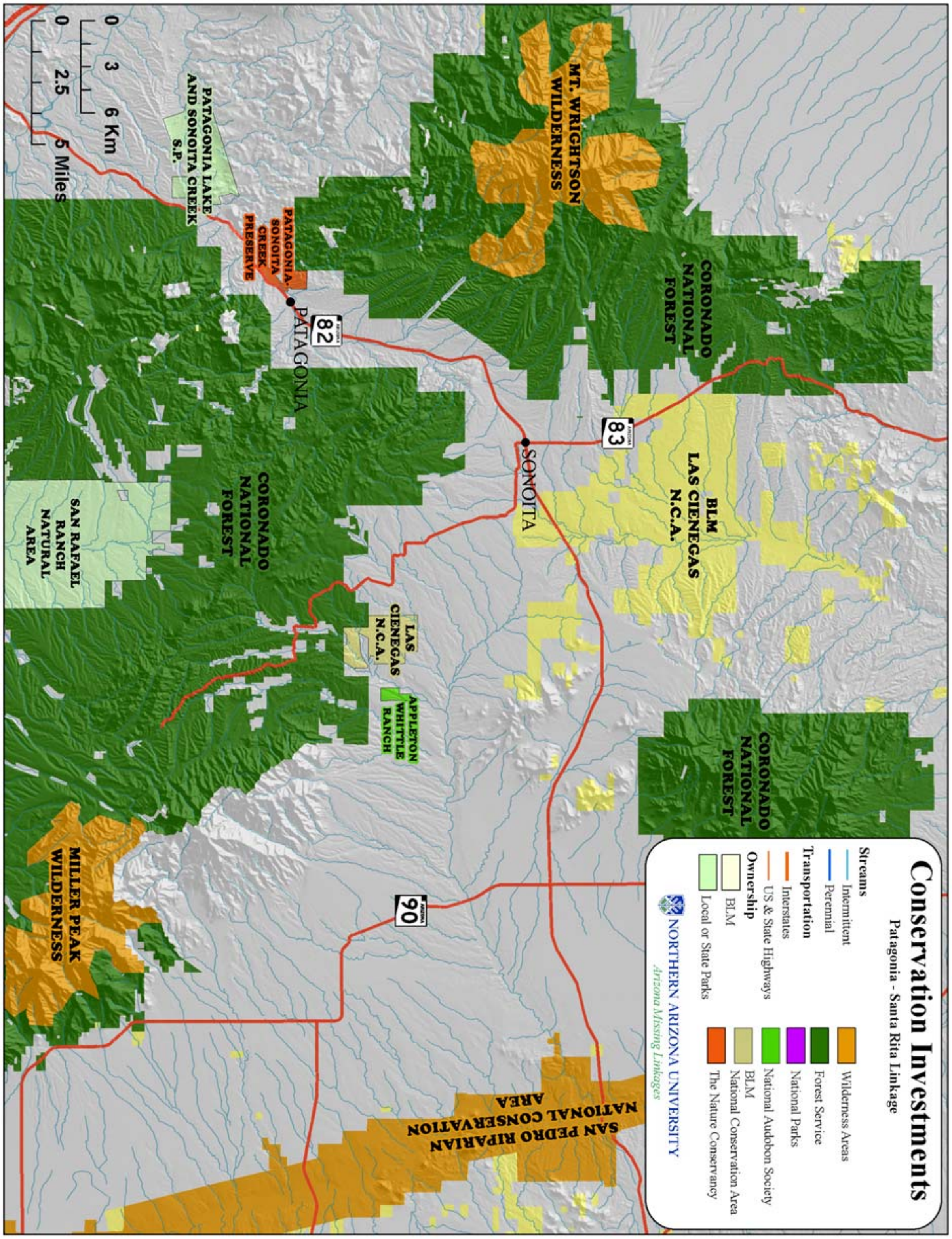


Figure 3: Existing conservation investments in the linkage planning area.

Linkage Design & Recommendations

The Linkage Design[1] (Figure 1) is composed of four strands which together provide habitat for movement and reproduction of wildlife between USFS lands adjacent to Patagonia. In this section, we describe the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Four Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of three distinct strands that connect the Santa Rita and Patagonia wildland blocks, as well as one riparian strand along Sonoita Creek.

LINKAGE DESIGN GOALS

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

Strand A encompasses the biologically best corridors for b1ack bear, Coues' white-tailed deer, Mexican gray wolf, and mountain lion. This westernmost strand runs from Ranger Station Spring in the Santa Ritas Mountains toward Red Mountain in the Patagonia Mountain range. The strand is about 13 km long, and primarily composed Encinal (Oak Woodland) (46%), Pine-Oak Forest and Woodland (23%), Mesquite Upland Scrub (14%), and Semi-Desert Grassland and Steppe (10%). This strand is the most topographically diverse strand of the linkage, with an average slope of 29% (Range: 0-111%, SD: 16.9), and steep slopes comprising 58% of the land.

Strand B is the biologically best corridor for jaguar. It runs from the upper reaches of Little Casa Blanca Canyon in the Santa Rita Mountain range to the southwestern face of the Canelo Hills. The strand is approximately 13 km long, and is primarily composed of Encinal (Oak Woodland) (39%), equal parts Pine-Oak Forest and Woodland (20%), and Semi-Desert Grassland and Steppe (20%), and 12% Mesquite Upland Scrub. This strand has a fair amount of topographic complexity, with an average slope of 21% (Range: 0-79%, SD: 12.7). About one-fourth (24%) of the land in this strand is classified as flat to gentle slopes, while over half (58%) is steep slopes and the remainder (18%) is canyon bottom or ridgetop.

Strand C is made up of the biologically best corridors for badger and mule deer. This easternmost strand runs from Gardner Canyon in the Santa Rita Mountains to Papago Springs in the Patagonia Mountains. This strand has three branches ranging from 13 to 16 km in length. It is primarily composed of Semi-Desert Grassland and Steppe (60%), with smaller amounts of Encinal (Oak Woodland) (22%) and Mesquite Upland Scrub (14%). This strand has the gentlest topography, with an average slope of 7% (Range: 0-45%, SD: 5.8). Over three-quarters (78%) of the land within this strand is classified as flat to gentle slopes, 21% as steep slopes and the remaining 1% as canyon bottoms or ridgetops. Although pronghorn were not suggested as a focal species, Strand C contains by far the best pronghorn habitat in the linkage design and linkage planning area.

The **Sonoita Creek strand** winds along roughly 40 km of the creek through strands C, B, and A, terminating at Patagonia Lake. This strand provides for species dependent on riparian or aquatic habitat,

[1] The reader will note that the strands of the linkage design extend well into each wildland block. For modeling purposes we had to redefine the wildland blocks such that the facing edges were parallel lines about 15 km apart ().

such as the Desert Sucker, Gila Topminnow, Longfin Dace, and Razorback Sucker. It has gentle topography with an average slope of 10%, (Range: 0-90%, SD: 10.5). Nearly three-quarters (67%) of the land within this strand is classified as flat to gentle slopes, and 29% as steep slopes.

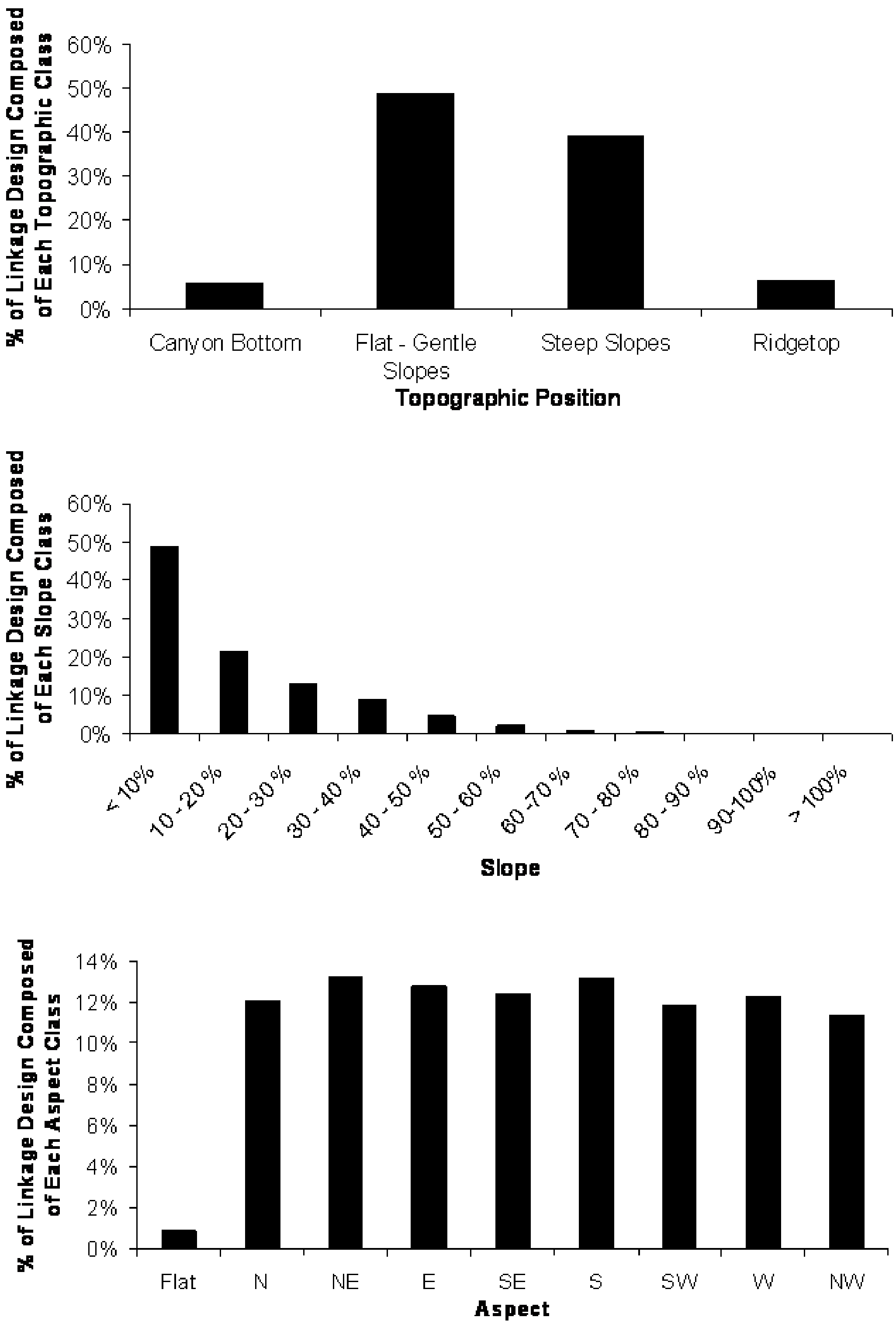


Figure 4 Topographic diversity in the linkage design.

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

The Linkage Design encompasses 28,711 acres (11,619 ha), 59% of which is private land, 37% National Forest land, and the remaining 4% is either State Trust of Local or State Parks (Figure 5). Three natural vegetation communities account for over 97% of the land cover, open water accounts for 0.9%, and agricultural land accounts for approximately 0.3% of the linkage design (Table 2). Natural vegetation is dominated by Evergreen Forest associations in the higher elevations and Grassland-Herbaceous communities in the lower elevations.

The Linkage Design captures a range of topographic diversity, providing for the present ecological needs of the focal species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, 49% of the land is classified as gentle slopes, 39% is classified as steep slopes, and 12% is classified as either canyon bottom or ridgetop (Figure 4). The linkage has roughly as much southern aspects as northern aspects.

Table 2: Approximate land cover in Linkage Design

Land Cover Class	Acres	Hectares	% of total area
Scrub-Shrub (16.9%)			
Mesquite Upland Scrub	4860	1967	17%
Evergreen Forest (45.1%)			
Pinyon-Juniper Woodland	866	351	3%
Pine-Oak Forest and Woodland	3001	1215	11%
Encinal (Oak Woodland)	8652	3502	30%
Conifer-Oak Forest and Woodland Chaparral	441	178	1.5%
Grassland-Herbaceous (35.3%)			
Semi-Desert Grassland and Steppe	9802	3967	34%
Juniper Savanna	332	134	1.2%
Open Water (0.9%)			
Open Water	251	102	0.9%
Developed and Agriculture (0.3%)			
Agriculture	79	32	0.3%

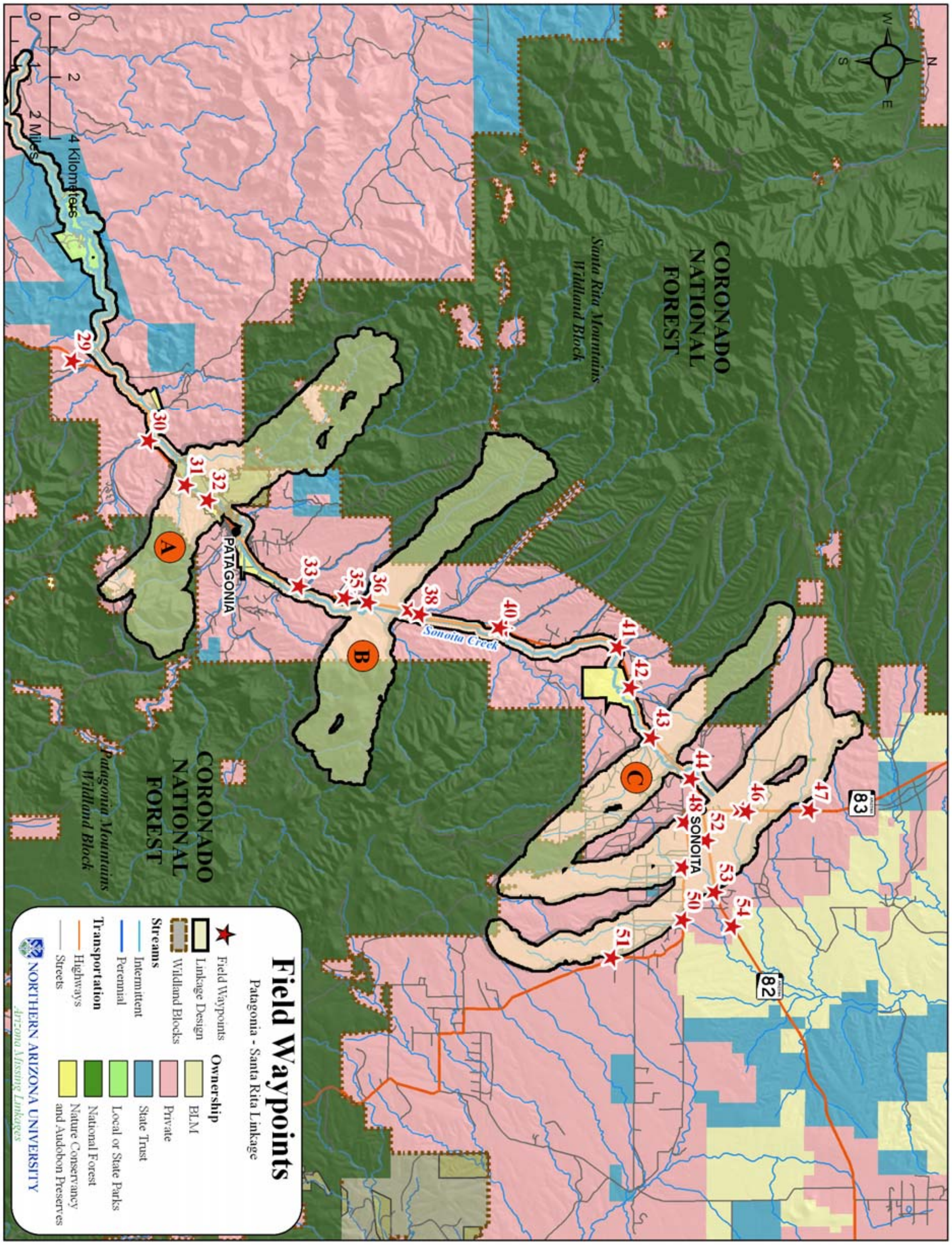


Figure 5: Property ownership and field investigation waypoints within the linkage design; the accompanying CD-ROM includes photographs taken at most waypoints

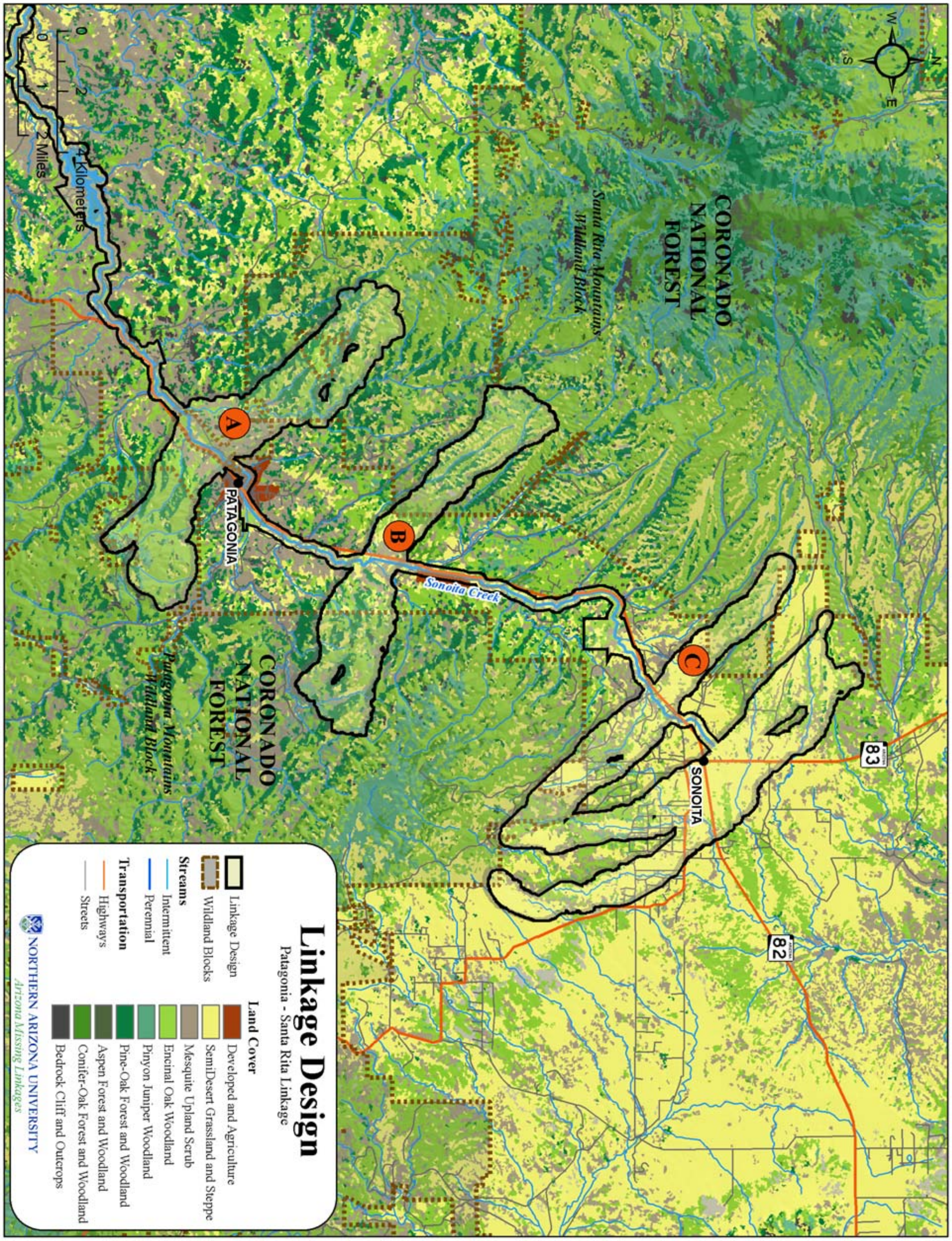


Figure 6: Land cover within the linkage design.

a)

b)

c)

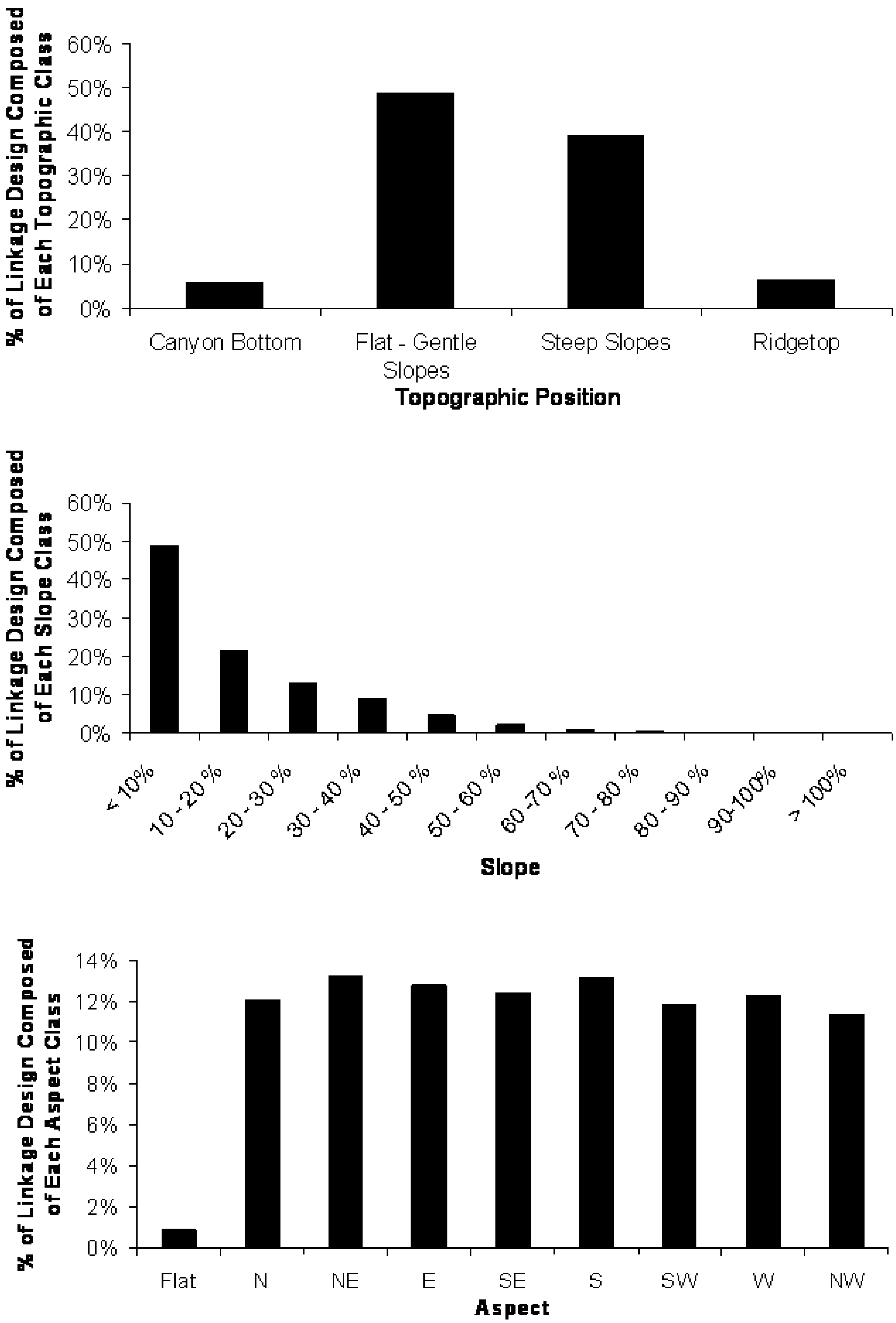


Figure 7: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect

Removing and Mitigating Barriers to Movement

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

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

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

Table 3. Characteristics that make species vulnerable to the three main direct effects of roads (from Foreman et al. 2003).

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

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 8). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

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

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

Despite their disadvantages, well-designed and located culverts can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species, including mice, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin III 2003; Dodd et al. 2004; Ng et al. 2004). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). In south Texas, bobcats most often used 1.85 m x 1.85 m box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Some cases located in fill dirt have openings far above the natural stream bottom.

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

Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

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

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

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

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

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

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

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

Existing Roads in the Linkage Design Area

There are about 178 km (110 mi) of roads in the Linkage Design, including 20 km (13 mi) of highways, and 157 km (98 mi) of local roads (Table 4). We investigated many of these roads to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 4. Roads in the Linkage Design.

ROAD NAME	KILOMETERS	MILES
State Highway 82	13.78	8.56
State Highway 83	6.43	4.00
Patagonia Hwy	5.48	3.41
Santa Rita Rd	3.85	2.39
Windmill Dr	2.25	1.40
Naugle Ave	2.04	1.27
Bronco Trl	1.88	1.17
Blue Haven Rd	1.78	1.10
Mustang Trl	1.72	1.07
Wagon Wheel Ln	1.54	0.96
Kellog Ln	1.49	0.92
Harvest Dr	1.47	0.91
Papago Springs Rd	1.38	0.85
Callejon de Los Sobaipurl	1.26	0.79
Holdbrook Dr	1.23	0.76
Thunderhead Trl	1.20	0.75
Roland Ln	1.11	0.69
Canyon Rd	1.09	0.68
Unnamed Roads	66.51	41.33
Roads less than 1 km	30.1	18.7
Total	177.6	110.4

Existing Crossing Structures on SR-82 and SR-83

SR-82 runs east-west through the linkage design, and SR-83 runs north-south through the eastern strand. During the field investigation, we documented 11 existing, large crossing structures on these roads:

- SR-82, Milepost 16.8, Waypoint 30, 5-box culvert with 10x10' boxes
- SR-82, Milepost 18, Waypoint 31, 10x10' box culvert
- SR-82, Milepost 21.7, Waypoint 33, a 3-box culvert with 5x6'boxes and pouroffs, making them unusable by wildlife (Figure 11).
- SR-82, Milepost 23.2, Waypoint 36, a 6-box culvert with 8x2' boxes
- SR-82, Milepost 24.1, Waypoint 37, a 6x10' single-box culvert
- SR-82, Milepost 24.3, Waypoint 38, large bridge over Casa Blanca Wash
- SR-82, Milepost 26, Waypoint 39, a 4-box culvert with 10x10' boxes and a sloped 2' concrete pouroff extending beyond the boxes
- SR-82, Milepost 27.5, Waypoint 40, large bridge
- SR-82, Milepost 28.5, Waypoint 41, a large bridge
- SR-82, Milepost 29.4, Waypoint 42, a large bridge
- SR-83, Milepost 34, Waypoint 46, a low bridge

Recommendations for Highway Crossing Structures

The existing crossing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between the Santa Rita and Patagonia wildland blocks must traverse at least one, and in some cases both of the state highways between the wildland blocks, crossing structures along these highways are crucial to success of the corridor. We recommend implementing the Standards and Guidelines for Roads (above), and specifically recommending upgrading crossing structures as follows:

- In strand C, install 4 bridged crossings (suitable for mule deer) on SR-82 (two in each sections of strand C) and two bridged crossings on SR-83.

- Within the Sonoita Creek strand, replace SR-82 culverts over Sonoita Creek with bridged crossings. By maintaining natural stream and upland contours under the bridge, movement of fishes, amphibians, reptiles, and mammals will be assured.
- For the existing structures, remove wire fences across structure entrances. Instead use fencing to guide animals toward the crossing structures. Manage these crossings to ensure that they do not become filled with sediments or otherwise impede movement.

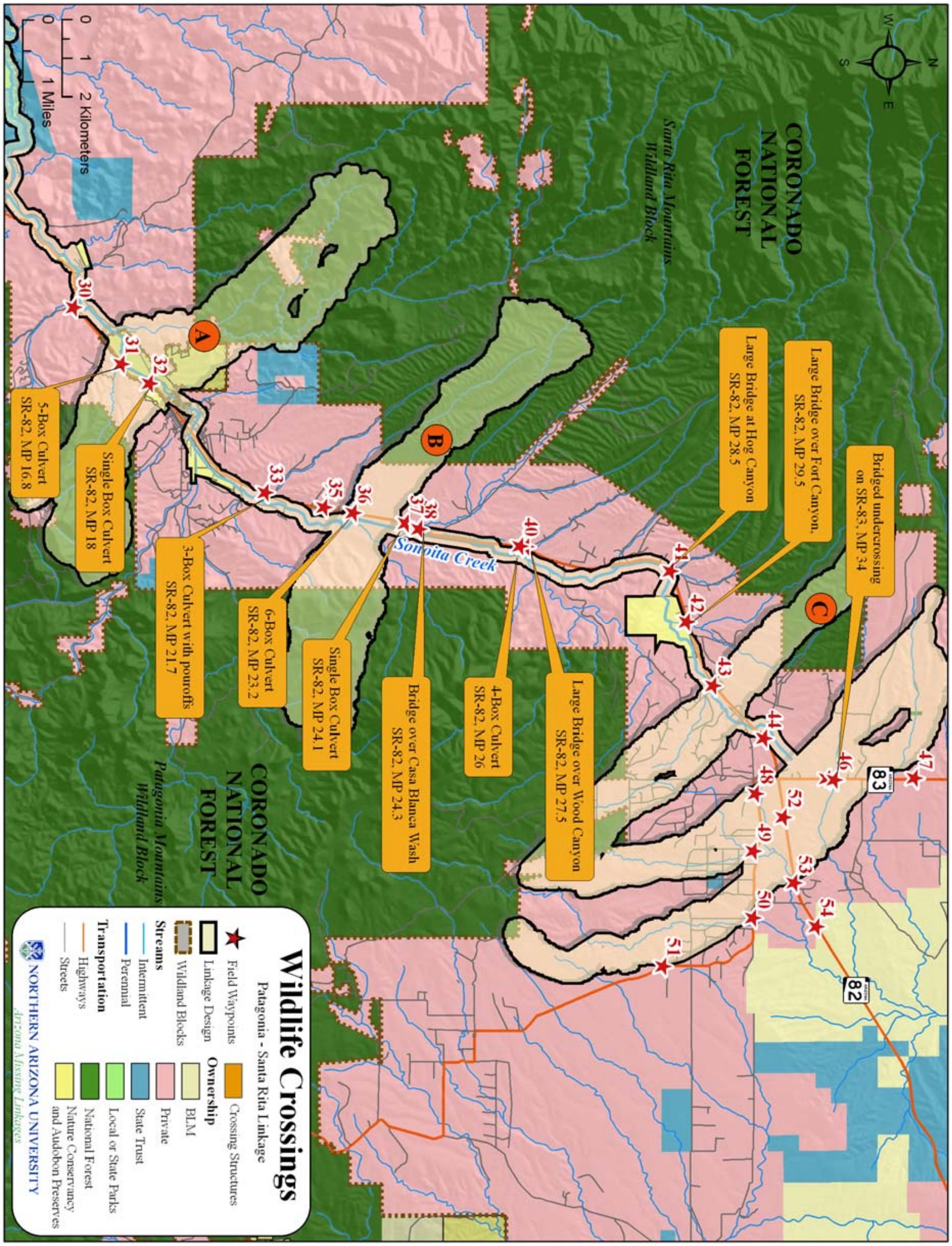


Figure 9: Existing crossing structures in the linkage planning area

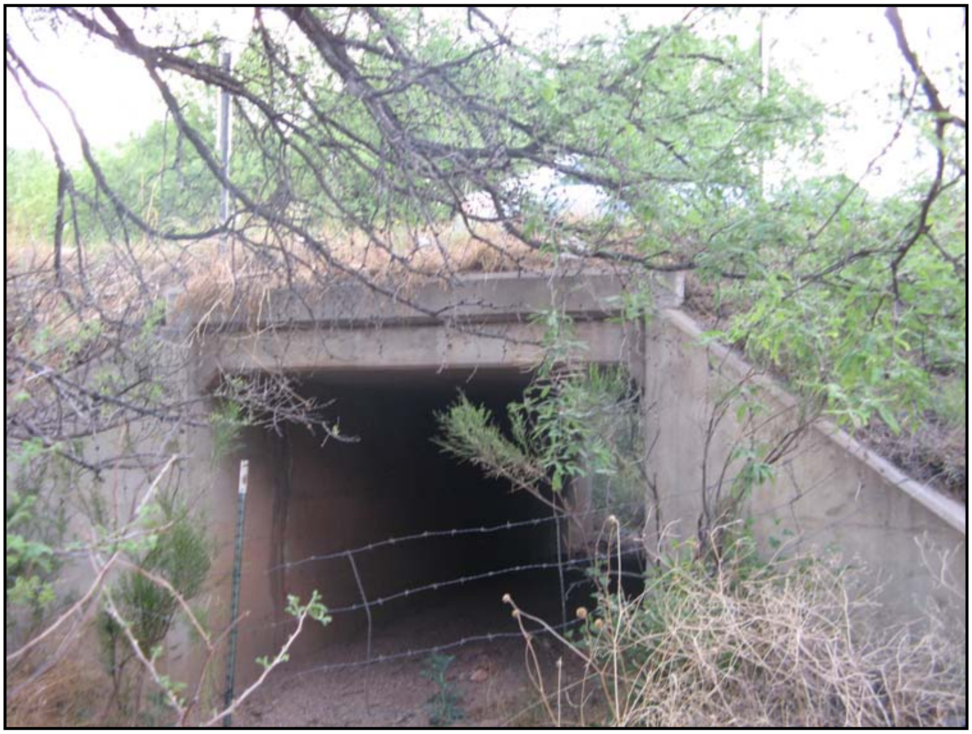


Figure 10: A 10x10' box culvert blocked by barbed wire at Waypoint 30, Milepost 18 on SR-82

Figure 11: 5x6' pour-offs in 3 box culverts at Waypoint 33, Milepost 21.7 on SR-82

Figure 12: A large bridge over Casa Blanca Wash, Waypoint 38, Milepost 24.3 on SR-82

Figure 13: A bridged undercrossing over an unnamed stream at Waypoint 46, Milepost 34 on SR-83

Impediments to Sonoita Creek

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). Sonoita Creek and its associated riparian vegetation are preferred habitat for many species in the linkage area, including Chiricahua leopard frog, desert sucker, gila topminnow, longfin dace, and razorback sucker.

Stream Impediments in the Linkage Design Area

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

The Sonoita Creek watershed is a verdant floodplain in the linkage area. The area boasts some of the richest remaining riparian habitat in the region, including a rare Fremont cottonwood-Gooding willow forest. Furthermore, there is growing urban development in the watershed within the linkage area. This urban growth is minimal today; thus this is the time to ensure such growth is controlled. Rural residential development is greatest north and east of the junction of SR-82 and SR-83. The goal of the riparian corridor is to maintain a functioning riparian ecosystem. The Sonoita Creek strand is 400 m wide (200 m on each side of the stream), except where the strand is widened to encompass existing conservation investments.

Mitigating Stream Impediments

We endorse the following management recommendations for riparian connectivity and habitat conservation on the Sonoita Creek.

1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency, and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).

- Urban development contributes to a “flashier” (more flood-prone) system. Check dams and settling basins should be required in urban areas within the Sonoita Creek watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000)].
- Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
- Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993). However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kupferberg 1997, Kiesecker and Blaustein 1998, Maret et al. 2006).

2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops, and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).
3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of the river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite *bosques* should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).
4) **Maintain biotic interactions within evolved tolerance ranges**. Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas (Belsky et al. 1999, National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).
5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, with a few becoming significant problems like tamarisk and Russian olive. Removing stressors and reestablishing natural flow regimes can help bring riparian communities back into balance, however some exotics are persistent and physical eradication is necessary to restore degraded systems (Stromberg 2000, Savage 2004, but see D'Antonio and Meyerson 2002). Elimination of unnatural perennial surface pools can eradicate water-dependent invasives like bullfrogs, crayfish, and mosquitofish.]
6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.
7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

Urban Development as Barriers to Movement

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

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure 14). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

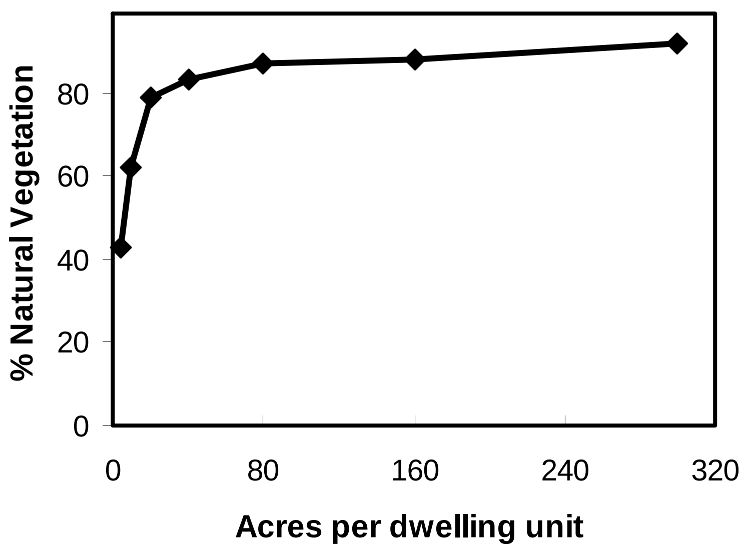


Figure 14: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres.

- decreased abundance and diversity of native species, and replacement by non-native species. In Arizona, these trends were evident for birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001), and loss of native species increased as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.
- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).

- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized "suburban native predators" such as raccoons, foxes, and crows, that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).
- mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).
- artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

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

Urban Barriers in the Linkage Design Area

Currently, most of the linkage design is unaffected by urban development (Figure 15). However, several urban areas and low-density rural residential areas occur in or near the linkage design. Because of the low level of threat and the relatively intact nature of the landscape, this is an ideal time to secure this linkage.

The town of Patagonia lies northwest of strand A within the Sonoita Creek corridor, with a population of 881. South of strand B there are two growing residential areas (Figure 18). On the northwest side of SR-82 is the 1,760-acre Three Canyons development. There are now 66 homesites for sale each 4 to 16 acres.

This community has many restrictions on land use that should retain native vegetation on about 90% of the land. Across the highway from Three Canyons, is Sonoita Springs Ranch, with plans to develop up to 21 parcels of 36 acres each. Because housing in these developments is denser than the threshold at which native vegetation typically degrades (Figure 14), we excluded these areas from the linkage design. However, we applaud the innovative steps taken by these developers, and we hope these experiments may demonstrate that residential development this dense can be compatible with wildlife movement. These parcels abut Strand B and the Sonoita Creek strand, and should be good neighbors for the linkage design.

In the eastern arm of strand C, low-density ranchettes (Figure 16) occur east of Sonoita (population 1,132). Because these rolling grasslands have few topographic impediments to development and a road network, aggressive action will be needed to conserve a grassland corridor through this area. Although pronghorn were not suggested as a focal species, Strand C contains by far the best pronghorn habitat in the linkage design (Figure 17).

Figure 15: Undeveloped portion of Strand C, west of SR-83 from Waypoint 47.

Figure 16: Low-density development in Strand C, Waypoint 47, near Milepost 35 on SR-83

Figure 17: Grasslands in Strand C, Waypoint 47, near Milepost 35 on SR-83

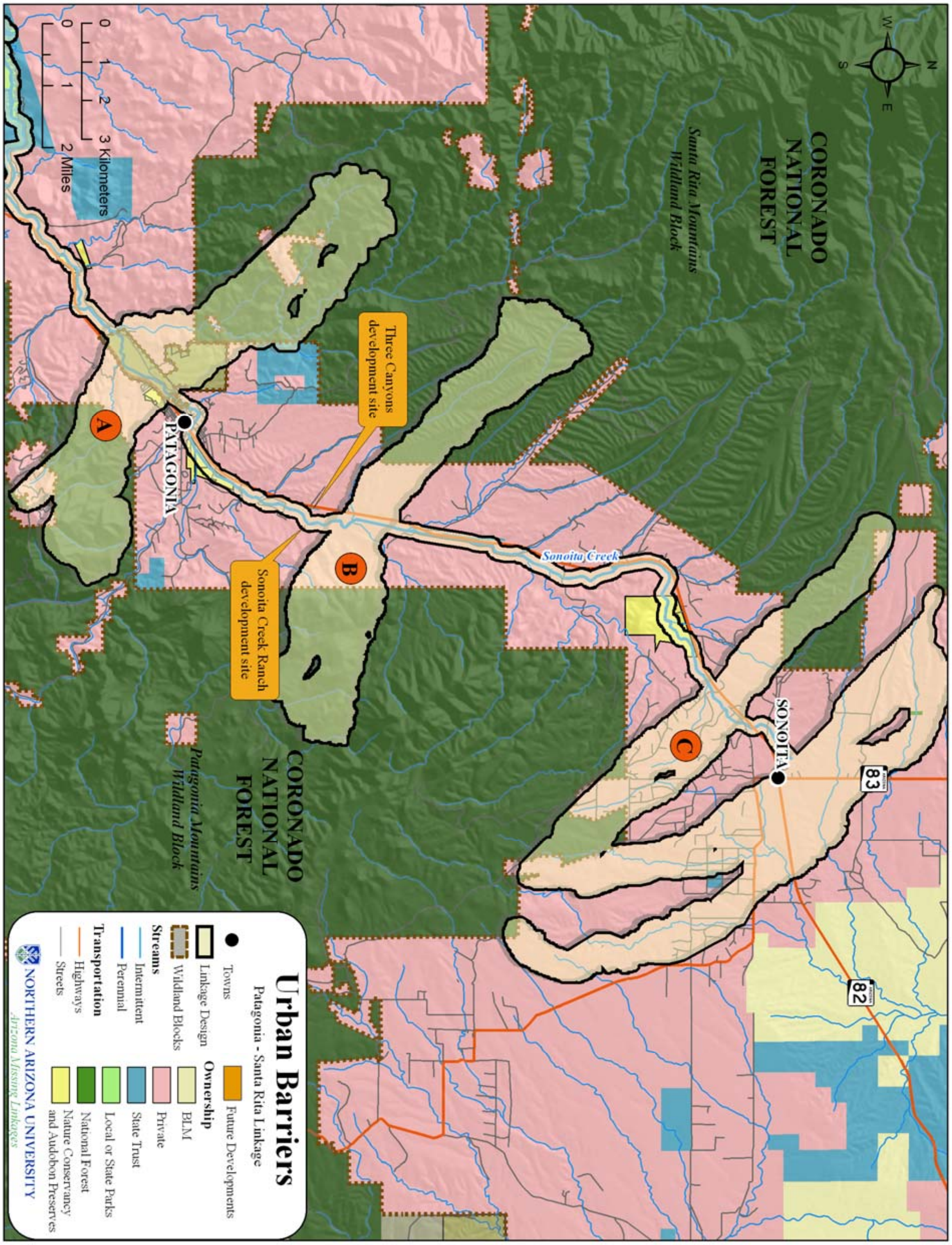


Figure 18: Existing and future development within the linkage planning area

Mitigation for Urban Barriers

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

1) Integrate this Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design.
2) Where development is permitted within the linkage design, encourage small building footprints on large (> 40 acre) parcels with a minimal road network.
3) Integrate this Linkage Design into county general plans, and conservation plans of governments and nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as recreation and protection of water quality.
6) One reason we imposed a minimum width on each strand of the linkage design was to allow enough room for a designated trail system without having to compromise the permeability of the linkage for wildlife. Nonetheless, because of the high potential for human access, the trail system should be carefully planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.
7) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area.
8) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.
9) Develop a public education campaign to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.
10) Discourage residents and visitors from feeding or providing water for wild mammals, or otherwise allowing wildlife to lose their fear of people.
11) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.
12) Do not install artificial night lighting on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
13) Encourage the use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.
14) Discourage the killing of ‘threat’ species such as rattlesnakes.

15) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.
16) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.

In addition, we offer the following recommendations to minimize the impact of urban development on the linkage design:

- Work with homeowners and residents to manage the residential areas in strand C for wildlife permeability. Many people already live in this optimal movement corridor for mule deer, badger, and pronghorn. Although these species are somewhat tolerant of human disturbance, unrestrained pets, fencing, road kill on neighborhood streets, and artificial night lighting could make this strand ineffective. We advocate innovative programs that respect the rights of residents and enlist them as stewards of the linkage area.
- Discourage further residential development and subdivision of large parcels in the Linkage Design.

Appendix A: Linkage Design Methods

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

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[2]. By carefully selecting a diverse group of focal species and capturing a range of topography to accommodate climate change, the Linkage Design should ensure the long-term viability of all species in the wildland blocks. 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 22 species (Table 1) that had one or more of the following characteristics:

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

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

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

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

Habitat Suitability Models

We created habitat suitability models (Appendix B) for each species by estimating how the species responded to four habitat factors that were mapped at a 30x30 m level of resolution (Figure 19):

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

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

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

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

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

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

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

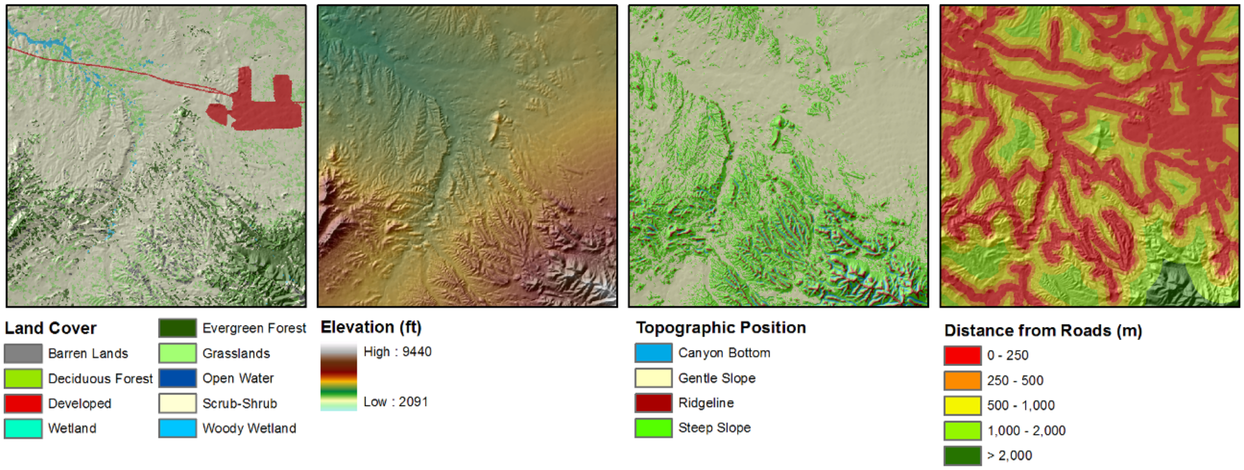


Figure 19: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

Identifying Potential Breeding Patches & Potential Population Cores

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

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

To do so, we first calculated the suitability of any pixel as the average habitat suitability in a neighborhood of pixels surrounding it (Figure 20). We averaged habitat suitability within a 3x3-pixel neighborhood (90 x 90 m^2, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[5]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) into polygons that represented potential breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

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

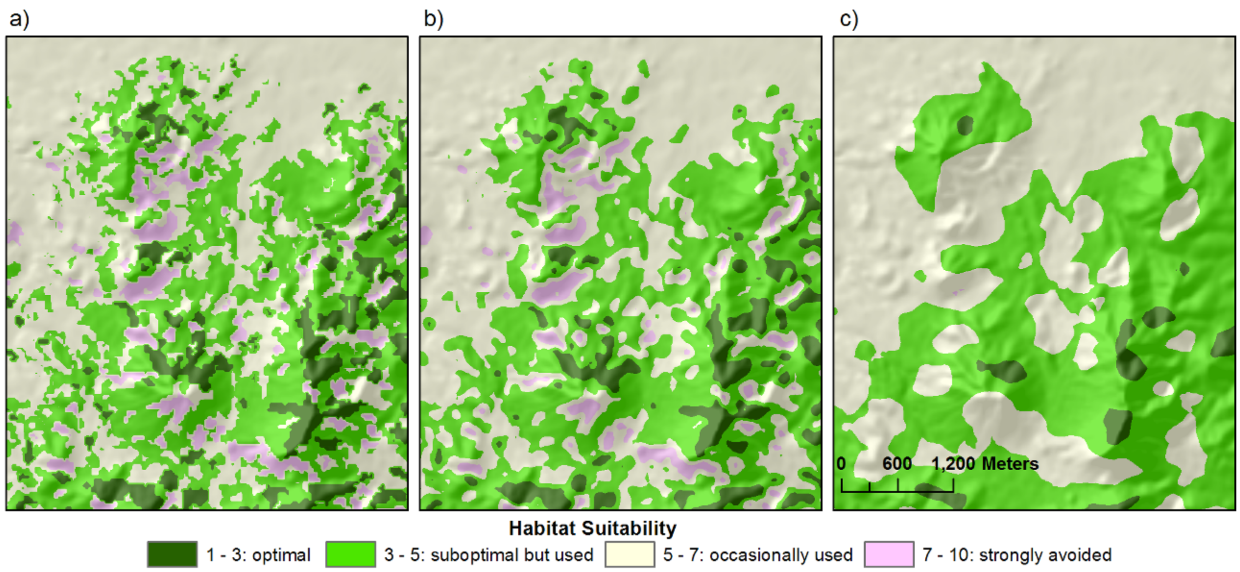


Figure 20: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window

Identifying Biologically Best Corridors

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

We developed BBCs only for some focal species, namely species that (a) exist in both wildland blocks, or have historically existed in both and could be restored to them, (b) can move between wildland blocks in less time than disturbances such as fire or climate change will make the current vegetation map obsolete, and (c) move near the ground through the vegetation layer (rather than flying, swimming, or being carried by the wind), and (d) have habitat preferences that can reasonably be represented using GIS variables. For focal species that did not meet these criteria, we conducted patch configuration analysis (next section).

In some locations, the two wildland blocks are separated by only 2 km (Figure 1). The close proximity of the blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[7]. A BBC drawn in this way has 3 problems: (1) It could be unrealistic (previous footnote). (2) It could serve small wildlife populations near the narrow gap while failing to serve much larger populations in the rest of the wildland block. (3) It would not provide any guidance relevant to the future road alignments. To address these 3 problems, for purposes of BBC analyses we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel and about 12 km apart from each other, and set back at least 1 mile from any existing highway or any new or potential urban area (Figure 21).

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

We then identified potential population cores and habitat patches that fell completely within each wildland block. If potential population cores existed within each block, we used these potential cores as the starting & ending points for the corridor analysis. Otherwise, the start-end points were potential habitat patches within the wildland block or (for a wide-ranging species with no potential habitat patch entirely within a wildland block) any suitable habitat within the wildland block.

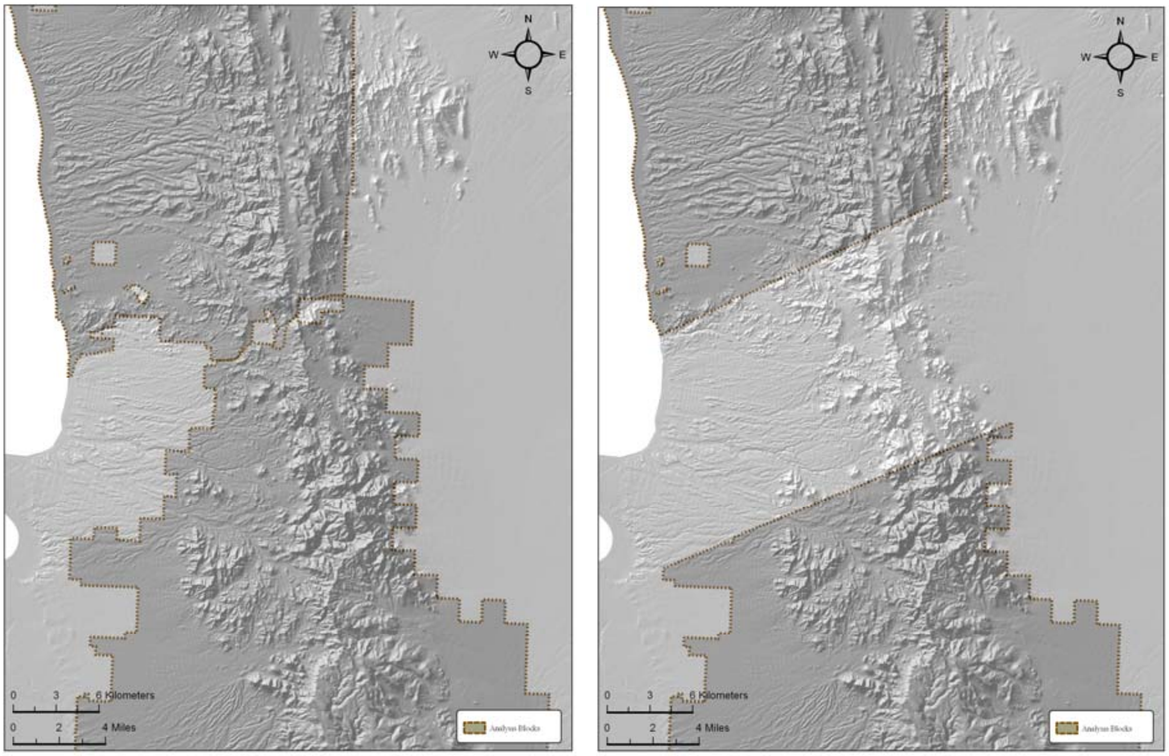


Figure 21: To give our corridors models "room to run," for the purposes of BBC analyses, we modified the wildland blocks used in our analyses, as seen in the example above, so that the facing edges were parallel lines about 12km apart. This forces the models to identify corridors with the best habitat; without this modification, the models tend to identify the shortest corridors regardless of habitat quality.

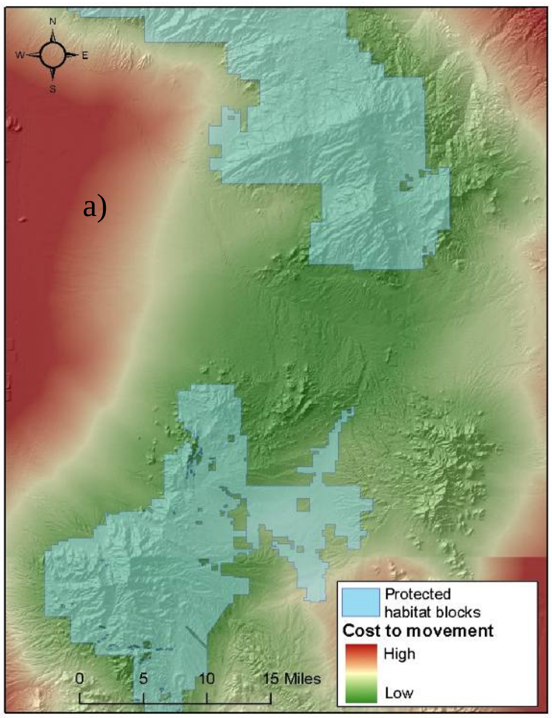
To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[8]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1000 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).

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

Patch Configuration Analysis

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



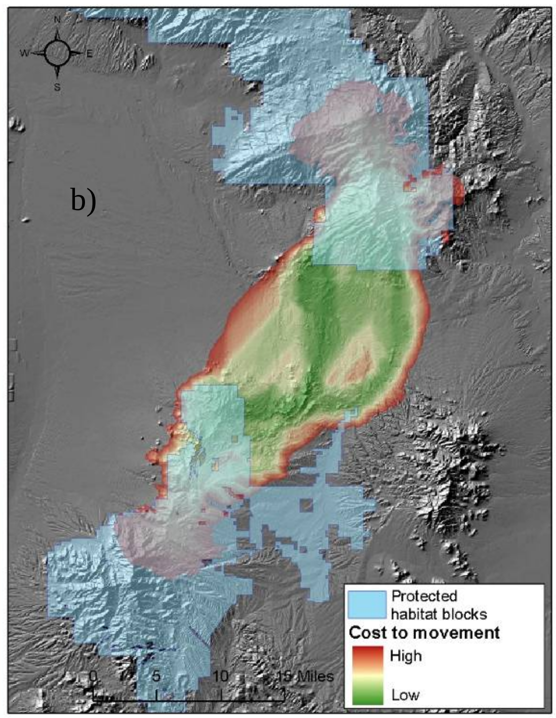


Figure 22: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

Minimum Linkage Width

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

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

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 400 meter minimum width on the Sonoita Creek, a critical feature to amphibians, riparian-obligate birds such as the southwestern willow flycatcher, and fish. Because riparian areas are unlikely to change location with climate change, we reasoned that a 1-km width was not needed. 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 Sonoita Creek 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 Sonoita Creek 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 G, as well as in a MS Access database on the CD-ROM accompanying this report.

Appendix B: Individual Species Analyses

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

	Badger	Black Bear	Coues' White-tailed Deer	Jaguar
Factor weights				
Land Cover	65	75	65	60
Elevation	7	10	5	5
Topography	15	10	15	15
Distance from Roads	13	5	15	20
Land Cover				
Conifer-Oak Forest and Woodland	6	1	2	2
Encinal	6	1	1	2
Mixed Conifer Forest and Woodland	6	3	4	3
Pine-Oak Forest and Woodland	5	1	2	3
Pinyon-Juniper Woodland	4	6	3	2
Ponderosa Pine Woodland	5	4	5	4
Aspen Forest and Woodland	6	5	5	6
Montane-Subalpine Grassland	2	4	6	4
Semi-Desert Grassland and Steppe	1	5	6	1
Pinyon-Juniper Shrubland	4	6	3	4
Riparian Mesquite Bosque	6	5	3	1
Riparian Woodland and Shrubland	6	5	2	1
Bedrock Cliff and Outcrop	9	10	8	6
Agriculture	6	6	7	9
Developed, Medium - High Intensity	10	10	10	10
Developed, Open Space - Low Intensity	7	10	9	10
Open Water	9	10	7	7
Elevation (ft)				
	0-5500: 1	0-2500: 8	0-2000: 7	0-2000: 3
	5500-8000: 3	2500-4000: 6	2000-3000: 6	2000-4000: 3
	8000-11000: 6	4000-6500: 2	3000-4000: 2	4000-6000: 1
		6500-8500: 3	4000-6000: 1	6000-8000: 3
		8500-11000: 4	6000-8000: 3	8000-11000: 4
			8000-11000: 7	
Topographic Position				
Canyon Bottom	5	3	1	1
Flat - Gentle Slopes	1	6	5	5
Steep Slope	8	3	2	2
Ridgetop	7	4	4	4
Distance from Roads (m)				
	0-250: 6	0-100: 10	0-250: 8	0-250: 10
	250-1500: 1	100-500: 4	250-500: 6	250-500: 7
		500-15000: 1	500-750: 2	500-1000: 5
			750-15000: 1	1000-2000: 2
				2000-15000: 1

	Mexican Gray Wolf	Mountain Lion	Mule Deer
Factor weights			
Land Cover	25	70	80
Elevation	15	0	0
Topography	15	10	15
Distance from Roads	35	20	5
Land Cover			
Conifer-Oak Forest and Woodland	1	1	4
Encinal	1	1	3
Mixed Conifer Forest and Woodland	1	3	3
Pine-Oak Forest and Woodland	1	1	3
Pinyon-Juniper Woodland	1	1	5
Ponderosa Pine Woodland	1	4	5
Aspen Forest and Woodland	1	3	1
Montane-Subalpine Grassland	6	6	4
Semi-Desert Grassland and Steppe	6	5	2
Pinyon-Juniper Shrubland	5	2	5
Riparian Mesquite Bosque	1	4	3
Riparian Woodland and Shrubland	1	2	3
Bedrock Cliff and Outcrop	8	6	8
Agriculture	6	10	6
Developed, Medium - High Intensity	8	10	9
Developed, Open Space - Low Intensity	8	8	5
Open Water	1	9	10
Elevation (ft)			
	0-3000: 6		
	3000-4500: 4		
	4500-6500: 3		
	6500-8500: 1		
	8500-11000: 2		
Topographic Position			
Canyon Bottom	2	1	2
Flat - Gentle Slopes	1	3	2
Steep Slope	5	3	4
Ridgetop	1	4	6
Distance from Roads (m)			
	0-1000: 4	0-200: 8	0-250: 7
	1000-2000: 3	200-500: 6	250-1000: 3
	2000-5000: 2	600-1000: 5	1000-15000: 1
	5000-15000: 1	1000-1500: 2	
		1500-15000: 1	

Badger (*Taxidea taxus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results depict a significant amount of suitable habitat for badger within the potential linkage area, and a significant amount of optimal habitat located largely in the northern and eastern portions of the linkage planning area (Figure 23). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.0 to 6.0, with an average suitability cost of 1.9 (S.D: 0.7). The BBC is comprised largely of optimal habitat with some suitable habitat, and the entirety of the corridor is a potential habitat core (Figure 24).

Union of biologically best corridors – Strands B and C capture additional optimal habitat for badger, while strand A and the Sonoita Creek strand capture more suitable habitat. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as SR-82 and SR-83, and habitat fragmentation.

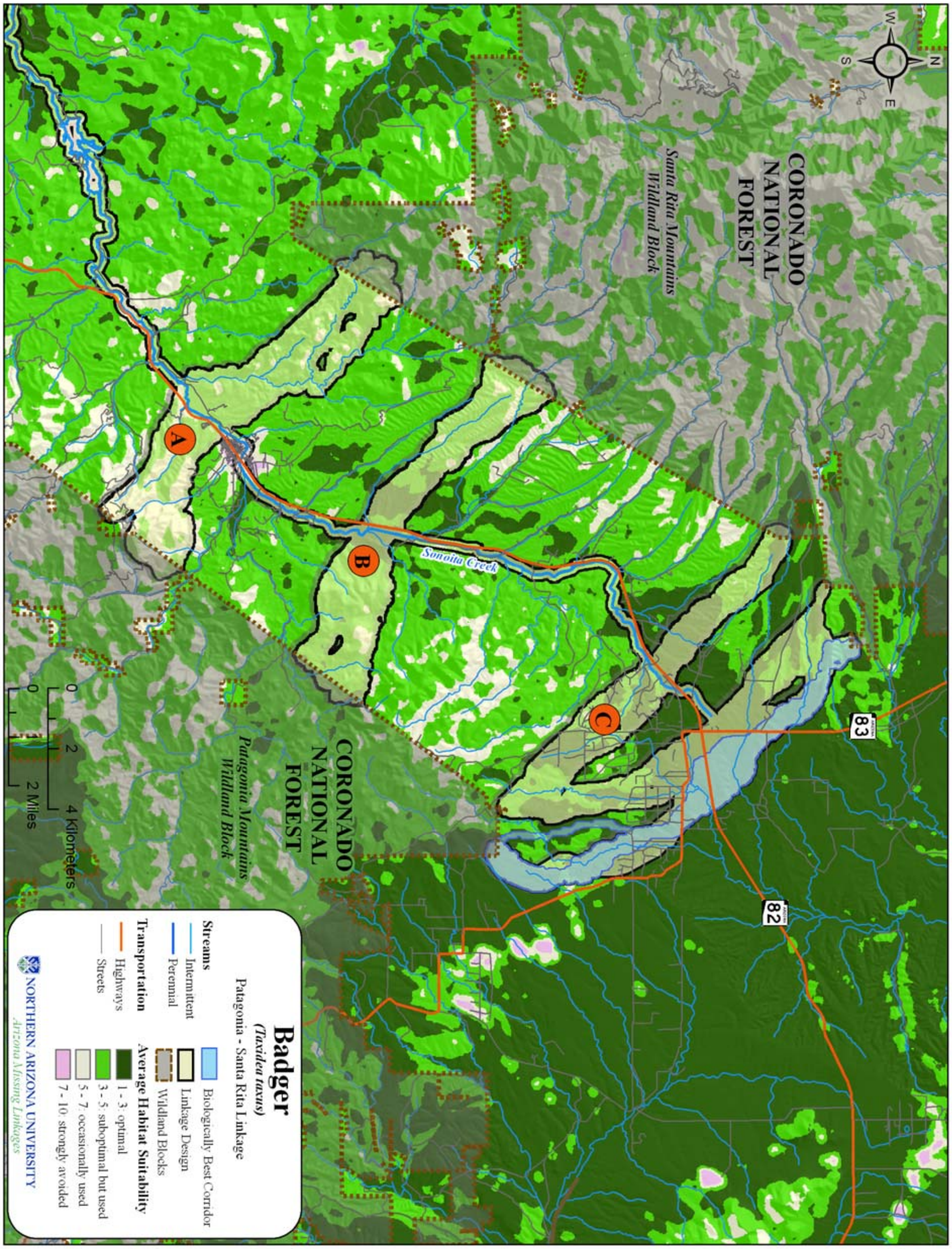


Figure 23: Modeled habitat suitability of badger

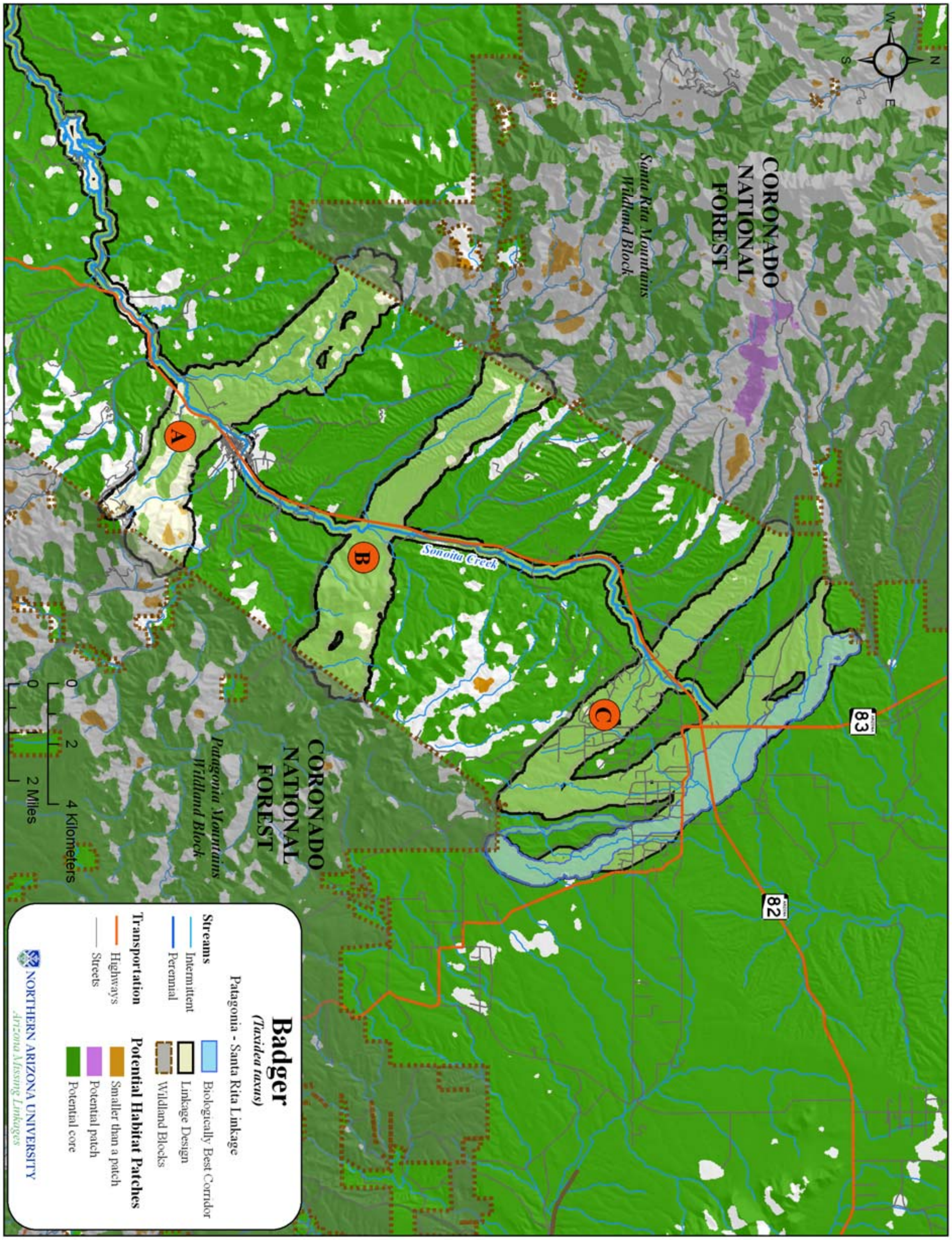


Figure 24: Potential habitat patches and cores for badger

Black Bear (*Ursus americanus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat interspersed with patches of optimal habitat occurring largely within the wildland blocks (Figure 25). Within the biologically best corridor, habitat suitability scores ranged from 1.3 to 6.7, with an average cost of 3.1 (S.D: 1.1). Within the corridor, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 26).

Union of biologically best corridors – The additional strands of the UBBC capture some additional suitable habitat for black bear, with some smaller patches of optimal habitat near the wildland blocks. There appears to be ample black bear habitat within and around the wildland blocks, while the land adjacent to the highways and around developments was rated as less suitable. Protecting a suitable corridor through this matrix is integral to maintaining connectivity for black bears.

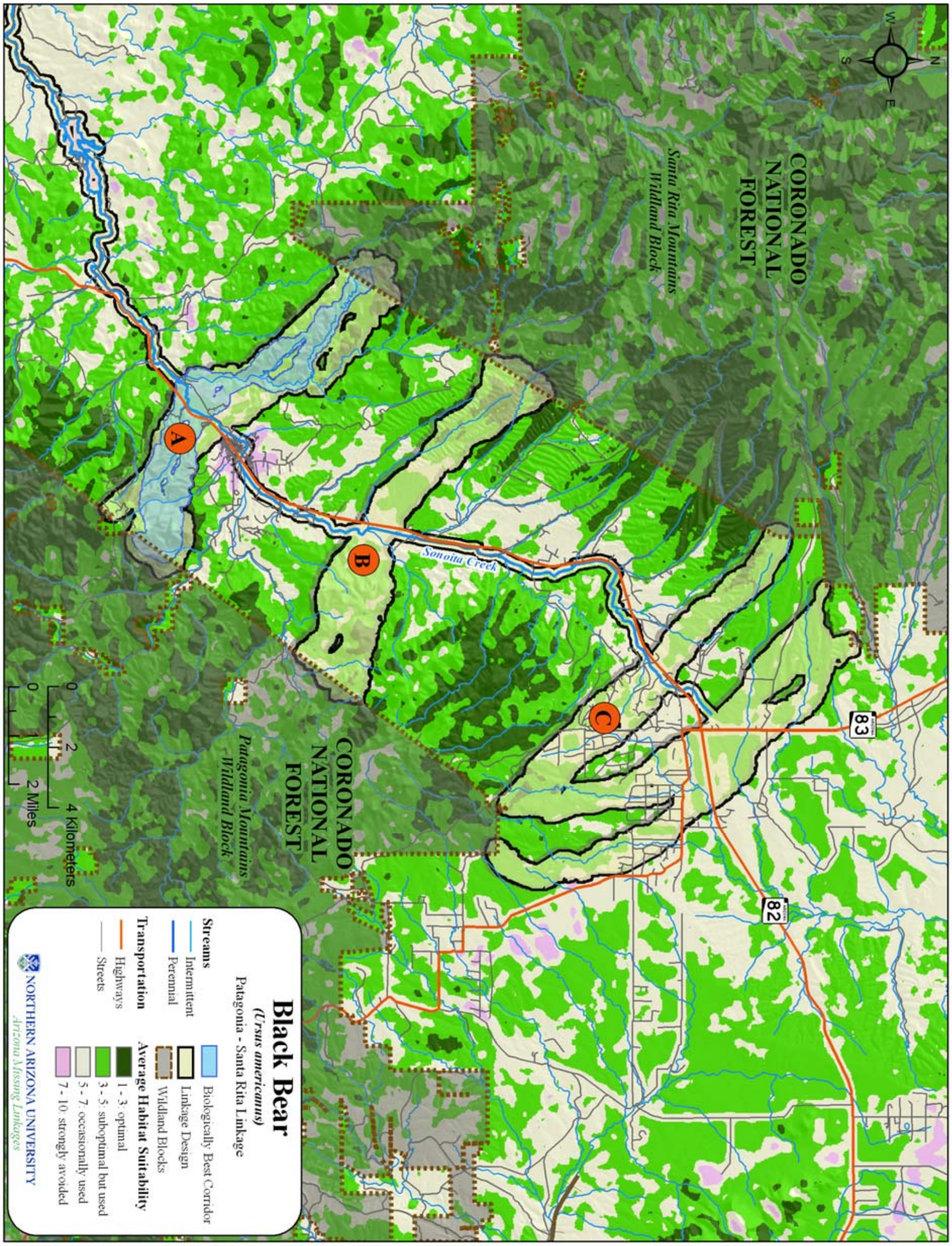


Figure 25: Modeled habitat suitability of black bear

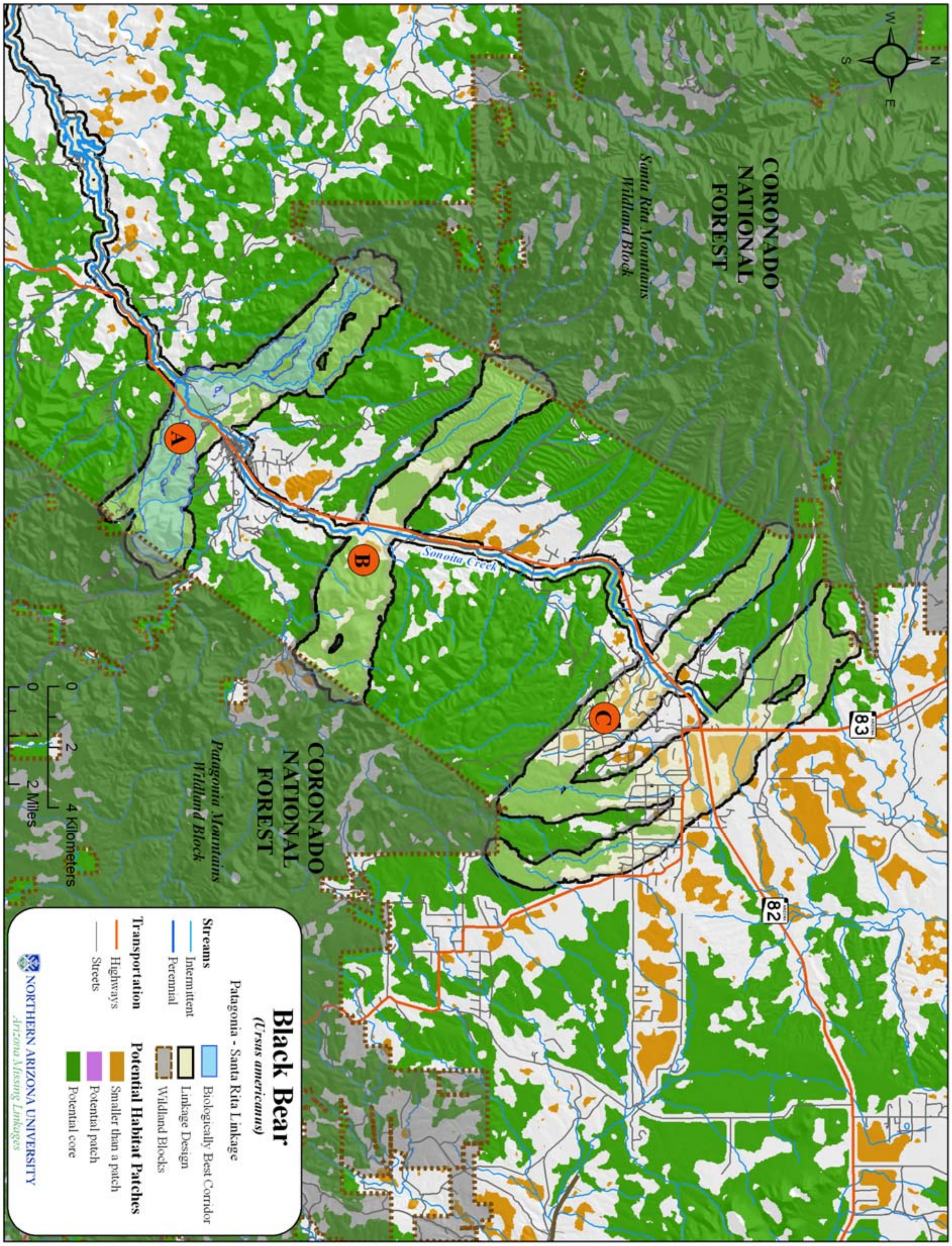


Figure 26: Potential habitat patches and cores for black bear

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

Justification for Selection

Coues' white-tailed 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 an 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 conterminous 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

.

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 – We used the methods described in Appendix A to identify the biologically best corridor for the Coues' white-tailed deer.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for Coues' white-tailed deer, with large patches of optimal habitat occurring largely within the wildland blocks (Figure 27). Within the biologically best corridor, habitat suitability scores ranged from 1.1 to 8.0, with an average cost of 3.3 (S.D: 1.0). Within the corridor, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 28).

Union of biologically best corridors – Strand B is comprised mostly of suitable habitat for Coues' white-tailed deer, with some optimal habitat on occurring near the wildland blocks. Strand C also captures some additional suitable and optimal habitat, though it is mostly comprised of less suitable habitat. with some smaller patches of optimal habitat near the wildland blocks. Within and around the wildland blocks, there appears to be ample habitat for this species, while the land around developments was rated as less suitable. The greatest threat to connectivity and persistence for mountain lion is most likely high-traffic roads such as SR-83 and SR-83, and development.

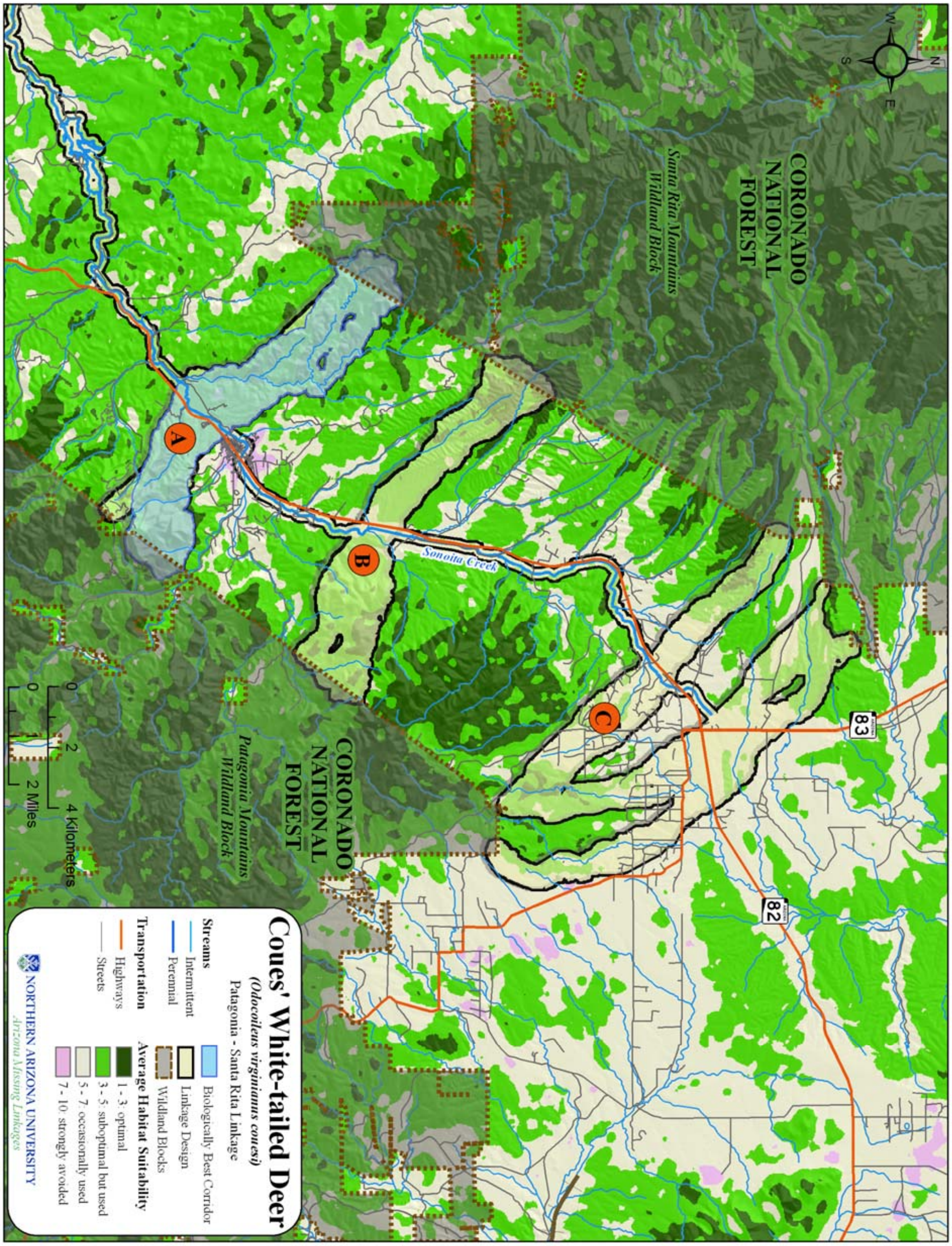


Figure 27: Modeled habitat suitability for Coues' white-tailed deer

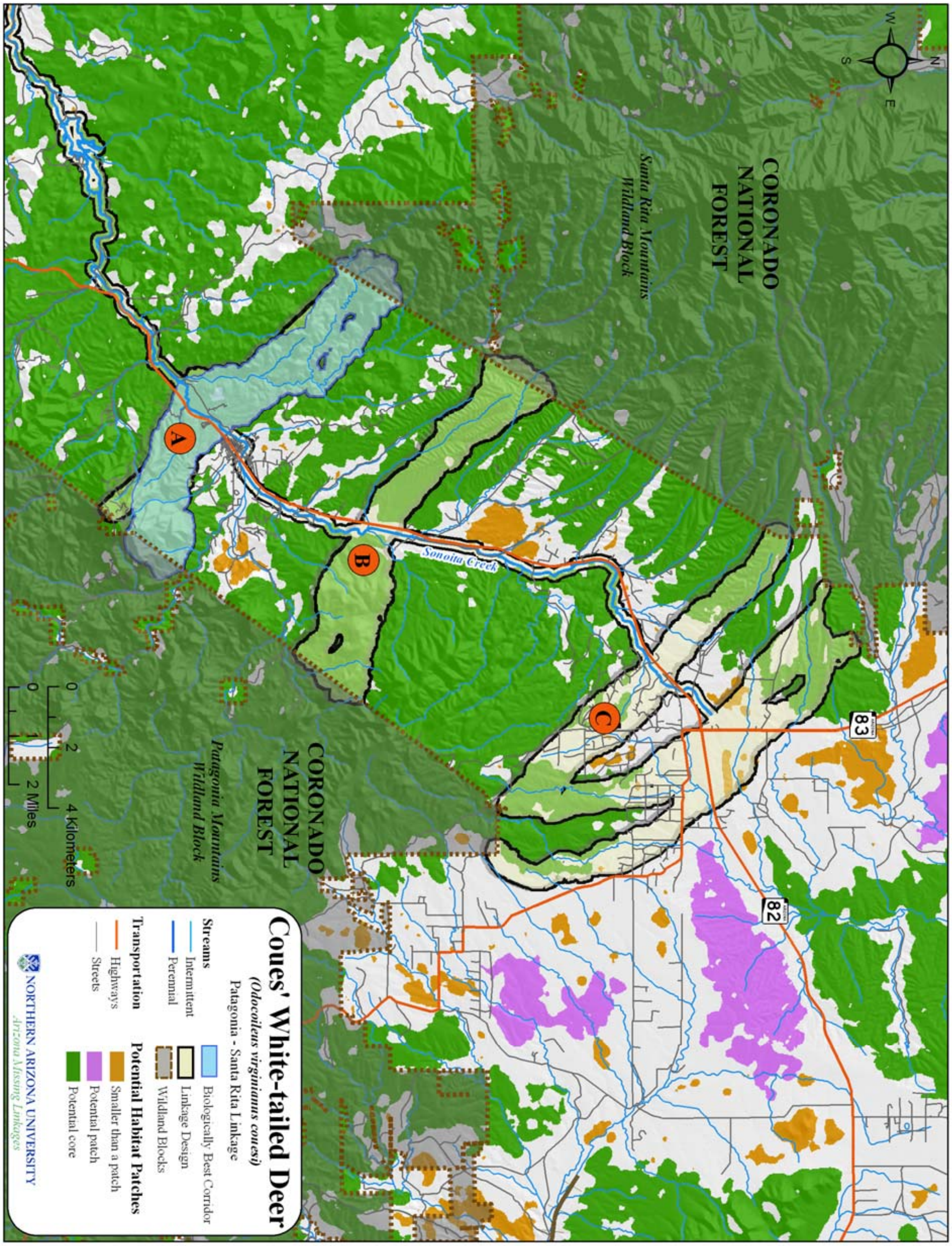


Figure 28: Potential habitat patches and cores for Coues' white-tailed deer

Jaguar (*Panthera onca*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results depict large patches of optimal habitat fringed with suitable habitat for jaguar, with strongly avoided habitat along roads and developments (Figure 29). Within the biologically best corridor, habitat suitability scores ranged from 1.4 to 10.0, with an average cost of 2.9 (S.D: 1.4). Within the corridor, potential suitable and optimal habitat appears to be abundant although it encompasses strongly avoided habitat near SR-82. The northern portion of the BBC is part of a potential habitat core, while the area sough of SR-82 is part of a potential patch not large enough to serve as a core (Figure 30).

Union of biologically best corridors – The additional strands of the UBBC capture some patches of potential jaguar habitat with strongly avoided habitat occurring near the roads and developments. Protecting a suitable corridor through this matrix is integral to maintaining connectivity for jaguars.

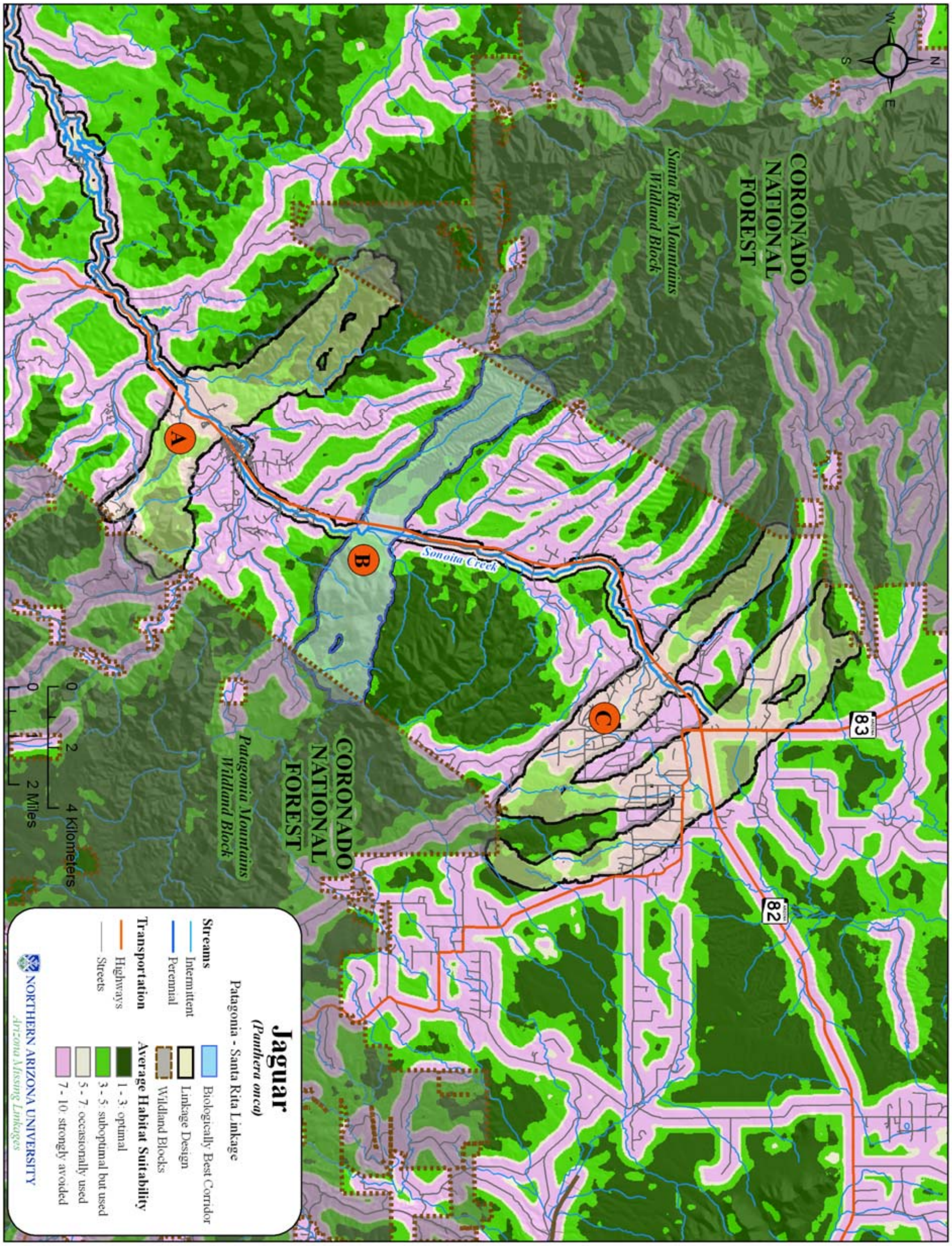


Figure 29: Modeled habitat suitability of jaguar

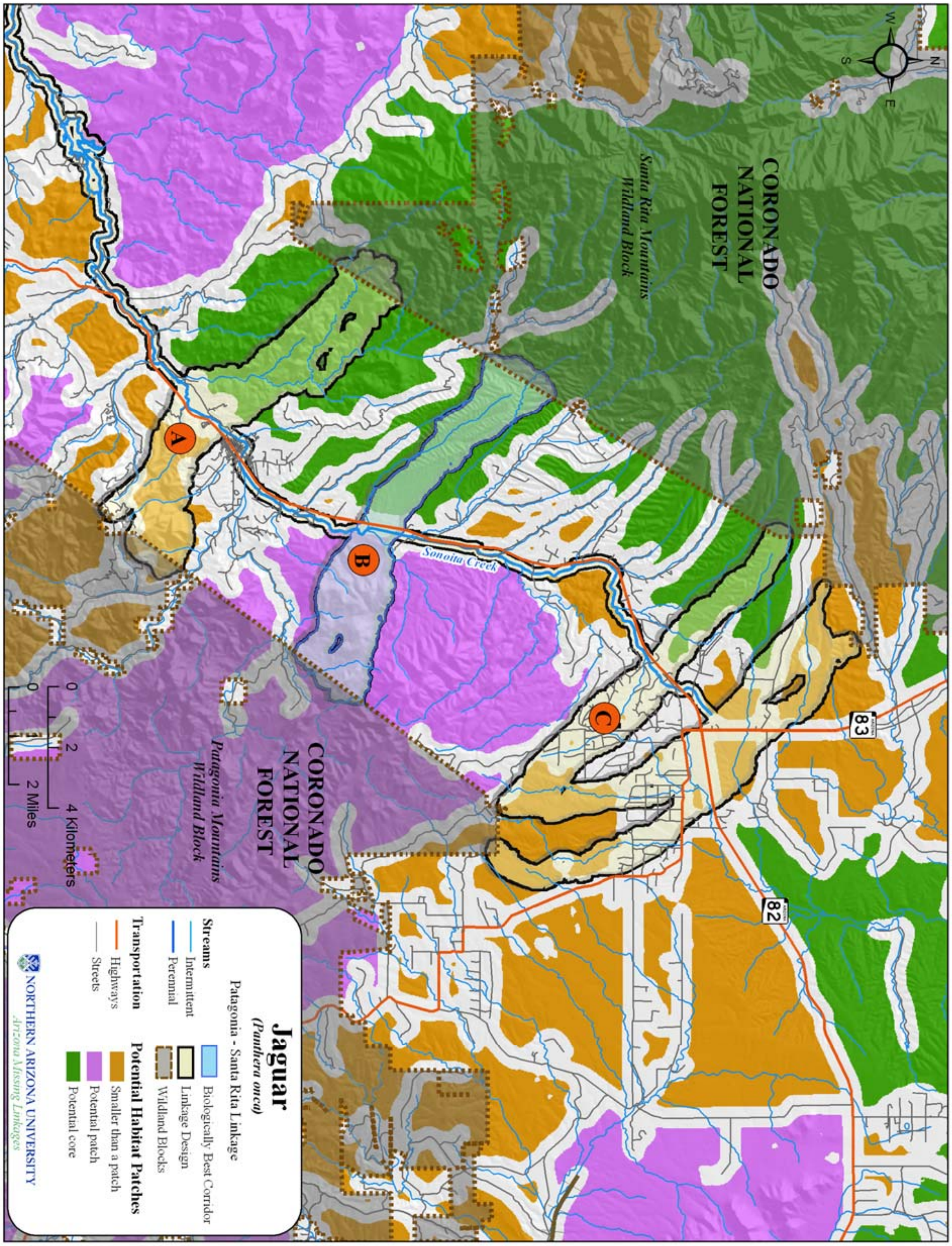


Figure 30: Potential habitat patches and cores for jaguar

Mexican Gray Wolf (*Canis lupus baileyi*)

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

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

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

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

Conceptual Basis for Model Development
Habitat suitability model – Historically, Mexican gray wolves preferred montane woodlands in Arizona and New Mexico. They do not show an aversion to roads (quote someone), which makes them sensitive to high road mortality, while also providing access to poachers. Vegetation received an importance weight

of 25%, elevation 15%, topography 15%, and distance from roads received 35%. For specific scores of classes within each of these factors, see Table .

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for the Mexican gray wolf.

Results & Discussion

Initial biologically best corridor – Modeling results depict large patches of suitable wolf habitat in the wildland blocks, with less suitable habitat occurring in the land between the wildland blocks (Figure 31). Within the biologically best corridor, habitat suitability scores ranged from 3.8 to 5.7, with an average cost of 4.7 (S.D: 0.4). Within the corridor, potential suitable habitat occurs near the wildland blocks, and the BBC encompasses some less suitable habitat north of SR-82. Most of the BBC encompasses a potential core, with the exception of the less suitable habitat north of SR-82 (Figure 32).

Union of biologically best corridors – The additional strands of the UBBC capture some patches of suitable wolf habitat, although less suitable habitat occurs near the center of each strand. The greatest threat to wolf habitat connectivity is most likely high-traffic roads such as SR-83 and SR-83, and habitat fragmentation.

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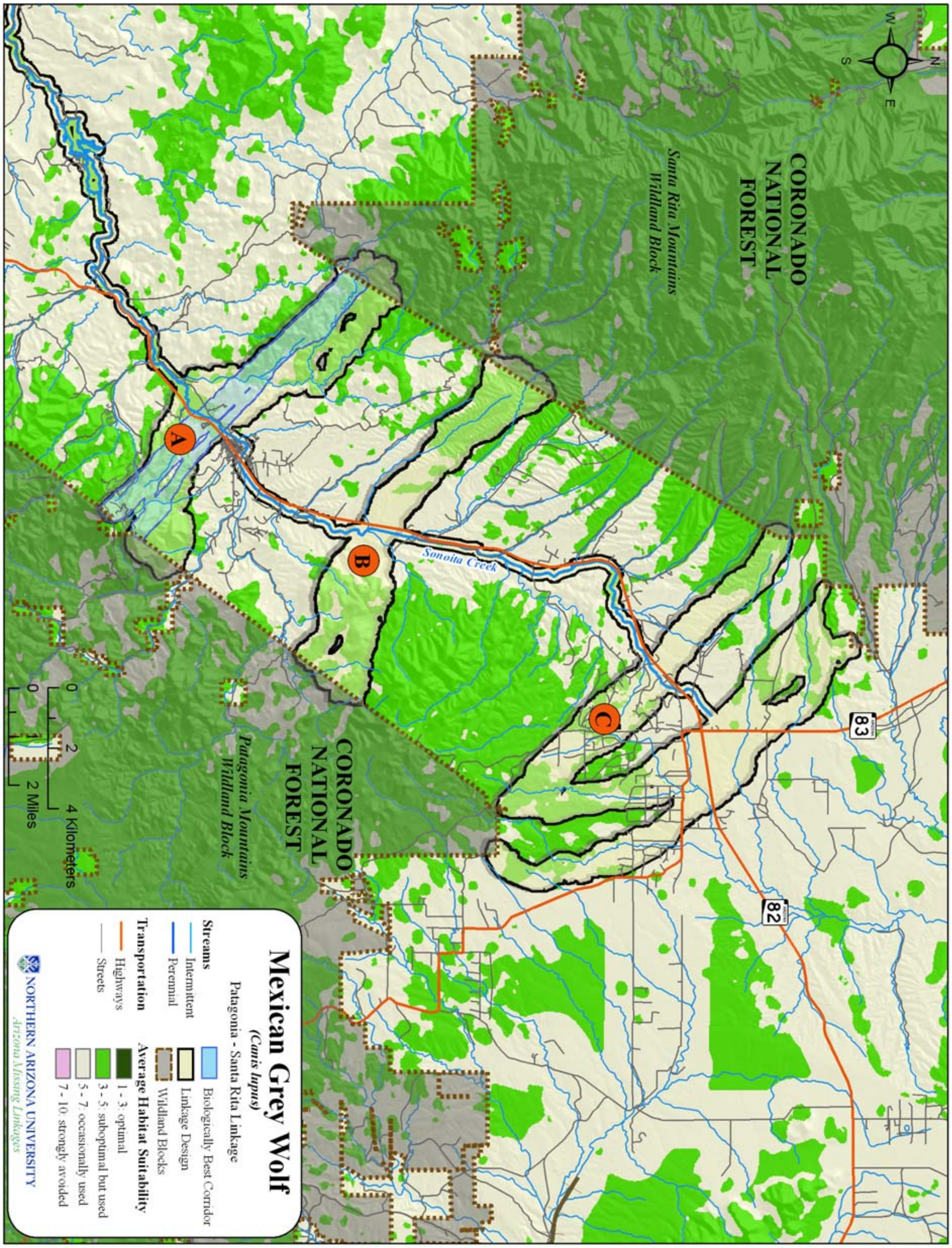

Figure 31: Modeled habitat suitability of Mexican gray wolf

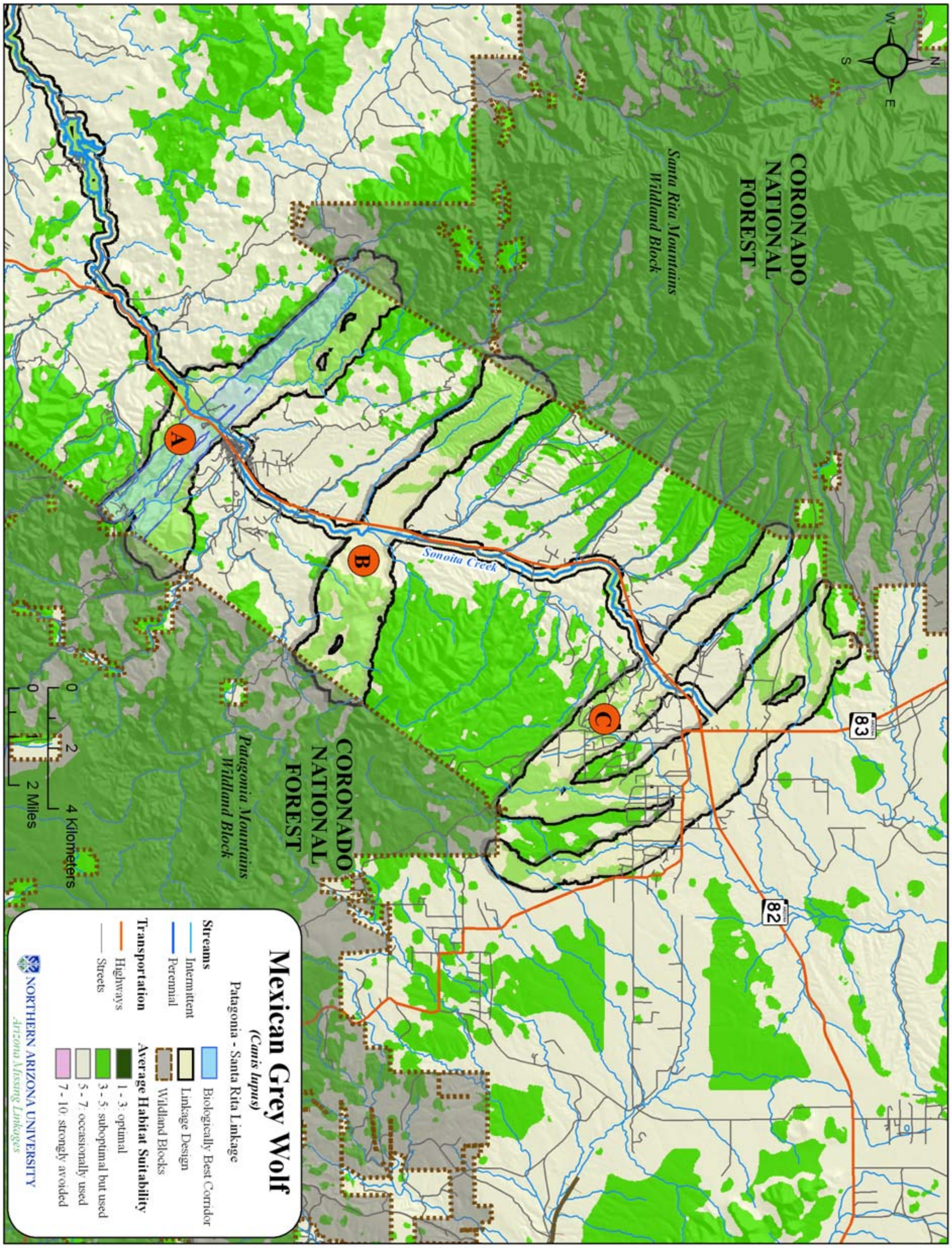

Figure 32: Potential habitat patches and cores for Mexican gray wolf

Mountain Lion (*Puma concolor*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat, with large patches of optimal habitat located within the wildland blocks (Figure 33). Within the biologically best corridor, habitat suitability scores ranged from 1.3 to 6.7, with an average cost of 3.1 (S.D: 1.1). Within the corridor, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 34).

Union of biologically best corridors – The additional strands of the UBBC capture some additional suitable habitat for mountain lion, particularly Strand B. There appears to be ample mountain lion habitat within the potential linkage area, and most of the UBBC serves as a potential habitat core, except for the middle portion of Strand C near development. The greatest threat to connectivity and persistence for mountain lion is most likely high-traffic roads such as SR-83 and SR-83, and habitat fragmentation.

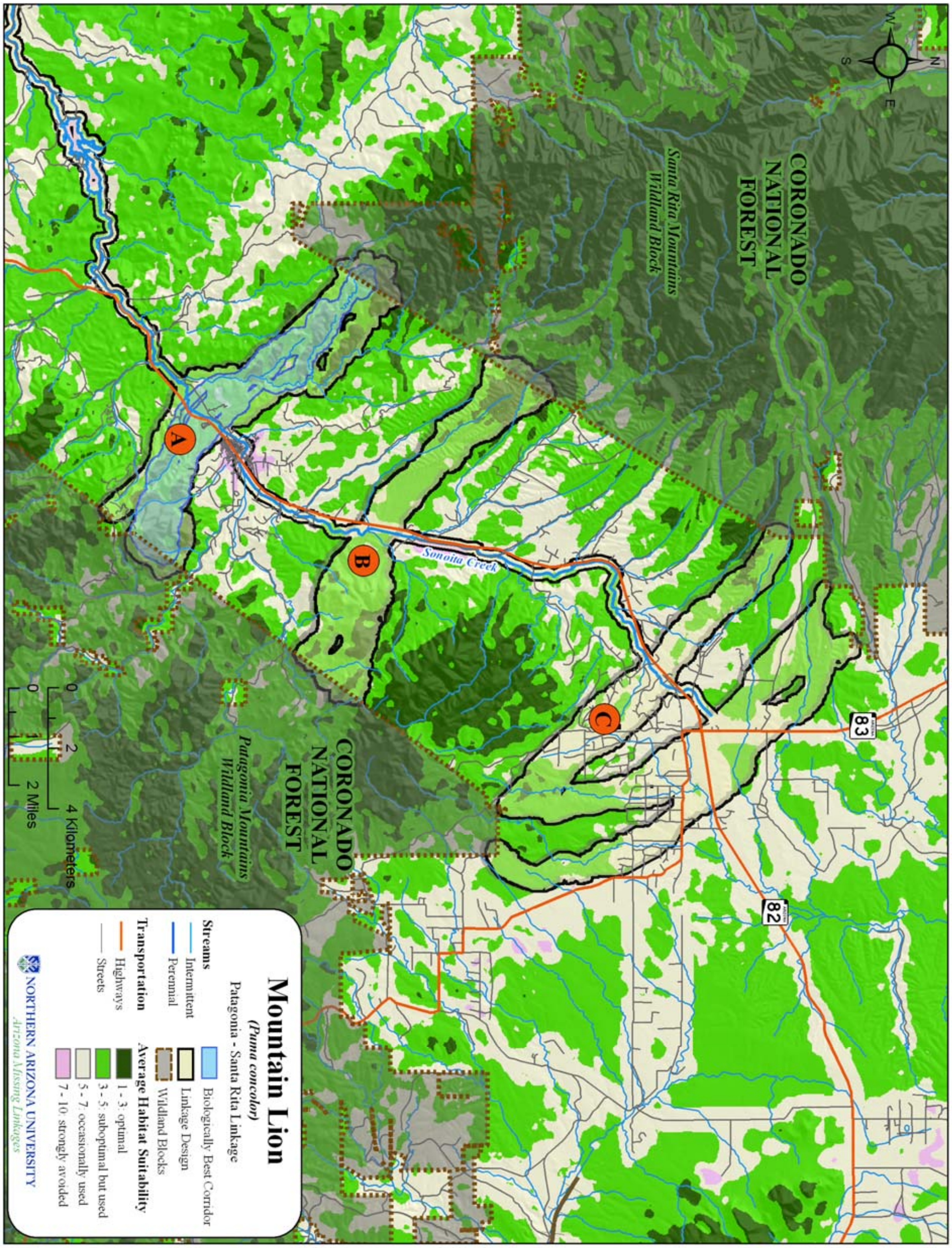

Figure 33: Modeled habitat suitability of mountain lion

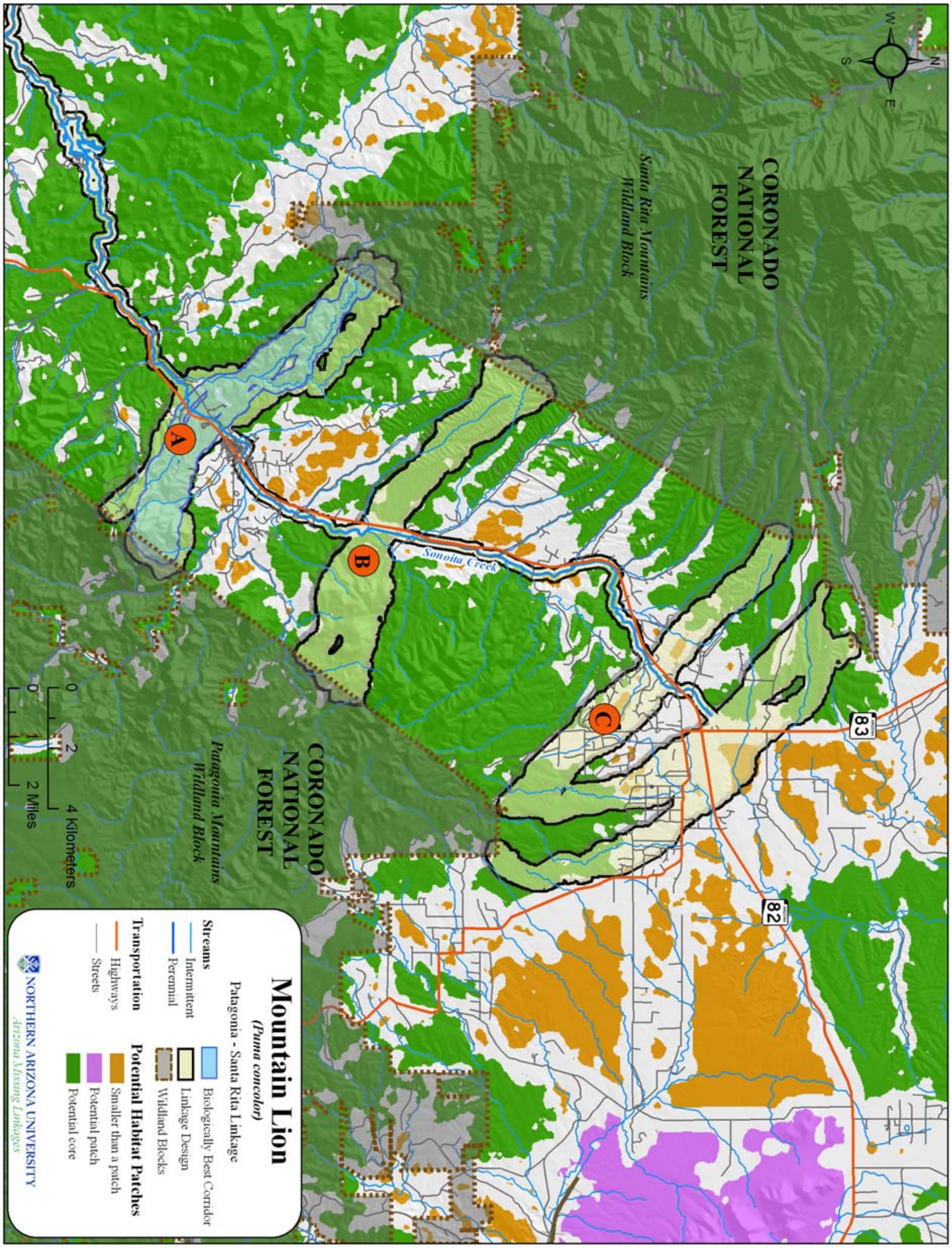

Figure 34: Potential habitat patches and cores for mountain lion

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation has the greatest role in determining deer distributions in desert systems, followed by topography (Jason Marshal, personal comm.). For this reason, vegetation received an importance weight of 80%, while topography and distance from roads received weights of 15% and 5%, respectively. For specific scores of classes within each of these factors, see
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Patch size & configuration analysis – Minimum patch size for mule deer was defined as 9 km^2 and minimum core size as 45 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for mule deer

Results & Discussion

Initial biologically best corridor – Modeling results depict suitable habitat for muledeer throughoutthe potential linkage area, with a significant amount of optimal habitat located largely in the northern and eastern portions of the linkage planning area (Figure 35). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 2.0 to 5.9, with an average cost of 3.0 (S.D: 0.7). The BBC encompasses a mixture of optimal and suitable habitat, and is made up entirely of a potential habitat core (Figure 36).

Union of biologically best corridors – Strands A and B capture additional suitable mule deer habitat, and potential core habitat. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as SR-82 and SR-83, and habitat fragmentation.

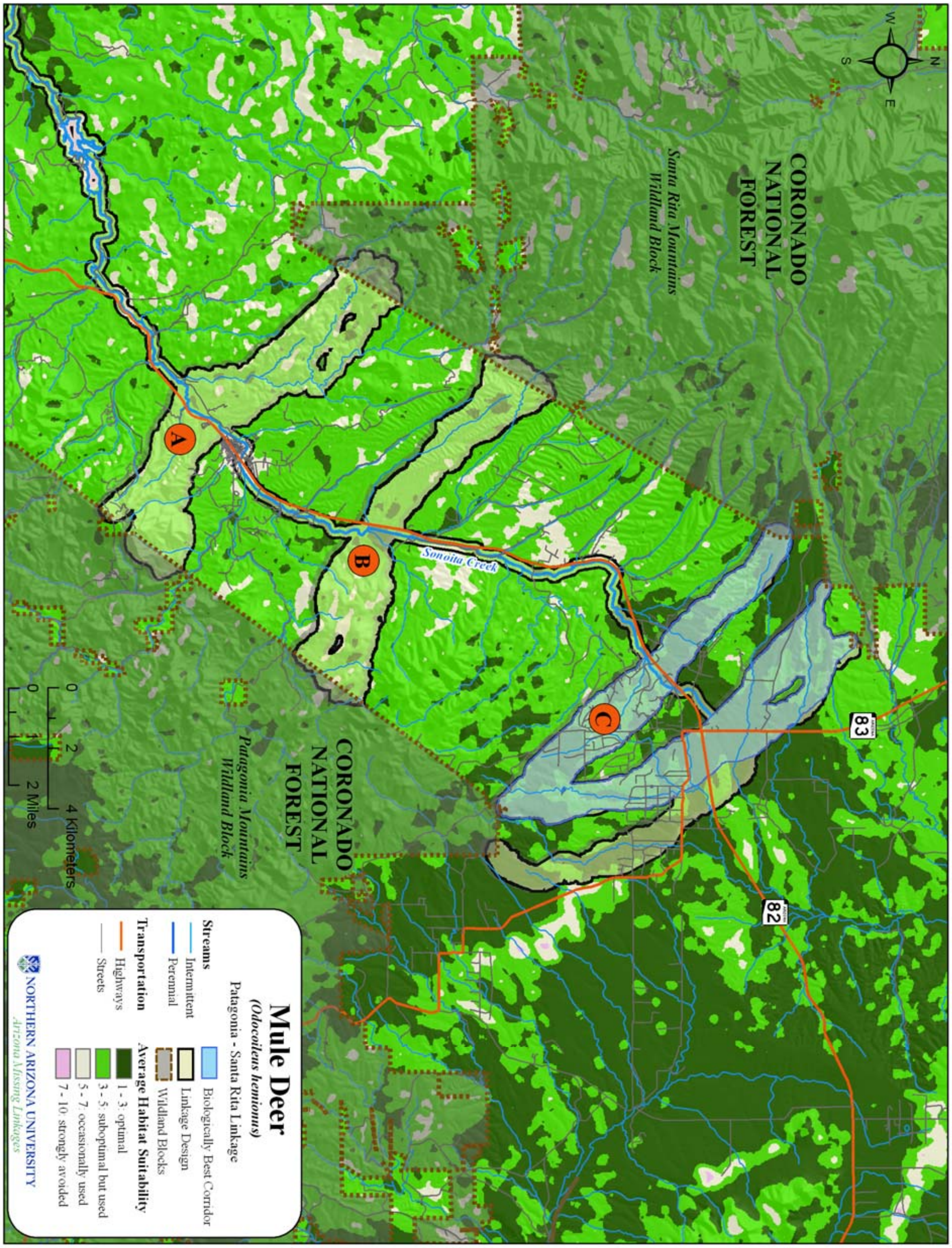

Figure 35: Modeled habitat suitability for mule deer

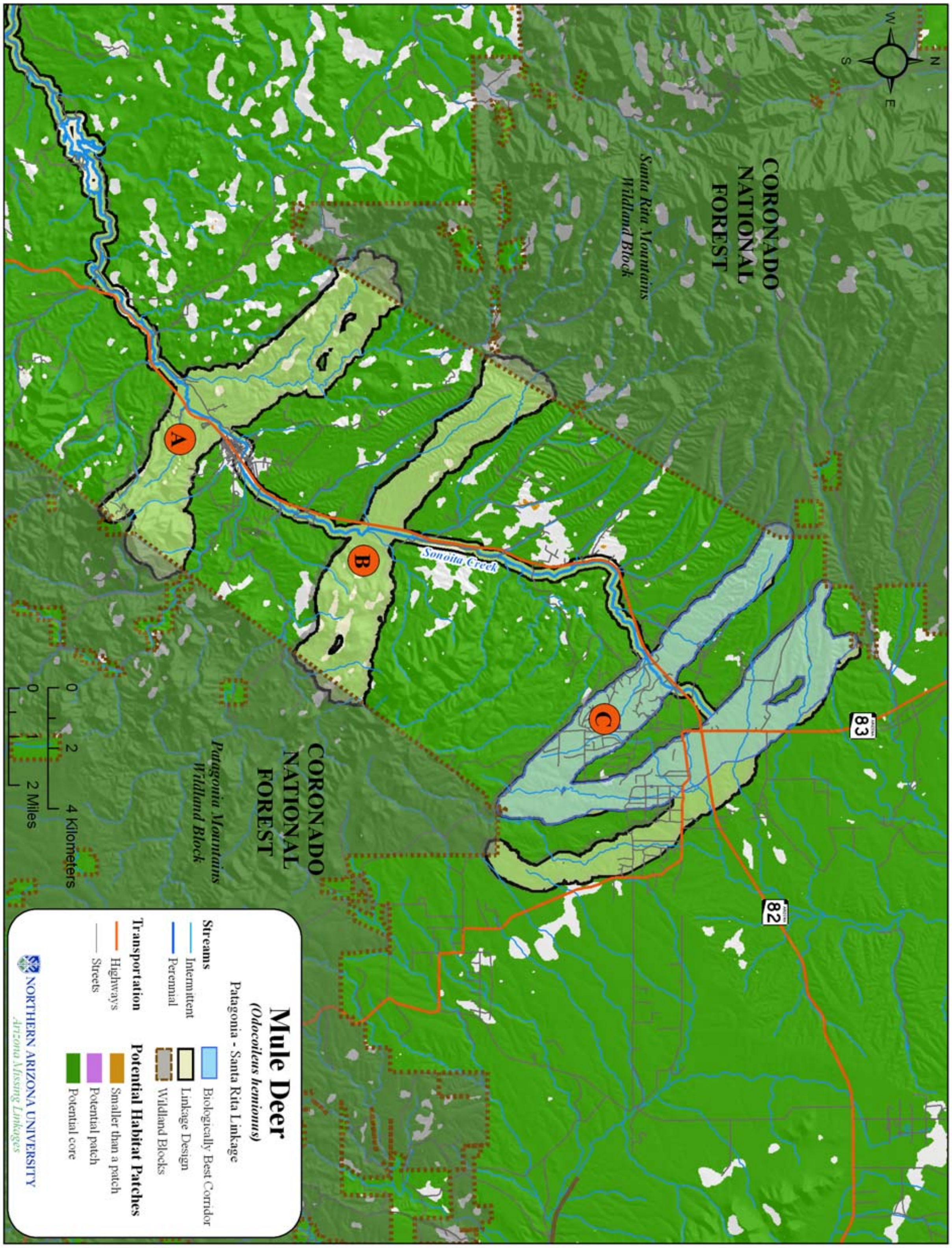

Figure 36: Potential habitat patches and cores for mule deer

Riparian and Aquatic Obligates

Several fish, amphibians, reptiles, and birds associated with riparian or aquatic habitats were suggested as focal species for this linkage design. Although we could not model their habitat requirements using the same analyses employed for terrestrial species, we ensured that the riparian and aquatic habitats in the linkage design along Sonoita Creek were adequately incorporated in the linkage design (Figure 1). A list of important riparian and aquatic obligate species follows:

Fish

- Desert Sucker (*Catostomus clarki*) –listed as sensitive by the BLM River (Heritage Data Management System 2004) and considered a Species of Concern by the U.S. Fish and Wildlife Service though it is thought to be fairly common in Arizona (New Mexico Game and Fish 2006).

- Gila Topminnow (*Poeciliopsis occidentalis occidentalis*) – The Gila topminnow is listed as federally endangered by the U.S. Fish and Wildlife Service, and is a Wildlife Species of Special Concern in Arizona.

- Longfin Dace (*Agosia chrysogaster*) – longfin dace is listed as BLM Sensitive, threatened in Mexico, and considered a Species of Concern by the U.S. Fish and Wildlife Service. (Arizona Game and Fish Department 2002).

- Razorback Sucker (*Xyrauchen texanus*) – The razorback sucker is listed as federally endangered with critical habitat by the U.S. Fish and Wildlife Service.

Amphibian

- Chiricahua Leopard Frog (*Rana chiricahuensis*) – This frog is listed as threatened and the population is declining in Arizona. It has been extirpated from about 75 percent of its historic range in Arizona and New Mexico (USFWS 2002). Threats include habitat fragmentation, major water manipulations, water pollution, and heavy grazing (AGFD 2001). It is an aquatic species that prefers oak and pine woodlands, chaparral, grassland, and even desert (AGFD 2001).

Birds

- Black-bellied Whistling Duck (Dendrocygna autumnalis) – This species is a riparian obligate listed as an Arizona Species of Special Concern (AGFD 1996). While they were formerly more common in the wooded marshes in central and southeastern Arizona they now breed only in south-central Arizona (AGFD 1996). Threats include loss of wetland and riparian habitat and increased use of waterways for recreational activities (AGFD 2002). Northern Gray Hawk

- Northern Gray Hawk(*Buteo nitidus maximus)* – In the U.S., this migratory species occurs in southern Arizona, southern New Mexico and southern Texas, and goes south for the winter. In Arizona, it is known to ocur the watersheds of the San Pedro, Santa Cruz, and Verde Rivers. It prefers riparian woodlands with large trees including cottonwoods, usually near mesquite forests.

- Rose Throated Becard (*Pachyramphus aglaiae*) – This species occurs in desert riparian deciduous woodlands and marshes (ADGF 2001), including low-elevation (<1200 m) riparian corridors along perennial streams throughout canyons and desert valleys. It was recently found breeding along Sonoita Creek and Patagonia, and is considered a summer resident in Sonoita Creek (Phillips et al. 1978, Monson and Phillips 1981, Edison et al. 1995).

Appendix C: Focal Species not Modeled

The habitat requirements and connectivity needs of several other suggested focal species were not modeled in this study because their habitat preferences cannot be easily modeled using standard GIS layers. A list of these species follows:

Mammals

- Yellow-nosed Cotton Rat (*Sigmodon ochrognathus*) – In the U.S., this species occurs in southeastern Arizona, southwestern New Mexico, and southwestern Texas. In Arizona, its range is bounded by the Baboquivari, Santa Rita, and Santa Catalina mountains to the northwest, the Galiuro Mountains to the north, and the Chiricahua Mountains to the east. They prefer grassy, dry, rocky slopes in or near oak woodlands, as well as montane meadows within ponderosa pine and Douglas fir forests such as the habitat found in Madrean evergreen woodlands, and semidesert grasslands.

- Ocelot (*Leopardus pardalis*) – The ocelot was listed as endangered in 1982 in the U.S., where only two known breeding populations remain in southern Texas (Haines et al. 2006). They are threatened by loss and fragmentation of habitat, and individuals are susceptible to collisions with vehicles. Historically, they were present in the U.S. from Arkansas to Arizona. The last confirmed Ocelot in Arizona was taken in the Huachuca Mountains, in 1964 (Hoffmeister 1986). In the majority of its range, the ocelot occurs in tropical, humid habitats. In Texas, ocelots occur in the dense thorny chaparral of the Rio Grande Valley (Tewes and Schmidly 1987). In Arizona, there is dearth of data regarding ocelot occurrence and habitat use.

Herpetofauna

- Northern Mexican Gartersnake (*Thamnophis eques megalops)* – In the U.S., this species ranges from southeastern Arizona and southwestern New Mexico southward. It is known to occur in the Sonoita grasslands area. In Arizona, these snakes are most abundant in densely vegetated habitat surrounding cienegas, cienega-streams, and stock tanks and in or near water along streams in valley floors and generally open areas, but not in steep mountain canyon stream habitat (Rosen and Schwalbe 1988).

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

Birds

- Cactus Ferruginous Pygmy Owl (*Glaucicium brasilianum cactorum*) – This species was delisted from the federal list of endangered and threatened wildlife in 2006. They occur in a variety of vegetation communities including riparian communities, mesquite bosques, Sonoran desertscrub, and semidesert grasslands. They require dense thickets and cavities for nesting (DOI 2006).

- Common black-hawk (*Buteogallus anthracinus anthracinus*) – Common black-hawks occur in riparian woodlands, especially cottonwood forests (New Mexico Game and Fish 2006). They tend to nest witing 500 meters of permanent, flowing water (Heritage Data Management System 2004). They are also highly mobile.

- Mexican Spotted Owl (*Strix occidentalis lucida*) – Spotted owl habitat includes large, steep canyons with dense old-growth forestsof Douglas fir, White fir, western hemlock, hardwoods, mixed evergreen, and pine-oak forests (Andrews and Righter 1992, Gutiérrez et al. 1995, Kingery1998). Fairly isolated populations occur in southern Utah and central Colorado south through Arizona, New Mexico, and western Texas. In Arizona, populations are patchily distributed in forested mountains and steep canyons.

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor edits to the union of biologically best corridors (Figure 37):

- We widened the UBBC in several locations to ensure that each strands running between the wildland blocs was at least 1 km wide, and buffered Sonoita Creek approximately 200 m on either side.
- We filled-in holes that were created as an artifact of the modeling process if they were composed of natural vegetation, and not high-density developed land.
- We removed a narrow, redundant branch of badger habitat in the southeastern portion of strand C.

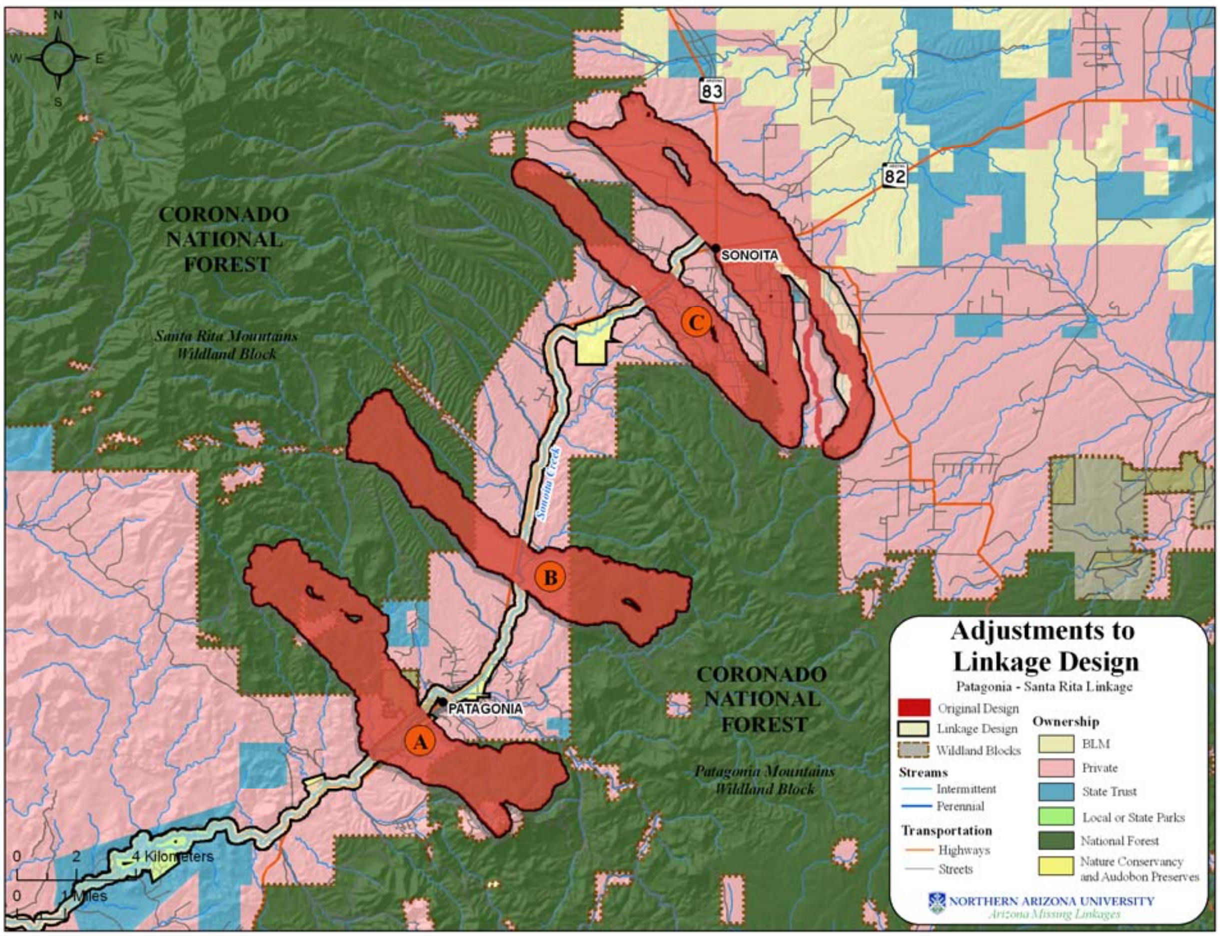

Figure 37 Adjustments made to union of biologically best corridors to create the linkage design include adding to the original design.

Appendix E: Description of Land Cover Classes

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

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

<u>Pine-Oak Forest and Woodland</u> – 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.*

<u>Pinyon-Juniper Woodland</u> – 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.

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

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

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

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

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

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

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

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

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

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

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

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

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

<u>Barren Lands, Non-specific</u> – 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.

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

<u>Agriculture</u>

<u>Developed, Medium - High Intensity</u> – *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.

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

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

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Appendix G: Database of Field Investigations

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

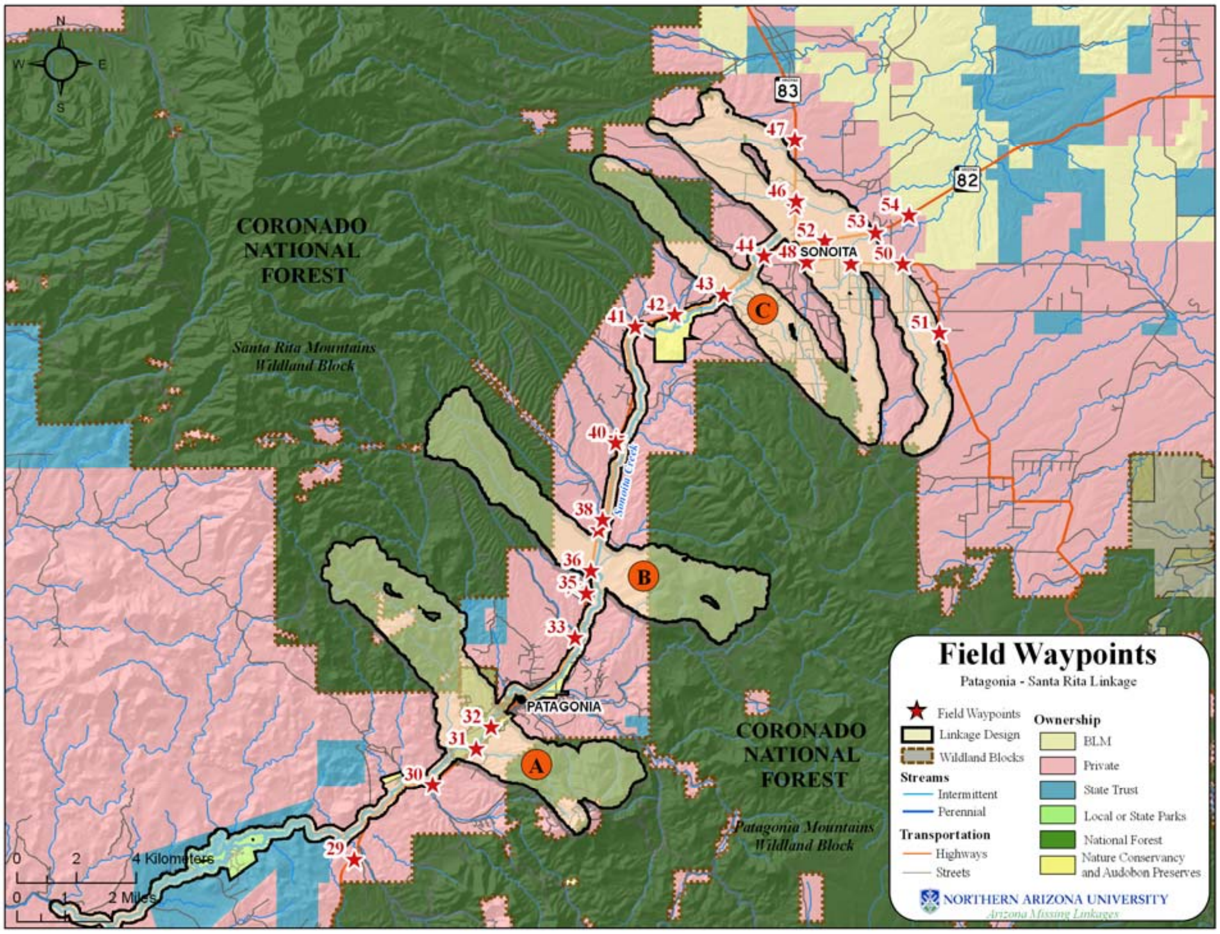


Figure 38:Field investigation waypoints in the linkage planning area

Appendix G: Database of Field Investigations

Linkage #: 96

Linkage Zone: Patagonia

Observers: Paul Beier

Field Study Date: 5/12/2007

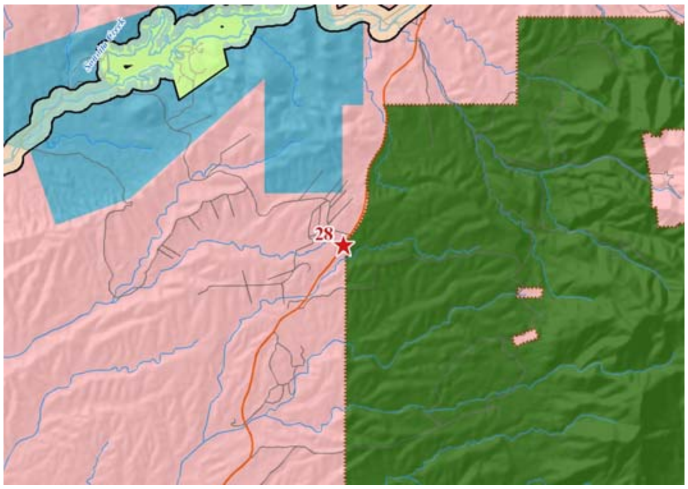
Waypoint #: 28

Latitude: 31.46277 **Longitude:** -110.82498

UTM X: 516627.2497 **UTM Y:** 3480903.573

Last Printed: 1/4/2008

Waypoint Map



Waypoint Notes

SR 82, MP 12

Site Photographs

Name: IMG_0802.jpg

Azimuth: 280 **Zoom:** 2

Notes: Oak savannah in the foreground, Tumacacori Mountains in the background

Name: IMG_0803.jpg

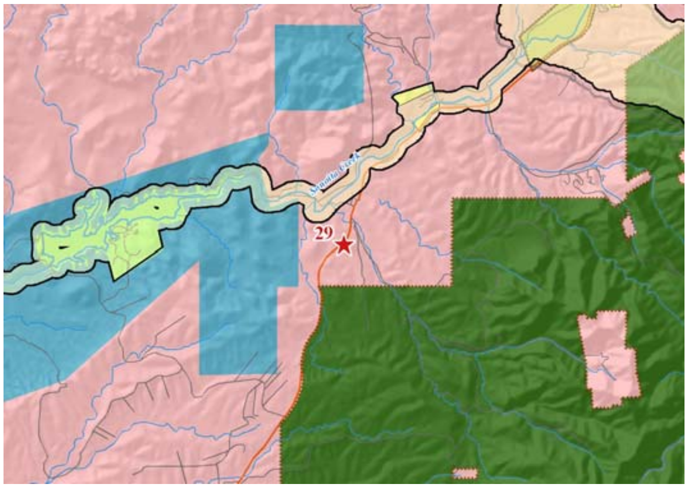
Azimuth: 70 **Zoom:** 1

Notes: The Patagonia Mountains

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	29		
Linkage Zone:	Patagonia	**Latitude:**	31.49267	**Longitude:**	-110.81246
Observers:	Paul Beier	**UTM X:**	517811.0125	**UTM Y:**	3484219.463
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 14.3

Site Photographs

Name: IMG_0804.jpg

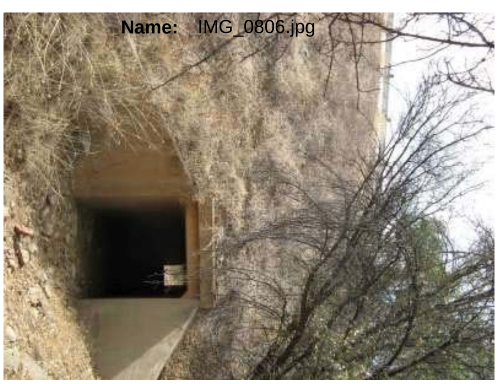
Azimuth: 320 **Zoom:** 1

Notes: Oak woodland

Name: IMG_0805.jpg

Azimuth: 135 **Zoom:** 1

Name: IMG_0806.jpg



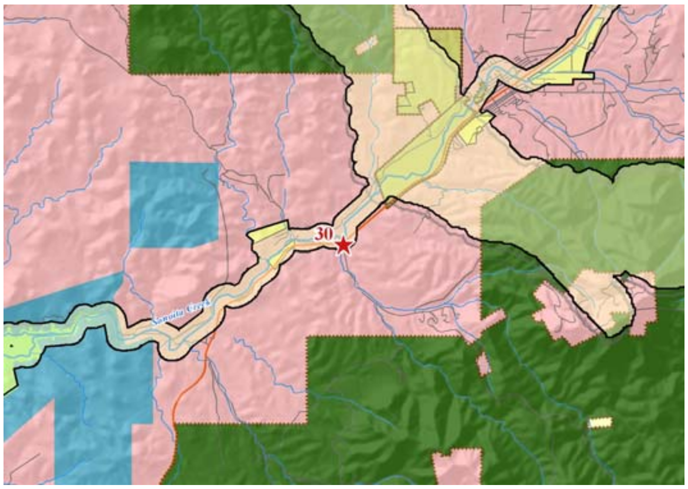
Zoom: 1

Notes: 6x8' Box culvert under about 15' of fill dirt

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	30		
Linkage Zone:	Patagonia	**Latitude:**	31.51514	**Longitude:**	-110.78464
Observers:	Paul Beier	**UTM X:**	520448.2419	**UTM Y:**	3486714.759
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 16.8

Site Photographs

Name: IMG_0807.jpg

Azimuth: 310 **Zoom:** 1

Notes: A 5-box culvert undercrossing, boxes 10x10', note the fencing blocking the entrance.

Name: IMG_0808.jpg

Azimuth: 130 **Zoom:** 1

Notes: Ranch outbuildings

Name: IMG_0809.jpg

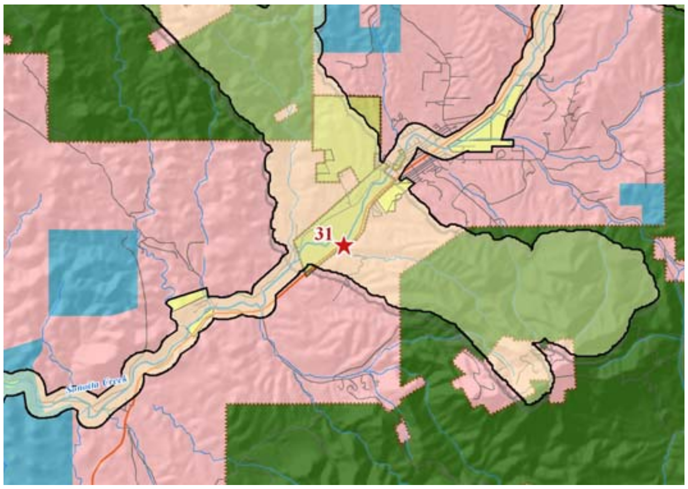
Azimuth: 170 **Zoom:** 1

Notes: Creek bed with heavy horse use evident

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	31		
Linkage Zone:	Patagonia	**Latitude:**	31.52621	**Longitude:**	-110.76914
Observers:	Paul Beier	**UTM X:**	521917.3721	**UTM Y:**	3487944.693
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 18

Site Photographs

Name: IMG_0810.jpg

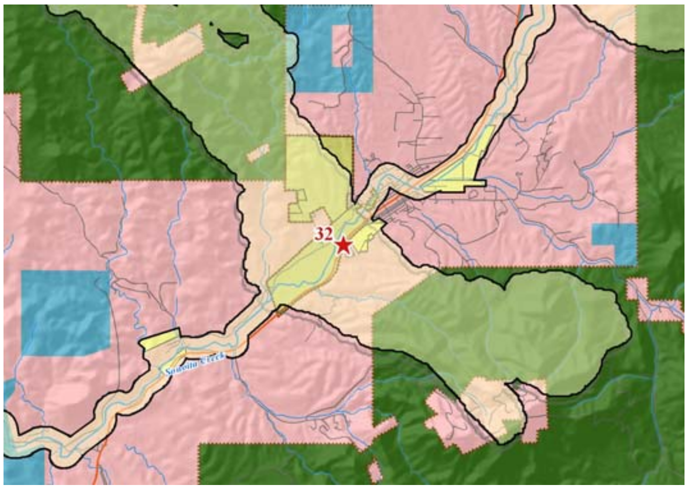
Notes: 10x10' box culvert with barbed wire blocking access

Name: IMG_0811.jpg

Notes: From inside the box culvert

Linkage #:	96	**Waypoint #:**	32		
Linkage Zone:	Patagonia	**Latitude:**	31.53279	**Longitude:**	-110.76385
Observers:	Paul Beier	**UTM X:**	522418.0232	**UTM Y:**	3488675.056
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

Cemetery south of SR 82, near MP 18.7

Site Photographs

Name: IMG_0812.jpg

Azimuth: 290 **Zoom:** 2

Notes: Sonoita Creek in the foreground, the Santa Rita Mountains beyond, with some ranch buildings visible in between

Name: IMG_0813.jpg

Azimuth: 20 **Zoom:** 1

Notes: SR 82 toward Patagonia

Name: IMG_0814.jpg

Azimuth: 65 **Zoom:** 1

Notes: Sonoita Creek and Patagonia

Name: IMG_0815.jpg

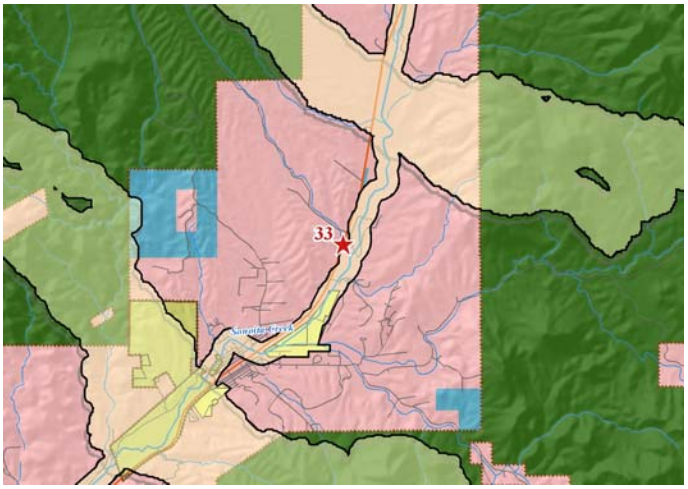
Azimuth: 110 **Zoom:** 2

Notes: Patagonia Mountains

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	33		
Linkage Zone:	Patagonia	**Latitude:**	31.55983	**Longitude:**	-110.73397
Observers:	Paul Beier	**UTM X:**	525247.2985	**UTM Y:**	3491678.538
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 21.7

Site Photographs

Name: IMG_0816.jpg

Azimuth: 300 **Zoom:** 1

Notes: 5x6' pouroffs in 3 box culverts

Name: IMG_0817.jpg

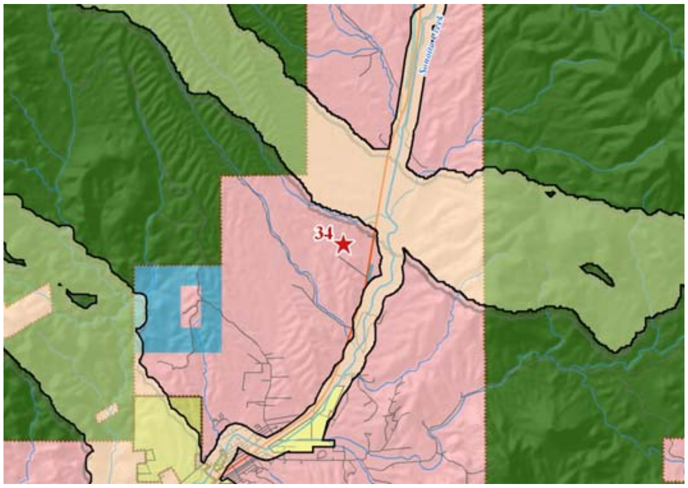
Azimuth: 300 **Zoom:** 1

Notes: Pouroffs

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	34		
Linkage Zone:	Patagonia	**Latitude:**	31.57562	**Longitude:**	-110.73475
Observers:	Paul Beier	**UTM X:**	525169.0316	**UTM Y:**	3493428.450
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

Junctions of Tanglehead and Foxtail north of SR 82

Site Photographs

Name: IMG_0818.jpg

Azimuth: 295 **Zoom:** 1

Notes: Three Canyon custom home lots

Name: IMG_0819.jpg

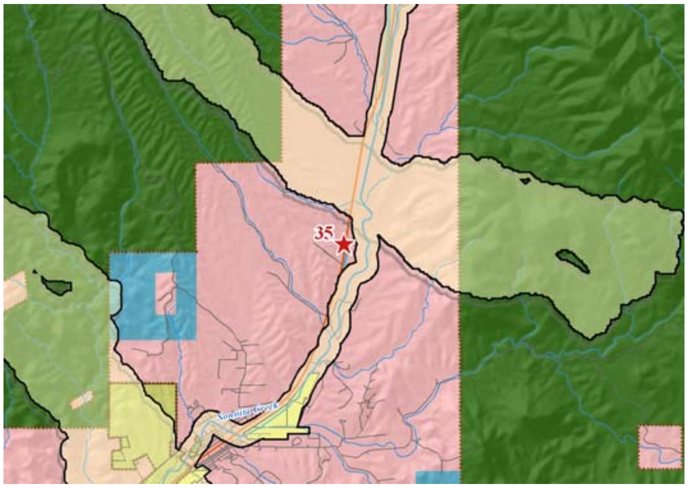
Azimuth: 819 **Zoom:** 4

Notes: Tanglehead Lane toward SR 82

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	35		
Linkage Zone:	Patagonia	**Latitude:**	31.57348	**Longitude:**	-110.72995
Observers:	Paul Beier	**UTM X:**	525625.0807	**UTM Y:**	3493192.376
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

Junction of Tanglehead and SR 82

Site Photographs

Name: IMG_0820.jpg

Azimuth: 280 **Zoom:** 1

Notes: Three Canyons sign

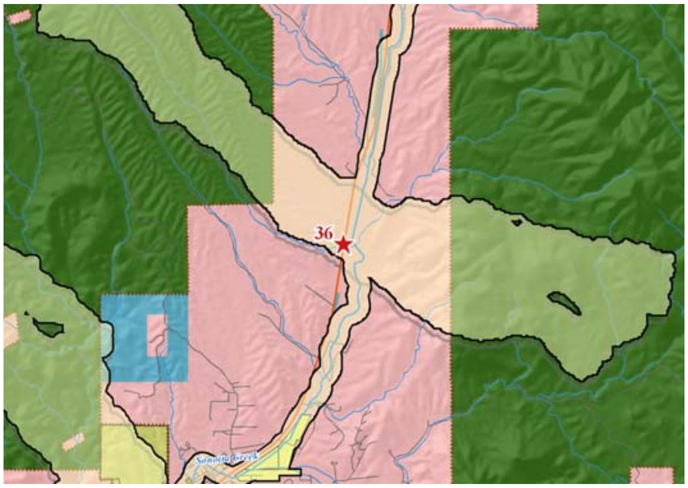
Name: IMG_0821.jpg

Azimuth: 100 **Zoom:** 1

Notes: Site of future Sonoita Springs Ranch, 21 parcels of over 36 acres each

Linkage #:	96	**Waypoint #:**	36		
Linkage Zone:	Patagonia	**Latitude:**	31.58036	**Longitude:**	-110.72833
Observers:	Paul Beier	**UTM X:**	525776.91	**UTM Y:**	3493955.306
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 23.2, at Blueline Wash

Site Photographs

Name: IMG_0822.jpg

Zoom: 1

Notes: Six 8x2' box culverts

Name: IMG_0823.jpg

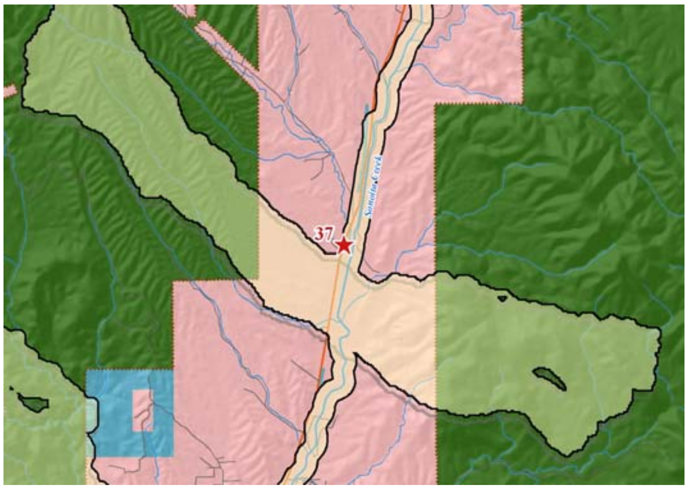
Azimuth: 70 **Zoom:** 1

Notes: The Patagonia Mountains

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	37		
Linkage Zone:	Patagonia	**Latitude:**	31.59259	**Longitude:**	-110.72548
Observers:	Paul Beier	**UTM X:**	526043.9261	**UTM Y:**	3495311.503
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 24.1

Site Photographs

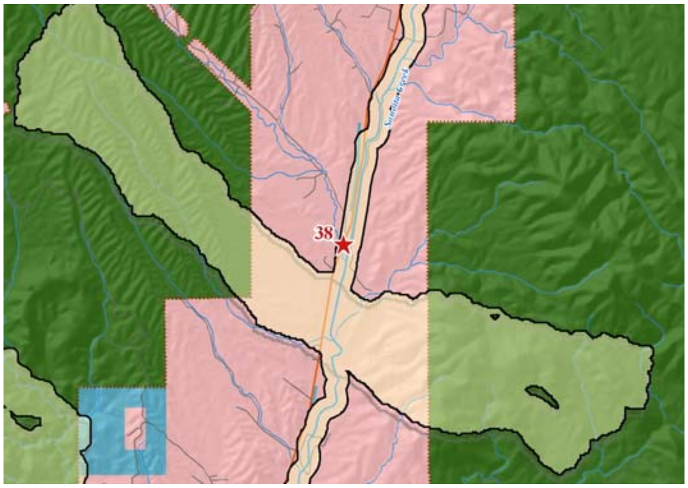
Name: IMG_0824.jpg

Azimuth: 280 **Zoom:** 1

Notes: 6x10' Box Culvert

Linkage #:	96	**Waypoint #:**	38		
Linkage Zone:	Patagonia	**Latitude:**	31.59572	**Longitude:**	-110.72404
Observers:	Paul Beier	**UTM X:**	526179.6651	**UTM Y:**	3495658.763
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 24.3

Site Photographs

Name: IMG_0825.jpg

Azimuth: 290 **Zoom:** 1

Notes: Bridge over Casa Blanca wash

Name: IMG_0826.jpg

Azimuth: 290 **Zoom:** 1

Name: IMG_0827.jpg

Azimuth: 290 **Zoom:** 1

Notes: Barbed wire blocks access underneath bridge

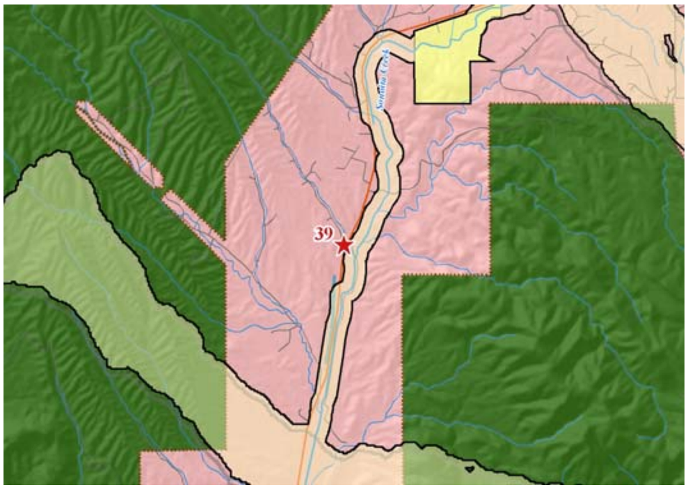
Name: IMG_0828.jpg

Azimuth: 130 **Zoom:** 1

Notes: Looking downstream, riprap on the left bank

Linkage #:	96	**Waypoint #:**	39		
Linkage Zone:	Patagonia	**Latitude:**	31.62063	**Longitude:**	-110.71916
Observers:	Paul Beier	**UTM X:**	526635.5279	**UTM Y:**	3498420.872
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 26

Site Photographs

Name: IMG_0829.jpg

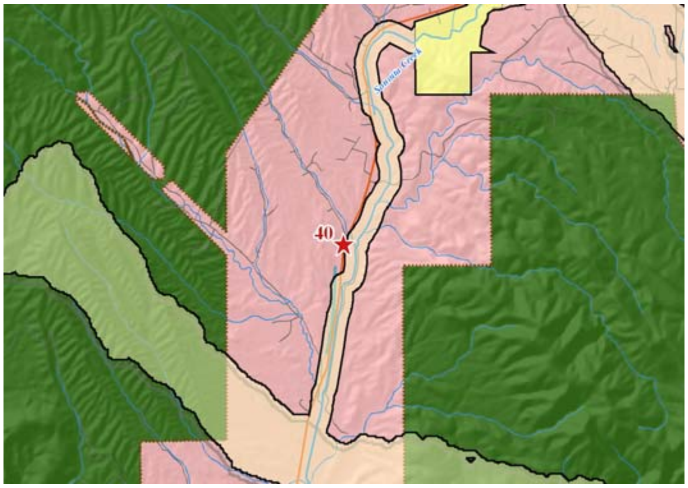
Zoom: 1

Notes: Four 10x10' box culverts adjacent to a sloped 2' concrete pouroff

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	40		
Linkage Zone:	Patagonia	**Latitude:**	31.61923	**Longitude:**	-110.71933
Observers:	Paul Beier	**UTM X:**	526619.8032	**UTM Y:**	3498265.66
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 27.5, at Wood Canyon

Site Photographs

Name: IMG_0830.jpg

Azimuth: 270 **Zoom:** 1

Notes: Bridge

Name: IMG_0831.jpg

Azimuth: 270 **Zoom:** 1

Notes: Bridge with no pouroff, and a fence upstream

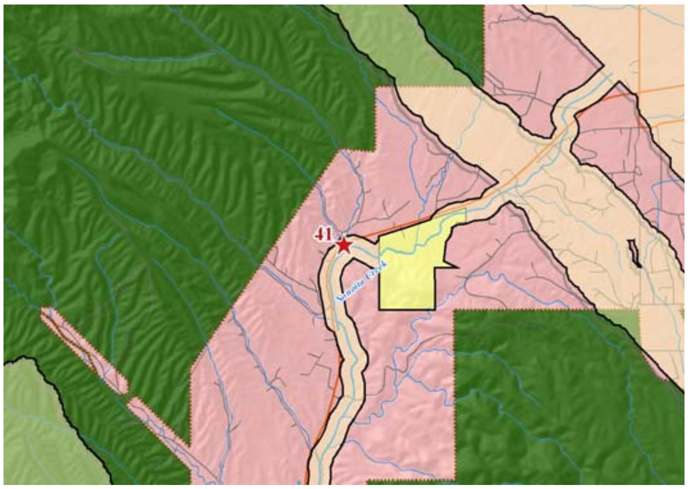
Name: IMG_0832.jpg

Azimuth: 270 **Zoom:** 1

Notes: Fence upstream from bridge

Linkage #:	96	**Waypoint #:**	41		
Linkage Zone:	Patagonia	**Latitude:**	31.65443	**Longitude:**	-110.7123
Observers:	Paul Beier	**UTM X:**	527276.2815	**UTM Y:**	3502168.847
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, MP 28.5 at Hog Canyon

Site Photographs

Name: IMG_0833.jpg

Azimuth: 150 **Zoom:** 1

Notes: Bridged undercrossing, looking downstream

Name: IMG_0834.jpg

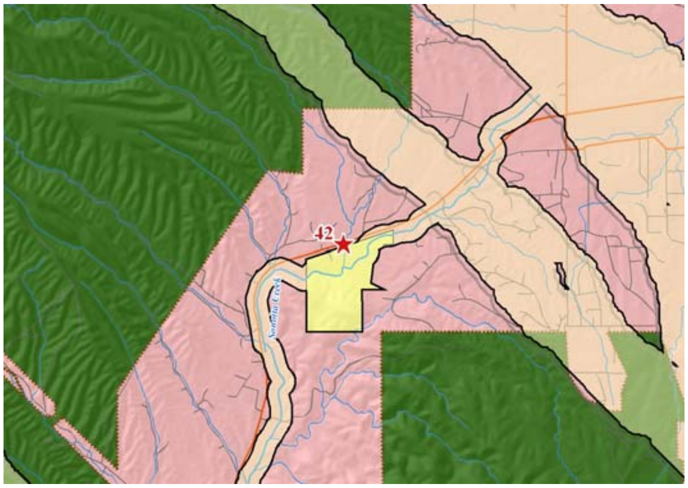
Azimuth: 150 **Zoom:** 1

Notes: Plants under bridge

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	42		
Linkage Zone:	Patagonia	**Latitude:**	31.65815	**Longitude:**	-110.69836
Observers:	Paul Beier	**UTM X:**	528596.7722	**UTM Y:**	3502584.729
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 29.4

Site Photographs

Name: IMG_0835.jpg

Azimuth: 325 **Zoom:** 1

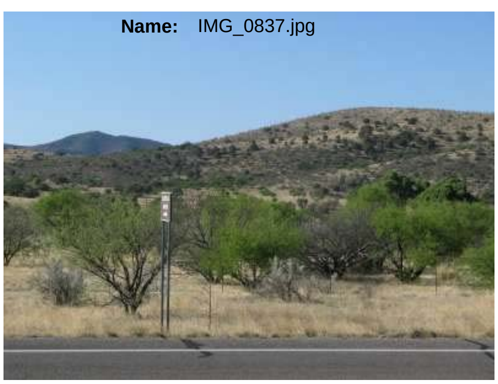
Notes: Bridged undercrossing

Name: IMG_0836.jpg

Azimuth: 270 **Zoom:** 1

Notes: Savannah and the Santa Rita Mountains

Name: IMG_0837.jpg



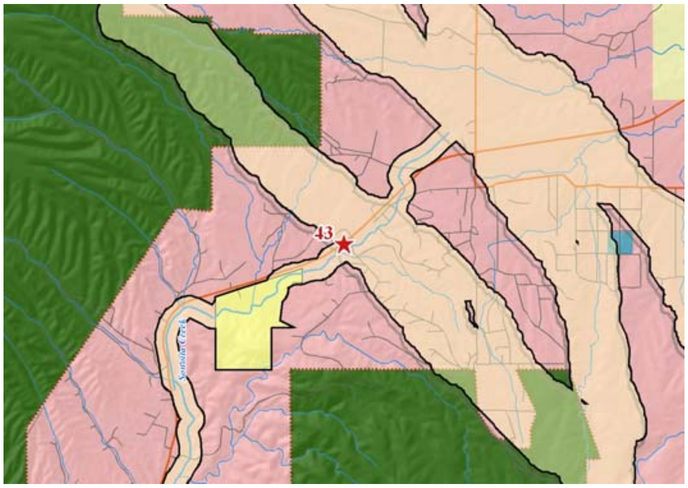
Azimuth: 140 **Zoom:** 1

Notes: Savannah

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	43		
Linkage Zone:	Patagonia	**Latitude:**	31.66433	**Longitude:**	-110.68094
Observers:	Paul Beier	**UTM X:**	530246.2686	**UTM Y:**	3503274.399
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 30.5

Site Photographs

Name: IMG_0838.jpg

Azimuth: 260 **Zoom:** 4

Notes: Savannah and the Santa Rita Mountains

Name: IMG_0839.jpg

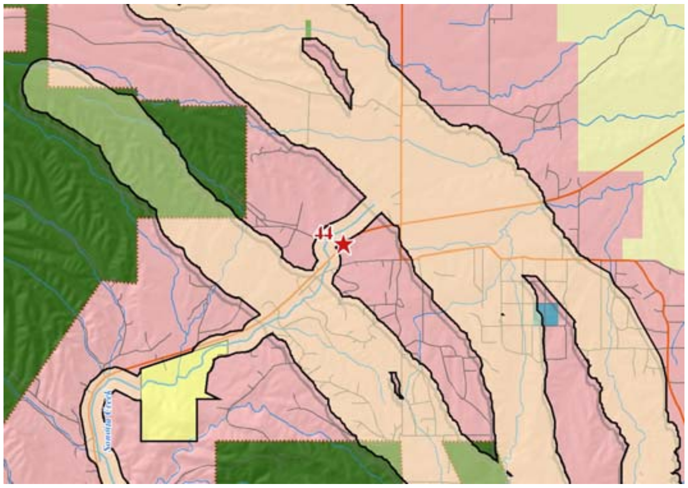
Azimuth: 135 **Zoom:** 3

Notes: Homes interspersed in savannah

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	44		
Linkage Zone:	Patagonia	**Latitude:**	31.6761	**Longitude:**	-110.6666
Observers:	Paul Beier	**UTM X:**	531601.694	**UTM Y:**	3504583.02
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 31.5

Site Photographs

Name: IMG_0840.jpg

Azimuth: 135 **Zoom:** 3

Notes: Low-density housing cromprised of rural ranchettes with horse corrals and outbuildings

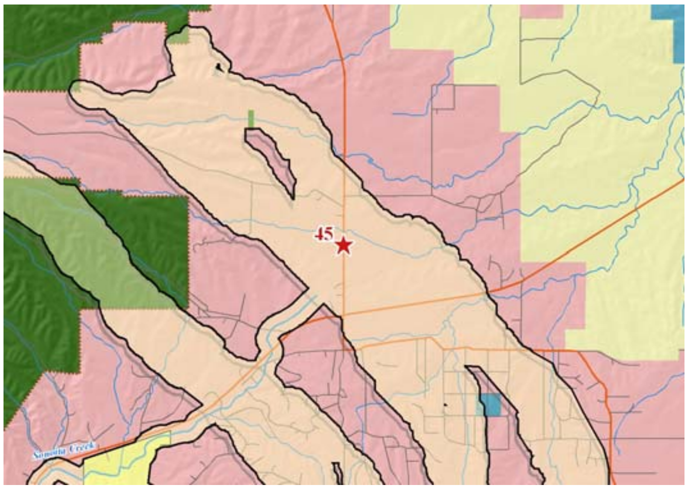
Name: IMG_0841.jpg

Azimuth: 290 **Zoom:** 6

Notes: Rural ranchettes

Linkage #:	96	**Waypoint #:**	45		
Linkage Zone:	Patagonia	**Latitude:**	31.69082	**Longitude:**	-110.65555
Observers:	Paul Beier	**UTM X:**	532643.9346	**UTM Y:**	3506217.806
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 83, near MP 34

Site Photographs

Name: IMG_0842.jpg

Azimuth: 50 **Zoom:** 4
Notes: Grassland

Name: IMG_0843.jpg

Azimuth: 2235 **Zoom:** 3

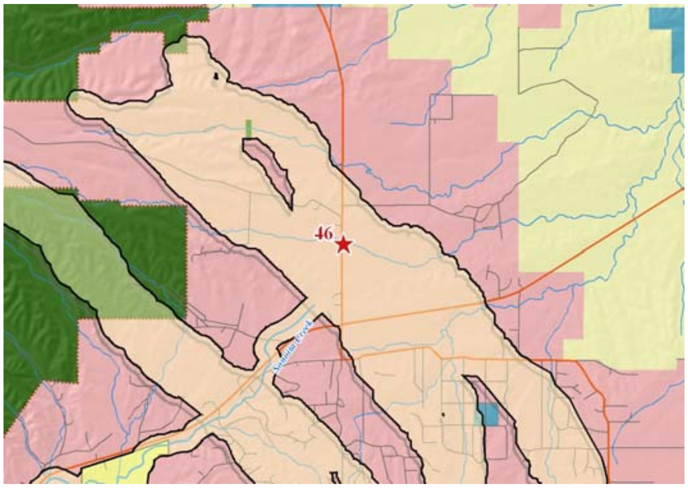
Name: IMG_0844.jpg

Azimuth: 305 **Zoom:** 3
Notes: Ranchettes

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	46		
Linkage Zone:	Patagonia	**Latitude:**	31.69253	**Longitude:**	-110.65516
Observers:	Paul Beier	**UTM X:**	532680.2962	**UTM Y:**	3506407.456
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 83 near MP 34

Site Photographs

Name: IMG_0845.jpg

Azimuth: 270 **Zoom:** 1

Notes: Downstream from bridged undercrossing

Name: IMG_0846.jpg

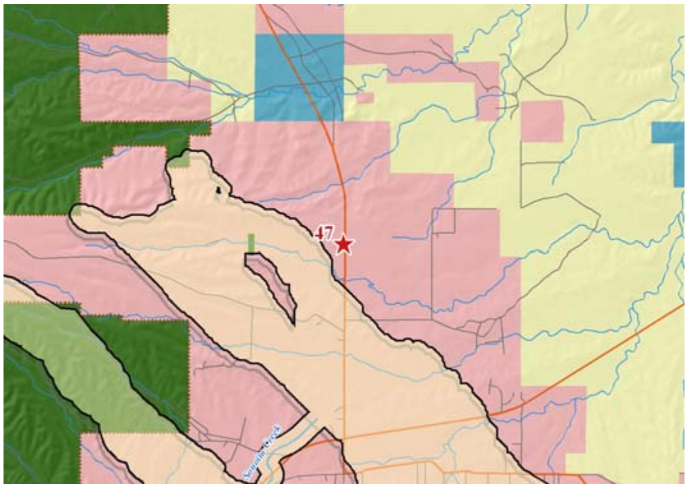
Azimuth: 270 **Zoom:** 1

Notes: Fences and buildings upstream from bridged undercrossing

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	47		
Linkage Zone:	Patagonia	**Latitude:**	31.71132	**Longitude:**	-110.65555
Observers:	Paul Beier	**UTM X:**	532636.7564	**UTM Y:**	3508489.988
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 83, near MP 35

Site Photographs

Name: IMG_0847.jpg

Azimuth: 245 **Zoom:** 5

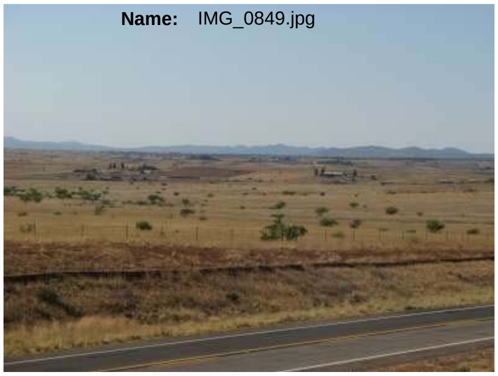
Notes: Grasslands and the Santa Rita Mountains

Name: IMG_0848.jpg

Azimuth: 90 **Zoom:** 5

Notes: Grasslands and the Whetstone Mountains

Name: IMG_0849.jpg



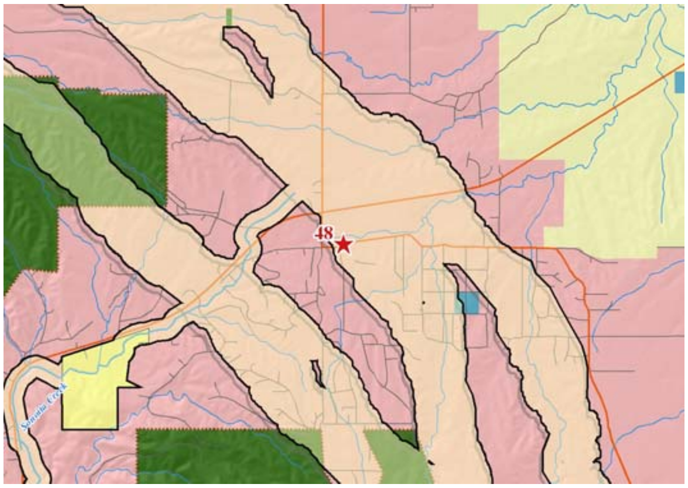
Azimuth: 120 **Zoom:** 5

Notes: Grasslands and the Canelo Hills

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	48		
Linkage Zone:	Patagonia	**Latitude:**	31.67413	**Longitude:**	-110.65147
Observers:	Paul Beier	**UTM X:**	533036.5133	**UTM Y:**	3504369.151
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 83, MP 31

Site Photographs

Name: IMG_0851.jpg

Azimuth: 155 **Zoom:** 1

Notes: Grasslands

Name: IMG_0852.jpg

Azimuth: 125 **Zoom:** 3

Notes: Grasslands and homes

Name: IMG_0853.jpg

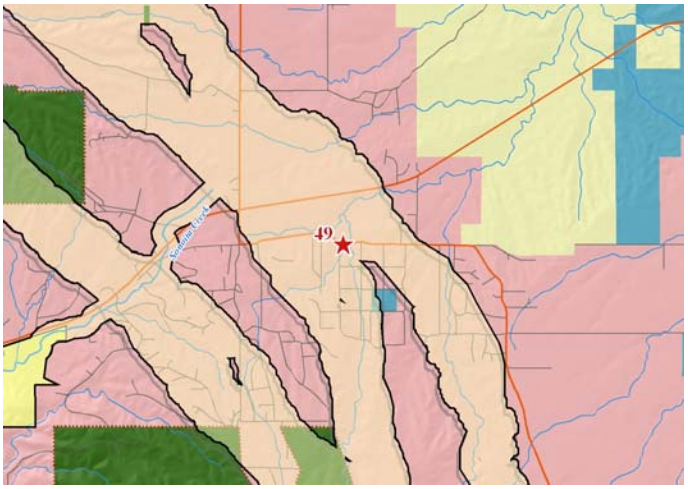
Azimuth: 335 **Zoom:** 2

Notes: Commercial area along SR 82

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	49		
Linkage Zone:	Patagonia	**Latitude:**	31.67354	**Longitude:**	-110.6357
Observers:	Paul Beier	**UTM X:**	534531.5497	**UTM Y:**	3504308.639
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 83, near MP 30

Site Photographs

Name: IMG_0854.jpg

Azimuth: 170 **Zoom:** 2

Name: IMG_0855.jpg

Azimuth: 350 **Zoom:** 2

Name: IMG_0856.jpg

Azimuth: 310 **Zoom:** 2

Appendix G: Database of Field Investigations

Linkage #: 96

Linkage Zone: Patagonia

Observers: Paul Beier

Field Study Date: 5/12/2007

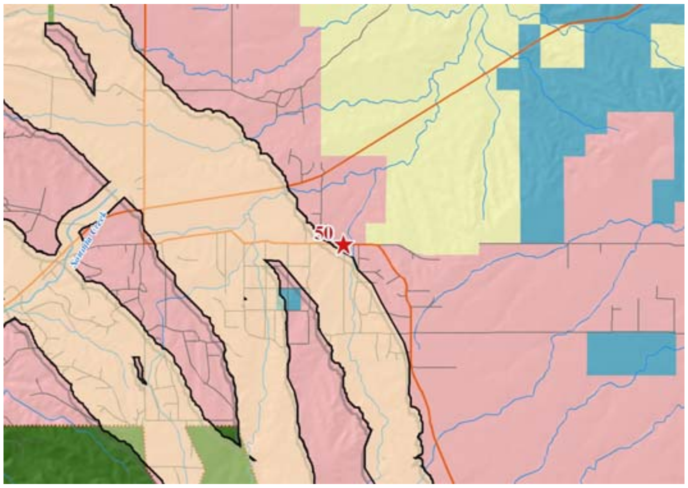
Waypoint #: 50

Latitude: 31.67345 **Longitude:** -110.61735

UTM X: 536270.9700 **UTM Y:** 3504304.617

Last Printed: 1/4/2008

Waypoint Map



Waypoint Notes

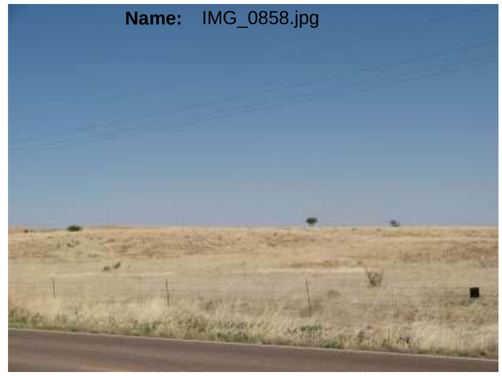
SR 83, near MP 29, on Harvest Drive

Site Photographs

Name: IMG_0857.jpg

Azimuth: 180 **Zoom:** 3

Name: IMG_0858.jpg



Azimuth: 310 **Zoom:** 3

Name: IMG_0859.jpg

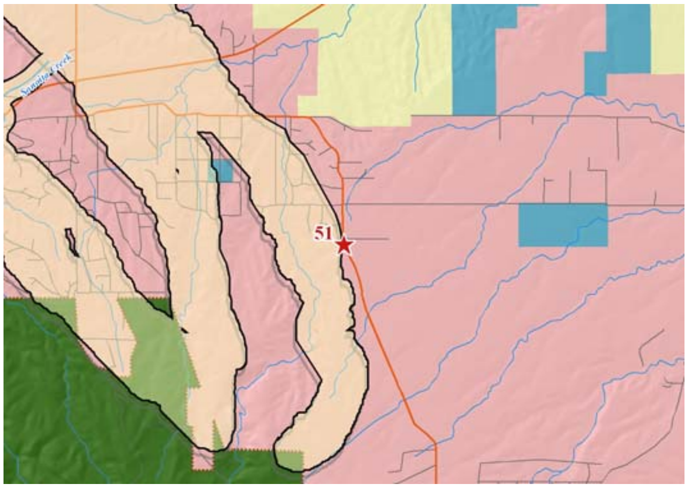
Azimuth: 350 **Zoom:** 6

Notes: Vehicle on SR 82 visible

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	51		
Linkage Zone:	Patagonia	**Latitude:**	31.65235	**Longitude:**	-110.60439
Observers:	Paul Beier	**UTM X:**	537507.9192	**UTM Y:**	3501970.321
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map

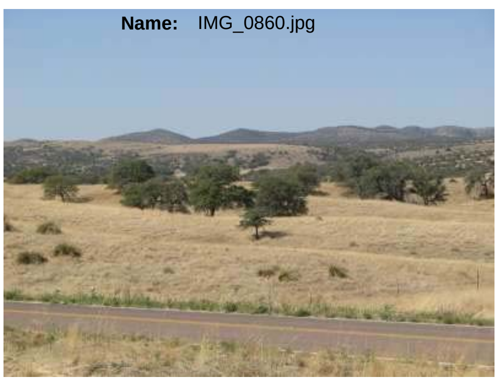


Waypoint Notes

SR 83, MP 27

Site Photographs

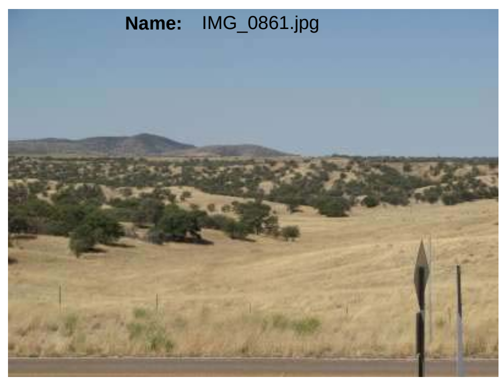
Name: IMG_0860.jpg



Azimuth: 175 **Zoom:** 3

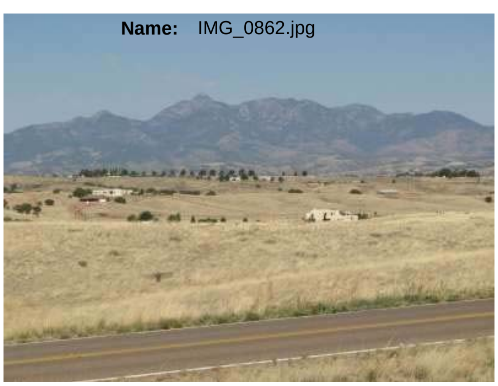
Notes: Oak Woodland and the Canelo Hills

Name: IMG_0861.jpg



Azimuth: 230 **Zoom:** 3

Name: IMG_0862.jpg



Azimuth: 260 **Zoom:** 3

Notes: Sonoita Homes and the Santa Rita Mountains

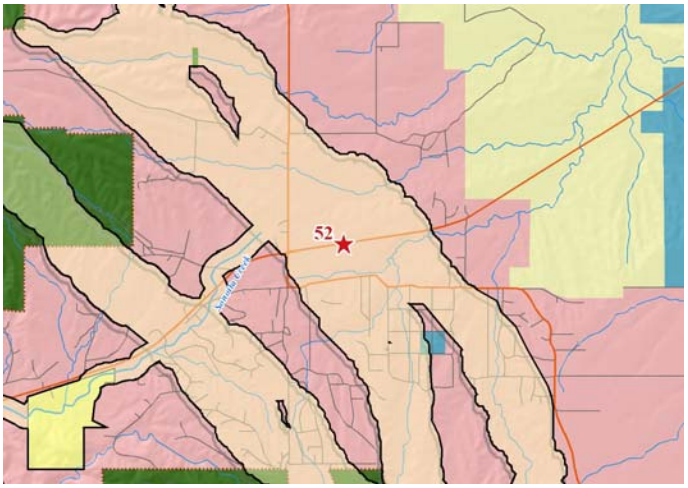
Name: IMG_0864.jpg

Azimuth: 295 **Zoom:** 3

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	52		
Linkage Zone:	Patagonia	**Latitude:**	31.68065	**Longitude:**	-110.64497
Observers:	Paul Beier	**UTM X:**	533650.2883	**UTM Y:**	3505093.8
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 33

Site Photographs

Name: IMG_0865.jpg

Azimuth: 165 **Zoom:** 6

Notes: Canelo Hills behind low density housing in grasslands

Name: IMG_0866.jpg

Azimuth: 210 **Zoom:** 3

Notes: Sonoita

Name: IMG_0867.jpg

Azimuth: 235 **Zoom:** 3

Notes: Sonoita

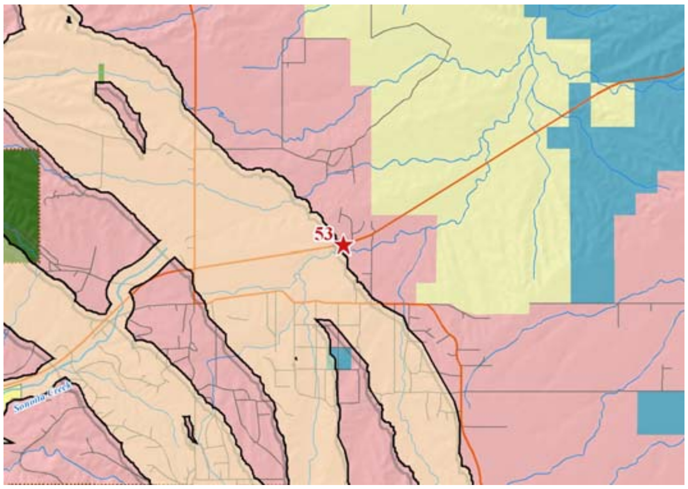
Name: IMG_0868.jpg

Azimuth: 265 **Zoom:** 3

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	53		
Linkage Zone:	Patagonia	**Latitude:**	31.68307	**Longitude:**	-110.62696
Observers:	Paul Beier	**UTM X:**	535356.3971	**UTM Y:**	3505367.724
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map

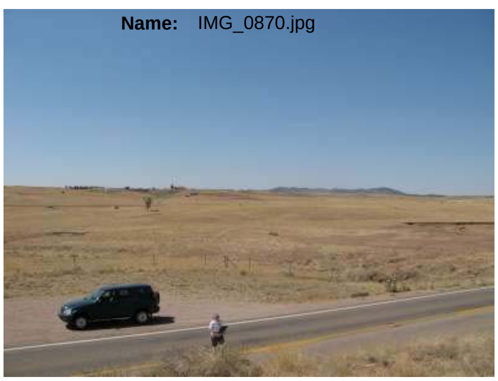


Waypoint Notes

SR 82, near MP 34

Site Photographs

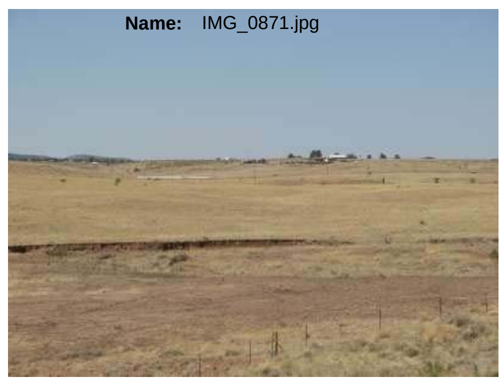
Name: IMG_0870.jpg



Azimuth: 170 **Zoom:** 1

Notes: Grasslands

Name: IMG_0871.jpg



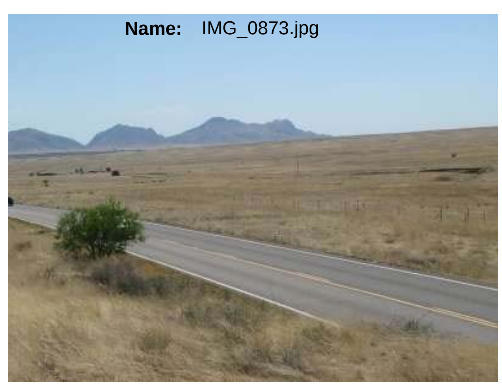
Azimuth: 205 **Zoom:** 3

Name: IMG_0872.jpg

Azimuth: 270 **Zoom:** 1

Notes: Homes in grasslands

Name: IMG_0873.jpg



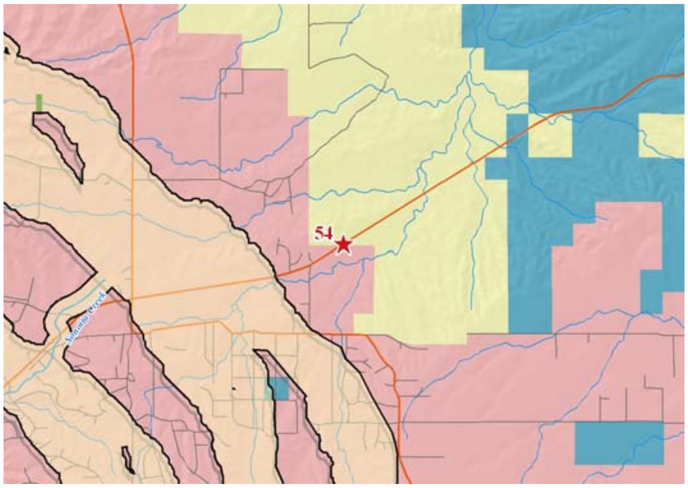
Azimuth: 70 **Zoom:** 2

Notes: Grasslands

Appendix G: Database of Field Investigations

Linkage #:	96	**Waypoint #:**	54		
Linkage Zone:	Patagonia	**Latitude:**	31.68819	**Longitude:**	-110.61499
Observers:	Paul Beier	**UTM X:**	536488.9076	**UTM Y:**	3505939.157
Field Study Date:	5/12/2007	**Last Printed:**	1/4/2008		

Waypoint Map



Waypoint Notes

SR 82, near MP 35

Site Photographs

Name: IMG_0874.jpg

Azimuth: 180 **Zoom:** 6

Notes: Grasslands

Name: IMG_0875.jpg

Azimuth: 200 **Zoom:** 3

Notes: Homes in grasslands

Name: IMG_0876.jpg

Azimuth: 250 **Zoom:** 2

Notes: Santa Rite Mountains visible beyond grassland