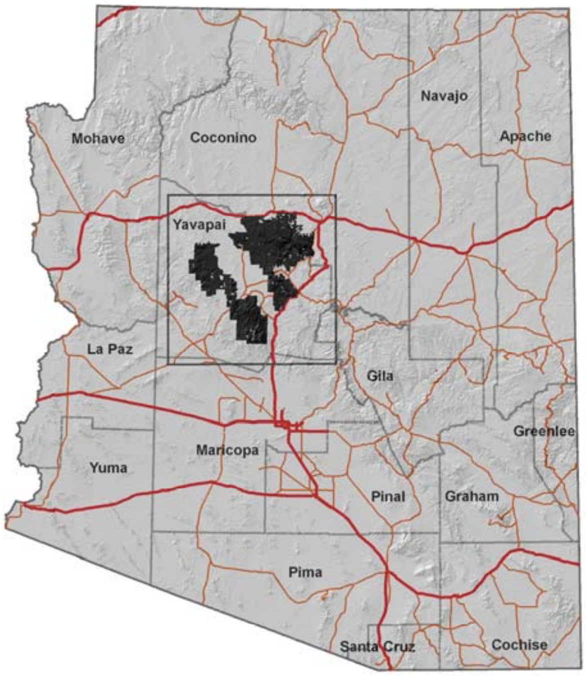
ARIZONA MISSING LINKAGES

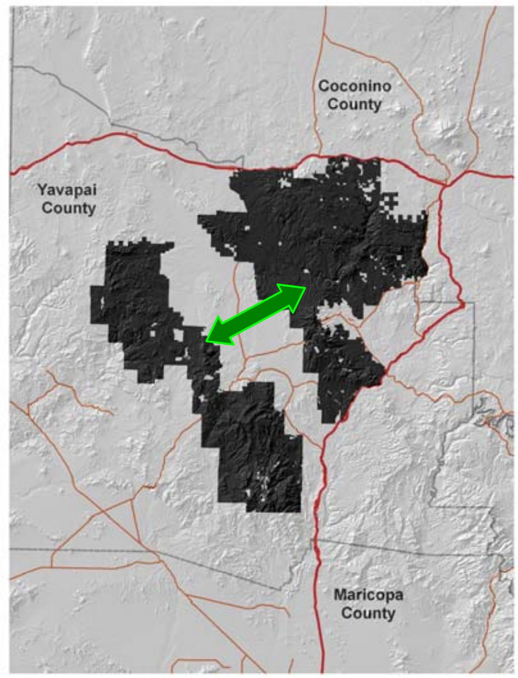
Granite Mountain - Black Hills Linkage Design

Paul Beier, Emily Garding, Daniel Majka

2008

GRANITE MOUNTAIN-BLACK HILLS 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 Arizona State Land Department (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 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 mutualisms. 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 areas of USFS-administered wildlands surrounding the towns of Prescott, Prescott Valley, and Chino Valley, Arizona. Major transportation routes in this region including State Route 89, State Route 89A, State Route 69, State Route 169, Fain Ranch Road, the Burlington Northern Santa Fe Railroad, and future urban development serve as an impediment to wildlife movement between the Black Hills, Mingus Mountain, and the Woodchute Mountain Wilderness to the east, and the Juniper Mountains, Santa Maria Mountains, Sierra Prieta, Bradshaw Mountains and Granite Mountain Wilderness to the west. 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 35 focal species that are sensitive to habitat loss and fragmentation, including 1 amphibian, 3 reptiles, 2 invertebrates, 7 birds, 7 fish, 6 plants, 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. black bear, mountain lion). Others are habitat specialists (e.g. southwestern willow flycatcher), and some are reluctant or unable to cross barriers such as freeways (e.g. elk, mule deer). Some species are rare and/or endangered (Arizona cliffrose, longfin dace), while others, like javelina, are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of Apache Highlands. Together, these 35 species cover a wide array of habitats and movement needs in the region, so that the Linkage Design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas, we used GIS methods to identify a biologically best corridor for each focal species to move between the 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 (Figure 1) is composed of 3 strands which together provide habitat for movement and reproduction of wildlife between the Granite Mountain Wildland Block to the west and the Black Hills Wildland Block to the east. The Linkage Design also includes recommendations (Figure 2) to minimize the risk that publicly owned roads isolate pronghorn populations conserved on private ranchlands. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The ecological, educational, recreational, and spiritual values of wildlands around Prescott, Chino Valley, and Prescott Valley are immense. Our Linkage Design represents an opportunity to protect a functional landscape-level connection between these wildlands. The cost of implementing this vision will be substantial—but reasonable in relation to the benefits and the existing public investments in wildlands. If implemented, our plan would not only permit movement of individuals and genes between the Granite Mountain and Black Hills 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 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 Granite Mountain – Black Hills Linkage

MAMMALS	FISH	BIRDS
Bats *Black Bear *Elk *Javelina *Mountain Lion *Mule Deer *Pronghorn Ringtail §River Otter	§Desert Sucker §Longfin Dace §Razorback Sucker §Roundtail Chub §Speckled Dace §Spikedace §Squawfish	Bald Eagle Cassin's Sparrow Common Black Hawk Gambel's Quail Northern Goshawk §Southwestern Willow Flycatcher §Yellow-billed Cuckoo
AMPHIBIANS & REPTILES	**INVERTEBRATES**	**PLANTS**
§Black-necked Garter Snake §Lowland Leopard Frog §Mexican Garter Snake §Narrow-headed Garter Snake	Obsolete Viceroy Butterfly Tiger Beetle	Arizona Cliffrose §Cottonwood Hualapai Milkwort Ripley's Buckwheat §Willow Salvia doreii memseii

* 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.
§ Riparian obligate species

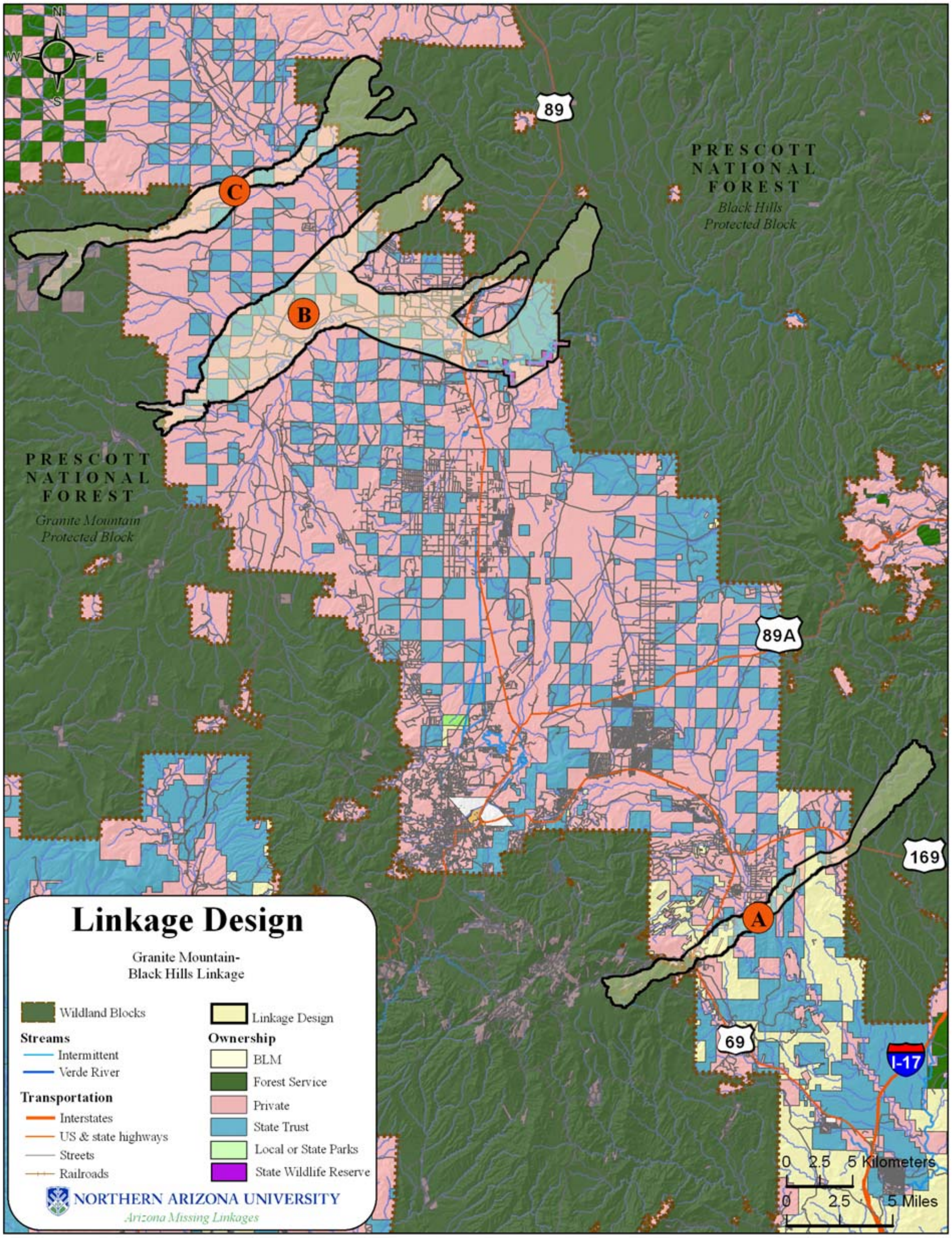

Figure 1: The Linkage Design between the Granite Mountain and Black Hills Wildland Blocks includes three strands (A, B, and C), each of which is important to different species.

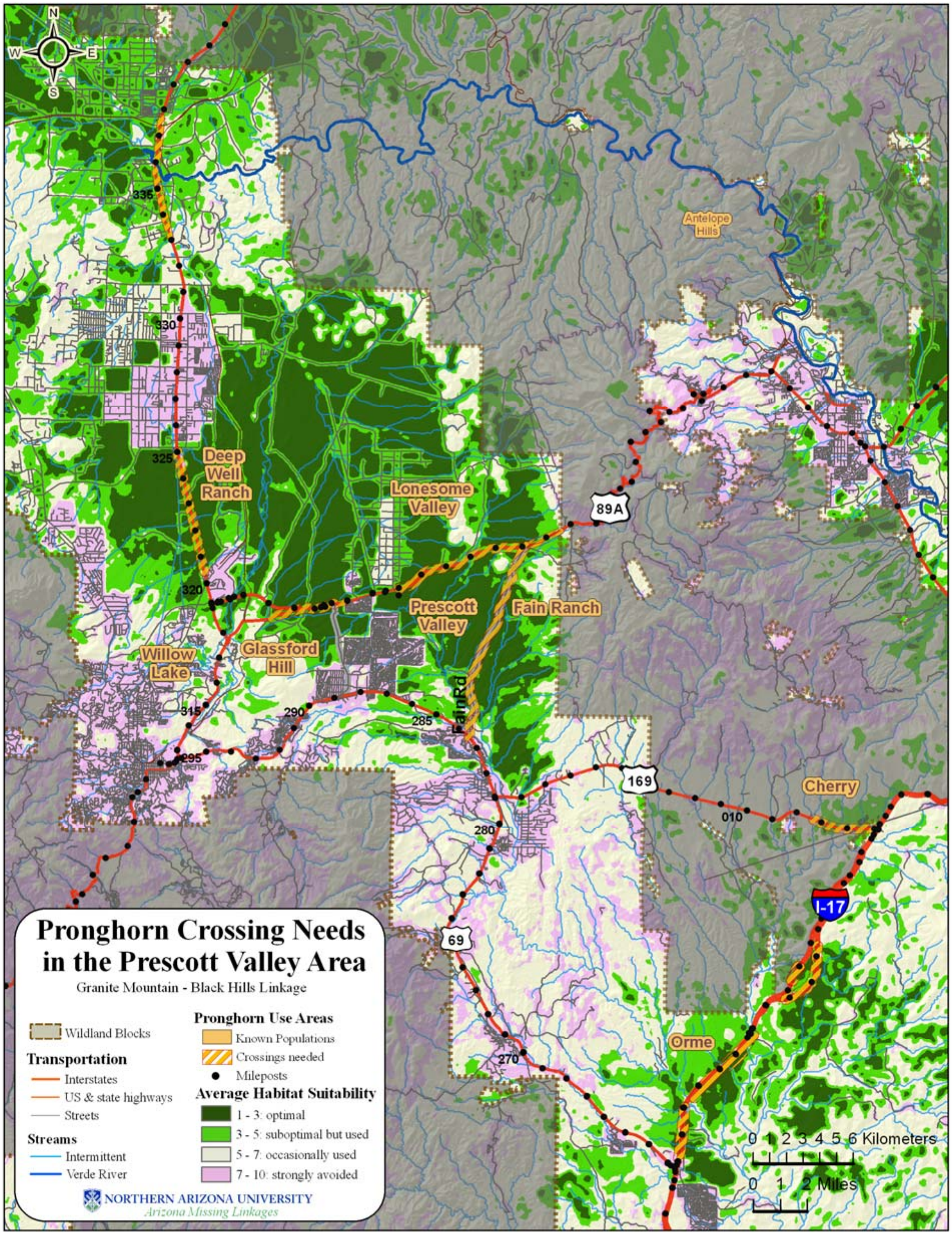

Figure 2. The linkage design includes pronghorn-friendly highway crossing structures every 2 miles along cross-hatched road segments to prevent isolating subpopulations of pronghorn on private and state lands in the Linkage Planning Area.

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 the Fiscal Year 2005-06. In the Fiscal Year 2006-07, eight additional linkages within 5 miles of an incorporated city were selected for linkage design planning. The Granite Mountain – Black Hills Linkage is one of these "urban" linkages.

Ecological Significance of the Granite Mountain – Black Hills Linkage

The Linkage Planning Area lies within two ecoregions typical of central and southern Arizona. All of the Granite Mountain Wildland Block, and most of the Black Hills Wildland Block, falls within the Apache Highlands Ecoregion. This ecoregion encompasses 30 million acres of central and southeastern Arizona, northern Sonora, northwestern Chihuahua, and southwestern New Mexico (Marshall et al 2004). It spans over 7,000 feet in elevation, and includes a variety of ecosystems such as sky island forests, lower elevation grasslands, and riparian corridors, and over 110 mammals, 265 birds, 75 reptiles, and 2000 plant species (The Nature Conservancy 2006). The eastern portion of the Black Hills Wildland Block transitions into the Arizona/New Mexico Mountains Ecoregion. This ecoregion encompasses 29 million acres of the mountains of Arizona and New Mexico north of the Mogollon Rim. It ranges from 4,500 to 12,600 ft in elevation. Typical ecosystems range from pinyon-juniper dominated woodlands at lower elevations, and ponderosa pine at mid-elevations, to mixed conifer and aspen at high elevations. This range of vegetation associations supports many species, including about 200 species considered rare (TNC 2006).

The Linkage Planning Area includes two wildland blocks separated by four State Highways (89, 89A, 69, and 169) and private lands in and near the towns of Prescott, Prescott Valley, and Chino Valley (Figure 1). We have named these wildland blocks the Granite Mountain and Black Hills Wildland Blocks[1]. Both areas are administered by the Prescott National Forest. Each wildland block is contiguous with hundreds of thousands of acres of National Forest land. For this report, we wanted to focus on animal movement across the lower-elevation valley that separates these mountainous National Forest lands.

The western Granite Mountain Wildland Block encompasses the Juniper Mountains, Santa Maria Mountains, Sierra Prieta, Bradshaw Mountains, Tank Creek Mesa, Sycamore Mesa, Cedar Mesa, Smith Mesa, South Mesa, Turkey Creek, Walnut Creek, Apache Creek, Sycamore Creek, Ash Creek, and the Hassayampa River. Elevation within this block ranges from about 3000 ft to over 7700 ft in the Bradshaw Mountains. The higher elevations support pinyon pine and juniper forests while chaparral dominates the lower elevations.

The eastern Black Hills Wildland Block encompasses the Black Hills, Mingus Mountain, Black Mesa, Oak Creek, and the headwaters of the Verde River. Elevations within this block range from roughly 3000 ft to over 7800 feet at the summit of Woodchute Mountain. It supports a matrix of mesquite upland scrub, pinyon-juniper woodlands, chaparral, and ponderosa pine woodlands at the highest elevations. Additionally, a unique geologic history has created the spectacular rock formations of the "Sedona Redrock Region."

Within the Linkage Planning Area, thousands of years of winter snowmelt and summer rains carved deep canyons into the Mogollon rim. This seasonal precipitation now sustains rich oases of riparian vegetation within the Verde River and Oak Creek. These perennial streams support many species dependent on these aquatic and riparian systems, including black-necked garter snake, Mexican garter snake, narrow-headed garter snake, lowland leopard frog, southwestern willow flycatcher, yellow-billed cuckoo, beaver, and river otter. These streams are also essential habitat for longfin dace, desert sucker, roundtailed chub, speckled dace, spikedace, and Colorado pikeminnow, and plants such as willows and cottonwoods. Because of this outstanding diversity, the Verde River is the only designated Wild and Scenic River in Arizona. The Wild and Scenic Rivers Act of 1968 mandates that designated rivers "shall be preserved in free-flowing condition."

[1] Both blocks of USFS land have no formal designation on most maps. We named them after prominent topographic features found in each block: Granite Mountain in the western block, and the Black Hills in the eastern block.

Local species listed as threatened or endangered by the U.S. Fish and Wildlife Service include Arizona cliffrose, southwestern willow flycatcher, yellow-billed cuckoo, bald eagle, razorback sucker, roundtail chub, spikedace, and the Mexican garter snake (USFWS 2005). The Linkage Planning Area is also home to far-ranging mammals such as mule deer, elk, 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 such as javelina also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

Existing Conservation Investments

The proposed Granite Mountain–Black Hills Linkage is designed to protect and enhance the public investments in the two wildland blocks and within the Potential Linkage Area (Figure 1). The 1.25 million acre Prescott National Forest, the adjacent 1.8 million acre Coconino National Forest, and 559,000 acres of the southern Kaibab National Forest are most directly affected by our linkage design. These forests are contiguous with the Tonto and Apache-Sitgreaves National Forests and several national monuments. Together, these investments in public land total over 8.5 million acres.

The **Granite Mountain Wildland Block**, administered by the Prescott National Forest, includes about 635,000 acres of pinyon-juniper woodlands and chaparral between Interstate 40 to the north, and Interstate-17 to the southeast. It includes four wilderness areas, namely the Castle Creek Wilderness (25,000 rugged acres ranging from Sonoran desert to pinyon-juniper woodlands), the Granite Mountain Wilderness (9,762 acres of highlands dominated by pinyon-juniper and pine-oak forests, with chaparral on the southern slopes), the Juniper Mesa Wilderness (7,400 acres of pinyon pines and junipers) and the Apache Creek Wilderness (5,600 acres of rolling hills dominated by junipers, pinyon pines, and granite). Important riparian ecosystems, including Apache Creek, are fed by natural springs.

The **Black Hills Wildland Block**, also administered by the Prescott National Forest consists of about 860,000 acres of pinyon-juniper and ponderosa pine woodlands, mixed bedrock canyon and tableland, and chaparral. Wilderness areas include the Woodchute Wilderness (5,833 adjacent acres of pinyon-juniper and ponderosa pine), the Red Rock-Secret Wilderness area (43,950 acres of cliffs, canyons, and pinyon-juniper and ponderosa pine woodlands) and the Sycamore Canyon Wilderness (56,000 acres of pine and fir forests, low elevation deserts, riparian areas, and the magnificent gorge of Sycamore Canyon). The area is famous for its rugged red rock geological formations, which dominate the 286-acre Red Rock State Park on Oak Creek. Arizona Game and Fish Department and the Northern Arizona Audubon Society co-manage lands in the Lower Oak Creek Important Bird Area (IBA), which supports many riparian and migratory birds.

In the **Linkage Planning Area between the Wildland Blocks**, there are several conservation investments. The BLM owns about 175,000 acres between SR-169 and SR-69. The uppermost perennial mile of the Verde River is protected within the Upper Verde River Wildlife Area (Arizona Game and Fish Department) and the Verde River Springs Reserve (The Nature Conservancy). This area includes riparian vegetation, floodplains, cliffs, and adjacent uplands. Adjacent to these two areas, the Rocky Mountain Elk Foundation has a 2,440-acre conservation easement on private ranch. The City of Prescott owns the 125-acre Watson Woods Riparian Preserve on Granite Creek.

Connectivity between the wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far-ranging species in north-central Arizona.

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include State Highways 89, 89A, 69, and 169, and expanding urban development in and near Prescott, Prescott Valley, and Chino Valley. Additionally, introduced species such as green sunfish, smallmouth and largemouth bass, flathead catfish, and tamarisk threaten native wildlife important riparian corridors in the Linkage Area. These barriers threaten to inhibit wildlife movement between Granite Mountain and Black Hills Wildland Blocks.

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

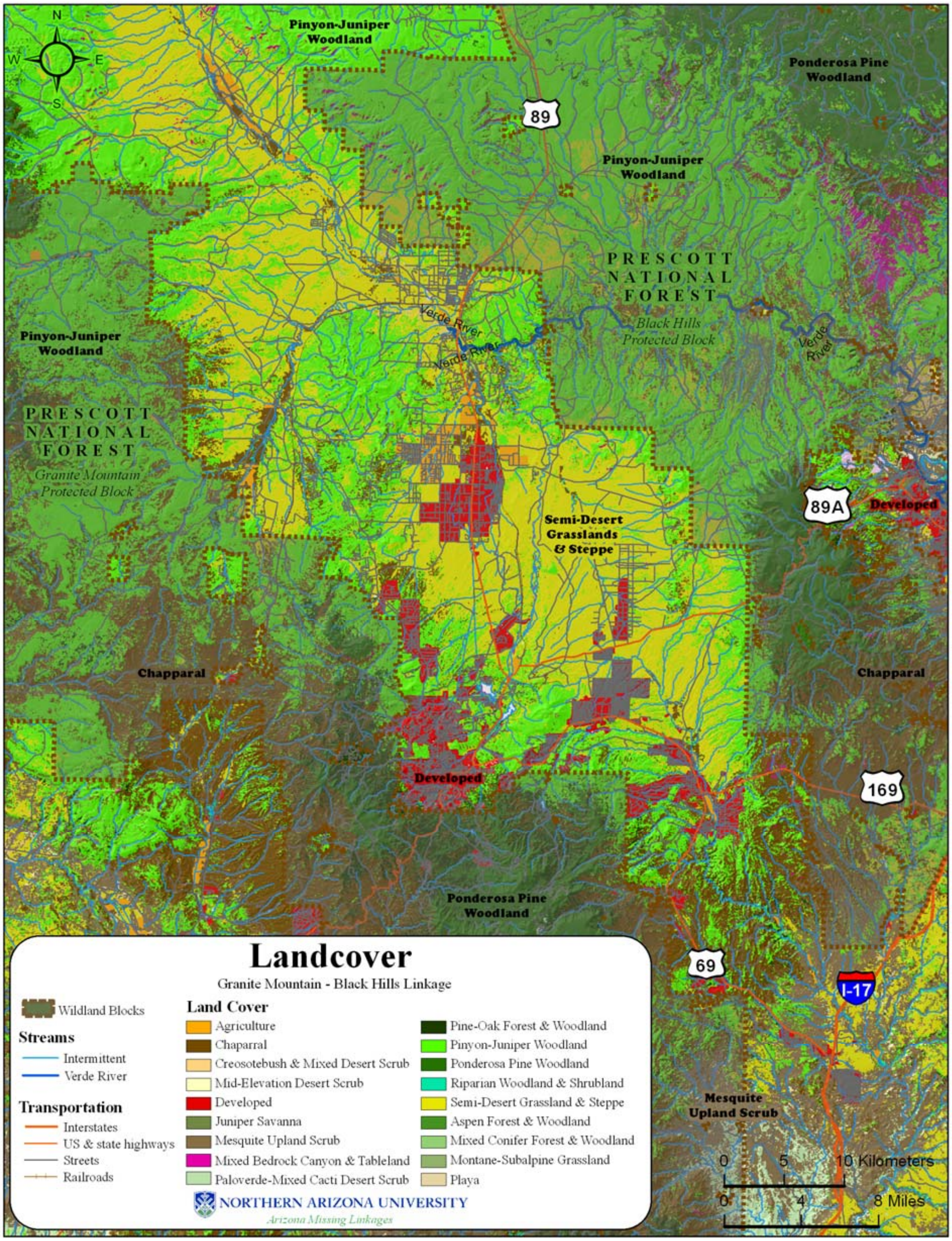

Figure 3: Land cover within the Linkage Planning Area.

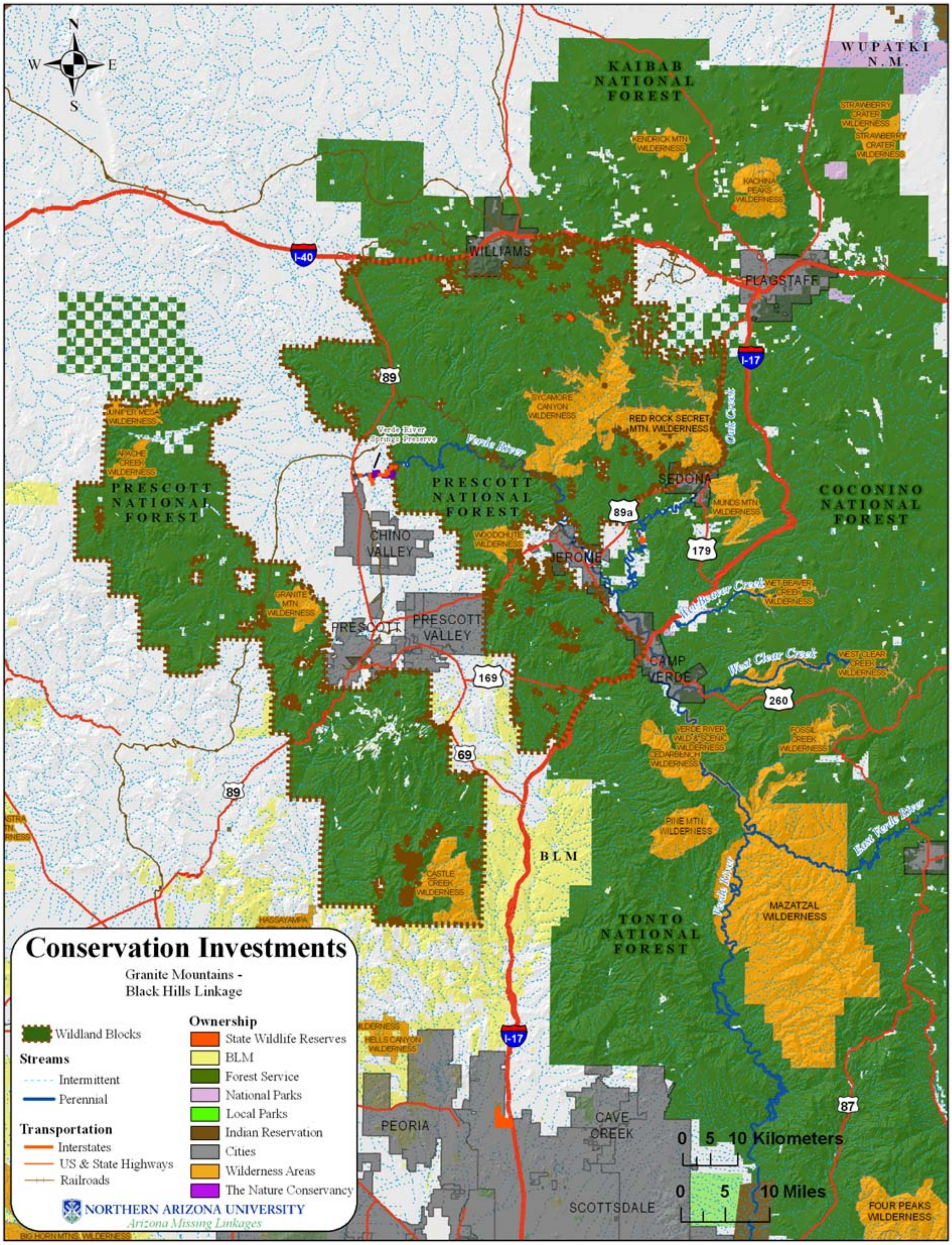

Figure 4: Existing conservation investments within the Linkage Planning Area.

Linkage Design & Recommendations

The Linkage Design (Figure 1, Figure 6) is composed of three strands which together provide habitat for movement and reproduction of wildlife between USFS-administered lands in the Chino Valley-Prescott-Prescott Valley area. In this section, we describe the land cover and ownership patterns in the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Three Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of three strands that connect the Granite Mountain and Black Hills wildland blocks. We describe these strands from south to north.

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 is located near the junction of Arizona State Highways 69 and 169 in the southern Linkage Planning Area. It is about 30.8 km long and is primarily composed chaparral (61%) and pinyon-juniper woodlands (21.8%). This strand is the most rugged of the three routes, with an average slope of 25% (range: 0-111%, SD: 15.2) and 61% of the area composed of steep (> 6 degree) slopes. This strand of the linkage provides live-in and pass-through habitat for black bear, mule deer, mountain lion, and other species that prefer rugged terrain and chaparral.

Strand B of the linkage design located north of Chino Valley. The eastern part of Strand B splits into three sub-strands. The length is roughly 43 km along the longest substrand. Strand B is dominated by semi-desert grassland and steppe (61%) and pinyon-juniper woodlands (29%). Almost all (93%) of the land in this strand is flat to gently sloped (average slope of 4%, maximum 110%, SD 6.9%). This strand provides live-in and pass-through habitat for pronghorn, javelina, mule deer, and other species that use habitat with gentle slopes.

Strand C, the northernmost strand, is primarily composed of semi-desert grassland and steppe (82%) with pinyon-juniper woodlands (11%). Strand C is more topographically complex than Strand B, with an average slope of 13% (Range: 0-81%, SD: 13%). While over half (55%) of the area has flat to gentle slopes, 37% is steep slopes. This strand provides live-in and pass-through habitat for elk and mountain lions, and other species that prefer steeper grasslands and woodlands.

Recognizing that ranchers are conserving pronghorn and grasslands on their private land and leased state land, Linkage Design also includes recommendations to minimize the risk that publicly-built roads will isolate these populations. Without these structures, increasing traffic will soon preclude movement among several important subpopulations of pronghorn on private ranchlands (Figure 2, see also page 33).

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

The Linkage Design encompasses 77,799 acres (31,484 ha) of land. Forty-three percent of this land is privately owned, 34% lies in the Prescott National Forest, 21% is state trust land, and 2% is owned by the Bureau of Land Management (Figure 1). Three natural vegetation communities account for 94% of the land cover(Figure 6), and developed land accounts for less than 1% of the linkage design (Table 2).

Natural vegetation is dominated by evergreen forests and scrublands. Riparian vegetation accounts for 1% of the linkage design. About 72% of the linkage design is classified as gentle slopes and 22% as steep slopes, and south and east facing aspects dominate the area (Figure 7).

Table 2: Approximate land cover found within Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (<42%)			
Pinyon-Juniper Woodland	31278	12658	40.2%
Pin-Oak forest and Woodland	1316	533	1.7%
Scrub-Shrub (<55%)			
Semi-Desert Grassland and Steppe	30985	12539	39.8%
Chaparral	10692	4327	13.7%
Creosotebush, Mixed Desert and Thorn Scrub	1041	421	1.34%
Developed and Agriculture (>0.5%)			
Medium – High Intensity Developed	111	45	0.14%
Agriculture	285	115	0.37%

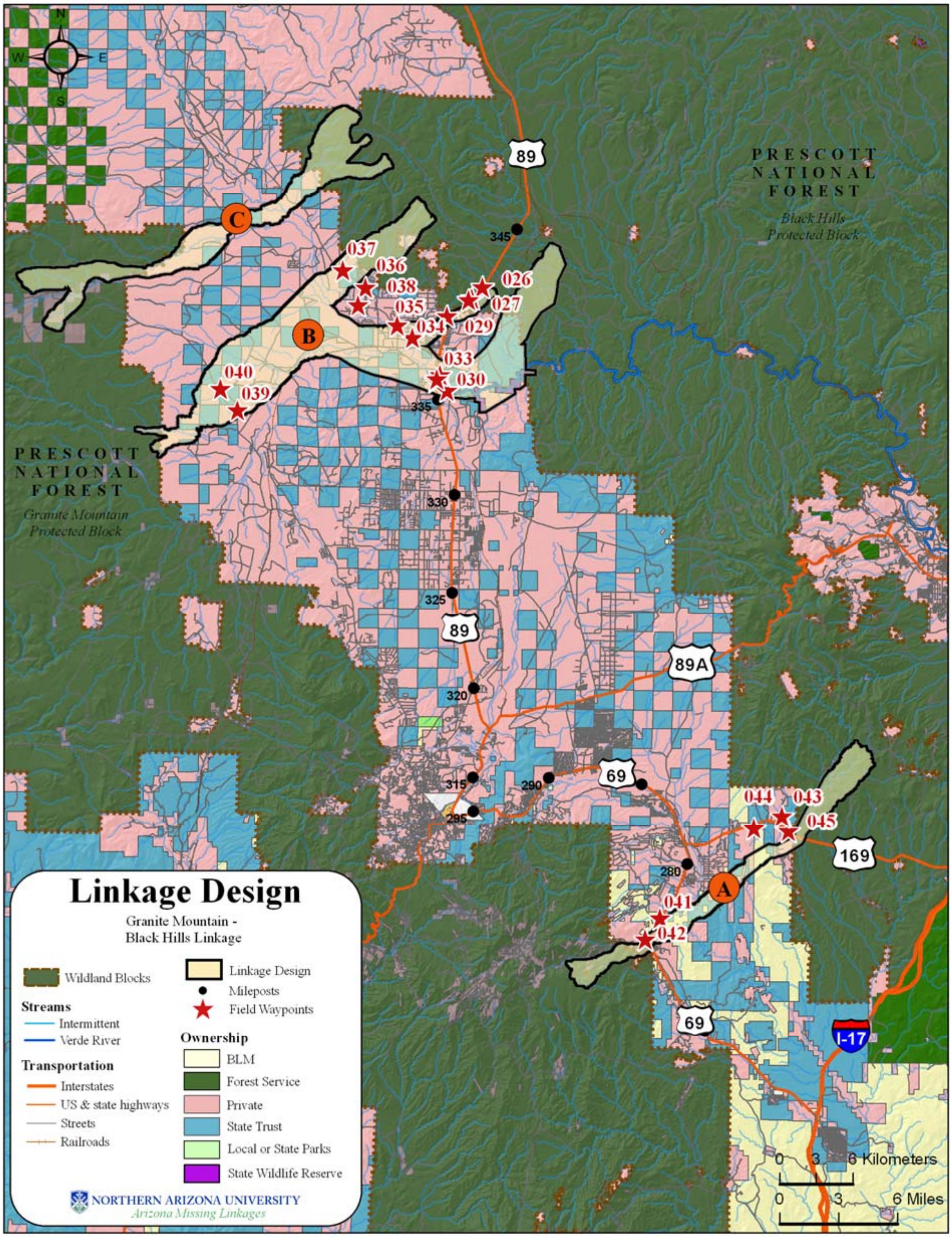

Figure 5: Property ownership and field investigation waypoints within the Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.

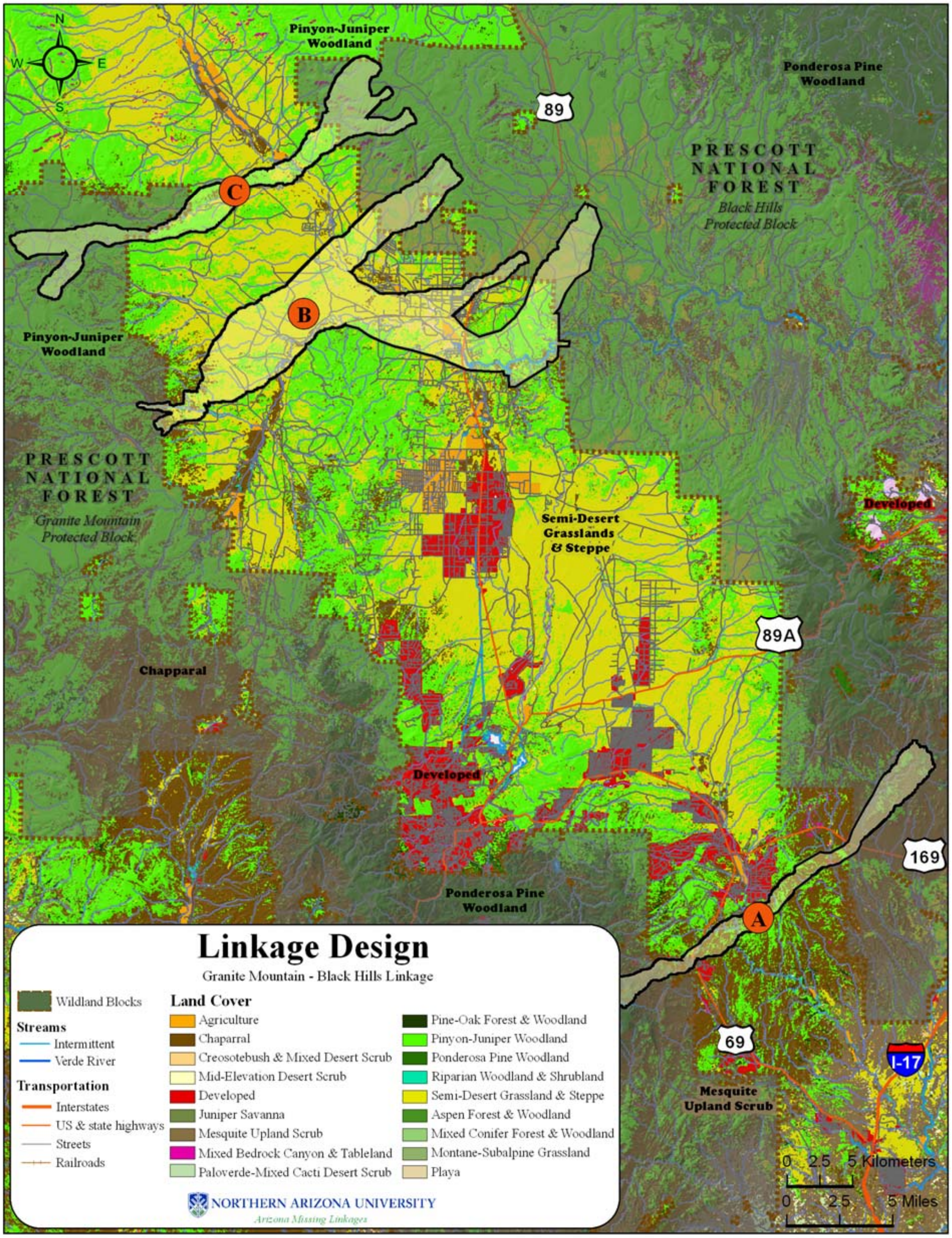

Figure 6: Land cover within Linkage Design.

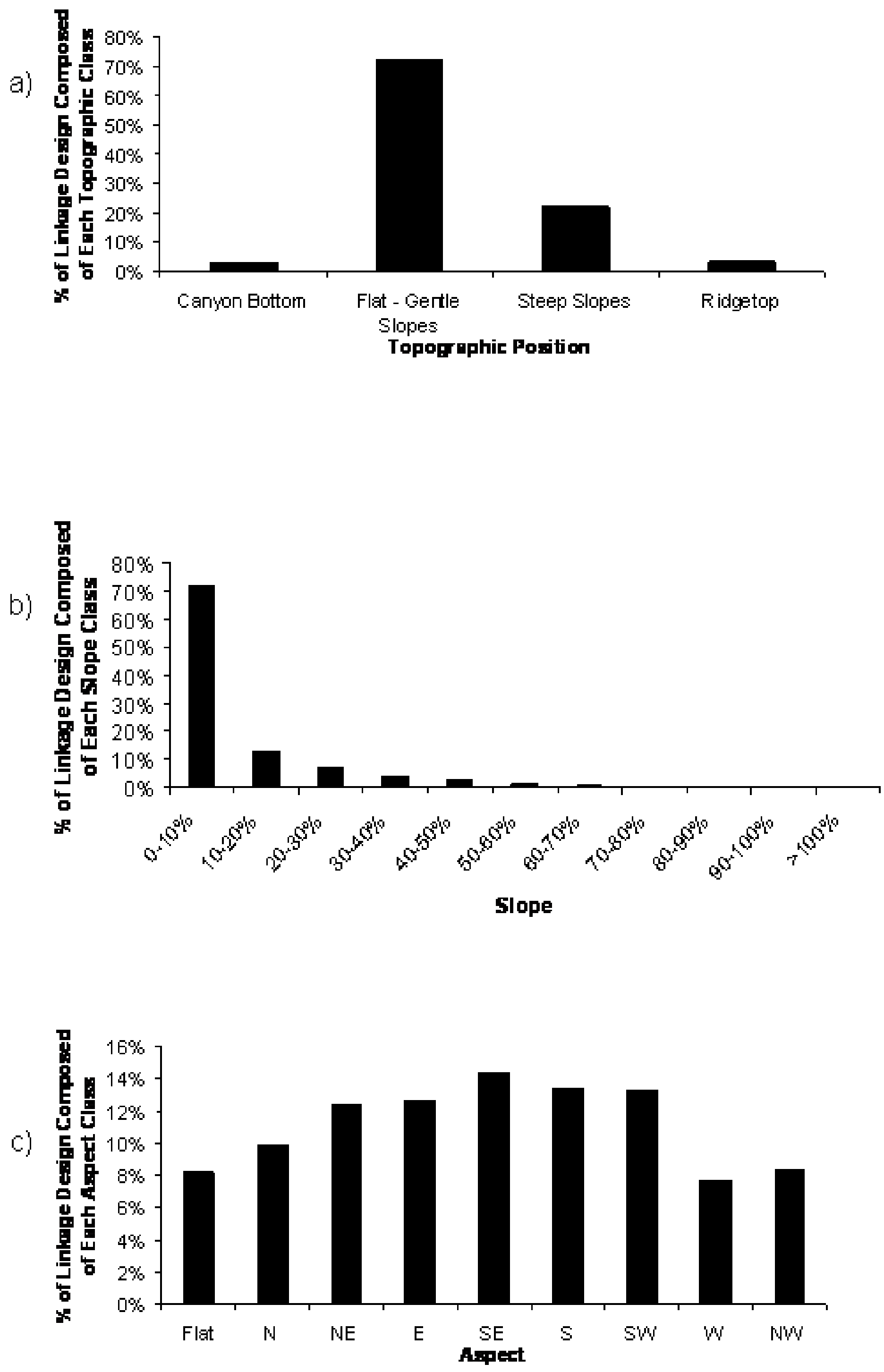

Figure 7: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, and c) Aspect.

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 Granite Mountain and Black Hills 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. 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).

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 pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be 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.

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

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

Despite their disadvantages, well-designed and located culverts can mitigate the effects of busy roads on 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). In south Texas, bobcats most often used 1.85 m x 1.85 m box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Some culverts located in fill dirt have openings far above the natural stream bottom. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

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

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

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

5) **Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement.** Small mammals, carnivores, and reptiles avoid crossing

structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004). In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches, Russian thistle, sand, or garbage that impede animal movement (Beier, personal observation). Bridged undercrossings rarely have similar problems.

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

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

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

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

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

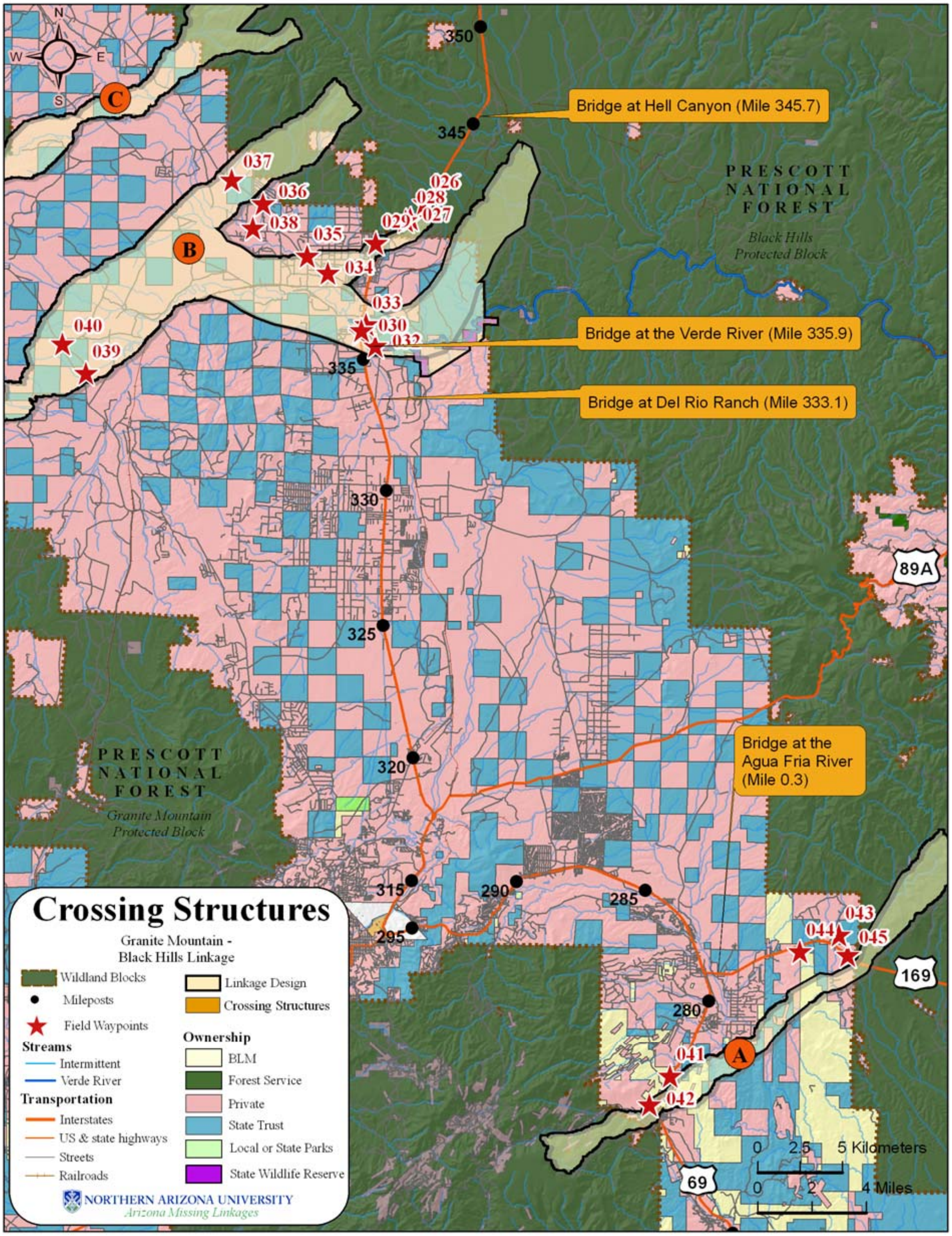

Figure 9: Locations of existing crossing structures, numbered mileposts, and field investigation waypoints in the Linkage Design.

Table 4: Roads in the Linkage Design (many of these are dirt roads).

ROAD NAME	KILOMETERS	MILES
Old Hwy 89	6.9	4.3
State Highway 89	5.0	3.1
State Highway 69	1.8	1.1
Williamson Valley Rd	3.4	2.1
Big Chino Rd	7.7	4.8
Curtis Ranch Rd	7.6	4.7
Forest Service 174 Rd	7.0	4.4
Santa Fe Rd	7.0	4.4
Bayberry Dr	5.5	3.4
Forest Service 6 Rd	5.0	3.1
Forest Service 635 Rd	4.5	2.8
Forest 105 Rte	4.3	2.7
Forest Service 9005	3.0	1.9
Feather Mountain Rd	3.0	1.9
Gas Pipeline Rd	2.8	1.8
Sweet Valley Rd	2.2	1.4
Forest Service 330 Rd	2.1	1.3
Profit Ln	1.9	1.2
Kings Court Rd	1.5	1.0
Naples St	1.5	0.9
Forest 323 Rte	1.4	0.9
Big Springs Ranch Rd	1.4	0.9
Poland Junction Rd	1.3	0.8
Catalina	1.3	0.8
Rancho Place	1.3	0.8
Forest Service 9805B Rd	1.2	0.7
Malapai Ridge Rd	1.2	0.7
Flagstone Rd	1.1	0.7
Forest Service 330 Rd	1.1	0.7
Saddle Rd	1.1	0.7
Orme Rd	1.1	0.7
Road 1 km or less	43.2	26.8
Unnamed Roads	159.3	99.0
Total length of Transportation Routes	**329.6**	**204.8**

Existing Roads in the Linkage Design Area

There are about 330 km (205 mi) of roads in the Linkage Design, including 7.8 km (4.8 mi) of highways. The three state highways are Highway 69, Highway 169, and Highway 89. Highway 89 is the major transportation route in the Linkage Planning Area. Currently, only 35 kilometers of the 106-km long Williamson Valley Road road between Prescott and Interstate 40 are paved, but there are several proposals to turn it into a major highway. About 3.4 unpaved kilometers (2.1 miles) of Williamson Valley Road occurs within the Linkage Design. We conducted field investigations of many of these roads to document crossing structures and identify sites where modifications could enhance wildlife movement.

Existing Highway Crossing Structures in the Linkage Design

Strand A of the linkage design intersects Highway 69 and Highway 169. We did not find any crossing structures larger than a pipe culvert on these highways within or within 5 highway miles of Strand A.

There was a 153-ft bridge over the Agua Fria River on Highway 169, but this was outside the linkage design, in a developed area in Dewey, and unlikely to serve wildlife movement.

The western portion of Strand B intersects Williamson Valley Road. No crossing structures were noted along this road. Highway 89 runs north-south through the eastern portion of Strand B. We noted several significant crossing structures on Highway 89, listed from south to north:

- 172’ bridge at Milepost 333.1, outside the linkage design (no photo) (Figure 9).
- 289’ bridge at Milepost 336, at Big Chino Wash, Waypoint 31 (Figure 9, Figure 10).
- four box culverts between Mileposts 345-346, one culvert at each of 4 crossings of an unnamed stream, near Waypoint 27 (Figure 11).
- 585’ bridge Milepost 345.7, Hell Canyon, outside the Linkage Design, (no photo) (Figure 9).

Strand C of the linkage design is located north and west of major highways in the Linkage Planning Area, although it intersects Williamson Valley Road. We found no road crossing structures in Strand C.

Figure 10: The SR-89 bridge over Big Chino Wash, near Waypoint 031, is the best existing crossing structure for pronghorn in the planning area, but it may not be good enough. The good features of this structure are its high openness ratio, and the fact that the bridge is elevated above the natural terrain so that pronghorn can cross at-grade. However, there is no documentation that pronghorn use this structure to cross SR-89. A vegetated wildlife overpass (Figure 8, top row) is a more effective way to make a road permeable for pronghorn.

Figure 11: Existing box culvert under Highway 89 that should be modified for use by deer and elk, Waypoint 027. There are 4 similar culverts along this un-named drainage within 1 mile of this location.

Figure 12: This fill slope on SR-69 east of Waypoint 42 in Strand A offers an opportunity for a wildlife underpass.

Recommendations for Highway Crossing Structures in Strand A, B, and C

The existing crossing structures are not adequate to serve the movement needs of wildlife between the Granite Mountain and Black Hills Wildland Blocks. Crossing structures along major roads are crucial to success of the linkage. We recommend upgrading the crossing structures and adding additional ones to be consistent with the Standards and Guidelines for Wildlife Crossing Structures above. In particular:

- Along every paved road in each strand of the linkage, there should be at least one pipe culvert every 300m for passage by small animals. Because we did not attempt to locate small culverts, we do not know how many new culverts will need to be installed.
- Along Highway 89 in Strand B, we recommend improving the existing box culvert crossings (Figure 11) to make them suitable for use by ungulates. Deer prefer open crossing structures, and avoid closed structures such as the existing box culverts.
- Within Strand A build a wildlife underpass near Milepost 285 on Highway 69 (Figure 12). There are currently no crossing structures suitable for medium to large sized animals along this Highway.
- Within Strand A there are currently no crossing structures suitable for medium to large sized animals like black bears and elk. Build suitable crossing structures along Highway 169 and Highway 69 that are approximately aligned, to facilitate passage across both of these highways.
- There are currently no crossing structures on Williamson Valley Road. Because high-quality pronghorn habitat occurs on both sides of this road, it is especially important to provide structures appropriate for pronghorn (e.g., Figure 10) and modify fences for pronghorn movement.

Additional Road Crossing Structures Needed to Avoid Isolation of Pronghorn Populations Not Served by the Three Main Linkage Strands

The three strands of the linkage design emphasize connecting the two halves of the Prescott National Forest on either side of Chino Valley. However, some of Arizona's most important populations of pronghorn occur within the Chino Valley, mostly on private land in a checkerboard with state land (Figure 34, Appendix C). These populations are at risk of becoming isolated by urban development and high-speed roads to service these new developments. Although Strand B of the linkage design provides connectivity for pronghorn between the two wildland blocks, the strands do not connect some of these pronghorn populations on private land. Recognizing that ranchers are conserving pronghorn and grasslands on their private land and leased state land, we provide these recommendations to minimize the risk that publicly-built roads will isolate these populations. There are no appropriate crossing structures to accommodate the movement among these subpopulations of pronghorn.

Figure 13 displays a map of suitable pronghorn habitat (Appendix C) and approximate locations of known pronghorn populations (AGFD 2006). The cross-hatched roads in Figure 13 indicate where known populations coincide with habitat modeled as optimal or suitable for pronghorn on both sides of the road. In these areas, we recommend one crossing structure approximately every 2 miles. Although we typically recommend one large crossing structure per mile, pronghorn are highly mobile animals that can cover long distances. Furthermore, some of these pronghorn populations will be significantly reduced, perhaps driven extinct, as urbanization destroys their habitat. We accordingly balance our recommendations for public investment in road crossing structures with the probability pronghorn will survive.

Specific road segments include (Figure 13):

- Highway 89, MP 325-321. Here the Deep Well Ranch provides optimal pronghorn habitat along both sides of the highway. The two cattle crossings under Highway 89 could be modified to allow for movement of the Deep Well Ranch pronghorn population.
- Fain Ranch Road connects Highways 89A and 69. Optimal and suitable pronghorn habitat occurs along the length of this road.
- Highway 89A, MP 320– 323. The Lonesome Valley, Glassford Hill, Prescott Valley and Deep Well Ranch pronghorn herds' ranges abut this stretch of highway.

- Highway 89A, MP 325-326, and MP 331-340. Optimal habitat occurs along both side of the road.
- Glassford Hill Road, northern half. This road bisects optimal pronghorn habitat.
- Highway 169 MP 13 and eastward. This section separates the Cherry and Orme herds.
- I-17, MP 273 to 271 and MP 269 to 263. Unlike the other areas, the pronghorn habitats along I-17 are entirely ASLD land. Therefore there should be one crossing structure per mile on this portion of I-17.

At least some of the crossing structures should be wildlife overpasses, in which the road is put in a trench or tunnel, and appropriate grassland habitat occurs on a bridge over the highway. Richard Ockenfels of AGFD has conducted decades of research documenting that pronghorn almost never use underpasses to cross highways. We recommend that transportation agencies follow the example of the SR-260 project east of Payson, where several designs of structures were built in the first 7 miles of highway expansion, wildlife movements were monitored intensively, and the results were used to ensure that wildlife-friendly designs were used in the remaining miles. Because the SR-260 project focused on elk (no pronghorn were documented using any of the SR-260 structures), the results of that study cannot be transferred to pronghorn in this region. The importance of these grasslands and these pronghorn populations justifies a similar investment in adaptive management here.

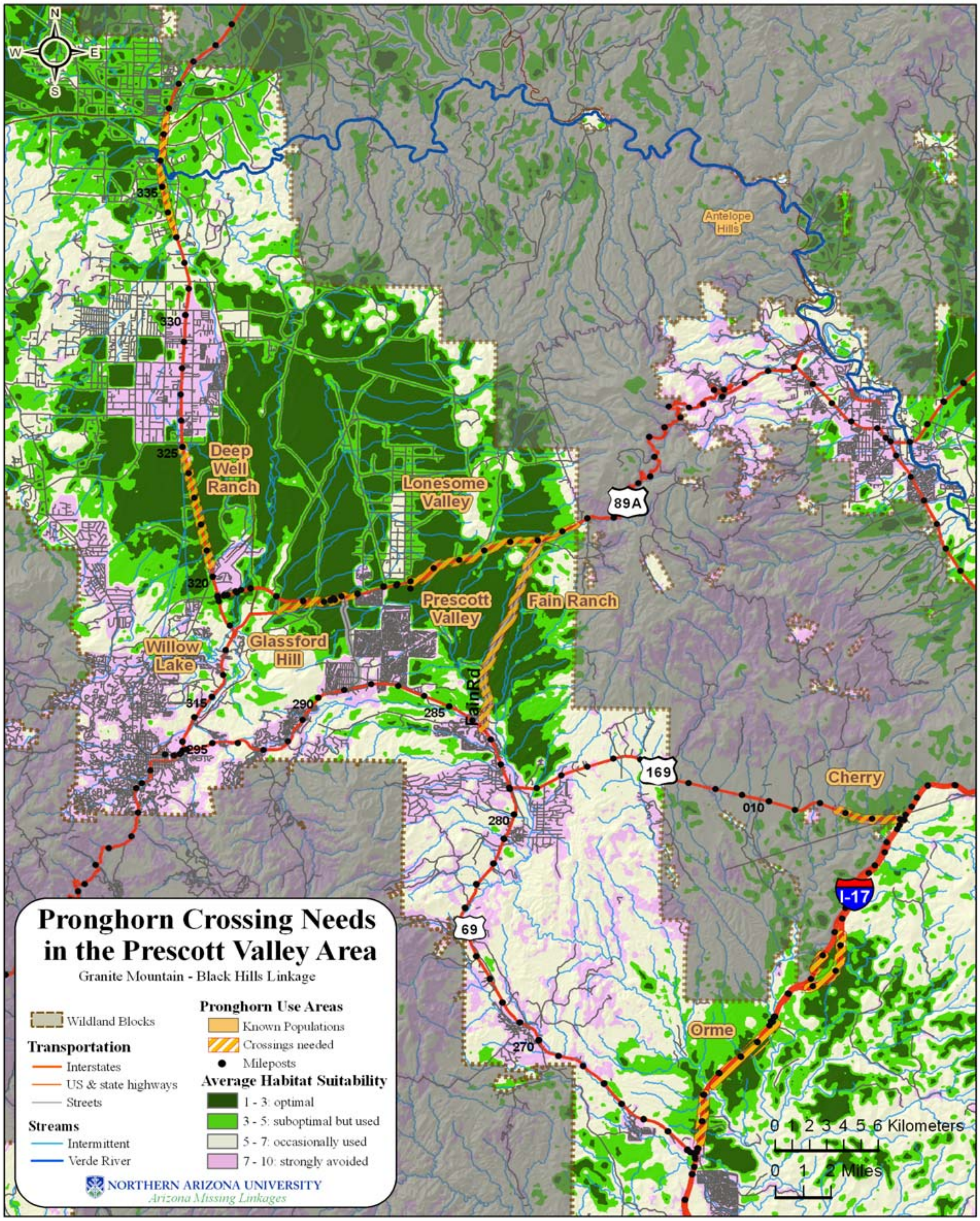

Figure 13: Approximate location of know pronghorn populations (gray text labels with salmon shadow) at risk of isolation. Pronghorn-friendly highway crossing structures should be spaced every 2 miles along cross-hatched road segments to allow movement among these populations.

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).

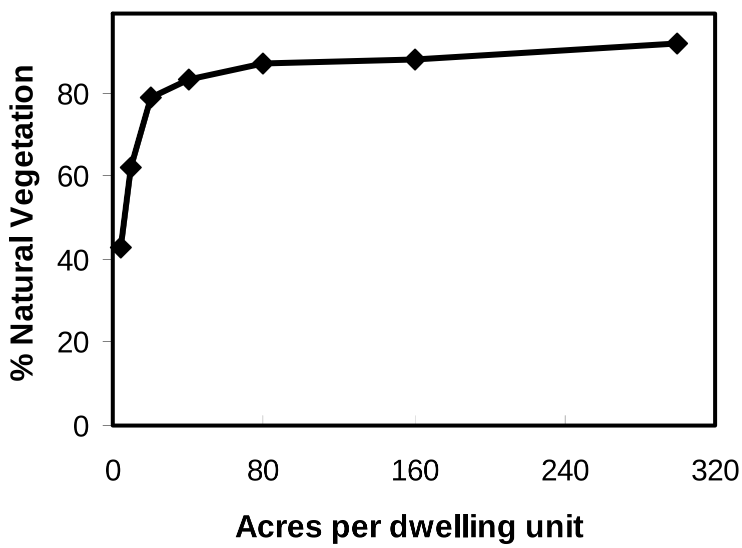

Figure 14: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

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

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

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas only accounted for 0.14% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

Yavapai County is the fourth largest county in Arizona by population, following only Maricopa, Pima and Pinal counties. The town of Prescott Valley is the seventh largest growing incorporated area in the state, with over 160% growth between 1990 and 2000 (AGFD 2006). The prevailing threat to wildlife populations in the Linkage Planning Area is loss and degradation of available habitat to urban development associated with a rapidly expanding human population. These threats are particularly severe for pronghorn populations and grasslands in and near Prescott, Prescott Valley, and Chino Valley. We noted new urban areas in two of the three linkage strands. These new developments were not depicted on the most recent land cover maps, illustrating the rapid rate of change. If steps are not taken to control urban sprawl in the next few years, we believe all three strands will be severed by urbanization.

We note the following urban land uses in or near linkage strands:

- Expanding residential development abuts Strand A near the intersection of Orme Road and Highway 169 (Waypoint 43, Figure 15).
- Strand B is broken into three substrands to avoid the densest areas of residential developments near Paulden. Because sprawl and leapfrog development (development that does not occur at the edge of existing development) is so widespread here, low-density housing is scattered throughout large parts within Strand B (Figure 16). Careful management of the associated roads and fencing (Figure 17) are needed to allow animal movement.
- The abandoned gravel mining operation in Stand B, Waypoint 34, should be restored to its natural gradient for pronghorn movement.
- Strand C is currently free of residential developments (Figure 18), but is threatened by proposed improvements to Williamson Valley Road, which would be followed by massive residential development.

Figure 15: Residential area along Highway 169 near Strand A, Waypoint 043.

Figure 16: Low-density residential housing in Strand B, Waypoint 036.

Figure 17: Impermeable fencing characteristic of residential development in and around the eastern portion of Strand B, Waypoint 038.

Figure 18: Strand C is free of urban development.

Mitigation for Urban Barriers

To reduce the barrier effects of urban development we recommend:

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 A and Strand B for wildlife permeability. Many people already live in this optimal movement corridor for javelina, black bear, and pronghorn. Unrestrained dogs and cats, fencing, road kill on neighborhood streets, and artificial night lighting could make these Strands ineffective. We advocate innovative programs that respect the rights of residents and enlist them as steward of the linkage area.

- Discourage further residential development and subdivision of large parcels in the Linkage Design.

Impediments to the Upper Verde River

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Verde River and its associated riparian vegetation are preferred habitat for many species in the linkage area, including southwestern willow flycatcher, yellow-billed cuckoo, black-necked garter snake, Mexican garter snake, narrow-headed garter snake, lowland leopard frog, beaver, river otter, longfin dace, desert sucker, roundtailed chub, speckled dace, spikedace, and Colorado pikeminnow.

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 Verde River is the only perennial flowing water in the linkage area, and the only Wild and Scenic River in the state of Arizona. The Verde River becomes a named stream at Sullivan Lake, near the confluence of Big Chino Wash and Granite Creek. In this area, the flow of Big Chino Wash and Granite Creek is underground for most of the year. Above-ground flows begin here because bedrock forces the flow to the surface. Although only a few miles of the Verde River occur in the linkage area, the headwaters are critically important to water quality and water quantity downstream, and several rare aquatic and riparian species occur here. Groundwater pumping in the Big Chino and Granite Creek watersheds, and potential impacts of urbanization on water quality, should be addressed now. A functioning riparian ecosystem can be restored and maintained along the Verde if action is taken promptly before conditions get worse.

Mitigating Stream Impediments

We endorse the following management recommendations to conserve riparian and aquatic habitat on the Verde River.

1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).
   - Urban development contributes to a "flashier" (more flood-prone) system. Check dams and settling basins should be required in urban areas within the watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000).
   - Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
   - Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993). However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kupferberg 1997, Kiesecker and Blaustein 1998, Maret et al. 2006).
2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, reducing agricultural water use, 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).

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, D'Antonio and Meyerson 2002, Savage 2004).
6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.
7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

Appendix A: Linkage Design Methods

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

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

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

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 35 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.

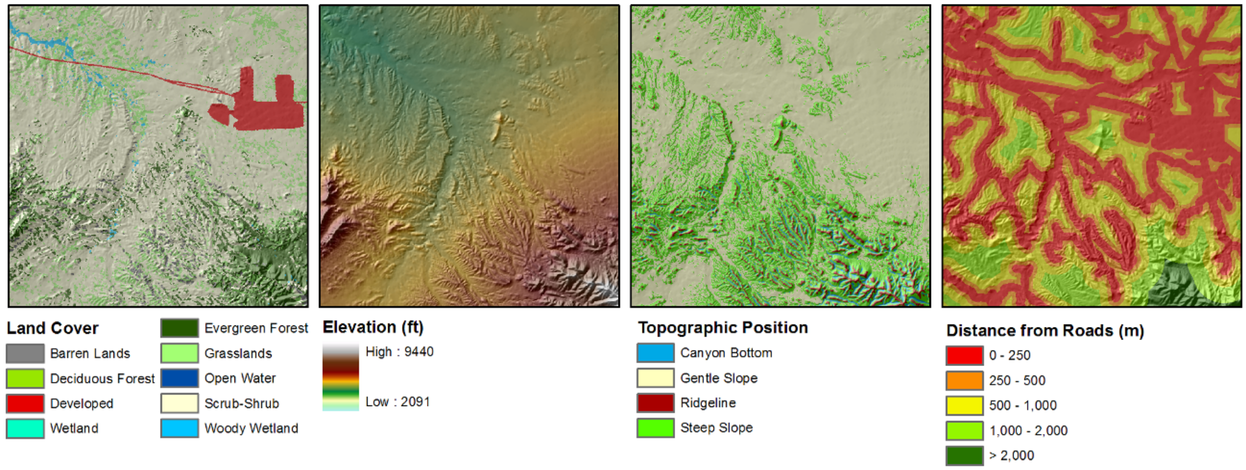

Figure 19: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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.

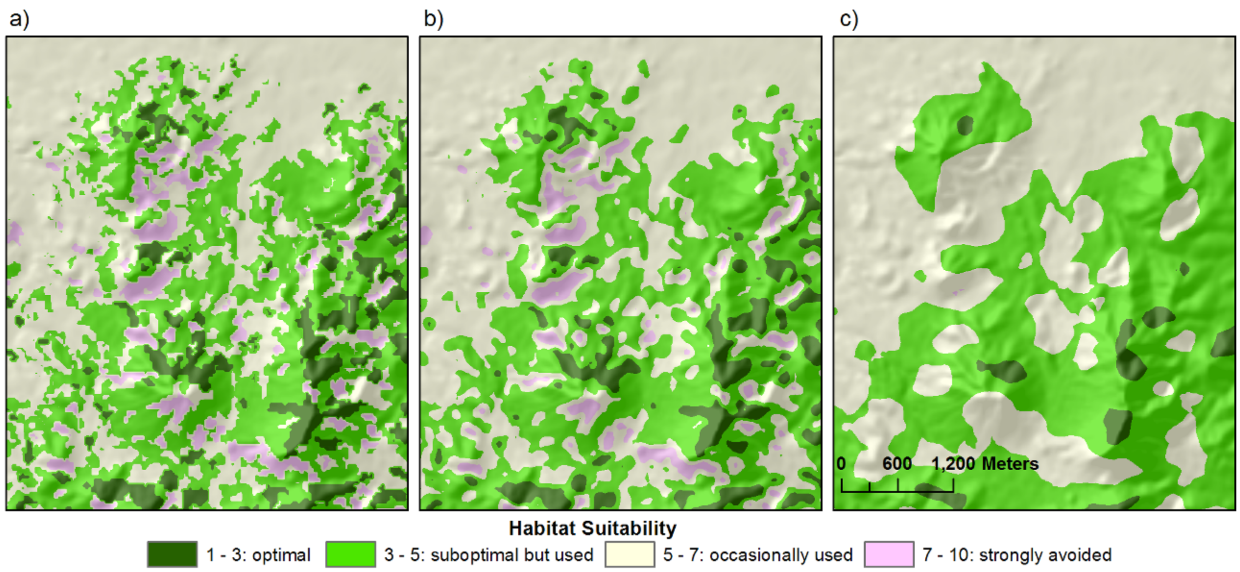

Figure 20: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

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 protected habitat block to a potential population core in the other protected habitat block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

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

The two wildland blocks are comprised of large units of the Prescott National Forest on either side of the Prescott and Chino Valleys (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 2 problems: (1) It could be unrealistic (previous footnote). (2) It could serve small wildlife populations near the road while failing to serve much larger populations in the rest of the protected habitat block. To address these problems, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel to each other, Thus for purposes of BBC analyses, we redefined the wildland blocks such that the Granite Mountain wildland block was at least 30 km (19.3 mi) from the Black Hills wildland block.

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[8]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected habitat block. We similarly calculated the lowest cumulative travel cost from the 2nd protected habitat block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 500 m (Figure 21). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[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 habitat block, we added these polygons to the UBBC to create a *preliminary linkage design*.

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

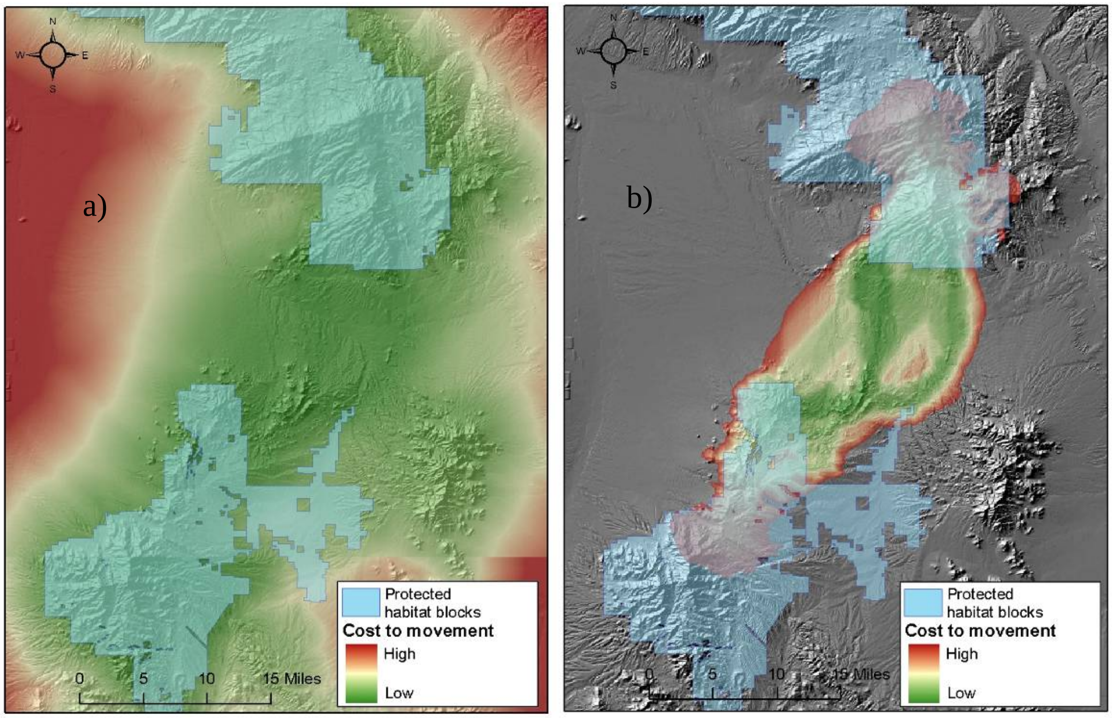

Figure 21: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

Minimum Linkage Width

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

To address these concerns, we established a minimum width of 1.5 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.

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.

	Black Bear	Elk	Javelina	Mountain Lion	Mule Deer
Factor weights					
Land Cover	75	75	50	70	80
Elevation	10	0	30	0	0
Topography	10	0	20	10	15
Distance from Roads	5	25	0	20	5
Land Cover					
Mixed Conifer Forest and Woodland	3	1	6	3	3
Pine-Oak Forest and Woodland	1	1	7	1	3
Pinyon-Juniper Woodland	6	1	5	1	5
Ponderosa Pine Woodland	4	1	6	4	5
Spruce-Fir Forest and Woodland	4	1	8	4	8
Aspen Forest and Woodland	5	1	10	3	1
Juniper Savanna	7	1	7	4	4
Montane-Subalpine Grassland	4	1	8	6	4
Semi-Desert Grassland and Steppe	5	7	2	5	2
Chaparral	3	4	3	3	4
Creosotebush, Mixed Desert and Thorn Scrub	6	9	3	6	6
Mesquite Upland Scrub	6	7	2	4	3
Paloverde-Mixed Cacti Desert Scrub	5	8	1	7	3
Riparian Woodland and Shrubland	5	2	2	2	3
Mixed Bedrock Canyon and Tableland	10	9	10	6	7
Playa	10	10	8	10	6
Recently Mined or Quarried	10	10	10	8	6
Agriculture	6	7	7	10	6
Developed, Medium - High Intensity	10	10	7	10	9
Developed, Open Space - Low Intensity	10	7	4	8	5
Elevation (ft)					
	0-2500: 8		0-5000: 1		
	2500-4000: 6		5000-7000: 3		
	4000-6500: 2		7000-11000: 10		
	6500-8500: 3				
	8500-11000: 4				
Topographic Position					
Canyon Bottom	3		1	1	2
Flat - Gentle Slopes	6		1	3	2
Steep Slope	3		7	3	4
Ridgetop	4		4	4	6
Distance from Roads (m)					
	0-100: 10	0-100: 9		0-200: 8	0-250: 7
	100-500: 4	100-200: 8		200-500: 6	250-1000: 3
	500-15000: 1	200-400: 6		600-1000: 5	1000-15000: 1
		400-1000: 5		1000-1500: 2	
		1000-2000: 2		1500-15000: 1	
		2000-15000: 1			

	Pronghorn
Factor weights	
Land Cover	45
Elevation	0
Topography	37
Distance from Roads	18
Land Cover	
Mixed Conifer Forest and Woodland	8
Pine-Oak Forest and Woodland	8
Pinyon-Juniper Woodland	6
Ponderosa Pine Woodland	7
Spruce-Fir Forest and Woodland	8
Aspen Forest and Woodland	10
Juniper Savanna	4
Montane-Subalpine Grassland	3
Semi-Desert Grassland and Steppe	1
Chaparral	8
Creosotebush, Mixed Desert and Thorn Scrub	2
Mesquite Upland Scrub	7
Paloverde-Mixed Cacti Desert Scrub	3
Riparian Woodland and Shrubland	8
Mixed Bedrock Canyon and Tableland	8
Playa	7
Recently Mined or Quarried	10
Agriculture	8
Developed, Medium - High Intensity	10
Developed, Open Space - Low Intensity	8
Elevation (ft)	
Topographic Position	
Canyon Bottom	7
Flat - Gentle Slopes	1
Steep Slope	8
Ridgetop	6
Distance from Roads (m)	
	0-100: 10
	100-250: 6
	250-1000: 3
	1000-15000: 1

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 5 for habitat suitability scores.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 10 km^2, since this is the minimum amount of optimum habitat necessary to support a female and cub (Bunnell & Tait

1981; S. Cunningham, pers. comm.). Minimum potential habitat core size was defined as 50km2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

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

Results & Discussion

Initial biologically best corridor- Modeling results indicate that most of the suitable habitat for black bear is found within the wildland blocks (Figure 22). The biologically best corridor encompasses the best available habitat between the blocks where habitat suitability ranges from 1.5 to 9.1, with an average suitability cost of 3.4 (S.D.:0.8). Almost all of the corridor serves as a potential habitat core (Figure 23). Two major highways, 69 and 169, could be an impediment to bear movement in this area, as well as causes of direct mortality. Effective crossing structures will reduce the risk of collisions and fragmentation for bear and other large mammals in this area.

Union of biologically best corridors- The UBBC captures some additional habitat for black bear. It includes additional, patchily distributed potential core and patch areas north of Prescott Valley. This may provide additional foraging habitat for bears in the fall, when they travel to lower elevations in search of prickly pear fruit and acorns.

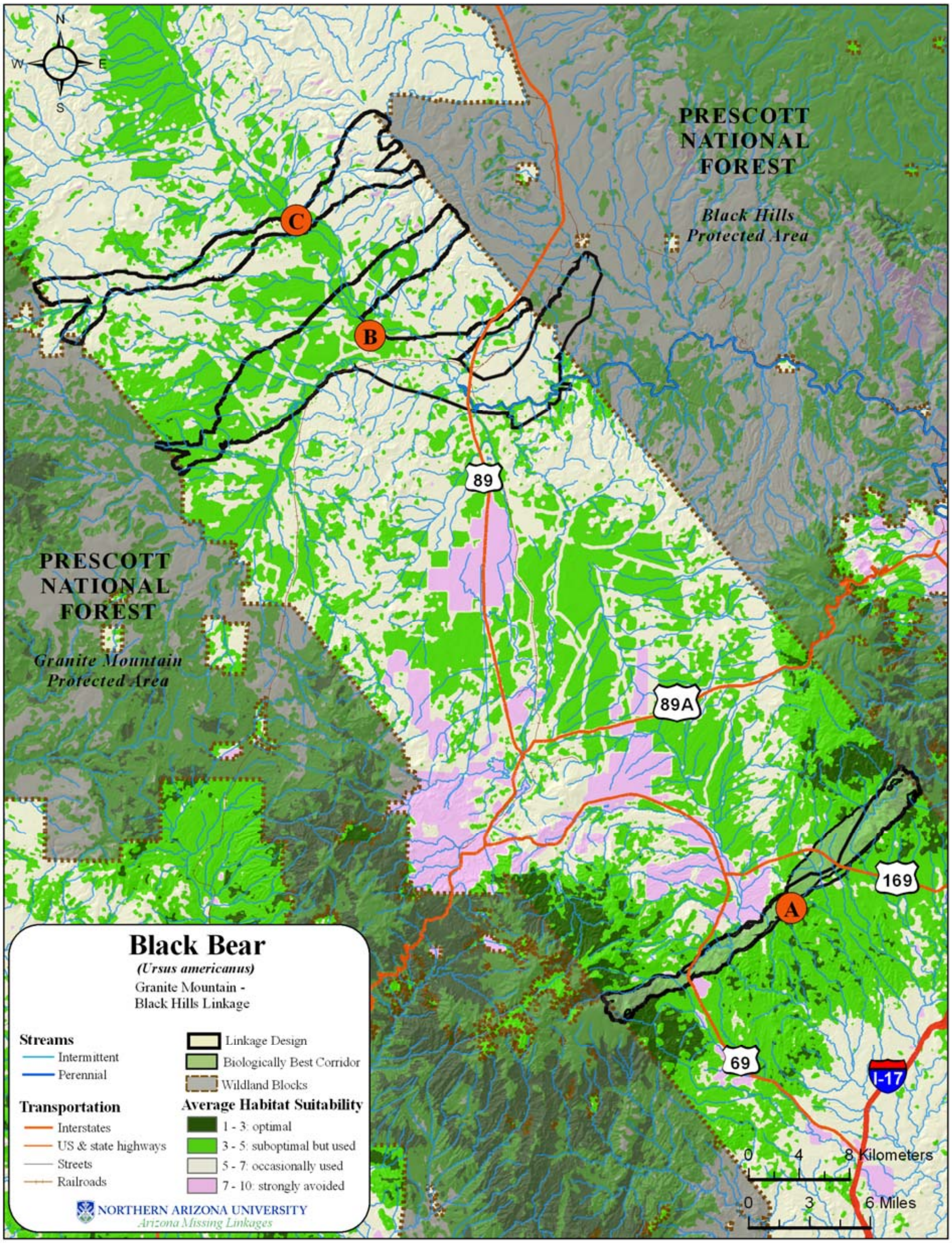

Figure 22: Modeled habitat suitability of black bear .

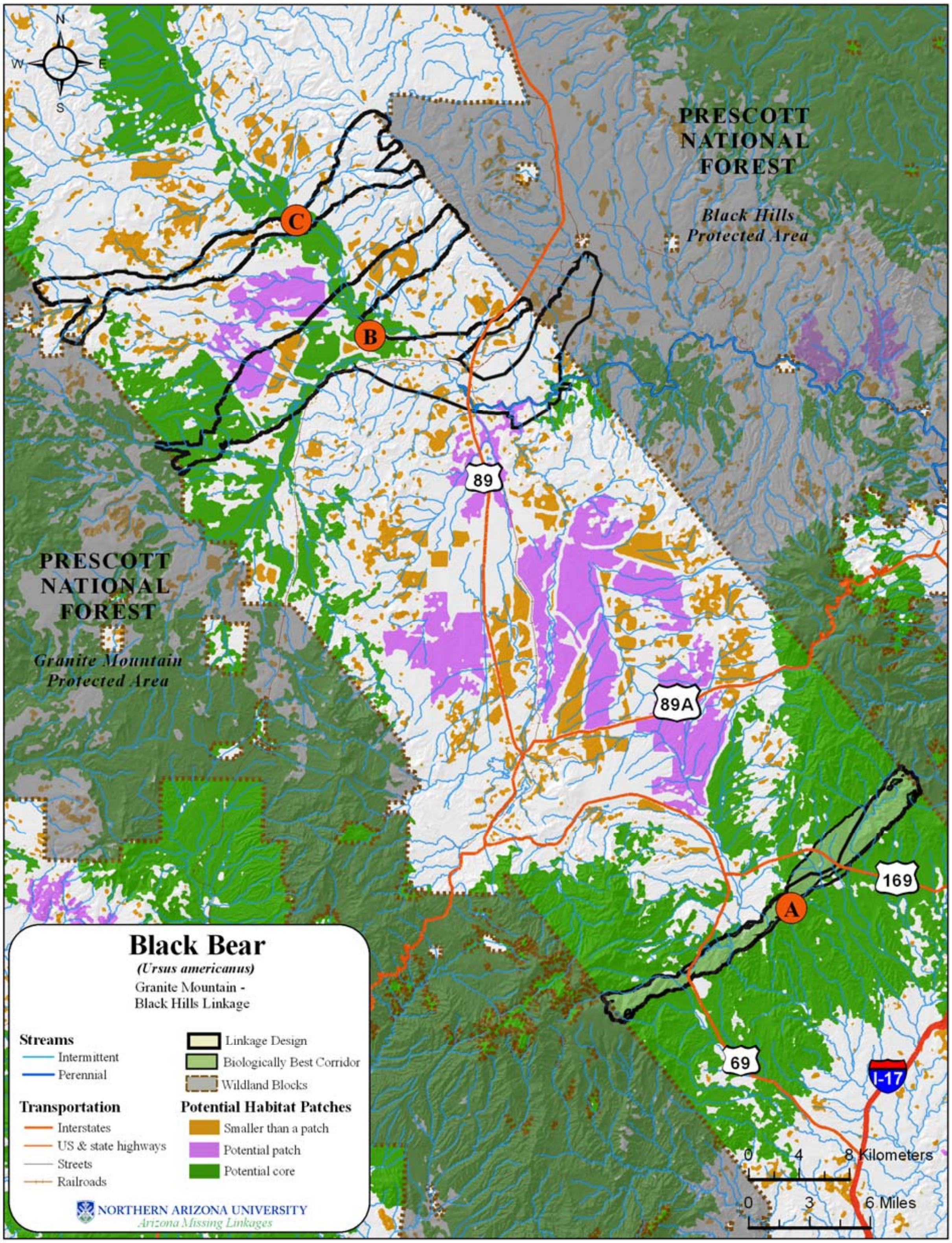

Figure 23: Potential habitat patches and cores for black bear.

Elk (*Cervus elaphus*)

Justification for Selection
Elk are seasonal migrants which require large tracts of land to support viable populations. They are prey for large carnivores such as mountain lion, and susceptible to human disturbance and busy roads.

Distribution & Status
By the late 1800's, native elk (*Cervus elaphus merriami*) were believed to be extinct in Arizona. Re-introduction efforts in the early 1900's established stable populations of non-indigenous Rocky Mountain elk (*Cervus elaphus nelsoni*) in virtually all historic elk habitat in the state (Britt and Theobald 1982). Populations were also established in the Hualapai Mountains south of Kingman and on the San Carlos Reservation near Cutter, Arizona. Both areas were believed to be previously uninhabited by elk (Severson and Medina 1983). Arizona elk populations have expanded to an estimated total of 35,000 animals (Arizona Department of Game and Fish 2006). Elk are most commonly found in woodlands and forests of northern Arizona extending from the Kaibab Plateau south and eastward along the Mogollon Rim to the White Mountains and into western New Mexico (Severson and Medina 1983). Within the Linkage Planning Area, elk currently occur within the Hualapai, Peacock, and Music mountains.

Habitat Associations
Elk are "intermediate feeders" capable of utilizing a mix of grasses, herbs, shrubs, and trees depending on the season and availability. Although capable of living in a range of habitats from desert chaparral and sagebrush steppe to tundra, elk are most commonly associated with forest parkland ecotones that offer a mix of forage and cover (Thomas et al. 1988; O'Gara and Dundes 2002). Elk are negatively impacted by roads, and have shown avoidance behavior up to 400 m (Ward et al. 1980), 800 m (Lyon 1979) and 2.2 km (Brown et al. 1980; Rowland et al. 2004) from roads.

Spatial Patterns
In Arizona, elk move annually between high elevation summer range (7000 to 10000 ft) and lower elevation winter range (5500 to 6500 ft) (Arizona Department of Fish and Game 2006). Elk may move as far as 100 km to lower elevations where there is less snow in the winter (Boyce 1991). Elk avoid human activity unless in an area secure from predation in which they are tolerant of human proximity (Morgantini and Hudson 1979, Lyon and Christensen 2002, Geist 2002).

Conceptual Basis for Model Development
Habitat suitability model –Vegetation received an importance weight of 75%, while distance from roads received a weights of 25%. For specific scores of classes within each of these factors, see Table 5.

Patch size & configuration analysis – Home ranges are highly variable for elk (O'Gara and Dundes 2002). In Montana, one herd had an average summer home range of 15 km^2 (Brown et al. 1980), while a herd in northwestern Wyoming had a winter range of 455 km^2 and a summer range of 4740 km^2 (Boyce 1991). Minimum patch size for elk was defined as 60 km^2 and minimum core size as 300 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for elk within the potential linkage area (Figure 24). Within the biologically best corridor, suitability scores ranged from 1.0 to 7.2, averaging a cost of 2.3 (S.D.: 1.2). Almost the entire corridor serves as a potential habitat core (Figure 25).

Union of biologically best corridors – The UBBC provides additional habitat to the south of Prescott Valley. While this addition of potential core habitat increases connectivity between the wildland blocks for elk, two major highways, 69 and 169, pose a threat in this area. Effective crossing structures will reduce the risk of collisions and fragmentation for elk and other large mammals dependent on this habitat.

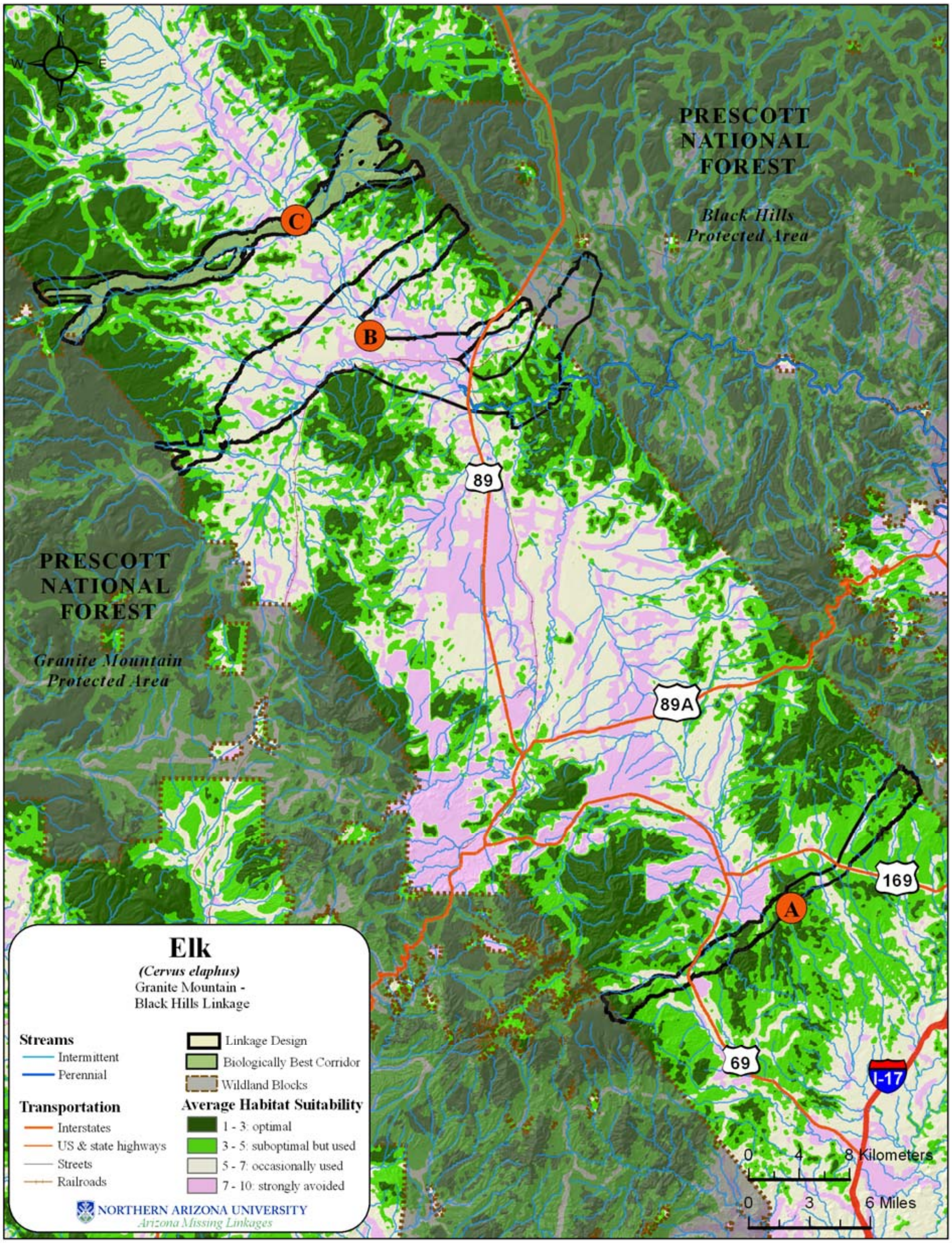

Figure 24: Modeled habitat suitability of elk.

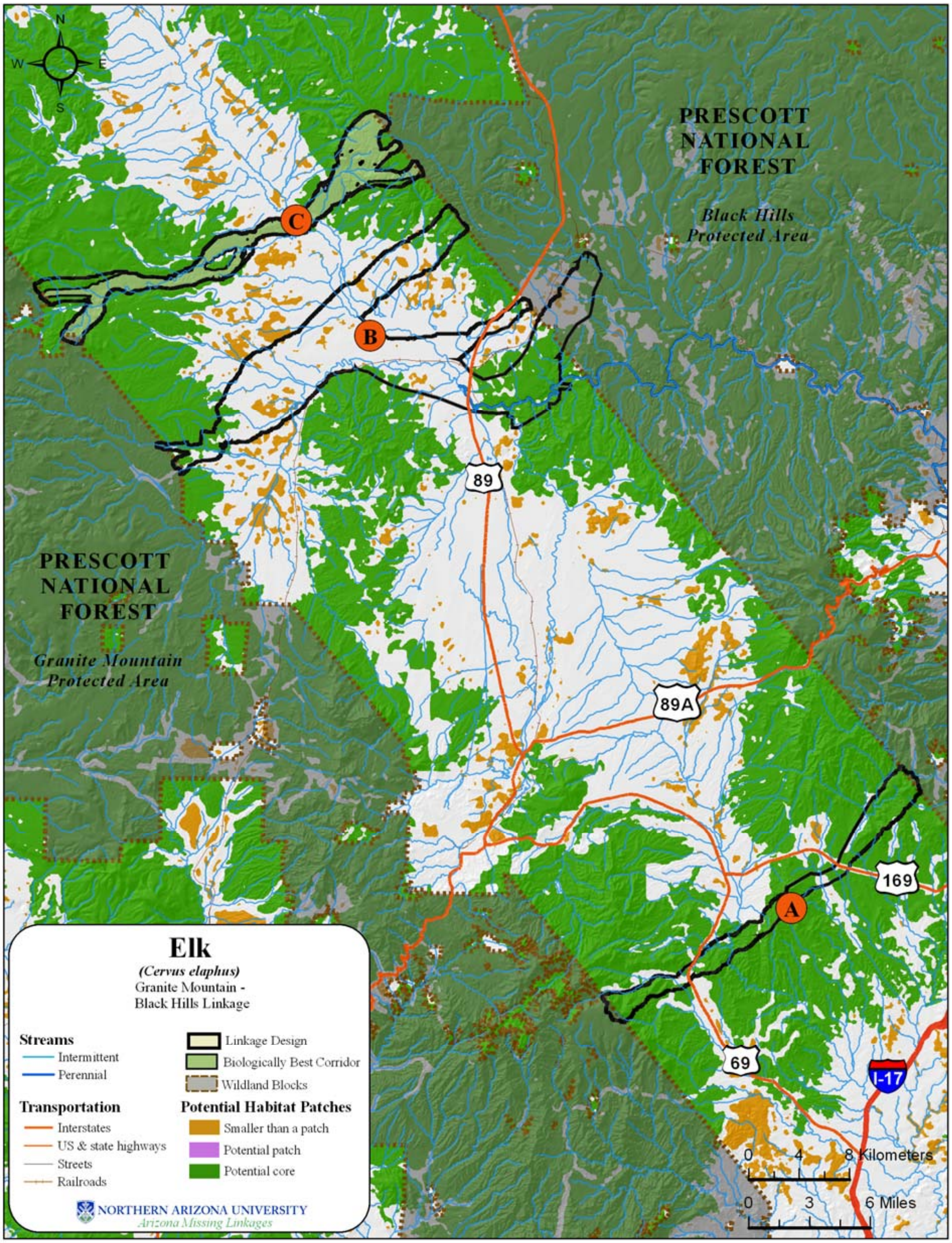

Figure 25: Modeled habitat patches and cores for elk.

Javelina (*Tayassu tajacu*)

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

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

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

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

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant suitable habitat for this species within the potential linkage area (Figure 26). Within the biologically best corridor for this species, habitat suitability ranged from 1.5 to 10.0, with an average suitability cost of 1.8 (S.D: 0.6). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 27).

Union of biologically best corridors – The additional strands of the UBBC significantly increase potential habitat for javelina. 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 including Highways 89, 89A, 169, 69, and Interstates 17 and 40.

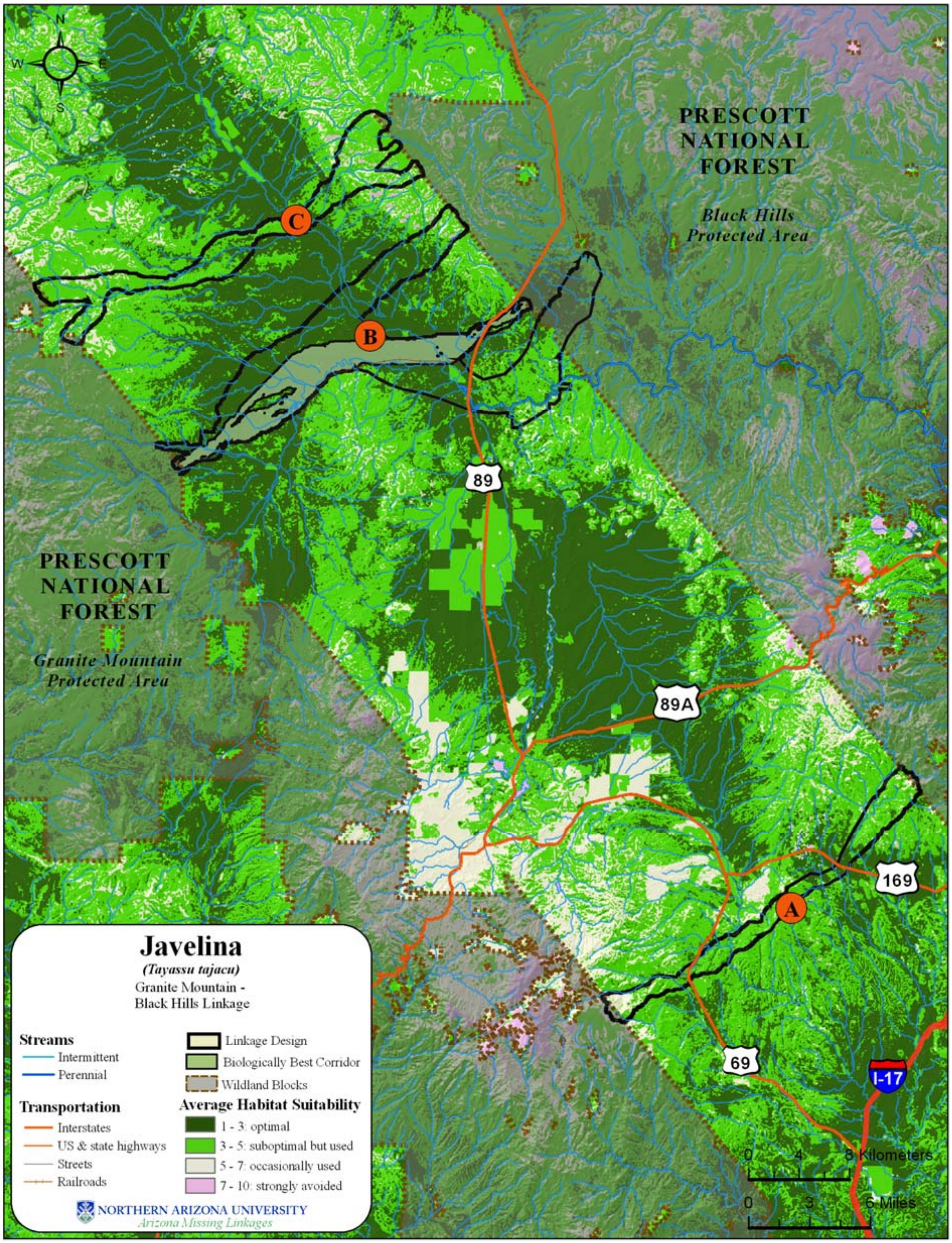

Figure 26: Modeled habitat suitability of javelina.

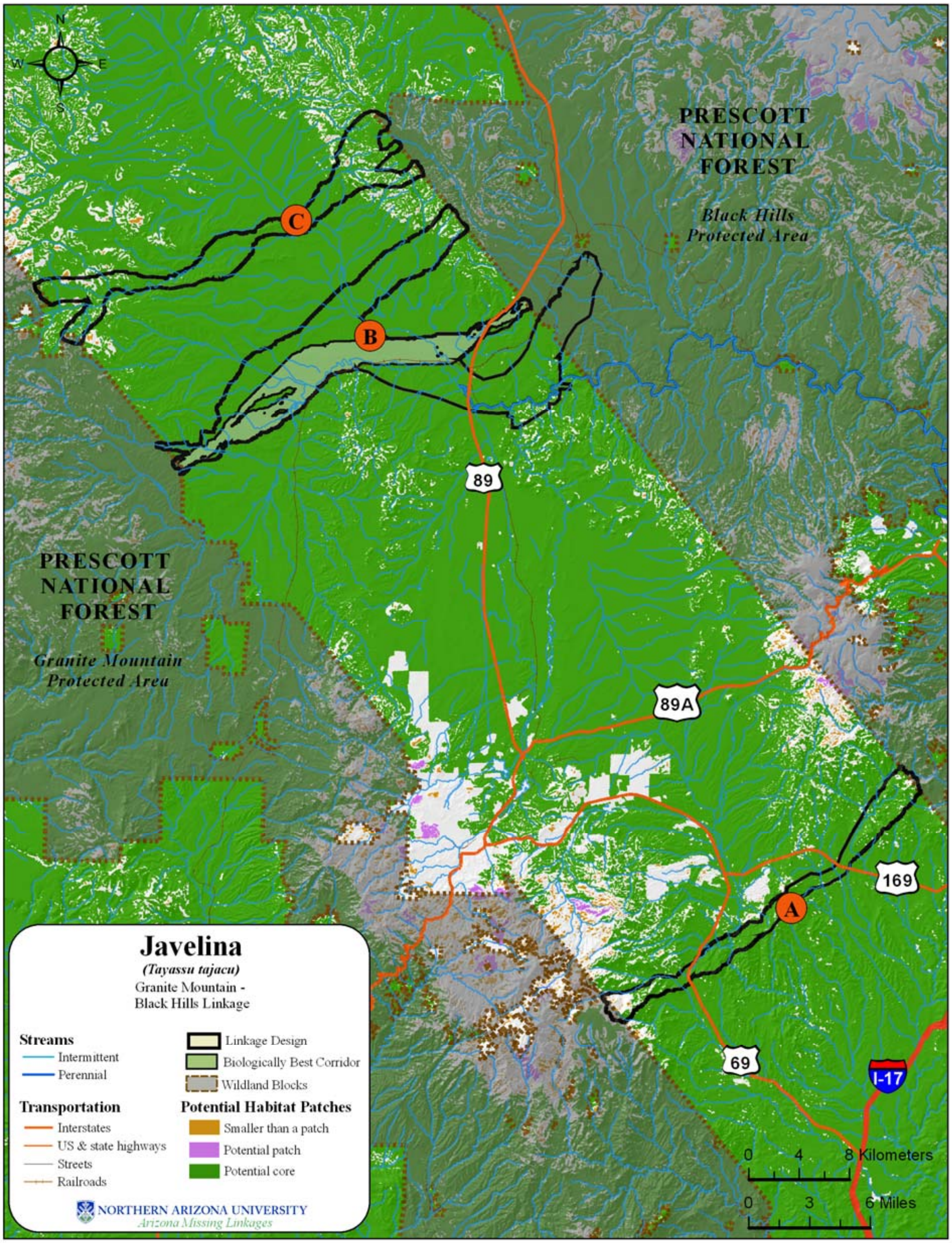

Figure 27: Potential habitat patches and cores for javelina.

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). In the Linkage Planning Area, mountain lions occur in all mountainous areas, including the Hualapai and Cerbat Mountains (AZGFD 2006).

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, and mixed forests, and shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Game and Fish Department 2004). Mountain lions are found at elevations ranging from 0 to 4000 m (Currier 1983).

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size & configuration analysis – Minimum patch size for mountain lions was defined as 79 km2, based on an average home range estimate for a female in excellent habitat (Logan & Sweanor 2001; Dickson & Beier 2002). Minimum core size was defined as 395 km2, or five times minimum patch size.

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for mountain lions within the potential linkage area, fragmented by less suitable and strongly avoided habitat including developed areas. Within the biologically best corridor, habitat suitability ranged from 1.1 to 5.4, with an average suitability cost of 2.1 (S.D.:0.8) (Figure 28).

Union of biologically best corridors – The UBBC provides little additional habitat for the mountain lion, since it is associated with more rugged terrain and tends to avoid developed areas. However, the additional two strands do encompass some suboptimal habitat, and a smaller amount of optimal habitat, most of which comprises a potential core (Figure 29). Because there is ample habitat for this species, and much of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely habitat fragmentation.

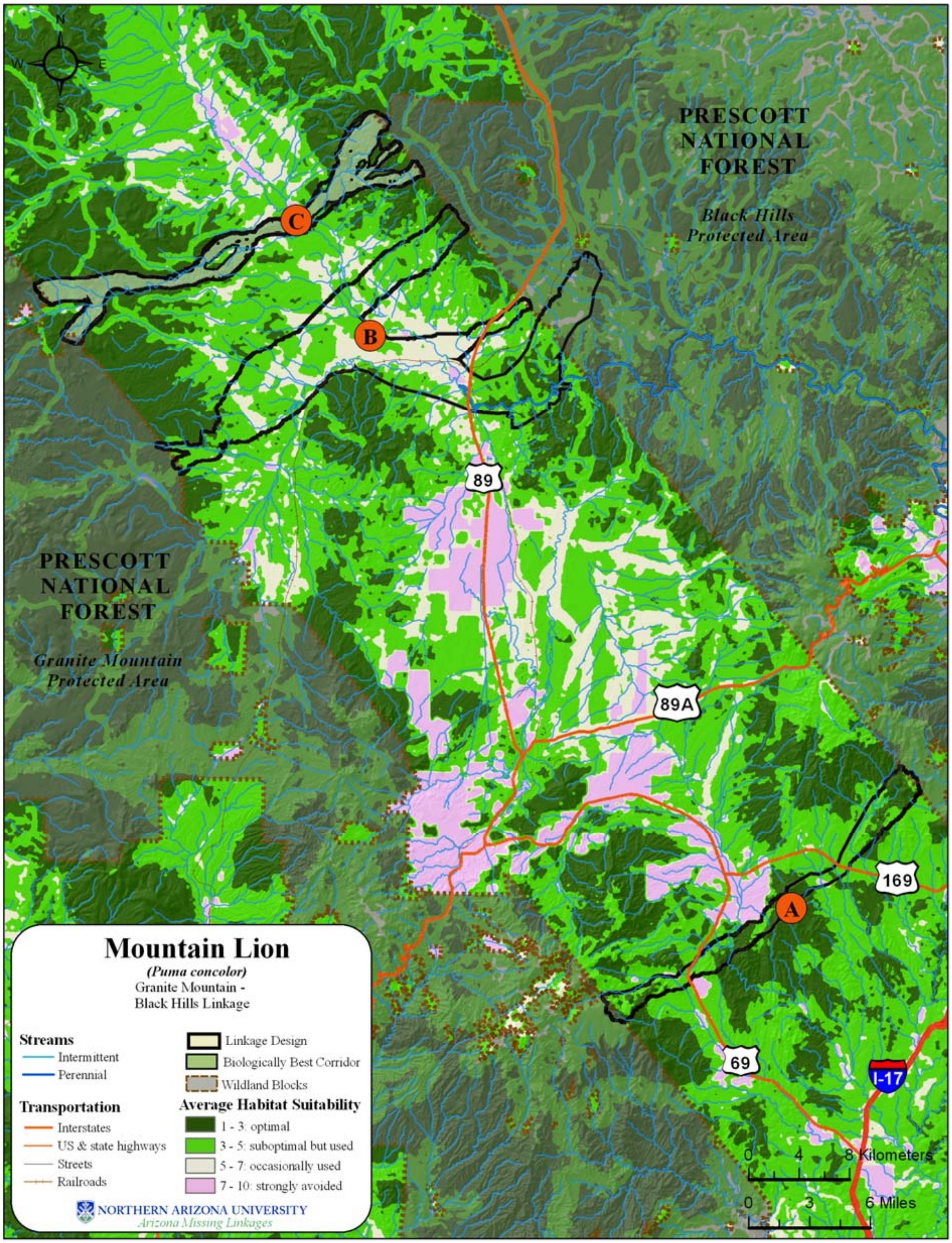

Figure 28: Modeled habitat suitability of mountain lion.

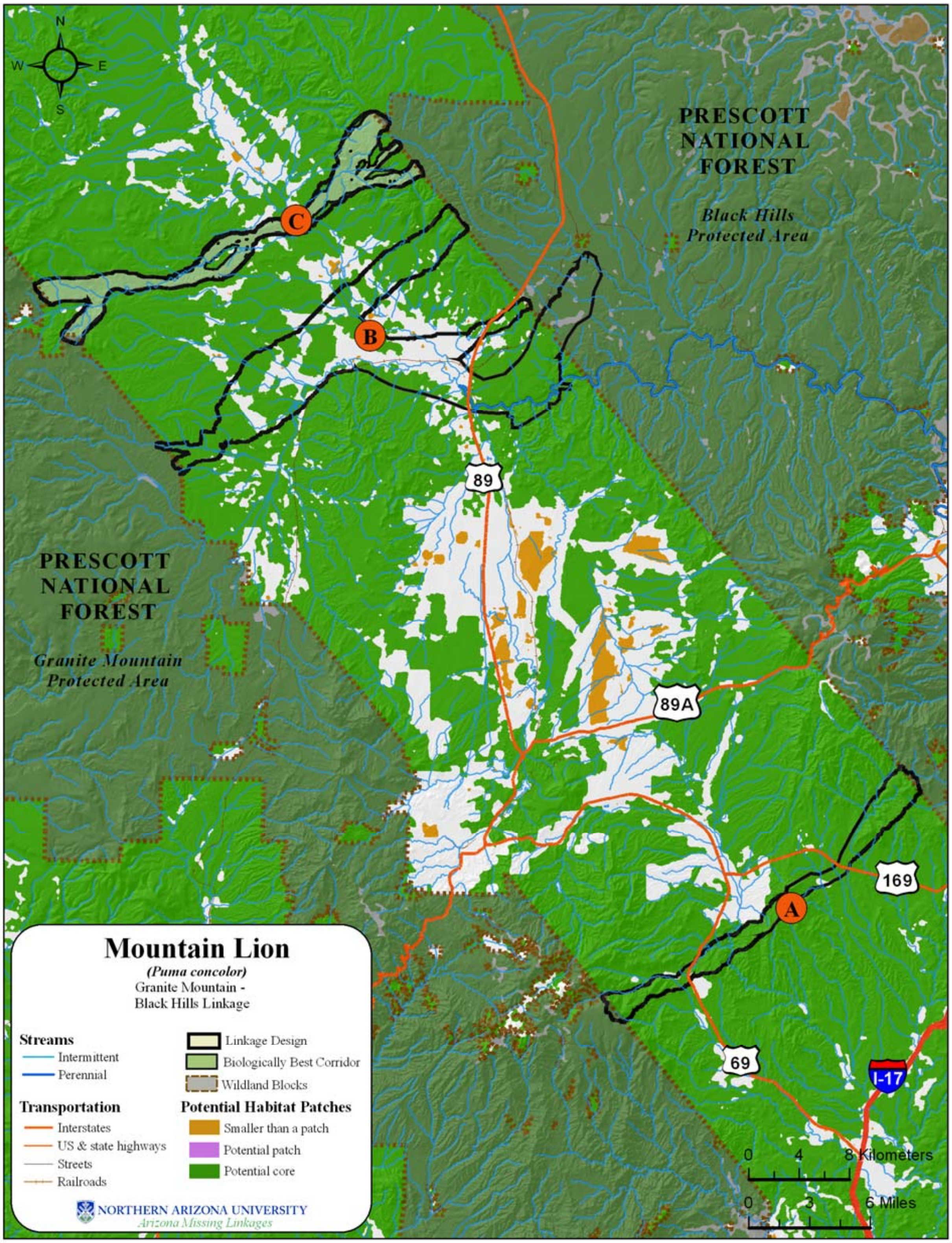

Figure 29: Potential habitat patches and cores for mountain lion.

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for mule deer within the potential linkage area (Figure 30). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 2.0 to 5.5, with an average suitability cost of 2.8 (S.D: 0.7). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core.

Union of biologically best corridors – The additional strands of the UBBC provide additional potential habitat for mule deer, although the majority of this habitat is classified as suboptimal. Most of the habitat identified as optimal for mule deer lies between the wildland blocks, and is located near developed areas. The greatest threats to mule deer populations in this area appear to be high-traffic roads including Highways 89, 89A, 169, 69, and Interstates 17 and 40, and continued development.

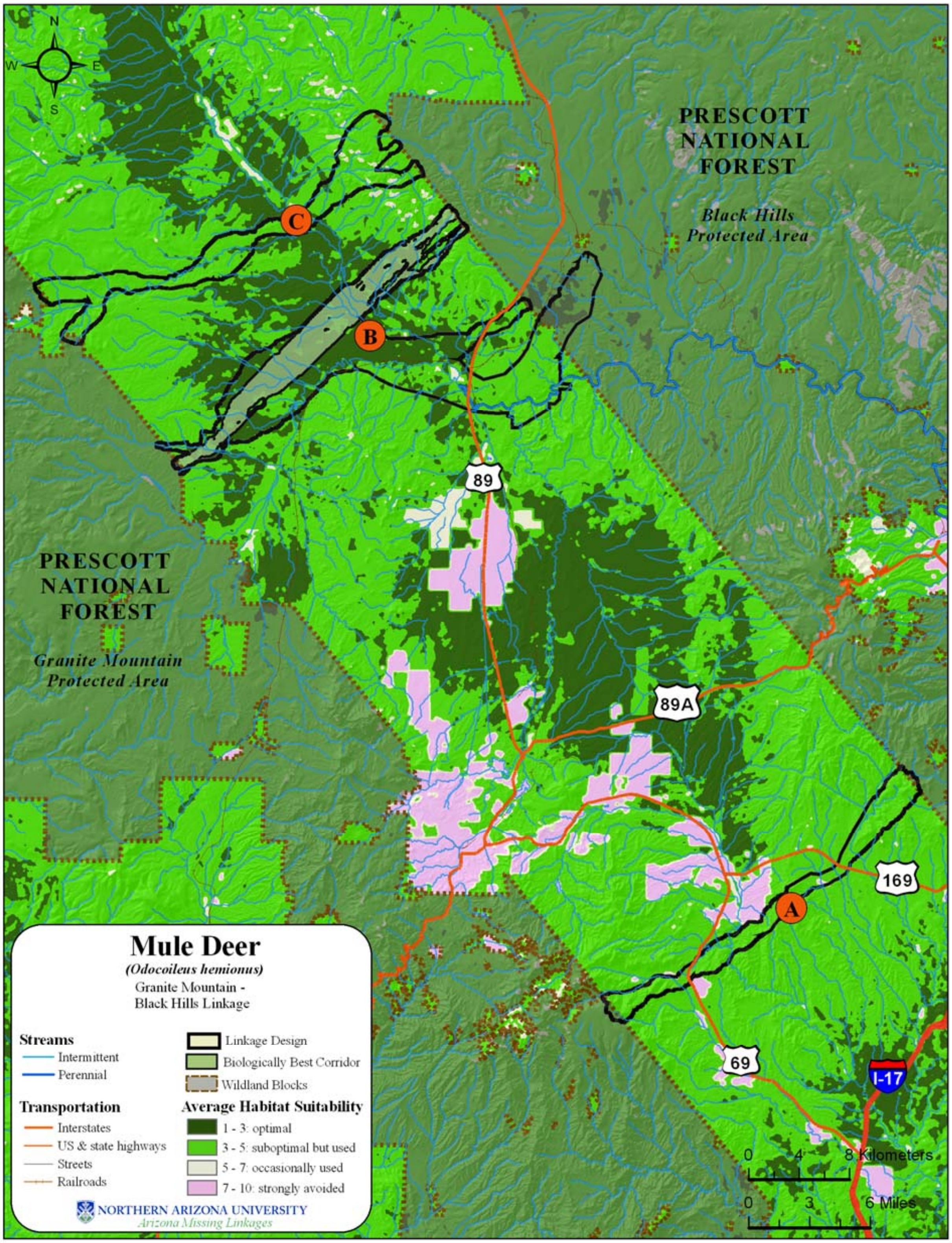

Figure 30: Modeled habitat suitability of mule deer.

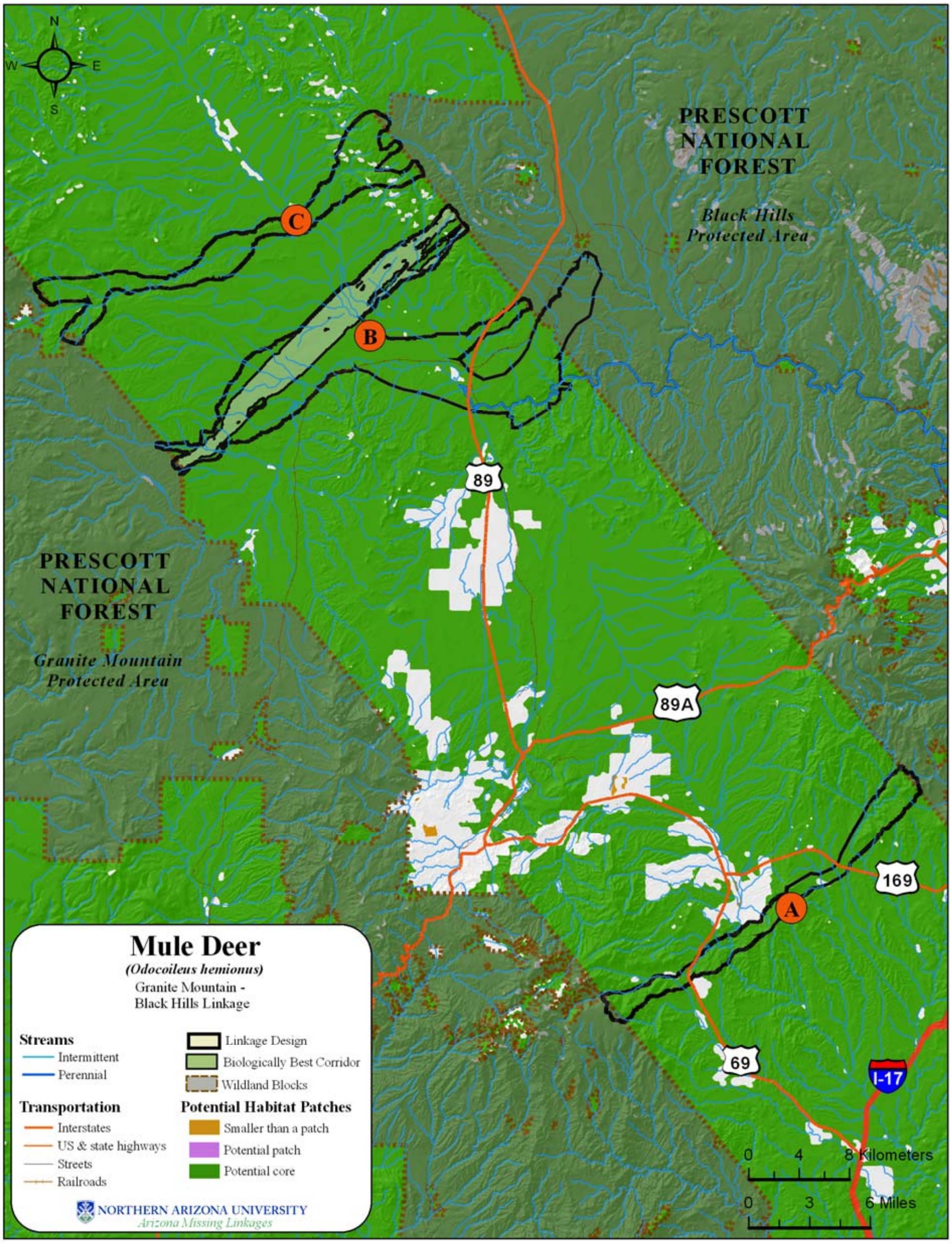

Figure 31: Modeled habitat patches and cores for mule deer.

Pronghorn (*Antilocapra americana*)

Justification for Selection

The Linkage Planning Area supports some of the highest density pronghorn populations in the state (AGFD 2006). Pronghorn are susceptible to habitat degradation and human development (AGFD 2002a). Right of way fences for highways and railroads are the major factor affecting pronghorn movements across their range (Ockenfels et al. 1997). Migration corridors to and from low elevation winter ranges are critical to pronghorn survival (Ockenfels et al. 2002). The prevailing threat to pronghorn populations in the Linkage Planning Area is loss and degradation of available habitat to urban development associated with a rapidly expanding human population (AGFD 2006).

Distribution

Pronghorn range through much of the western United States. They are found throughout the grasslands of Arizona, except in the southeastern part of the state (Hoffmeister 1986). Within the Linkage Planning Area, pronghorn occur primarily in the land between the wildland blocks. At least eleven distinct sub-populations inhabit the Linkage Planning Area in the Prescott and Chino Valleys where they are increasingly isolated by urban developments, major roads, and geographical features (Figure 34). The 11 populations are named Orme, Cherry, Fain Ranch, Prescott Valley, Antelope Hills, Glassford Hill, Lonesome Valley, Big Chino Valley, Juniper Woods Estates, Deep Well Ranch, and Willow Lake (Figure 34, AGFD 2006):

- The **Orme** herd resides north of Cordes Junction, between Highways 69, 169, and I-17. The group is threatened by isolation from larger herd units and habitat to the east by I-17, and from the Lonesome Valley area to the west by expansion of Highway 169.

- The **Cherry** herd of 20-30 animals resides north of highway 169 and west of I-17. This herd has limited connectivity with larger herd units and habitat to the east by I-17.

- The **Fain Ranch** herd is functionally isolated from other pronghorn herds by Highway 89A to the north, the town of Prescott Valley to the west, Mingus Mountain to the east, and Highway 169 to the south. This herd comprises about 275 animals. Within their range, Fain Ranch is bisected north to south by two double fenced roads connecting Highways 89A and 69. Recent expansion of these connector roads is projected to accelerate habitat fragmentation and increase the number of road kills, resulting in herd reduction.

- Recent expansion of Glassford Hill Road and Hwy 89A west of Fain Ranch has already impacted the 50-70 pronghorn of the **Prescott Valley** herd, as described above. This isolated herd relies on undeveloped areas within and around the municipal boundaries of Prescott Valley. Continued urban development will eliminate remaining habitat and the remainder of this herd.

- The **Antelope Hills** herd occupies the lower north slope of Mingus Mountain. This herd is decreasing in numbers. Pronghorn possibly use this area as a movement corridor between Lonesome Valley and areas north of the Verde River.

- The **Glassford Hill** herd is isolated by Highway 89A to the north, Glassford Hill Road to the east, and Highway 69 to the south. Historically, as many as 175 pronghorn may have occupied this area, however 2002 survey data indicated that about only 30-40 pronghorn occupied the area.

- Pronghorn in **Lonesome Valley** are confined by Highway 89A to the south, Mingus Mountain to the east, Highway 89 to the west, and the Verde River to the north.

- The **Big Chino Valley** grasslands extend northwest from Paulden to Picacho Butte and the Juniper Mountains. Rural residential housing is increasing rapidly around Paulden. Continued development on checker-boarded sections of private land significantly reduces pronghorn use on adjacent, undeveloped State Trust sections. Invasion of juniper trees into grassland habitat is also problematic. Although ranchers have modified many fences to facilitate pronghorn movements, unmodified fencing in parts of Big Chino Valley continues to impede pronghorn movement within this habitat.

- About 157 adult pronghorn inhabit the **Juniper Woods Estates** area. Extensive pronghorn habitat extends south and west, and gradually transitions to juniper woodlands. Over the past 12 years, scattered occupancy of 40-acre lots has greatly reduced pronghorn distribution and numbers.

- The **Deep Well Ranch** herd occupies habitat south of the town of Chino Valley. Presently, the ranch is threatened by fragmentation from adjacent open grasslands by urban infrastructure in Prescott, the town of Chino Valley, and Highway 89. The ranch currently supports a population of about 85 adult pronghorn.

- The **Willow Lake** herd consists of about 11-13 adult pronghorn persisting within the Prescott city limits. The herd occupies habitat that is being rapidly converted to a residential housing and golf courses. Construction of two major roads (and associated fencing) more than 30 years ago created the first major barrier to movement on the northern border of the area. Continued urban development has reduced habitat dramatically since 1990. The last square mile of pronghorn habitat is on the Yavapi-Prescott Indian Reservation; virtually all pronghorn habitat in private hands has been or is being developed. This herd is probably doomed to extinction, and offers a bleak view into the future of several other pronghorn populations if road improvements and land conservation are not implemented soon.

Habitat Associations

Pronghorn are found in areas of grasses and scattered shrubs with rolling hills or mesas (Ticer and Ockenfels 2001; New Mexico Department of Fish and Game 2004). They inhabit shortgrass plains as well as riparian areas of sycamore and rabbitbrush, and oak savannas (New Mexico Department of Fish and Game 2004). In winter, pronghorn rely on browse, especially sagebrush (O'Gara 1978). Pronghorn prefer gentle terrain, and avoid rugged areas (Ockenfels et al. 1997). Woodland and coniferous forests are also generally avoided, especially when high tree density obstructs vision (Ockenfels et al. 2002). Pronghorn prefer slopes that are less than 30%, typically less than 10% (Yoakum et al. 1996).

Spatial Patterns

In northern populations, home range has been estimated to range from 0.2 to 5.2 km^2, depending on season, terrain, and available resources (O'Gara 1978). However, large variation in sizes of home and seasonal ranges due to habitat quality and weather conditions make it difficult to apply data from other studies (O'Gara 1978). Other studies report home ranges that average 88 km^2 (Ockenfels et al. 1994) and 170 km^2 in central Arizona (Bright & Van Riper III 2000), and in the 75 – 125 km^2 range (n=37) in northern Arizona (Ockenfels et al. 1997). One key element in pronghorn movement is distance to water.

One study found that 84% of locations were less than 6 km from water sources (Bright & Van Riper III 2000), and another reports collared pronghorn locations from 1.5 – 6.5 km of a water source (Yoakum et al. 1996). Habitats within 1 km of water appear to be key fawn bedsite areas for neonate fawns (Ockenfels et al. 1992).

Conceptual Basis for Model Development

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

Patch size & configuration analysis – Minimum patch size for pronghorn was defined as 50 km^2 and minimum core size as 250 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 – Pronghorn habitat mainly occurs in small patches outside of the wildland blocks. Much of the unit's antelope population lives in or near the Prescott and Chino Valleys (AZGFD 2006). We used the methods described in Appendix A to identify the biologically best corridor for this species.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a fair amount of suitable habitat for this species within the potential linkage area (Figure 33: Potential habitat patches and cores for pronghorn). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.0 to 10.0, with an average suitability cost of 4.1 (S.D: 2.4). Within the BBC for this species, potential suitable habitat appears to be abundant, and the nearly all of the corridor has been identified as a potential populations core (Figure 33).

Union of biologically best corridors – The additional strands of the UBBC provides little additional potential habitat for pronghorn. Strand C captures some optimal and suboptimally classified potential core habitat to the north of the BBC, while the area within Strand A is largely avoided by pronghorn. The greatest threats to pronghorn populations in this area appear to habitat loss due to development of private lands and associated roads and fences.

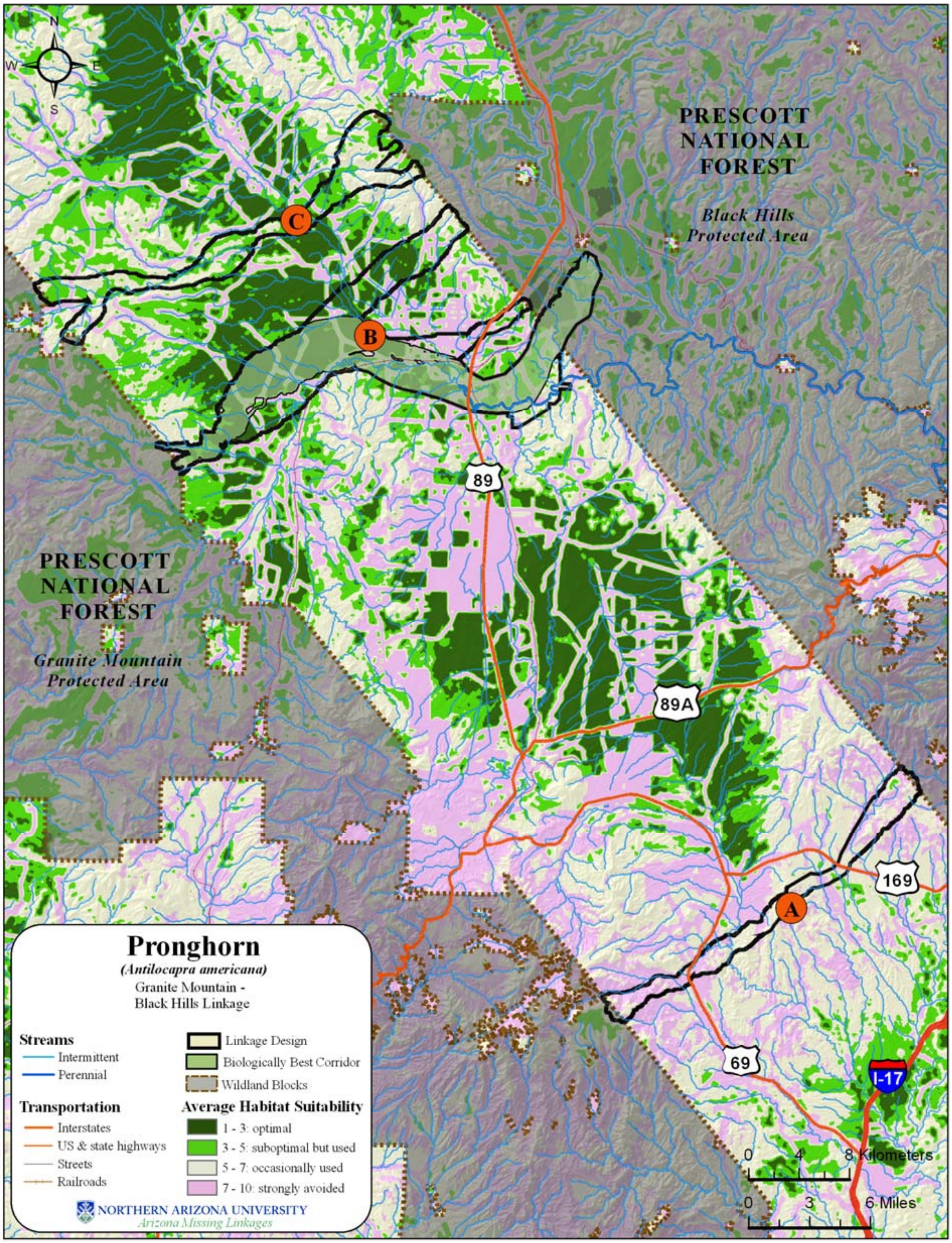

Figure 32: Modeled habitat suitability of pronghorn.

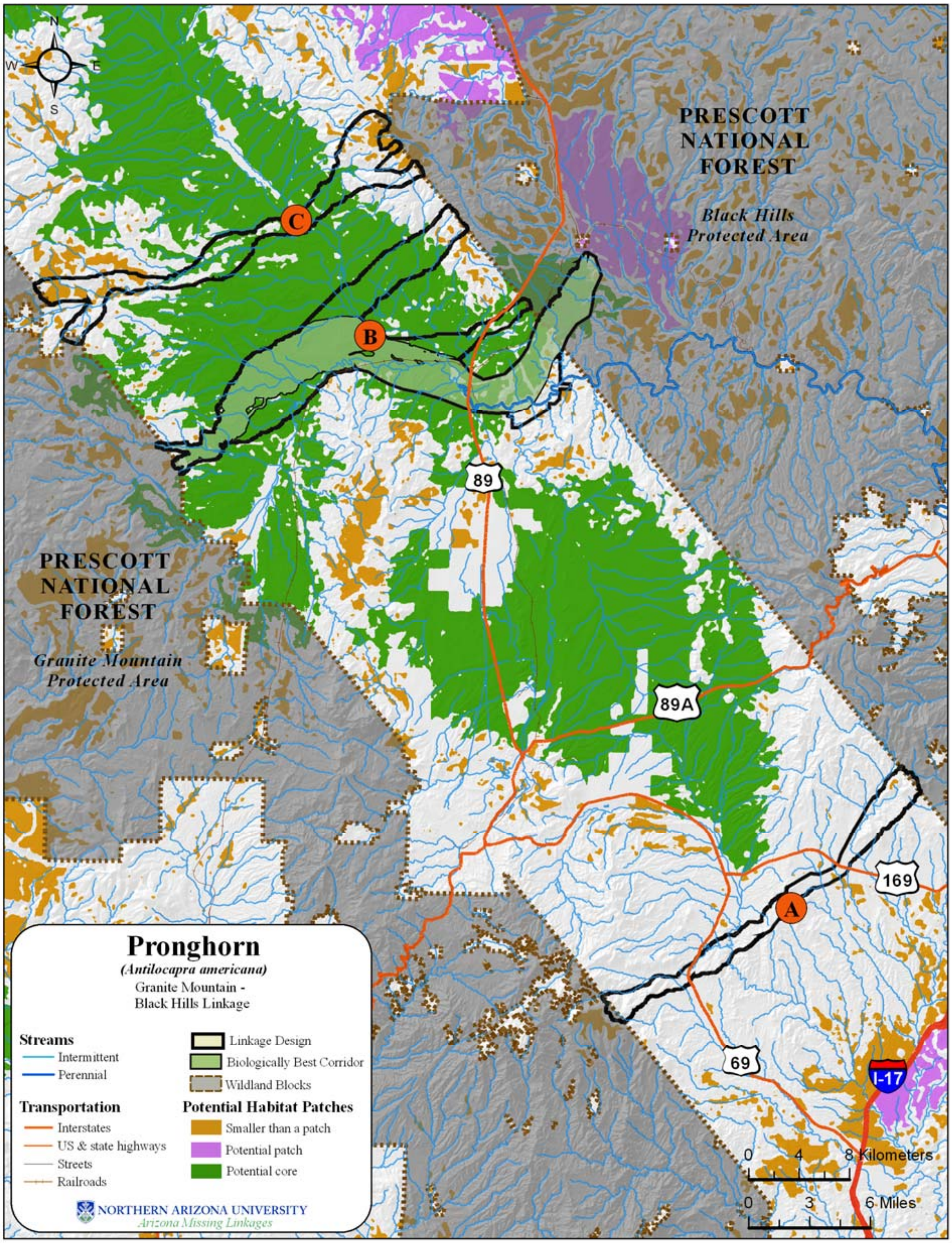

Figure 33: Potential habitat patches and cores for pronghorn.

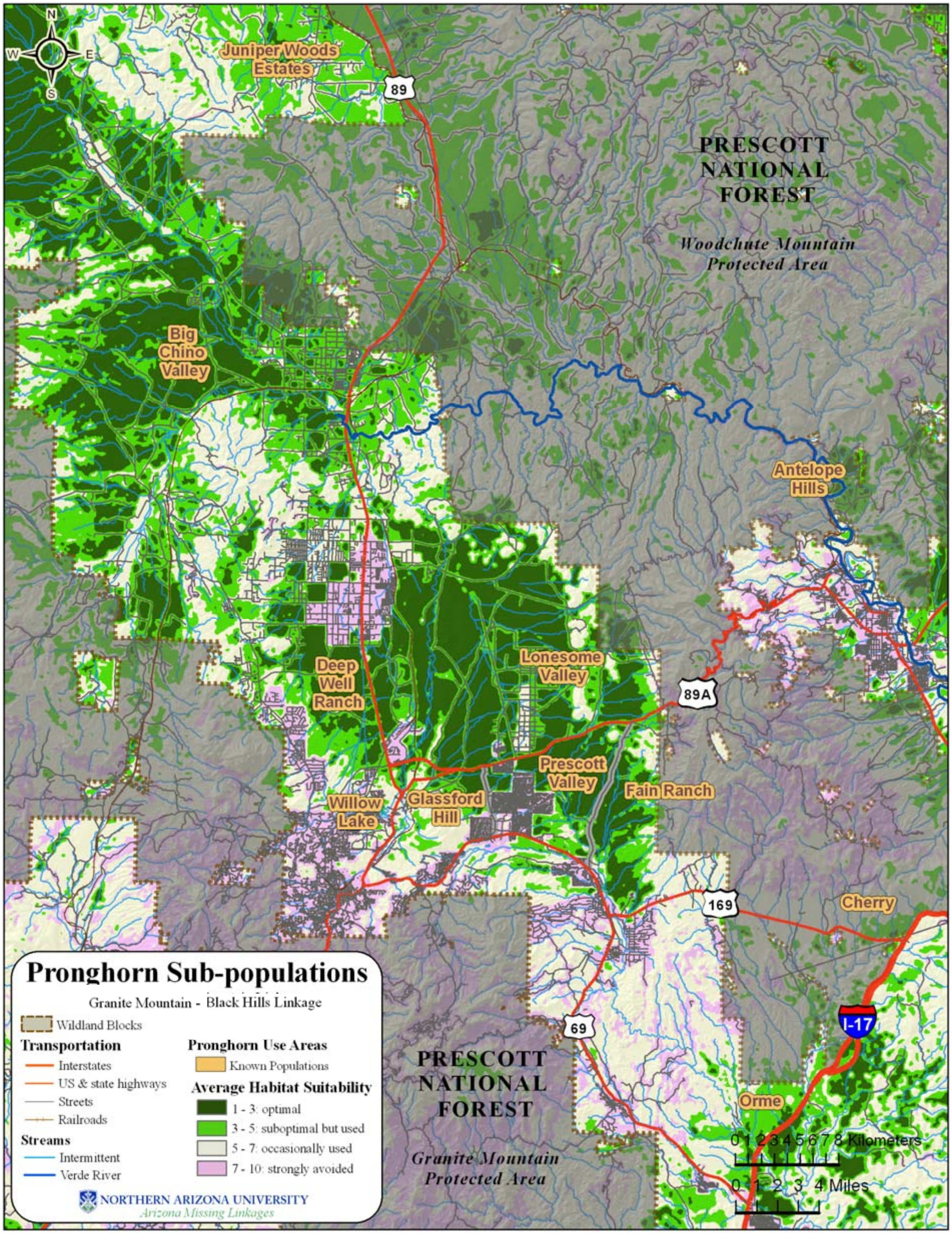

Figure 34: Known pronghorn sub-populations in the Prescott and Chino Valley area.

Riparian and Aquatic species in the Verde River

Local biologists and managers suggested several riparian and aquatic species as focal species for this linkage. Most of these species occur in the Verde River valley some 10-50 miles away from the linkage area. Nonetheless, the perennial flow of the Verde River begins in Strand B of the linkage. Furthermore, the preliminary linkage design, in particular strand B, covers the headwaters of the Verde River, most notably Big Chino Wash and Granite Creek. Thus management of these lands significantly affects water flows and water quality in the Verde River, thus ultimately affecting these species. The species are:

- Southwestern River Otter (Lontra canadensis sonora) – this rare species is a Species of Concern by the U.S. Fish and Wildlife Service and a Species of Special Concern in Arizona. The species appears to have been extirpated in Arizona (New Mexico Game and Fish 2006.) Another species (Lontra canadensis laxatina), from Louisiana was introduced into the Verde River in the early 1980's, though it is also appears to be rare (New Mexico Game and Fish 2006.)
- Southwestern willow flycatcher (*Empidonax traillii extimus*) – Southwestern willow flycatchers are listed as endangered by the U.S. Fish and Wildlife Service, Forest Service Sensitive, and a Species of Special Concern in Arizona. They occur in dense riparian habitats along rivers, streams, and wetlands where cottonwood, willow, boxelder, tamarisk, Russian olive, arrowweed, and buttonbrush are present.
- Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) – The yellow-billed cuckoo is listed as a candidate for endangered species by the USFWS and is a Wildlife Species of Special Concern in Arizona. In the West, cuckoos are closely associated with broadleaf riparian forests.
- Cottonwood – (*Populus fremontii*) occurs in moist habitats
- Black-neck gartersnake (*Thanmophis cyrtopsis*) –occupies riparian areas and rocky slopes of the Coconino and Prescott National Forests, and may be associated with pinyon-juniper woodlands (New Mexico Game and Fish 2006.)
- Mexican gartersnake (*Thamnophis eques megalops*) This subspecies is a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It is associated with riparian, marsh, and riverine habitats (New Mexico Game and Fish 2006) and is known to occur in Oak Creek (Heritage Data Management System 2004.)
- Narrow-headed gartersnake (*Thamnophis rufipunctatus rufipunctatus*) - This subspecies is considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It is an almost strictly aquatic species with good populations known in Oak Creek (Heritage Data Management System 2004.)
- Lowland leopard frog (*Rana yavapaiensis*) – Lowland leopard frog is considered a Species of Concern by the U.S. Fish and Wildlife Service, is USFS Sensitive, and a Wildlife Species of Special Concern in Arizona.
- Longfin dace (*Agosia chrysogaster*) – longfin dace is listed as sensitive by the BLM, 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 by the U.S. Fish and Wildlife Service.
- Roundtailed chub (*Gila robusta*)- This chub is considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It occurs in the mainstem and tributaries of the Verde River (Heritage Data Management System 2004), although populations appear to be declining (New Mexico Game and Fish 2006.)

- Speckled dace (*Rhinichthys osculus*) – speckled dace is listed as endangered in Mexico, its population trend is listed as “Declining” in the federal register, and its disappearance was documented along the main channels of the Gila drainage (New Mexico Game and Fish 2006).
- Spikedace (*Meda fulgida*) – listed as threatened in Arizona and by the U.S. Fish and Wildlife Service with critical habitat designated. Once abundant in Arizona, it is now found in 3 waterways in the state, including the upper Verde River (Heritage Data Management System 2004.)
- Colorado Pikeminnow (*Ptychocheilus lucius*) – listed as endangered by the U.S. Fish and Wildlife Service, this species was once widespread from Wyoming to Arizona. They are restricted to two “experimental, non-essential” reintroduced populations in Arizona including the Verde and Salt River drainages (Heritage Data Management System 2004.)
- Desert Sucker (*Catostomus clarki*) – desert sucker is 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.)

How these Species Affect the Linkage Design

Because the linkage design included almost no perennial waters, we could not model these species within the linkage area. Nonetheless, the Linkage Design area has a significant impact on the perennial waters of the Verde River. Accordingly, we modified Strand B of the Linkage Design (Appendix D) to include all of the perennial portions of the Verde River in the potential linkage area. This resulted in the addition of about 9.5 kilometers of the River and adjacent upland habitat.

Appendix C: Focal Species not Modeled

The habitat requirements and connectivity needs of several suggested focal species were not modeled in this study. Several of these species are riparian obligates whose preferred habitat does not occur within the Linkage Area. Because they occur in the nearby Verde Valley, many species were suggested by persons who thought our linkage design might cover a much larger geographic area. A list of these species follows:

Mammals

- Bats – 'Bats' were suggested as a focal taxon; however, their habitat preferences cannot be easily modeled using standard GIS layers, and they are highly mobile.
- Ringtail - (*Bassariscus astutus*) – Ringtails are most often associated with rocky habitats, which cannot be adequately modeled using the available GIS layers.

Birds

Most bird species are not good candidates for connectivity studies, because "either the species are resident and stay in the forested mountains or would simply fly over the inhospitable barriers" (Troy Corman, AZGFD, personal communication). For this reason, we did not model habitat suitability or perform corridor analyses for birds. Further, species that prefer riparian areas would be well-covered by protecting riparian and aquatic habitats along the Verde River, as suggested in Appendix B. Species suggested as focal species for this area include:

- Bald Eagle - (Haliaeetus leucocephalus) listed as threatened by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. Historically, Bald eagles have nested along the Verde River on cliff ledges and in live trees or snags, though long-term data are lacking (New Mexico Game and Fish 2006).. In order for the bald eagle population to recover these birds must have continued protection and management of their habitat, continued population monitoring, and re-establishment of breeding populations throughout their historic range.
- 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 within 500 meters of permanent, flowing water (Heritage Database Management System 2004). They are also highly mobile.
- Cassin's sparrow - a neotropical migrant that winters and builds ground nests in the mixed grass and shrublands of the southwest, populations are apparently secure in Arizona (New Mexico Game and Fish Department 2006).
- Northern Goshawk – (Accipter gentilis) listed as a Species of Special Concern both by the State of Arizona and the U.S. Fish and Wildlife Service, goshawks in Arizona nest in the coniferous forests of the mountains and mesas of northeastern and northcentral parts of the state (New Mexico Game and Fish 2006).
- Gambel's Quail (*Callipepla gambelii*) – Gambel's quail prefer xeric habitats dominated by shrubs and populations appear to be secure in Arizona (New Mexico Game and Fish 2006).

Plants

- Arizona Cliffrose – (*Purshia subintegra*) is a xeric evergreen shrub restricted to lake deposit limestone. The largest population occurs in the Verde Valley (Phillips et al. 1996).
- Hualapai (Rusby's) Milkwort – (*Polygala rusbyi*), a perennial subshrub in the Verde Valley.
- Ripley's wild buckwheat – (*Eriogonum ripleyi*) occurs on sandy clay flats and slopes and oak-juniper woodlands. Listed as a sensitive species in Arizona, this plant is restricted to a few areas in the state, including the Verde Valley (New Mexico Game and Fish 2006).

- Verde Valley Sage – (*Salvia Dorii Mearnsii*) Restricted to open Creosotebush-Shrub communities on gypseous limestone.
- Desert Willow – (*Chilopsis linearis*) Occurs in low floodplain terraces of the Verde Valley.

Insects

- Obsolete viceroy butterfly –(*Limenitis archippus*) Occur in moist open or shrubby areas such as lake and swamp edges and willow thickets
- Tiger beetle – (*ambycheila picolominii*) A large, flightless beetle reported in dry, open rocky country in Arizona (Hoback, 2001).

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor adjustments to the union of biologically best corridors (Figure 35):

- We edited Strand A, removing some of the habitat identified as suitable or optimal for black bear on the northeastern portion of the strand. During field investigations, we discovered that there are recent residential developments (that did not exist in our GIS layers) that would block movement. We added some habitat to the south of the original strand to provide for black bear movement and to ensure that the strand maintained a minimum width of 1 km.
- We edited Strand B, removing some of pronghorn habitat in the northeastern portion of the strand. During field investigations, we discovered that there are residential developments in this area are of a much higher density than was represented by our land cover data. These developments and associated roads and fences would block pronghorn movement. We added some habitat to the south of the original strand to provide for movement, include all perennial portions of the Verde River, and a minimum width of 1 km.
- We expanded Strand B to include the Verde River from Sullivan Lake to the boundary of the Prescott National Forest. This includes all 7.5 km of the Verde River with perennial flow in the linkage area.
- 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.

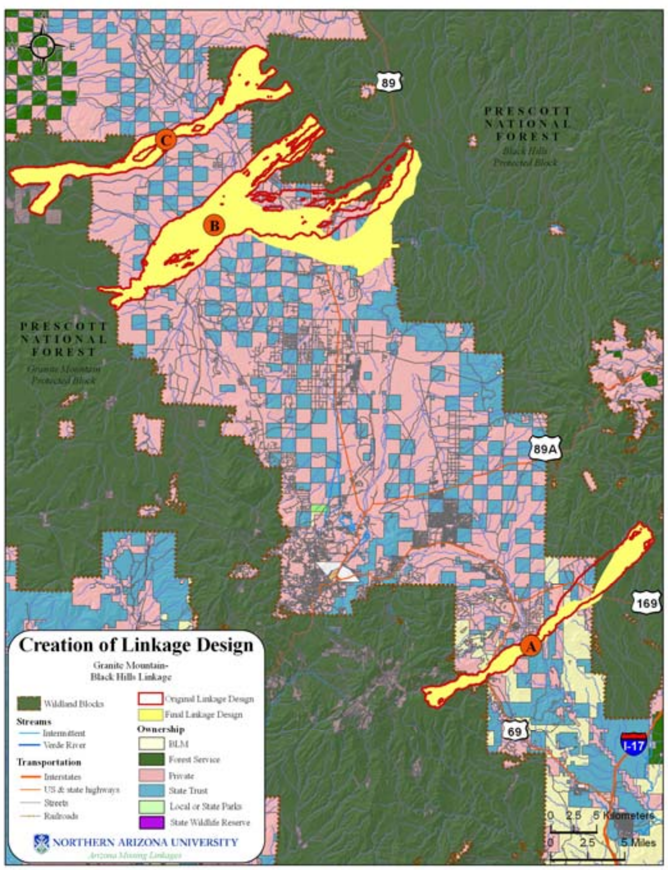

Figure 35: Adjustments to Linkage Design.

Appendix E: Description of Land Cover Classes

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

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

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

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

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

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

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

Semi-Desert Grassland and Shrub Steppe – Comprised of *Semi-Desert Shrub Steppe* and *Piedmont Semi-Desert Grassland and Steppe*. Semi-Desert Shrub is typically dominated by graminoids (>25% cover) with an open shrub layer, but includes sparse mixed shrublands without a strong graminoid layer. Steppe Piedmont Semi-Desert Grassland and Steppe is a broadly defined desert grassland, mixed shrub-succulent or xeromorphic tree savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico [Apacherian region], but extends west to the Sonoran Desert, north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is found on gently sloping bajadas that supported frequent fire throughout the Sky Islands and on mesas and steeper piedmont and foothill slopes in the Chihuahuan Desert. It is characterized by a typically diverse perennial grasses. Common grass species include *Bouteloua eriopoda, B. hirsuta,B. rothrockii, B. curtipendula, B. gracilis, Eragrostis intermedia, Muhlenbergia porteri, Muhlenbergia setifolia, Pleuraphis jamesii, Pleuraphis mutica*, and *Sporobolus airoides*, succulent species of *Agave, Dasylirion*, and *Yucca*, and tall shrub/short tree species of *Prosopis* and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica*).

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

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

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

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

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

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

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

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

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

Mountain and Colorado Plateau regions, this system occurs within a broad elevation range from approximately 900 to 2800 m., as a mosaic of multiple communities that are tree-dominated with a diverse shrub component.

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

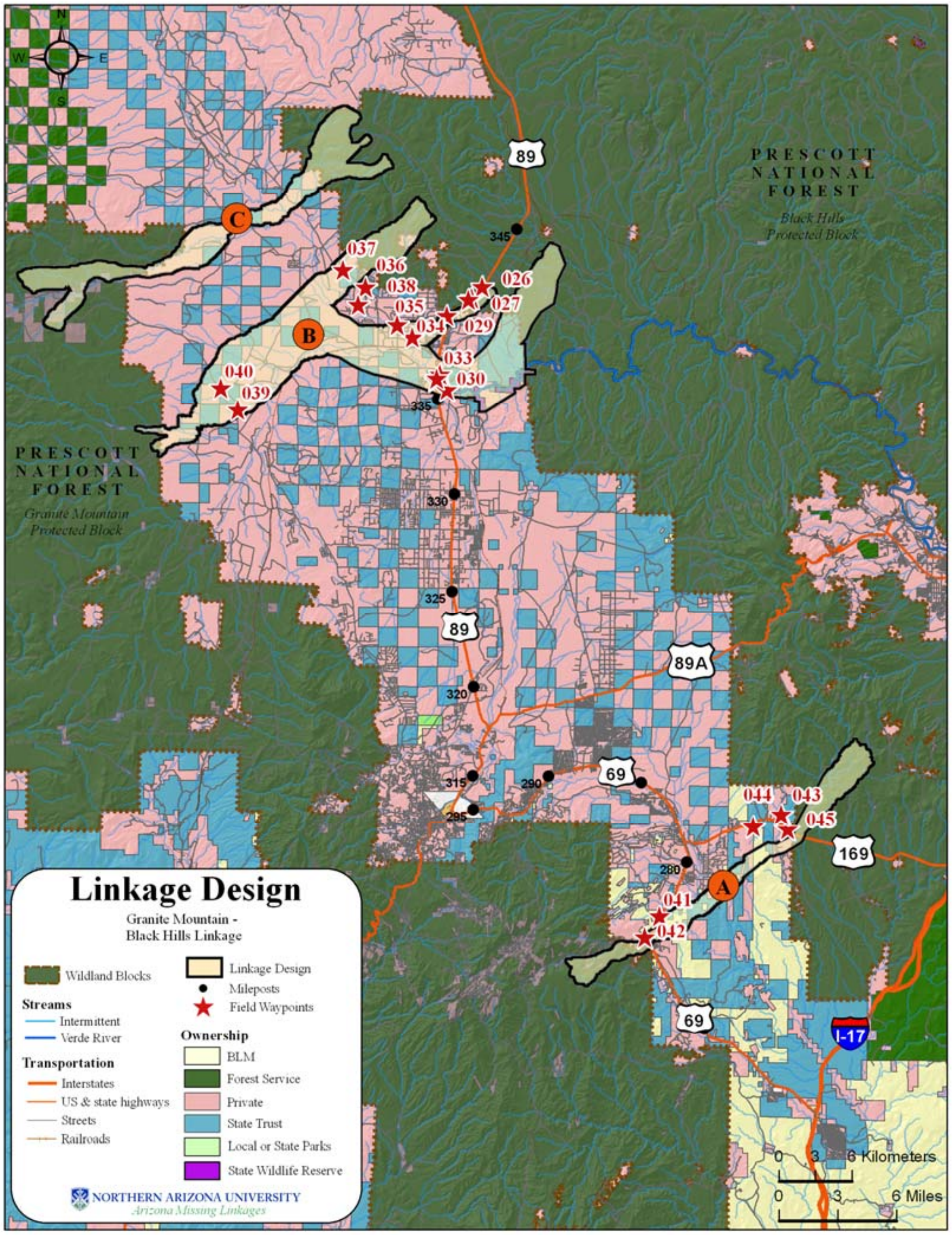
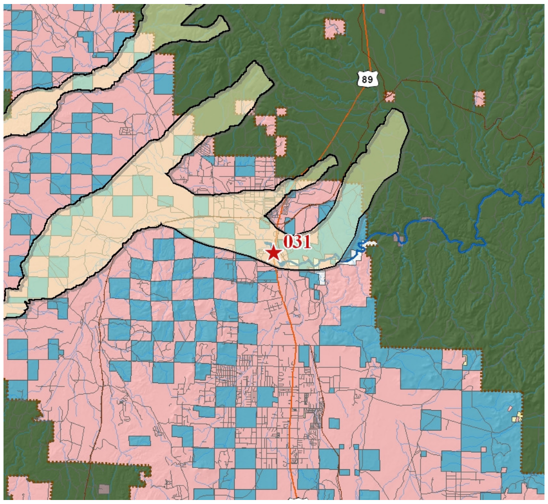


Figure 36: Field investigation waypoints within the Linkage Design.

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	031		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.87065509	**Longitude:**	-112.470266
Observers:	Paul Beier, Emily Garding	**UTM X:**	365619.8712	**UTM Y:**	3859685.235
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Big Chino Wash

Site Photographs

Name: IMG_0265.jpg

Azimuth: 135 **Zoom:** 1X

Notes: Bridge over Big Chino Wash

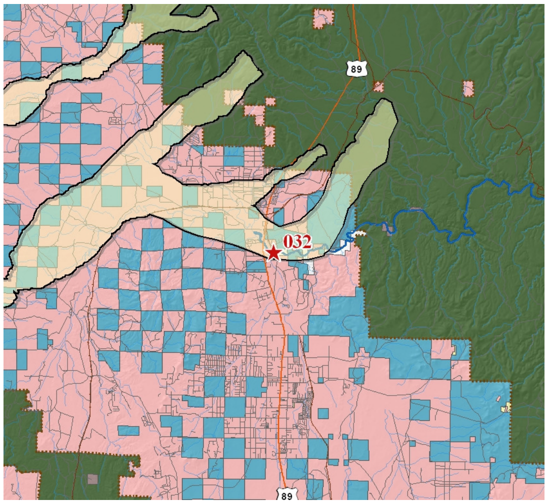
Name: IMG_0266.jpg

Notes: Looking downstream, cows in the distance.

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	032		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.86356693	**Longitude:**	-112.460554
Observers:	Paul Beier, Emily Garding	**UTM X:**	366496.1068	**UTM Y:**	3858886.13
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Sullivan Lake, just off of Old Highway 89, is the site of an historic dam in Chino wash, and the head of the Verde River.

Site Photographs

Name: IMG_0267.jpg

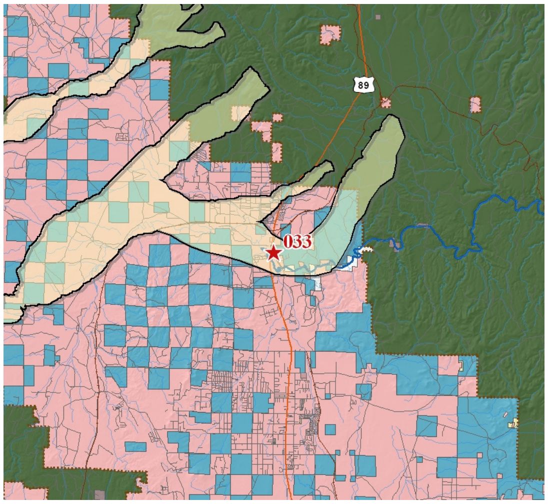
Notes: Sullivan Lake

Name: IMG_0268.jpg

Notes: Bridges over Old Highway 89 and an abandoned railroad track.

Linkage #:	35	**Waypoint #:**	033		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.8749276	**Longitude:**	-112.466827
Observers:	Paul Beier, Emily Garding	**UTM X:**	365941.1531	**UTM Y:**	3860154.477
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

North of the Chino Wash in a parcel of State land.

Site Photographs

Name: IMG_0269.jpg

Azimuth: 270 **Zoom:** 6X

Name: IMG_0270.jpg

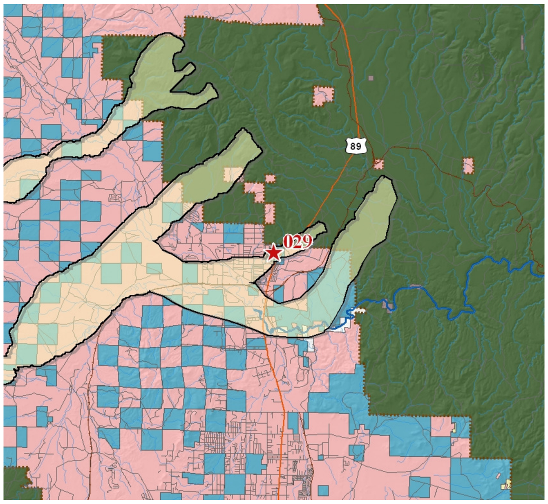
Azimuth: 90 **Zoom:** 1X

Name: IMG_0271.jpg

Azimuth: 270 **Zoom:** 1X

Linkage #:	35	**Waypoint #:**	029		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.91858876	**Longitude:**	-112.461412
Observers:	Paul Beier, Emily Garding	**UTM X:**	366506.7673	**UTM Y:**	3864989.567
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

From the watertower at Paulden, AZ.

Site Photographs

Name: IMG_0259.jpg

Azimuth: 180 **Zoom:** 4X

Notes: Overlooking Paulden

Name: IMG_0260.jpg

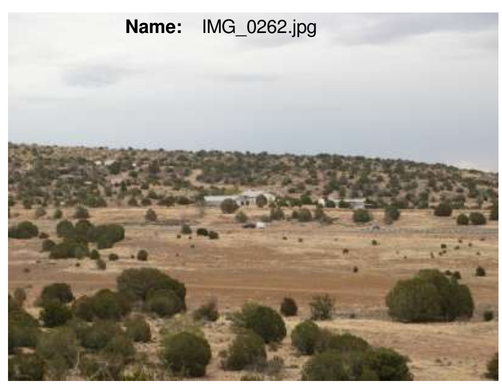
Azimuth: 270 **Zoom:** 6X

Notes: Overlooking Paulden

Name: IMG_0261.jpg

Azimuth: 225 **Zoom:** 6X

Notes: Overlooking Paulden



Name: IMG_0262.jpg

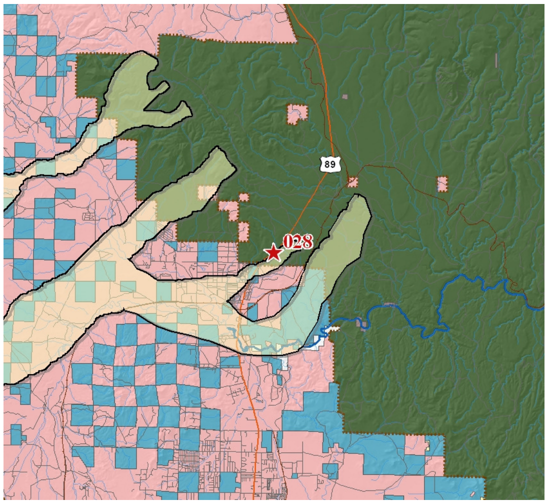
Azimuth: 80 **Zoom:** 3X

Notes: Highway 89 and a restaurant, seen from Paulden

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	028		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.9319185	**Longitude:**	-112.439163
Observers:	Paul Beier, Emily Garding	**UTM X:**	368560.5253	**UTM Y:**	3866438.473
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

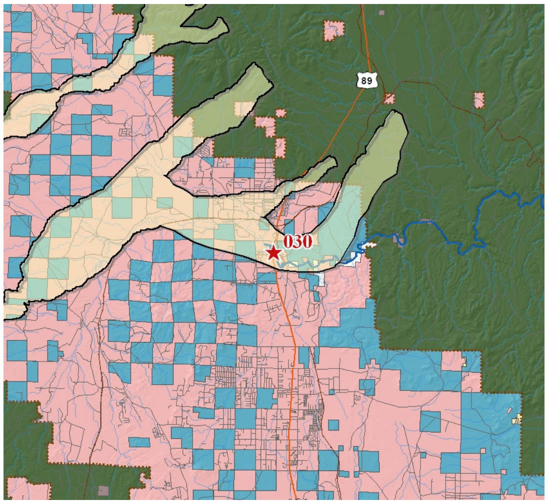
An existing concrete box culvert along the same unnamed stream as Waypoint 027 (no photo).

Site Photographs

Linkage #: 35
Linkage Zone: Woodchute - Granite Mountain Linkage
Observers: Paul Beier, Emily Garding
Field Study Date: 3/7/2007

Waypoint #: 030
Latitude: 34.87176217 **Longitude:** -112.469843
UTM X: 365660.3169 **UTM Y:** 3859807.451
Last Printed: 7/12/2007

Waypoint Map



Waypoint Notes

Big Chino Wash

Site Photographs

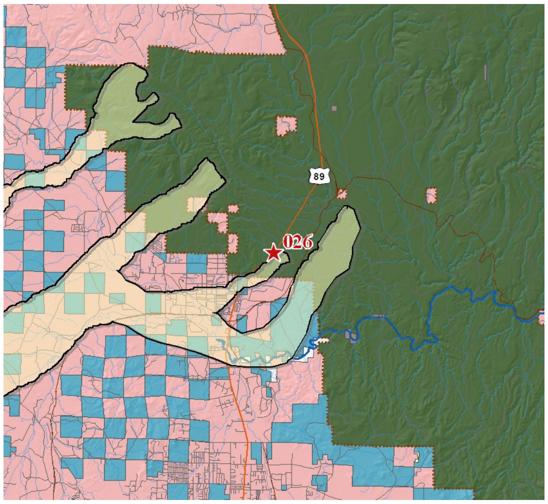
Azimuth: 305 **Zoom:** 1X

Azimuth: 40 **Zoom:** 1X
Notes: Highway 89

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	026		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.94036218	**Longitude:**	-112.429972
Observers:	Paul Beier, Emily Garding	**UTM X:**	369413.3844	**UTM Y:**	3867362.898
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map

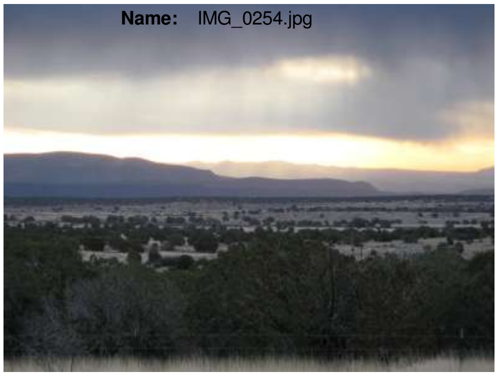


Waypoint Notes

Near the northern edge of Strand B along Highway 89, between Mileposts 341 and 342.

Site Photographs

Name: IMG_0254.jpg



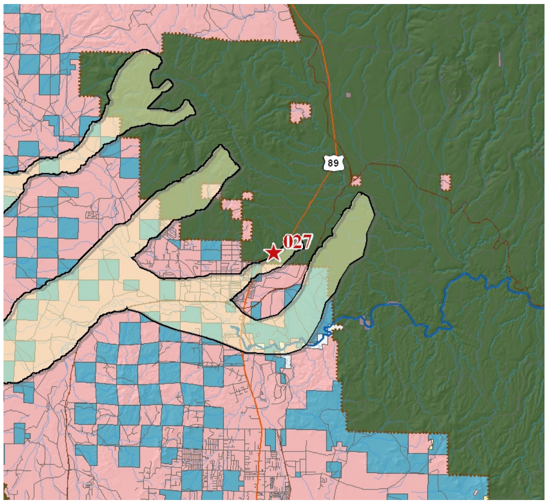
Azimuth: 90 **Zoom:** 6X

Name: IMG_0255.jpg

Azimuth: 90 **Zoom:** 2X

Linkage #:	35	**Waypoint #:**	027		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.93081578	**Longitude:**	-112.442080
Observers:	Paul Beier, Emily Garding	**UTM X:**	368292.3025	**UTM Y:**	3866320.010
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

An unnamed stream intersects Highway 89 4 times within the Linkage Zone. The existing undercrossings should be improved to provide open structures suitable for large ungulates including pronghorn and mule deer.

Site Photographs

Name: IMG_0256.jpg

Zoom: 1X

Notes: A 10x10 box culvert along an unnamed drainage under Highway 89.

Name: IMG_0257.jpg

Zoom: 1X

Notes: Same box culvert

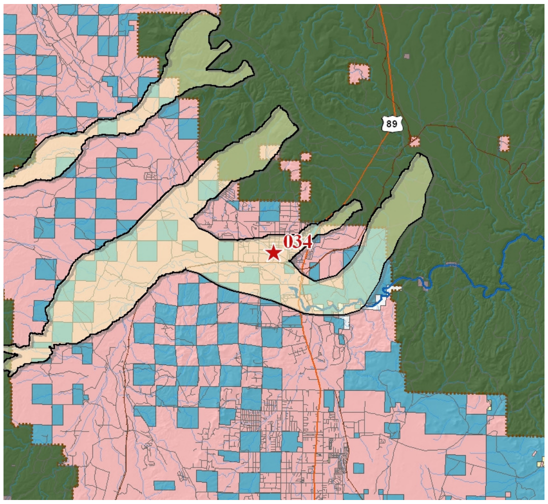
Name: IMG_0258.jpg

Zoom: 1X

Notes: From inside the box culvert

Linkage #:	35	**Waypoint #:**	034		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.90238202	**Longitude:**	-112.492064
Observers:	Paul Beier, Emily Garding	**UTM X:**	363679.8494	**UTM Y:**	3863233.436
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

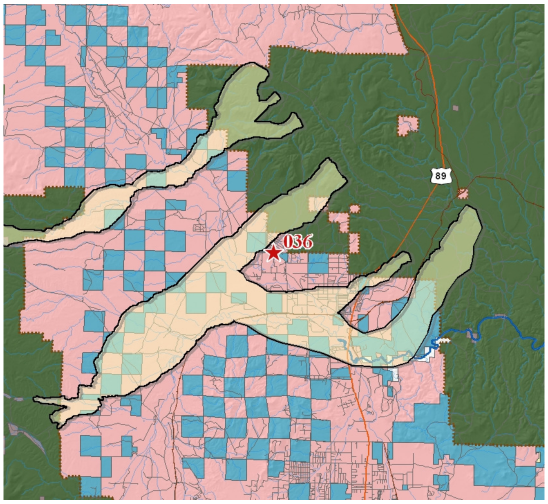
Remnants of gravel mining operations in Chino Wash. The wash should be resotred to its natural gradient (no photo).

Site Photographs

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	036		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.93890423	**Longitude:**	-112.534775
Observers:	Paul Beier, Emily Garding	**UTM X:**	359839.4153	**UTM Y:**	3867343.058
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Rural development outside of Paulden

Site Photographs

Name: IMG_0280.jpg

Azimuth: 60 **Zoom:** 2X

Name: IMG_0281.jpg

Azimuth: 240 **Zoom:** 2X

Name: IMG_0282.jpg

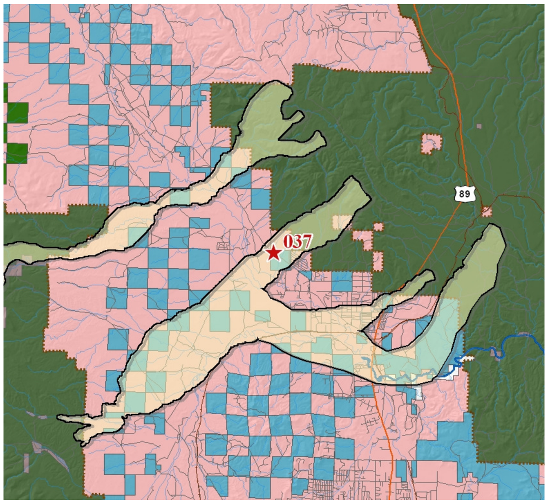
Azimuth: 240 **Zoom:** 1X

Name: IMG_0283.jpg

Azimuth: 30 **Zoom:** 1X

Linkage #:	35	**Waypoint #:**	037		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.95155269	**Longitude:**	-112.555514
Observers:	Paul Beier, Emily Garding	**UTM X:**	357967.1295	**UTM Y:**	3868775.151
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

In northern arm of Strand B.

Site Photographs

Name: IMG_0285.jpg

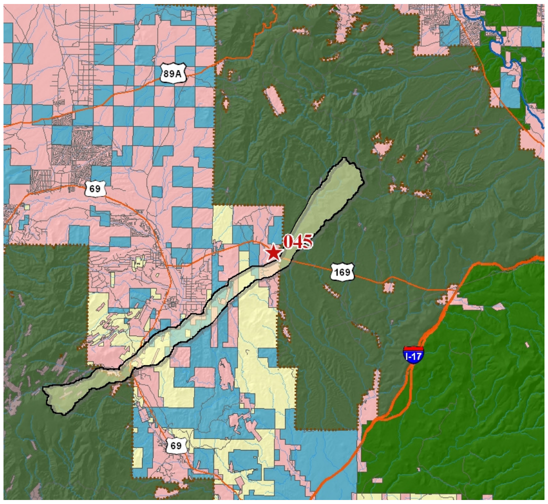
Azimuth: 75 **Zoom:** 1X

Name: IMG_0286.jpg

Azimuth: 220 **Zoom:** 1X

Linkage #:	35	**Waypoint #:**	045		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.54029218	**Longitude:**	-112.149576
Observers:	Paul Beier, Emily Garding	**UTM X:**	394513.4277	**UTM Y:**	3822665.197
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Developed area along Highway 169 where we trimmed Strand A.

Site Photographs

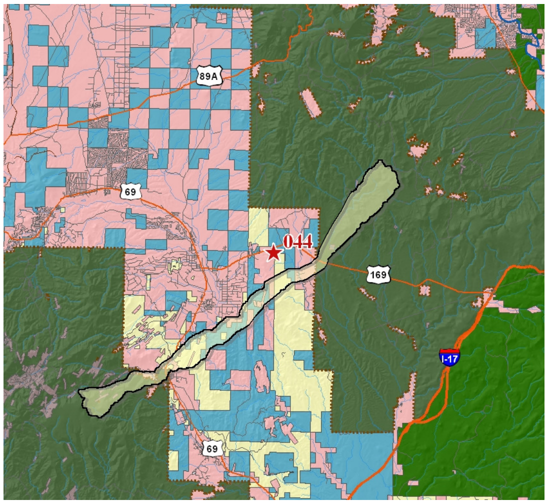
Name: IMG_0317.jpg

Azimuth: 340 **Zoom:** 1X

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	044		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.54192079	**Longitude:**	-112.180412
Observers:	Paul Beier, Emily Garding	**UTM X:**	391685.9045	**UTM Y:**	3822878.430
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

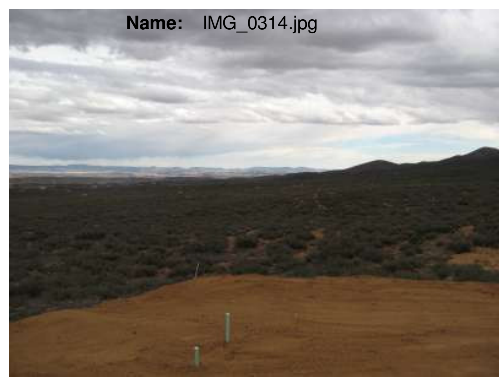
Site of future low-density development along Highway 169.

Site Photographs

Name: IMG_0313.jpg

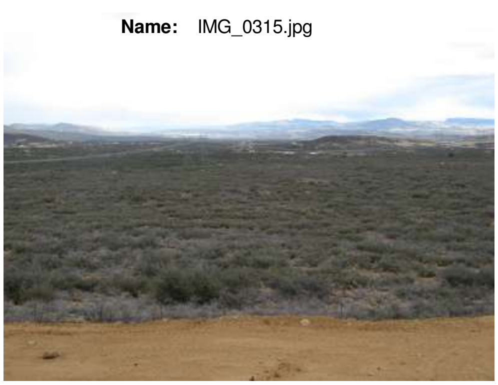
Azimuth: 195 **Zoom:** 1X

Name: IMG_0314.jpg



Azimuth: 145 **Zoom:** 1X

Name: IMG_0315.jpg



Azimuth: 95 **Zoom:** 2X

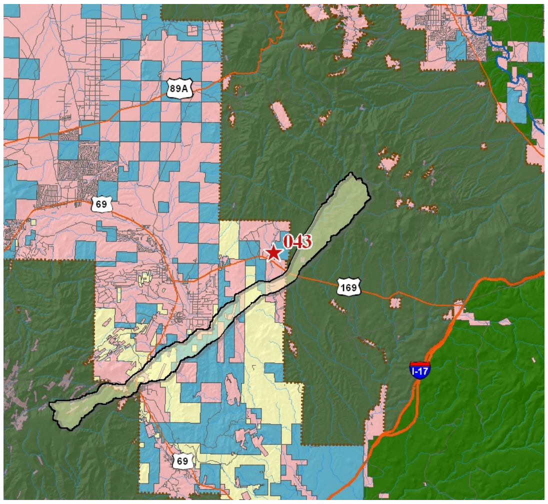
Name: IMG_0316.jpg

Azimuth: 55 **Zoom:** 2X

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	043		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.55108145	**Longitude:**	-112.155260
Observers:	Paul Beier, Emily Garding	**UTM X:**	394005.4886	**UTM Y:**	3823867.634
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

"White Horse Ranch;" a developed area along Highwasy 169.

Site Photographs

Name: IMG_0306.jpg

Azimuth: 100 **Zoom:** 1X

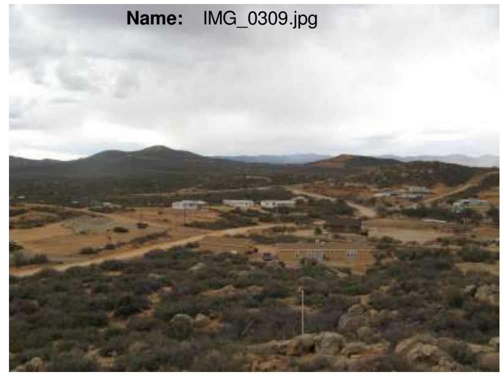
Name: IMG_0307.jpg

Azimuth: 135 **Zoom:** 3X

Name: IMG_0308.jpg

Azimuth: 180 **Zoom:** 3X

Name: IMG_0309.jpg

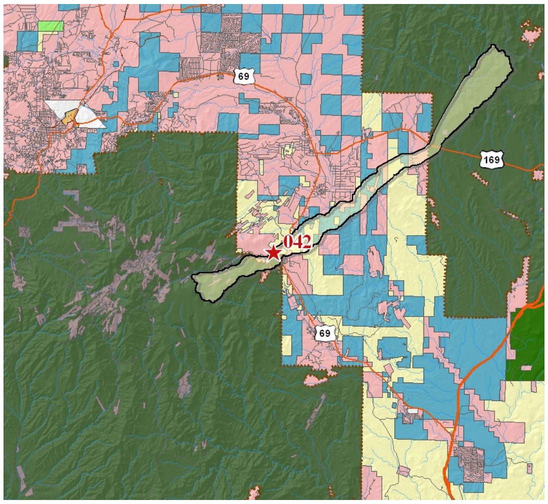


Azimuth: 230 **Zoom:** 1X

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	042		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.45883668	**Longitude:**	-112.276406
Observers:	Paul Beier, Emily Garding	**UTM X:**	382760.7012	**UTM Y:**	3813771.752
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map

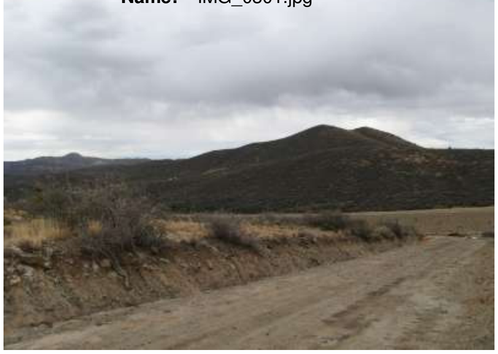


Waypoint Notes

Site of future development along Highway 69.

Site Photographs

Name: IMG_0301.jpg



Azimuth: 75 **Zoom:** 1X

Notes: Site of future development within Strand A.

Name: IMG_0302.jpg

Azimuth: 120 **Zoom:** 1X

Notes: A fill slope up to Highway 69 seen in the distance. This is a good potential area for placing new crossing structure such as a

Name: IMG_0303.jpg

Azimuth: 145 **Zoom:** 1X

Notes: Site of future development within Strand A.

Name: IMG_0304.jpg

Azimuth: 270 **Zoom:** 1X

Notes: Site of future development within Strand A.

Appendix G: Database of Field Investigations

Linkage #: 35

Linkage Zone: Woodchute - Granite Mountain Linkage

Observers: Paul Beier, Emily Garding

Field Study Date: 3/7/2007

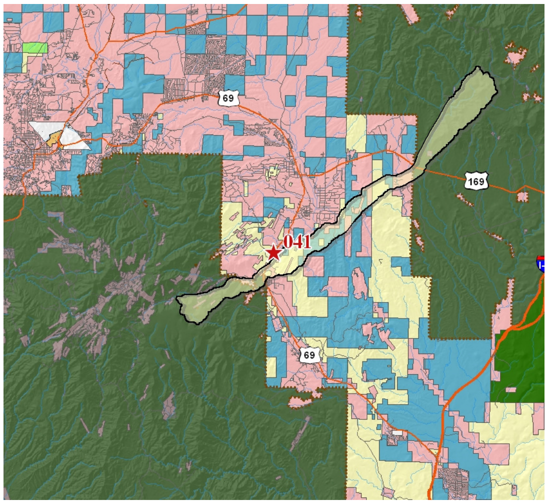
Waypoint #: 041

Latitude: 34.47441495 **Longitude:** -112.263336

UTM X: 383982.8029 **UTM Y:** 3815484.266

Last Printed: 7/12/2007

Waypoint Map



Waypoint Notes

Strand A.

Site Photographs

Name: IMG_0296.jpg

Azimuth: 50 **Zoom:** 1X

Notes: Highway 69 within Strand A.

Name: IMG_0297.jpg

Azimuth: 85 **Zoom:** 1X

Notes: Highway 69 within Strand A.

Name: IMG_0298.jpg

Azimuth: 125 **Zoom:** 1X

Notes: Highway 69 within Strand A.

Name: IMG_0299.jpg

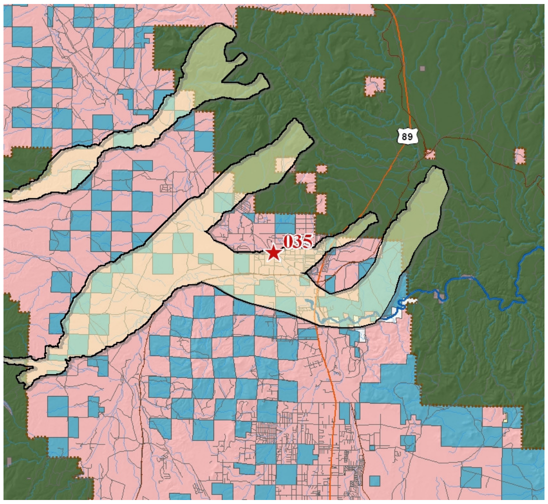
Azimuth: 165 **Zoom:** 1X

Notes: Highway 69 within Strand A.

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	035		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.91113742	**Longitude:**	-112.505732
Observers:	Paul Beier, Emily Garding	**UTM X:**	362445.6192	**UTM Y:**	3864223.176
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Rural development outside of Paulden, within Strand B.

Site Photographs

Name: IMG_0272.jpg

Azimuth: 0 **Zoom:** 1X

Name: IMG_0273.jpg

Azimuth: 0 **Zoom:** 3X

Name: IMG_0274.jpg

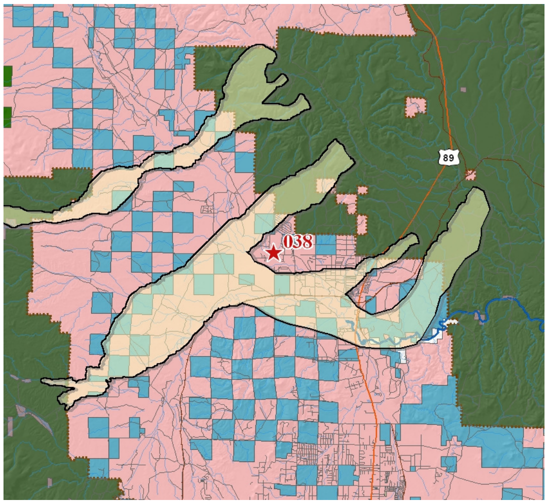
Azimuth: 90 **Zoom:** 1X

Name: IMG_0275.jpg

Azimuth: 90 **Zoom:** 3X

Linkage #:	35	**Waypoint #:**	038		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.92565479	**Longitude:**	-112.541223
Observers:	Paul Beier, Emily Garding	**UTM X:**	359227.879	**UTM Y:**	3865882.633
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Impermeable fencing in the rural development outside of Paulden.

Site Photographs

Name: IMG_0287.jpg

Zoom: 1X

Notes: A closer look at one of the fences.

Name: IMG_0288.jpg

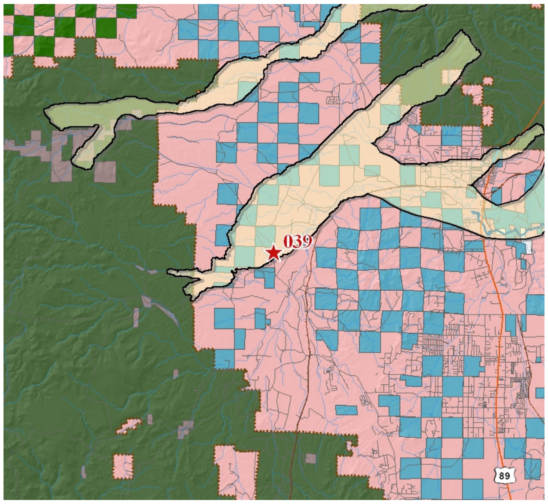
Zoom: 1X

Notes: The fenceline along a gravel road.

Appendix G: Database of Field Investigations

Linkage #:	35	**Waypoint #:**	039		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.84650792	**Longitude:**	-112.648155
Observers:	Paul Beier, Emily Garding	**UTM X:**	349315.5574	**UTM Y:**	3857260.131
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Williamson Valley, within Strand B

Site Photographs

Name: IMG_0289.jpg

Azimuth: 230 **Zoom:** 1X

Name: IMG_0290.jpg

Azimuth: 330 **Zoom:** 1X

Name: IMG_0291.jpg

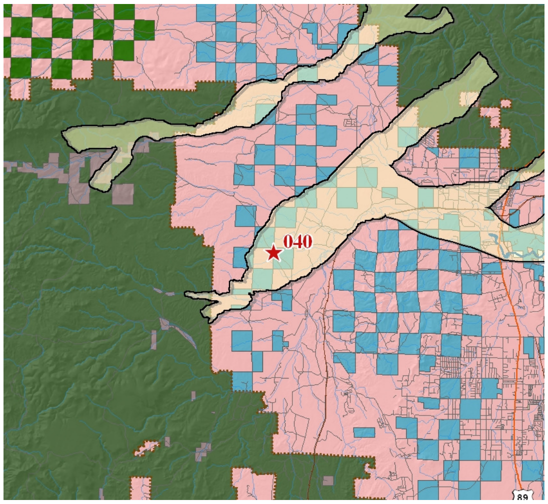
Azimuth: 50 **Zoom:** 1X

Name: IMG_0292.jpg

Azimuth: 50 **Zoom:** 6X

Linkage #:	35	**Waypoint #:**	040		
Linkage Zone:	Woodchute - Granite Mountain Linkage	**Latitude:**	34.86219482	**Longitude:**	-112.663687
Observers:	Paul Beier, Emily Garding	**UTM X:**	347924.2671	**UTM Y:**	3859023.422
Field Study Date:	3/7/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

In Strand B

Site Photographs

Name: IMG_0293.jpg

Azimuth: 240 **Zoom:** 6X

Name: IMG_0294.jpg

Azimuth: 20 **Zoom:** 1X

Name: IMG_0295.jpg

Azimuth: 50 **Zoom:** 1X