ARIZONA MISSING LINKAGES

Mount Perkins - Warm Springs Linkage Design

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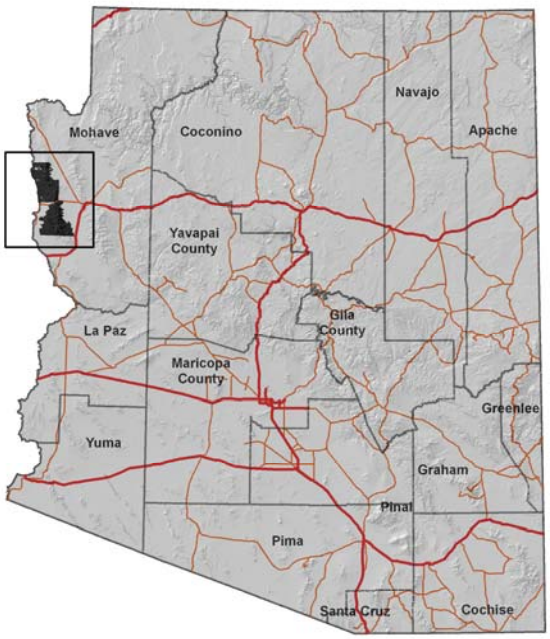
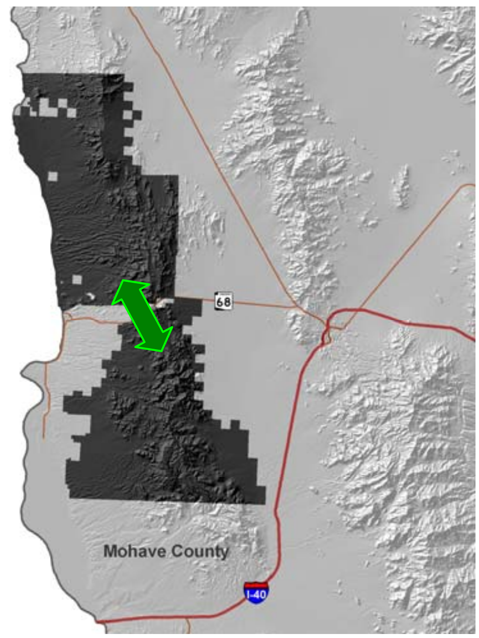
2008

NORTHERN ARIZONA UNIVERSITY

MOUNT PERKINS-WARM SPRINGS LINKAGE DESIGN





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Terminology

Key terminology used throughout the report includes:

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

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

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

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

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

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

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

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

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between two large areas of BLM-administered wildlands in the Black Mountains of western Arizona. Running east-west in this region, Arizona Highway 68 and future urban development can impede animal movement between the Mount Perkins area to the north, and the Warm Springs Wilderness Area to the south[1]. 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 14 focal species that are sensitive to habitat loss and fragmentation, including 5 reptiles, 3 birds, and 6 mammals (Table 1). These focal species cover a broad range of habitat and movement requirements. Some require huge tracts of land to support viable populations (e.g. mountain lion). Some species are habitat specialists (e.g. bighorn sheep, Gila Monster), and others are reluctant to cross barriers such as freeways (e.g. mule deer, desert tortoise). Some species are rare and/or endangered (desert tortoise), while others are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of rugged highlands and desert scrub. Together, these 14 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas, we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final Linkage Design (Figure 1) provides live-in or move-through habitat for each focal species. The Linkage Design (Figure 1) is composed of 5 strands which together provide habitat for movement and reproduction of wildlife between the Mount Perkins and Warm Springs wildland blocks. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The Black Mountains provide significant ecological, educational, recreational, and spiritual values of protected wildlands. This Linkage Design represents an opportunity to protect a functional landscape-level connection between the northern and southern halves of this mountain range. The cost of implementing this vision will be substantial—but reasonable in relation to the benefits and the existing public investments in protected wild habitat. If implemented, our plan would not only permit movement

[1] These blocks of BLM land have no formal designation on most maps; they are the northern and southern halves of the Black Mountains, separated by SR-68. We named the northern wildland block *Mount Perkins* after the highest peak in the Black Mountains, and we named the southern wildland block *Warm Springs* after the Warm Springs Wilderness Area in the southern Black Mountains.

of individuals and genes between the Mount Perkins and Warm Springs wildland blocks, but should also conserve large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the National Park Service, Bureau of Land Management, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and other conservancy lands.

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

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

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

Table 1: Focal species selected for the Mount Perkins-Warm Springs Linkage

MAMMALS	REPTILES	BIRDS
Bats	Arizona Chuckwalla	Peregrine Falcon
*Bobcat	Desert Rosy Boa	Swainson's Hawk
*Desert Bighorn Sheep	*Mohave Desert Tortoise	Western Burrowing Owl
*Kit fox	*Gila Monster	
*Mountain Lion	Speckled Rattlesnake	
*Mule Deer		

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

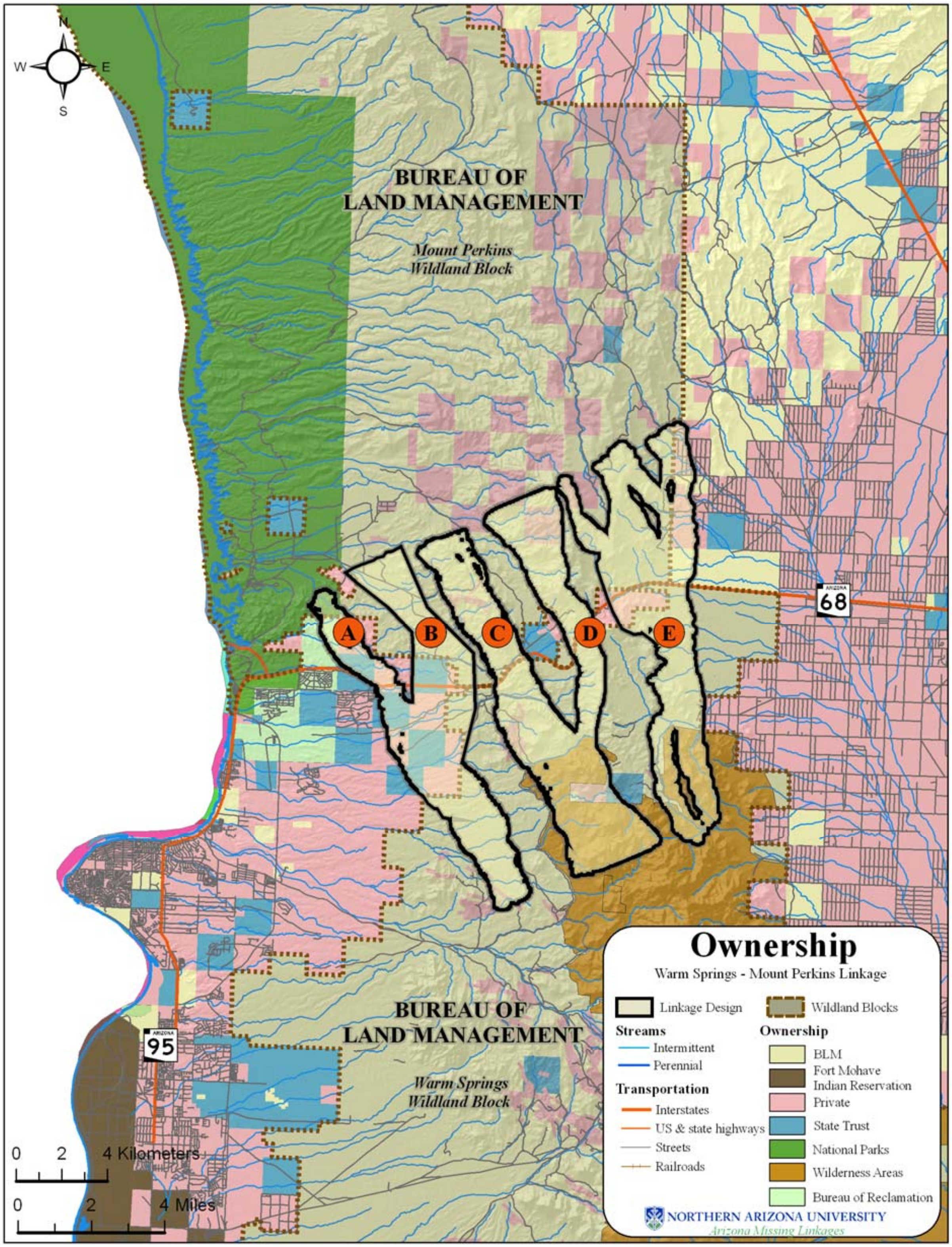

Figure 1: The Linkage Design between the Mount Perkins and Warm Springs wildland blocks includes 5 strands, each of which is important to different species.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

The workshop was convened by the Arizona Wildlife Linkage Workgroup, a collaborative effort led by Arizona Game and Fish Department, Arizona Department of Transportation, Federal Highways Administration, US Forest Service, Bureau of Land Management, US Fish and Wildlife Service, Sky Island Alliance, Wildlands Project, and Northern Arizona University. The Workgroup prioritized the potential linkages based on biological importance and the conservation threats and opportunities in each area (AWLW 2006). Eight linkage designs were produced in 2006. In 2007, eight additional linkages within 5 miles of an incorporated city were selected for linkage design planning. The Warm Springs – Mount Perkins Linkage is one of these "urban" linkages.

Ecological Significance of the Warm Springs – Mount Perkins Linkage

The Linkage Planning area is part of the 33-million acre **Mojave Desert Ecoregion** of northwestern Arizona, southeastern California, southern Nevada, and southwestern Utah. The Mojave Desert Ecoregion is drier than the Sonoran Desert, averaging less than 5 inches of annual precipitation (TNC 2006). This rugged ecoregion supports 250 plant species, 90 of which are endemic to the ecoregion (TNC 2006). The Mojave ecoregion supports 35 fish species, 21 reptiles & amphibians, 30 snails, and two threatened birds, the yellow-billed cuckoo and southwestern willow flycatcher (TNC 2006). The Colorado River and Lake Mohave are popular recreation areas and important water sources and habitat for fish and wildlife.

Within the Linkage Planning Area, two wildland blocks are separated by Arizona State route 68 (SR-68), and a matrix of private, state trust, and BLM land (Figure 2). We have named the wildland blocks the Mount Perkins and Warm Springs Wildland Blocks[2].

Existing Conservation Investments

The proposed linkage is designed to protect and enhance the public investments in conservation in the wildland blocks it would link. It is therefore important to understand the public investments at stake in each wildland block, and in the linkage area.

The **Mount Perkins** wildland block consists of roughly 197,000 acres of rugged terrain managed by the Bureau of Land Management and the National Park Service. The volcanic mountains are characterized by steep cliffs, sandy washes, and talus slopes encompassing a diverse range of habitats including Mojave desert scrub and Arizona chaparral communities at lower elevations to small stands of pinyon-juniper woodlands in the higher elevations. This varied landscape provides habitat for an array of wildlife species including desert bighorn sheep and mule deer. The Lake Mead National Recreation Area, managed by the National Park Service, is also dominated by Mohave Desert landscapes, but also contains riparian and aquatic habitat along the Colorado River and Lake Mojave.

The **Warm Springs** wildland block, approximately 203,000 acres of BLM land and the northern portion of Havasu National Wildlife Refuge, is contiguous with nearly 4.8 million acres of BLM land in west central and southwestern Arizona (Figure 1). It includes the 112,400-acre Warm Springs and the 27,660 acre Mount Nutt Wilderness. The rugged hills and valleys contain scattered springs and associated riparian areas important to bighorn sheep, mule deer, and quail. The lowest deserts contain a mixture of Sonoran and Mojave desert vegetation, and the northernmost population of Saguaro cactus.

The potential linkage area between these blocks is a mixture of ASLD land, ADOT land (SR-68), and private lands (Figure 2). Connectivity between these wildland blocks would help to provide the continuous habitat necessary to sustain viable populations of sensitive and far ranging species in this ecological transition zone of northwestern Arizona.

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include State Route 68 (SR-68), expanding urban development of Bullhead City and Golden Valley, and habitat degradation caused by invasive species including the wild burro. If not properly mitigated, these roads and urban developments could impede wildlife movement between the wildland blocks.

[2] These blocks of BLM land have no formal designation on most maps; they are the northern and southern halves of the Black Mountains, separated by SR-68. We named the northern wildland block *Mount Perkins* after the highest peak in the Black Mountains, and we named the southern wildland block *Warm Springs* after the Warm Springs Wilderness Area in the southern Black Mountains

State Route 68 is an east-west highway running from its western terminus at its junction with State Route 95 in Bullhead City to U.S. 93 northwest of Kingman. The route carries traffic to Bullhead City and Laughlin, Nevada; it now serves as a Hoover Dam bypass route for trucks and recreational vehicles going towards Las Vegas, Nevada because they are prohibited on the Hoover Dam since September 11, 2001. The restriction is temporary until a new by-pass near Hoover Dam is completed in about 2010. The highway was expanded to 4 lanes in the mid 1990s, and is separated by a median in parts of the linkage design.

Bullhead City limits overlap the linkage design (Figure 5). The population of Bullhead City was estimated at 39,101 in 2005, and is expected to double by 2022 (Bullhead City General Plan of 2002).

The community of Golden Valley is located to the east of the wildland blocks. The Golden Valley General Plan includes potential development of private and BLM lands adjacent to and within the eastern side of Strand E (Figure 5).

Native plants and wildlife are threatened by invasive exotic species, notably tamarisk along the Colorado River, and feral burros throughout the area. Burros consume and trample native vegetation, disturb water sources and soil crusts, and compete with native wildlife. Impacts are especially severe for the desert tortoise (Berry 1997).

Connectivity is an important part of sustaining this unique area's 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 will thrive for generations to come.

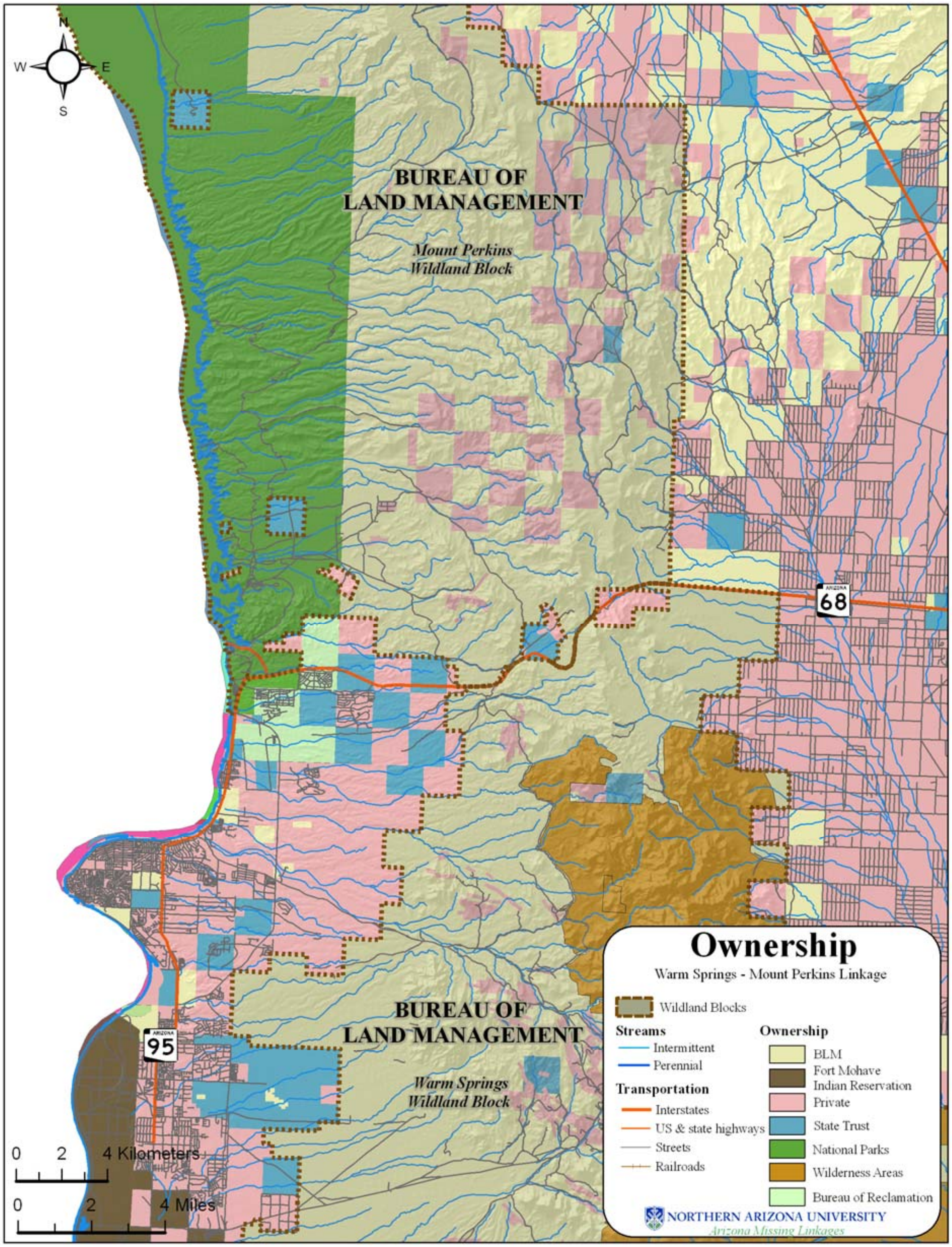

Figure 2: Land ownership in the linkage planning area.

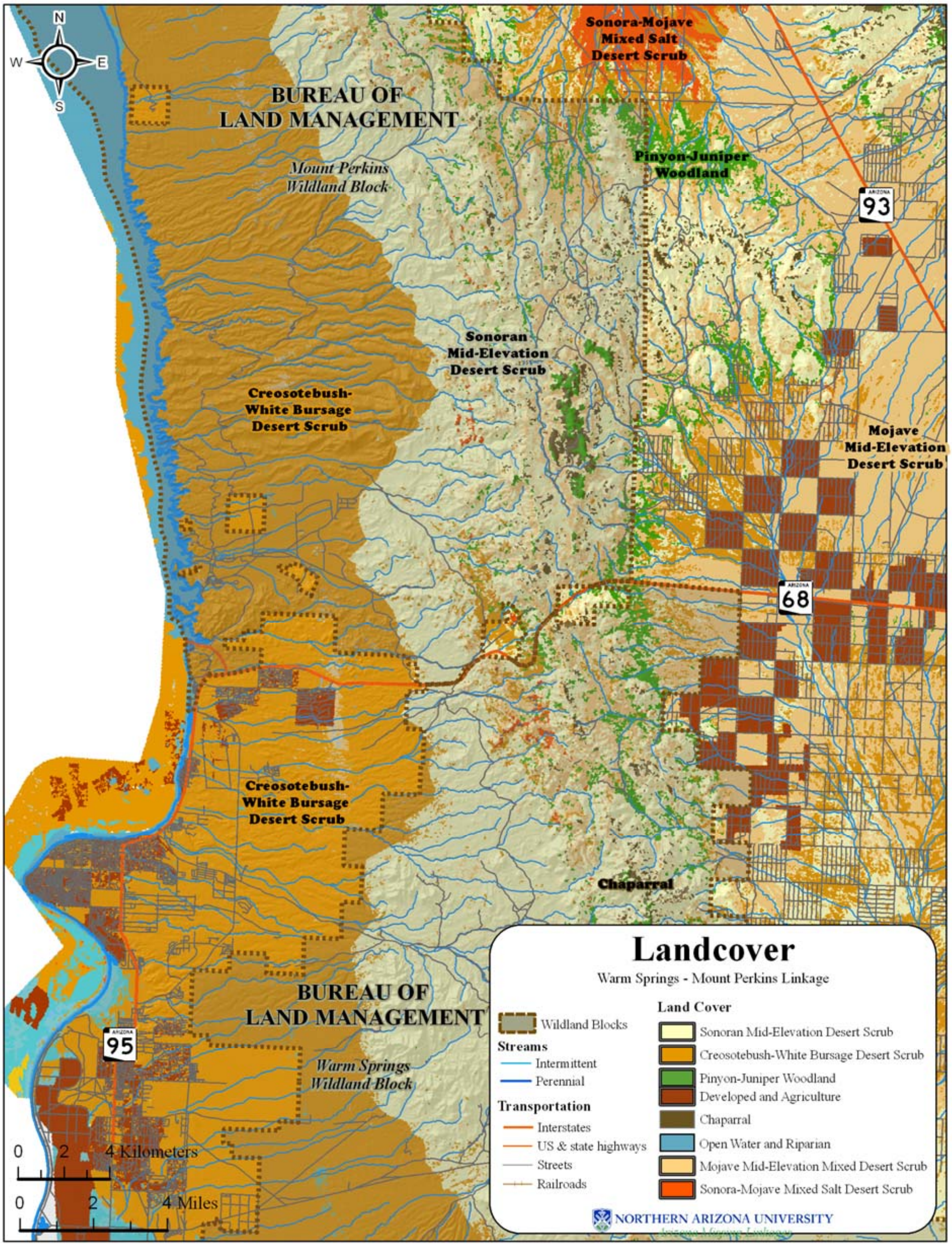

Figure 3: Land cover types within the linkage planning area

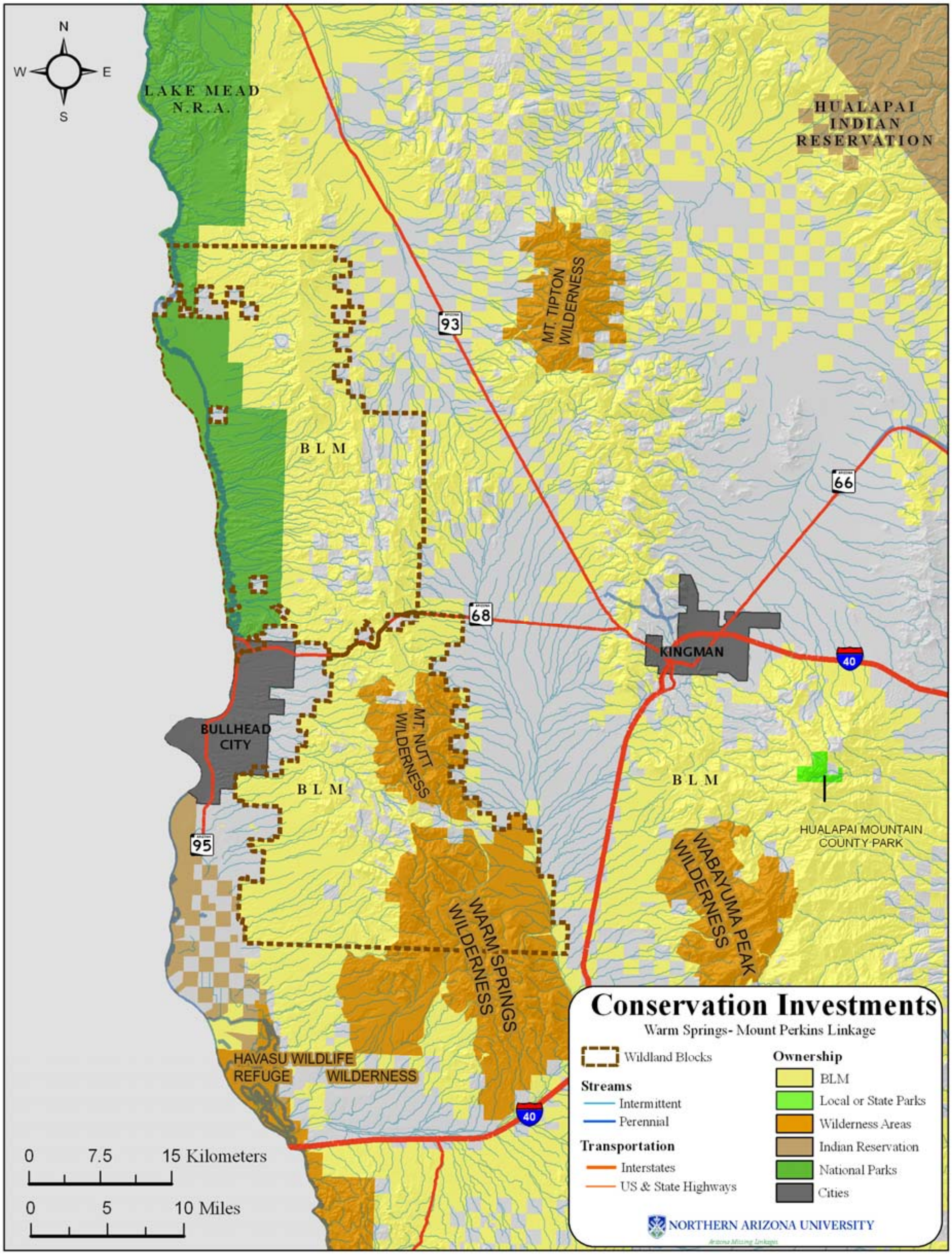

Figure 4: Existing conservation investments in the greater linkage planning area

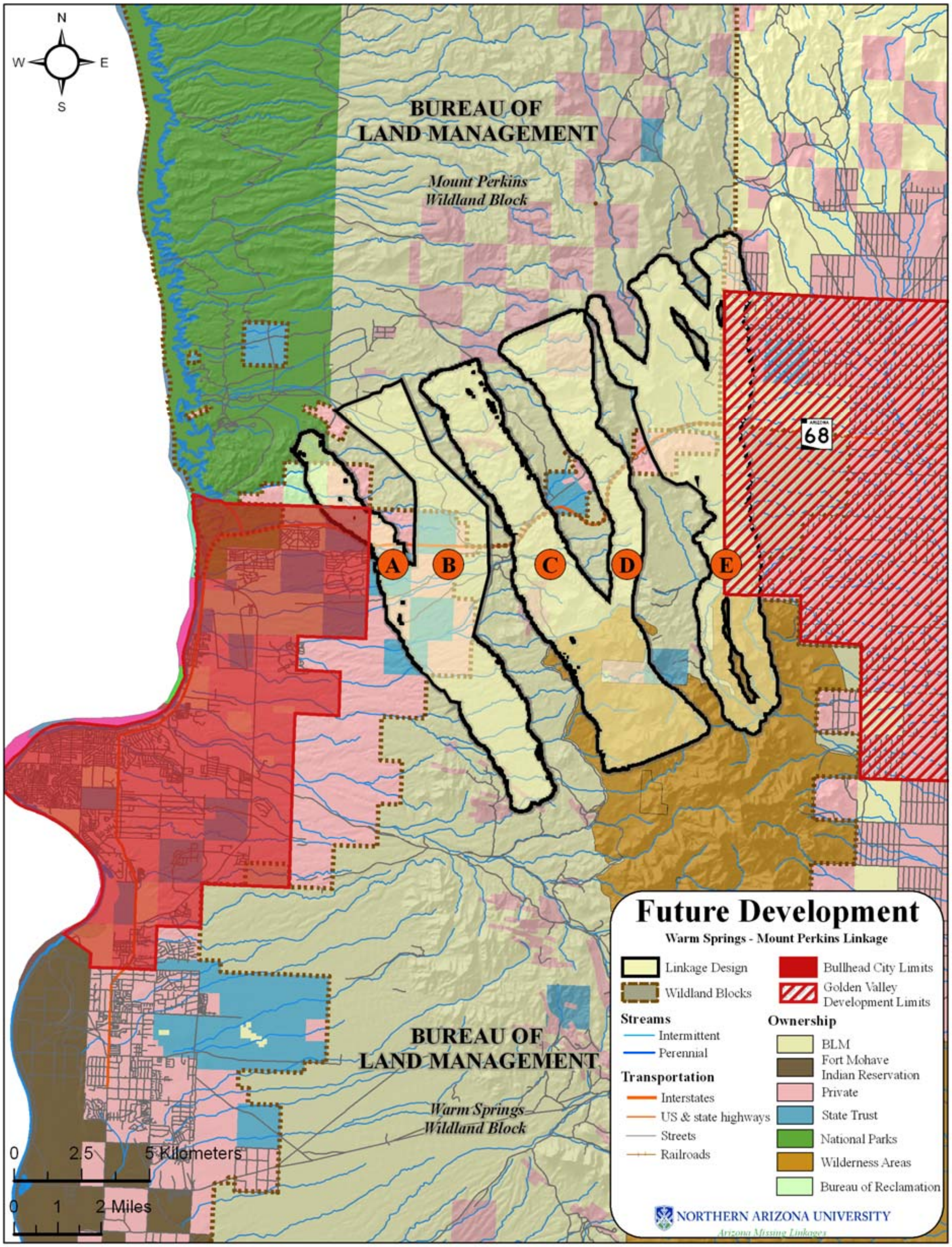

Figure 5. Bullhead City limits and the planned Golden Valley development overlap part of the linkage design.

Linkage Design & Recommendations

The Linkage Design[3] (Figure 1) is composed of five strands which together provide habitat for movement and reproduction of wildlife between wildlands near Bullhead City. In this section, we describe the linkage design and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Five Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of five strands which connect the Mount Perkins and Warm Springs wildland blocks. We describe these strands from west to east.

The westernmost strand of the linkage design, Strand A, provides important habitat for kit fox. It runs roughly from Finger Wash in the Warm Springs wildland block nearly to Katherine Wash in the Mount Perkins wildland block. The strand is primarily composed of Sonora-Mojave Creosotebush-White Bursage Desert Scrub (65.8%) and Sonoran Mid-elevation Desert Scrub (31.1%). This strand is situated on a relatively level floodplain with major washes running from east to west. It has the least topographic diversity within the linkage, with an average slope of 10% (Range: 0-67%, SD: 7) and 64.2% of the area having a flat topographic position.

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 B serves the Mohave desert tortoise. It originates in the east side of Strand A near Highway 68, and extends to Katherine Wash in the Mount Perkins wildland block. The vegetation in the strand is dominated by Sonora-Mojave Creosotebush-White Bursage Desert Scrub (70%) and Sonoran Mid-Elevation Desert Scrub (13%). This strand is largely comprised of flat to gentle slopes (60%) with and average slope of 11% (Range: 0.1-69%, SD: 8.1) although 37% of the land is classified as steep slopes.

Strand C provides the best habitat for desert bighorn, Mohave desert tortoise, and Gila monster. It runs along the western side of the Black Mountains, The strand is primarily composed of Sonoran Mid-elevation Desert Scrub (72%) and Mojave Mid-elevation Mixed Desert Scrub (16%). This strand is topographically complex, supporting alluvial fans on the western slope of the Black Mountains. It has an average slope of 30% (Range: 0-219%, SD: 21). Sixty-one percent of the land in this strand is classified as steep slopes, 14% as ridgetop, and 12% as canyon bottom.

Strand D provides the best habitat for Gila monster and good habitat for mule deer. It is dominated by Sonoran Mid-Elevation Desert Scrub (91%) and Mojave Mid-Elevation Mixed Desert Scrub (9%).. This strand has an average slope of 33% (Range: 0-191%, SD: 18). Sixty-six percent of this rugged strand is comprised of steep slopes, with ridgetops and canyon bottoms both making up 16% of the land.

[3] The reader will note that the strands of the linkage design extend well into each wildland block. As explained in Figure 20, for modeling purposes we had to redefine the wildland blocks such that the facing edges were parallel lines about 15 km apart.

The easternmost strand of the linkage design, Strand E, provides habitat for bobcat, mountain lion, and mule deer. Running along the eastern side of the Black Mountains, this strand is primarily composed of Sonoran Mid-elevation Desert Scrub (39%), Mojave Mid-elevation Mixed Desert Scrub (27%), and Pinyon-Juniper Woodlands (24%). It is topographically complex strand, with an average slope of 21% (Range: 0-162%, SD: 18). Nearly half (49%) of the land within this strand is classified as steep slopes, 9% as ridgetops, and 7% as canyon bottoms.

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

The Linkage Design encompasses about 39,300 acres (15,900 ha) of land, the majority of this land is managed by the BLM (nearly 32,000 acres), over 6,000 acres is privately owned land, and State Trust Lands make up roughly 2,300 acres. Three natural vegetation communities account for 82% of the land cover and no lands classified as developed were captured within the linkage design (Table 2). Natural vegetation is dominated by desert scrub associations, similar to land cover in each wildland block.

The Linkage Design captured a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, 34% of the land is classified as gentle slopes, 49% is classified as steep slopes, and 16% is classified as either canyon bottom or ridgetop (Figure 8). Most of the land in the linkage has southern aspects (Figure 8).

Table 2: Approximate land cover in the Linkage Design

LAND COVER CATEGORY	ACRES	HECTARES	% OF AREA
Evergreen Forest (>10%)			
Pinyon-Juniper Woodland	3721	1506	9.5%
Desert Scrub (86%)			
Mojave Mid-Elevation Mixed Desert Scrub	6248	2528	16%
Sonora-Mojave Creosote-White Bursage	9438	3819	24%
Sonoran Mid-Elevation Desert Scrub	18630	7539	47%

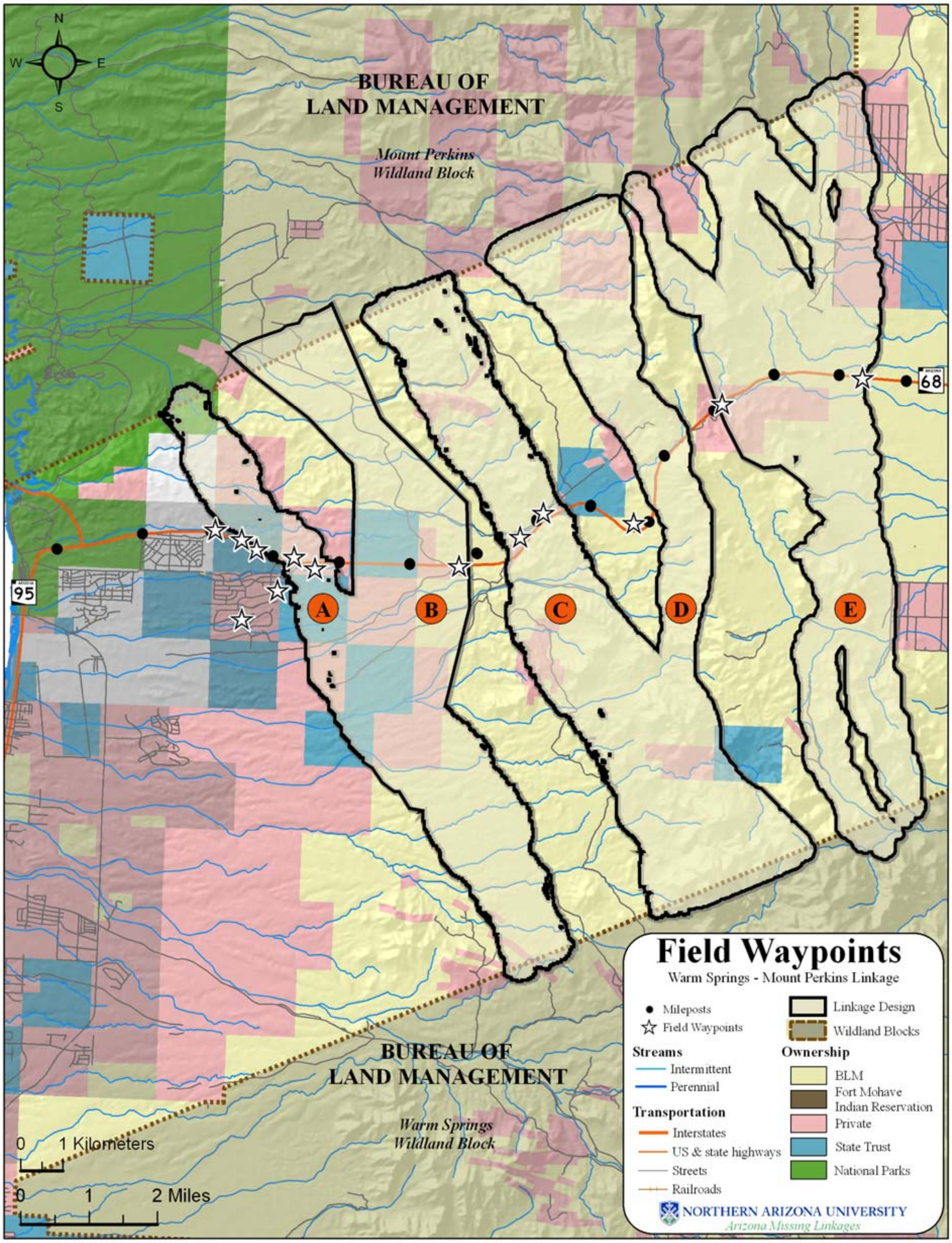

Figure 6: Property ownership and field investigation waypoints within Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints

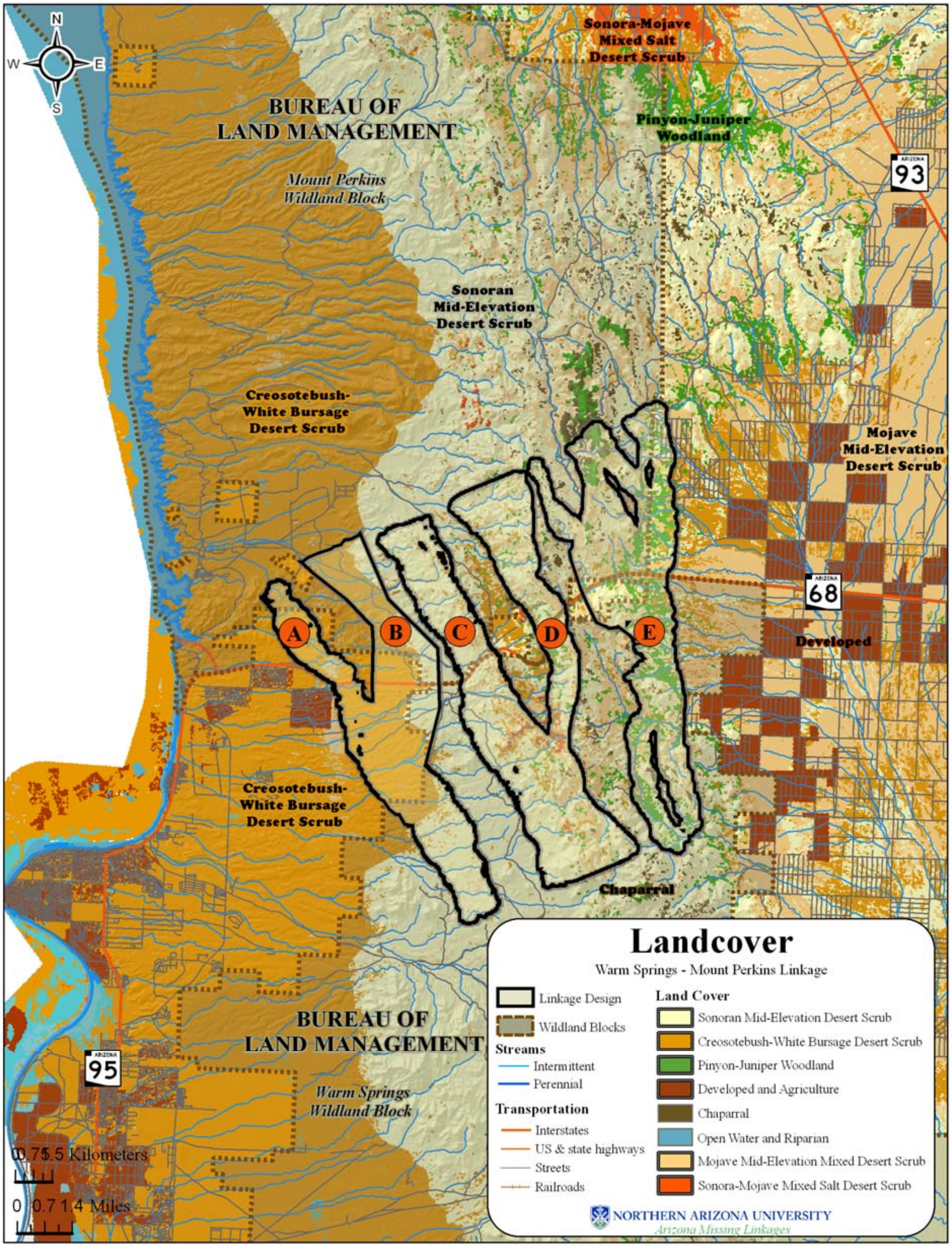

Figure 7: Land cover in the Linkage Design.

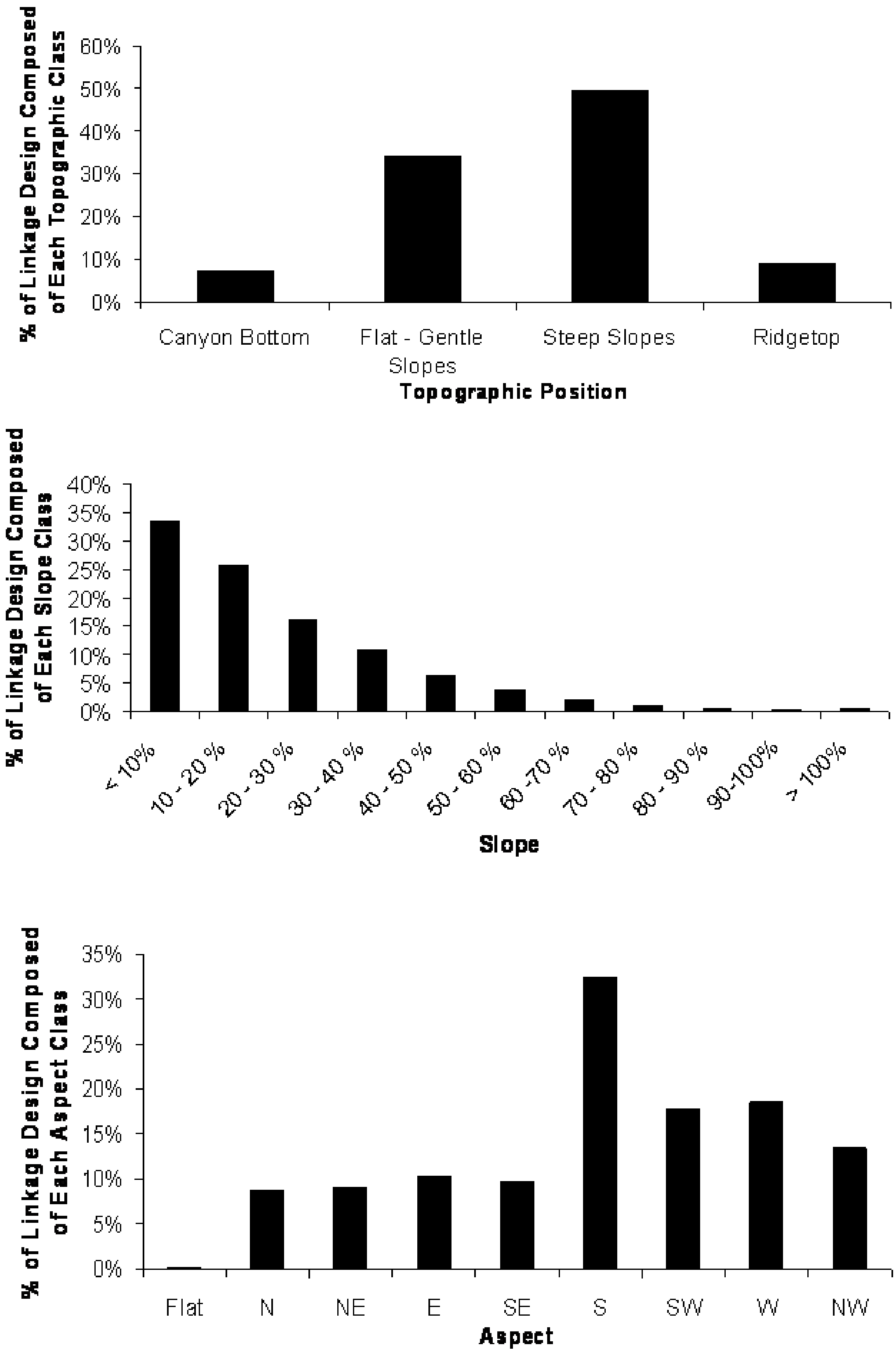

Figure 8: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect

Removing and Mitigating Barriers to Movement

Although roads, 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 Mount Perkins and Warm Springs wildland blocks, it is essential to consider the *entire* linkage design, including conserving the land in the linkage. Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either wildland block is lost.

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Figure 9). 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).

Figure 9: Characteristics which make species vulnerable to the three major direct effects of roads (from Forman et al. 2003).

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

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 10). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

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

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate drainage beneath highways. For ungulates such as deer that prefer open crossing structures, tall, wide bridges are best. Mule deer in southern California only used underpasses below large spanning bridges (Ng et al. 2004), and the average size of underpasses used by white-tailed deer in Pennsylvania was 15 ft wide by 8 ft high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures have increased connectivity for smaller species crossing bridges on floodplains (Forman et al. 2003). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005).

A bridge is a road supported on piers or abutments above a watercourse, while a culvert is one or more round or rectangular tubes under a road. The most important difference is that the streambed under a bridge is mostly native rock and soil (instead of concrete or corrugated metal in a culvert) and the area under the bridge is large enough that a semblance of a natural stream channel returns a few years after construction. Even when rip-rap or other scour protection is installed to protect bridge piers or abutments, stream morphology and hydrology usually return to near-natural conditions in bridged streams, and vegetation often grows under bridges. In contrast, vegetation does not grow inside a culvert, and hydrology and stream morphology are permanently altered not only within the culvert, but for some distance upstream and downstream from it.

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

Figure 10: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

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

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

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

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

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

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

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

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

Existing Roads in the Linkage Design Area

There are about 120 km (75 mi) of transportation routes in the Linkage Design, including 12 km (8 mi) of SR-68 (Table 3). We conducted field investigations of SR-68 to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 3: Roads in the Linkage Design

ROAD NAME	KILOMETERS	MILES
Unamed Roads	73.43	45.62
State Route 68	12.21	7.59
Katherine Mine Rd	9.30	5.78
Buck Wash Rd	8.35	5.19
Benson Rd	2.05	1.27
Old Kingman Hwy	1.76	1.09
Bapchule Rd	1.69	1.05
Ganado Rd	1.60	0.99
Beardsley Rd	1.48	0.92
Bellemont Rd	1.42	0.88
Bisbee Rd	1.28	0.79
Agua Fria Dr	0.90	0.56
Zuni Dr	0.88	0.55
Simon Dr	0.85	0.53
Chinle Dr	0.79	0.49
Old Hwy 68	0.53	0.33
Mancos Dr	0.52	0.33
Old Katheine Mine Rd	0.35	0.21
Mc Elmo Dr	0.34	0.21
Lakeview Dr	0.30	0.18
Aqua Fina Dr	0.22	0.14

Chuar Dr	0.10	0.06
Gold Stake Pl	0.08	0.05
Bolsa Dr	0.06	0.04
La Puerta Rd	0.01	0.00
Unamed Roads	73.4	45.6
Total Length of Roads in Union	120.5	74.9

Existing Crossing Structures on SR-68

We documented the following major crossing structures (Figure 11).

- MP 7.8 (waypoint 48), a large bridge on SR-68 spans a major wash near Arabian Mine. A fence funnels medium to large mammals under the road (Figure 12).
- MP 8.2 (waypoint 49), 2 sets of 3 large box culverts under SR-68 (Figure 13).
- MP 10.8, a large bridged structure (Figure 14)
- MP 12.1, a large bridged undercrossing near Union Pass (Figure 15)

Recommendations for Highway Crossing Structures

Although there are 3 excellent crossing structures in the area, the existing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between the wildland blocks must traverse SR-68, crossing structures at frequent intervals along the highways are crucial to success of the corridor. We recommend adding and upgrading the crossing structures described above as follows:

- Along Strand A, medium-sized soft-bottomed culverts should be installed for animals such as kit fox.
- In Strand A, we noted a potential location for a bridge to ensure wildlife connectivity (Figure 16).
- Along each arm of each strand, medium sized culvers suitable for gila monster and desert tortoise should be installed.
- Along Strand E, large culverts suitable for mountain lion and bobcat should be installed.
- Along Strand E, large bridged underpasses suitable for mule deer should be installed.
- Along every paved road in each Strand of the linkage design, 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.

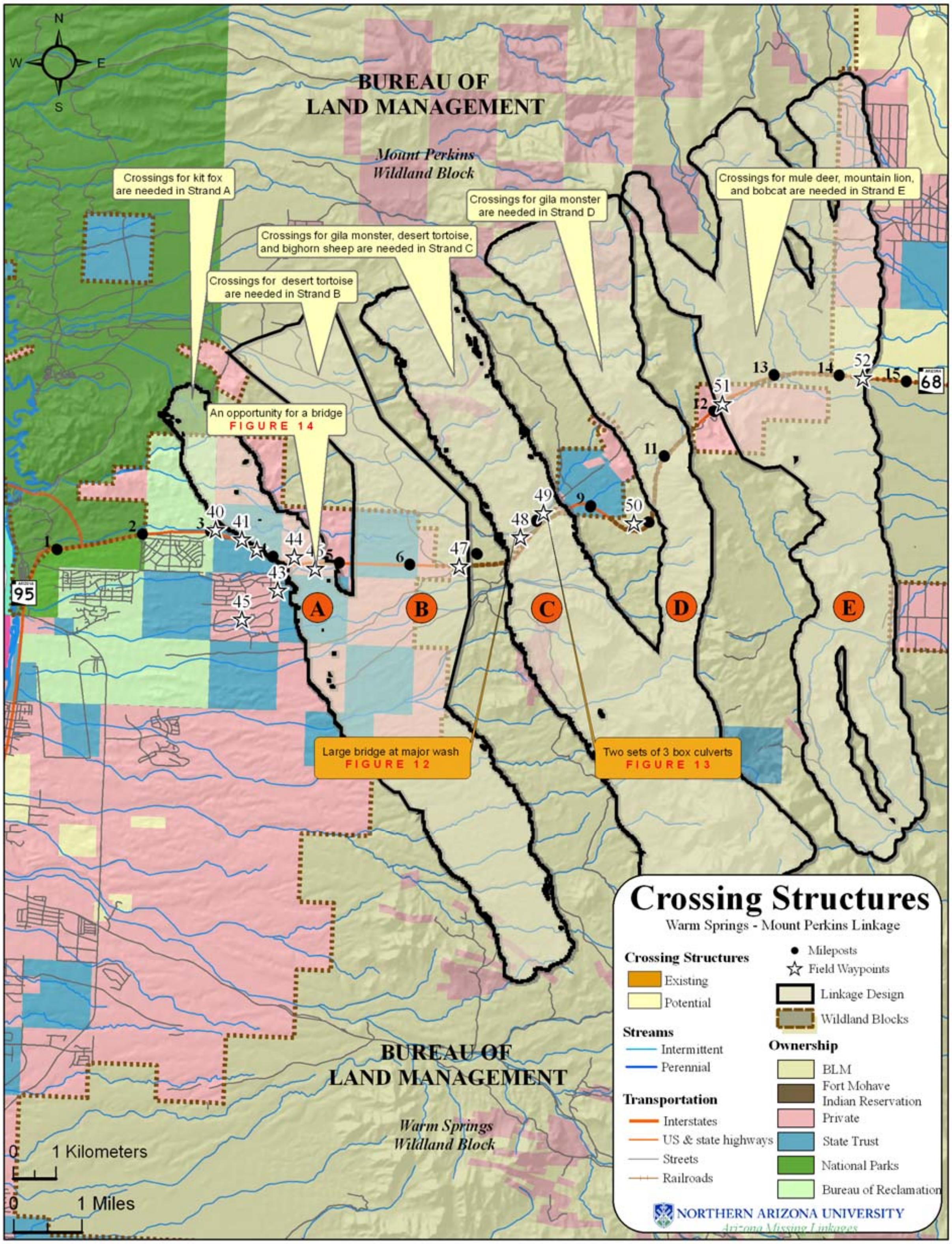

Figure 11: Locations of existing and potential crossing structures in the linkage design.

Figure 12: A large bridged underpass on SR-68 near Arabian Mine (MP 7.8; waypoint 48). Photo provided by K Bristow and M Crabb, AGFD.

Figure 13: Two sets of box culverts provide crossings underneath SR-68 near MP 8.2 (from waypoint 49).

Figure 14. Wildlife underpass at MP 10.8. Photo provided by K. Bristow and M. Crabb, AGFD. This structure was not used by bighorn sheep.

Figure 15. Wildlife underpass at MP 12.1, near Union Pass. Photo provided by K. Bristow and M. Crabb, AGFD. Bighorn sheep used this structure at least 22 times to cross SR-68.

Figure 16: This fill slope in Strand A (SR-68 MP 4.5) provides a good location for a bridged crossing structure (photo taken from waypoint 46).

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 land uses 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 17). 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).

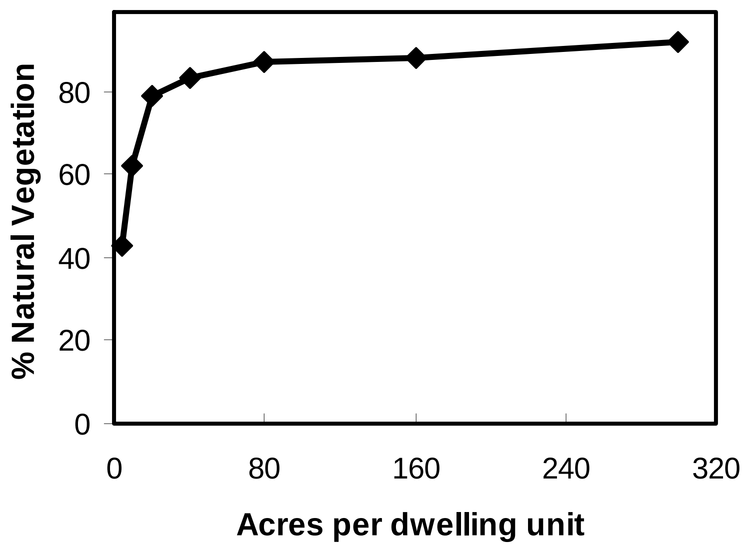

Figure 17: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres.

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

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

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

Urban Barriers in the Linkage Design Area

The city limits of Bullhead City overlap approximately 1.3 km^2 (0.5 $mile^2$) Strand A and the planned development of Golden Valley overlaps approximately 10.6 (4.1 $mile^2$) of Strand E (Figure 5). Future residential development of these areas may threaten connectivity. Biologically best corridors for kit fox, mountain lion, bobcat, and mule deer (see Appendix B) pass through these strands.

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 for wildlife permeability. Many people already live in this area. Unrestrained dogs and cats, fencing, road kill on neighborhood streets, and artificial night lighting could make this Strand ineffective. We advocate innovative programs that respect the rights of residents and enlist them as stewards of the linkage area.
- Discourage further residential development and subdivision of large parcels in the Linkage Design.

Appendix A: Linkage Design Methods

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

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[4]. 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 14 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

[4] 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 18):**

- *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[5].

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[6] 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.

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

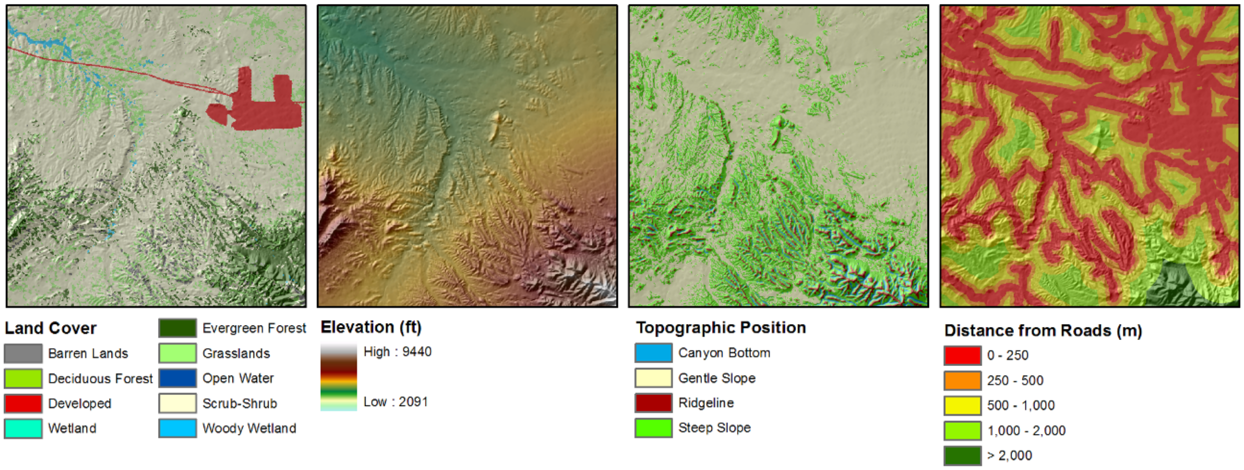

Figure 18: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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 19). 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[7]. 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.

[7] 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.

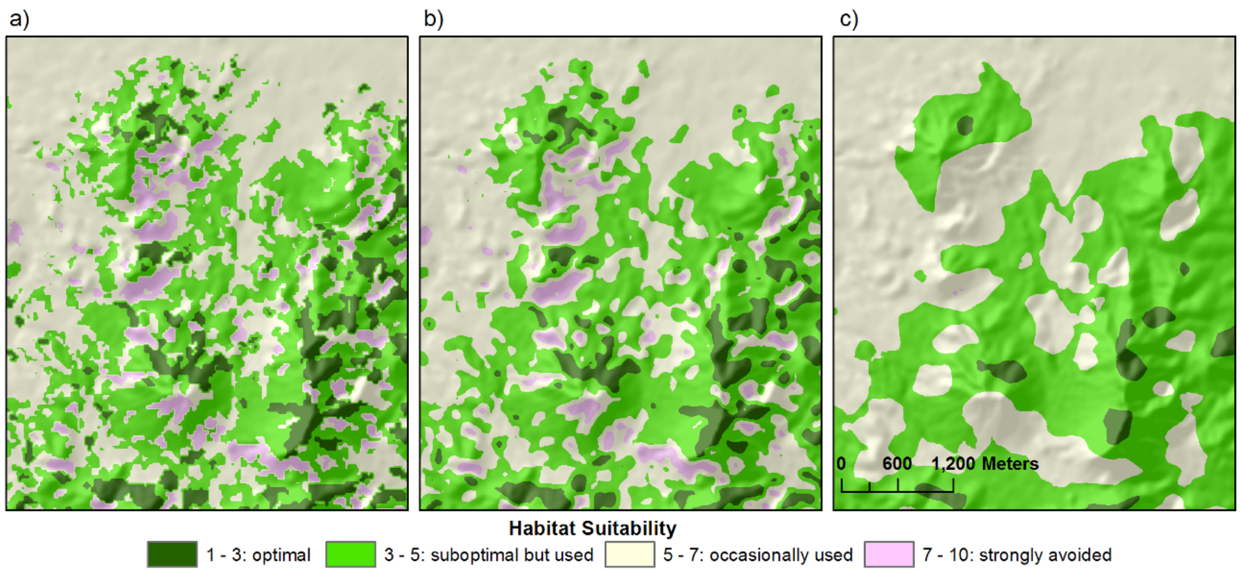

Figure 19: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window

Identifying Biologically Best Corridors

The *biologically best corridor*[8] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one wildland block to a potential population core in the other wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

We developed BBCs only for some focal species, namely species that (a) exist in both wildland blocks, or have historically existed in both and could be restored to them, (b) can move between wildland blocks in less time than disturbances such as fire or climate change will make the current vegetation map obsolete, and (c) move near the ground through the vegetation layer (rather than flying, swimming, or being carried by the wind), and (d) have habitat preferences that can reasonably be represented using GIS variables. The close proximity of the wildland blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[9]. 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 for purposes of BBC analyses so that the facing edges of the wildland blocks were parallel to each other (Figure 20).

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

[8] 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.
[9] 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.

entirely within a wildland block) any suitable habitat within the wildland block.

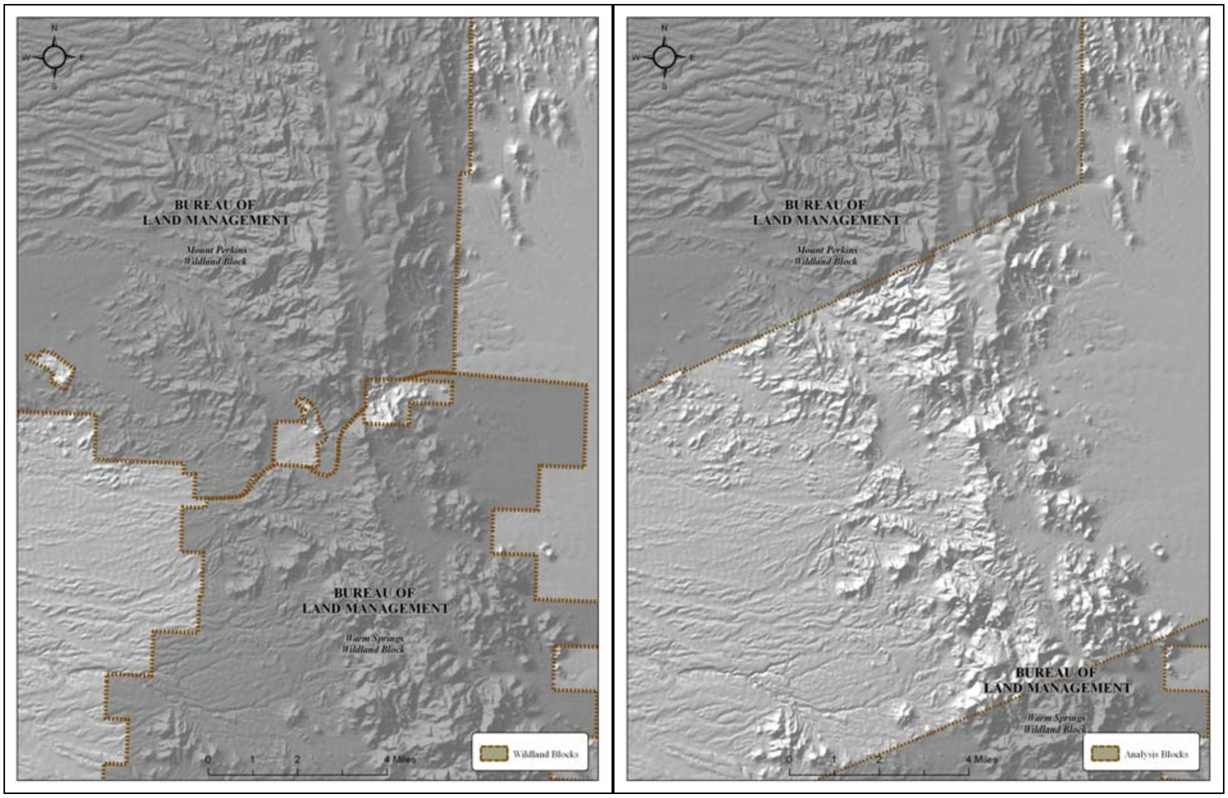

Figure 20: To give our corridors models "room to run," for the purposes of BBC analyses, we modified the wildland blocks used in our analyses, so that the facing edges were parallel lines about 15 km apart. This forces the models to identify corridors with the best habitat; without this modification, the models tend to identify the shortest corridors regardless of habitat quality.

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[10]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1 km. 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

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

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[11] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

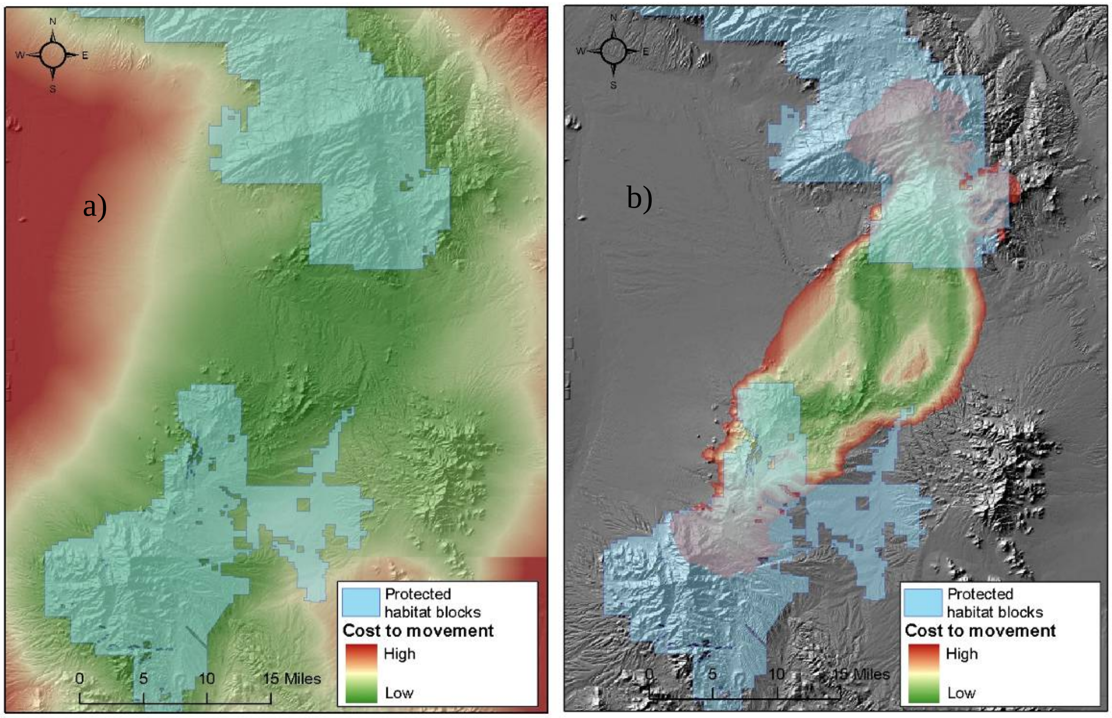

Figure 21: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

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

---

[11] 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.

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

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

Field Investigations

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

Appendix B: Individual Species Analyses

Table 4: 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.

	Bighorn Sheep	Bobcat	Desert Tortoise	Gila Monster	Kit Fox
Factor weights					
Land Cover	30	95	30	10	75
Elevation	10	5	25	35	0
Topography	50	0	40	45	15
Distance from Roads	10	0	5	10	10
Land Cover					
Pine-Oak Forest and Woodland	9	2	10	10	8
Pinyon-Juniper Woodland	9	2	10	6	8
Ponderosa Pine Woodland	9	2	10	10	8
Juniper Savanna	8	4	10	10	3
Semi-Desert Grassland and Steppe	5	4	8	5	1
Chaparral	9	2	10	6	6
Creosotebush, Mixed Desert and Thorn Scrub	6	4	2	3	1
Creosotebush-White Bursage Desert Scrub	6	4	1	7	1
Desert Scrub (misc)	2	4	3	3	1
Gambel Oak-Mixed Montane Shrubland	9	2	10	10	5
Mesquite Upland Scrub	7	4	7	4	5
Paloverde-Mixed Cacti Desert Scrub	3	4	5	1	3
Pinyon-Juniper Shrubland	8	2	10	6	4
Riparian Mesquite Bosque	9	3	4	5	4
Riparian Woodland and Shrubland	9	3	10	5	5
Barren Lands, Non-specific	8	6	10	10	9
Bedrock Cliff and Outcrop	2	6	10	2	9
Cliff and Canyon	1	6	10	2	9
Mixed Bedrock Canyon and Tableland	2	6	10	2	9
Warm Desert Pavement	9	6	6	6	9
Recently Mined or Quarried	10	6	10	10	10
Agriculture	10	9	10	10	7
Developed, Medium - High Intensity	10	9	10	9	9
Developed, Open Space - Low Intensity	10	7	7	1	7
Open Water	10	10	10	10	10
Elevation (ft)					
	0-2950: 2	0-7500: 1	0-5000: 1	0-1700: 4	
	2950-3300: 1	7500-10000: 5	5000-7000: 7	1700-4000: 1	
	3300-7000: 3	10000-11000: 9	7000-11000: 10	4000-4800: 4	
	7000-11000: 7			4800-5700: 7	
				5700-11000: 10	
Topographic Position					
Canyon Bottom	8		8	1	7
Flat - Gentle Slopes	7		3	5	1
Steep Slope	5		3	1	5
Ridgetop	1		7	1	4
Distance from Roads (m)					
	0-1000: 6		0-250: 5	0-1000: 5	0-50: 7
	1000-15000: 2		250-500: 4	1000-3000: 3	50-250: 3
			500-1000: 3	3000-15000: 1	250-500: 2
			1000-15000: 1		500-15000: 1

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

Bobcat (*Lynx rufus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

Bobcats are generally solitary and territorial (Riley 2003). Observed home ranges for one breeding pair ranged from 2 to over 50 km^2. Home range size varies greatly with prey density and habitat quality (Harrison, pers. comm.). In Marin County, California, Riley (2003) found that roads represented home range boundaries for 75% of radio-collared bobcats that lived near them, males had larger average home range requirements than females, and the spatial requirements for both genders varied widely according to whether they were located in an urban or rural landscape (mean home range size (MCP 95%) of males: urban zone 6.4 km^2, rural zone 13.5 km^2 , females: urban zone 1.3 km^2, rural zone5.3 km^2). Dispersal distances for young bobcats average near 25 km, while they have been recorded up to 182 km (Kamler et al 2000).

Conceptual Basis for Model Development

Habitat suitability model – Bobcats occur across a wide spectrum of vegetation types, and tend to cross paved roads infrequently (Riley 2003). Vegetation received an importance weight of 95%, while elevation was weighted at 5%, and topography and distance from roads did not receive any weight. While bobcats show some unwillingness to cross major roads, there is dearth of information on their use of habitat in relation to distance to roads, though Riley (2003) found that roads frequently represented their home range boundaries. For specific scores of classes within each of these factors, see Table 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 20 km^2 (Anderson and Lovallo 2003). Minimum potential habitat core size was defined as 300 km^2 (Harrison, pers. comm.), approximately enough area to support 20 effective breeders over a 10 year period, provided the population is not harvested.

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

Results & Discussion

Initial biologically best corridor – Modeling results reveal that almost all of the potential linkage area is comprised of suitable habitat for bobcat, with less suitable habitat occurring in developed areas and optimal habitat located on the eastern side of the Black Mountains (Figure 22). The BBC captures a discontinuous swath of optimal habitat in Strand E. Within the BBC, habitat suitability scores range from 2.0 to 3.9, with an average suitability cost of 3.2 (S.D: 2.3).

Union of biologically best corridors – The two additional strands of the Linkage Design capture additional suitable habitat and a continuous potential habitat core for bobcat (Figure 22).

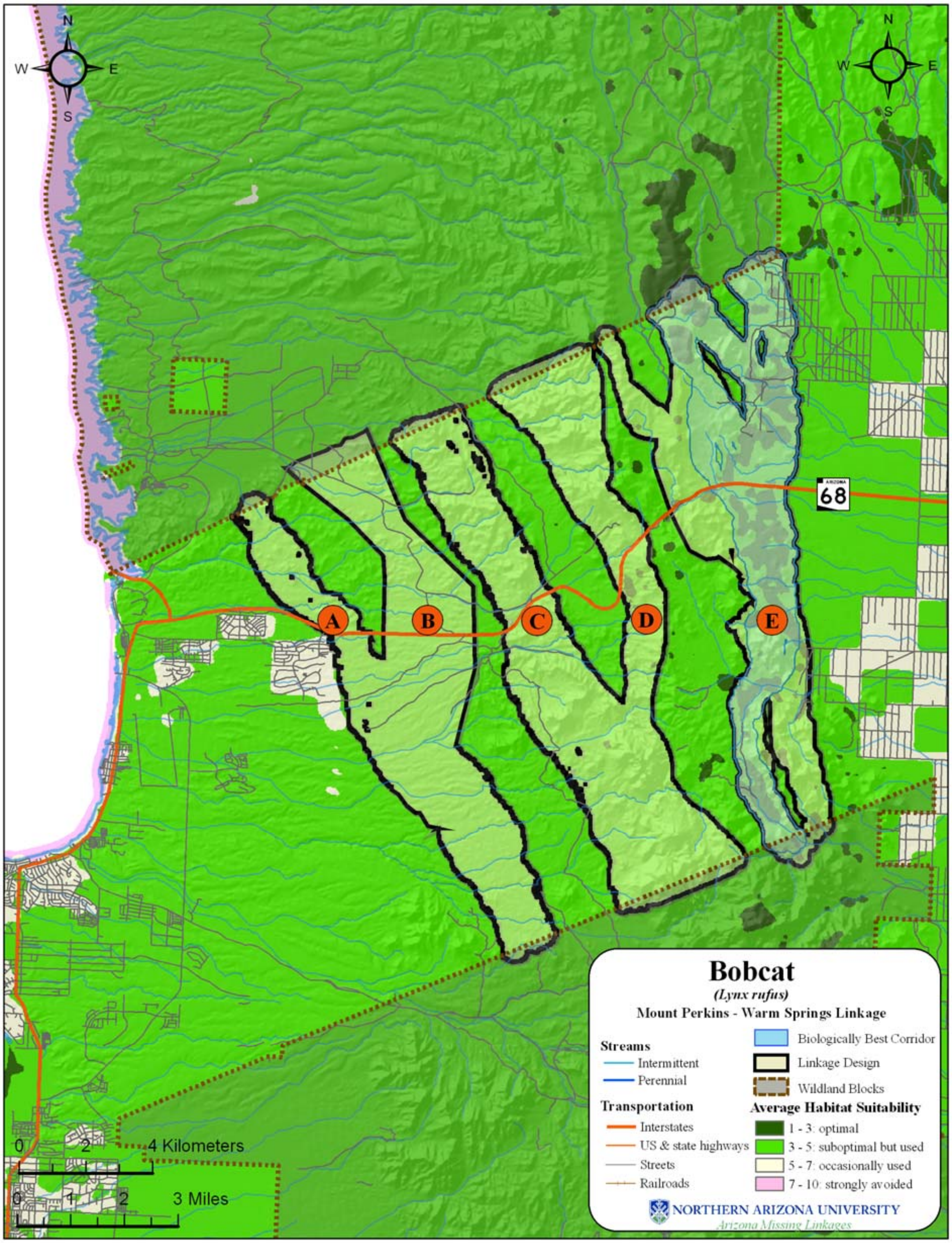

Figure 22: Modeled habitat suitability of bobcat

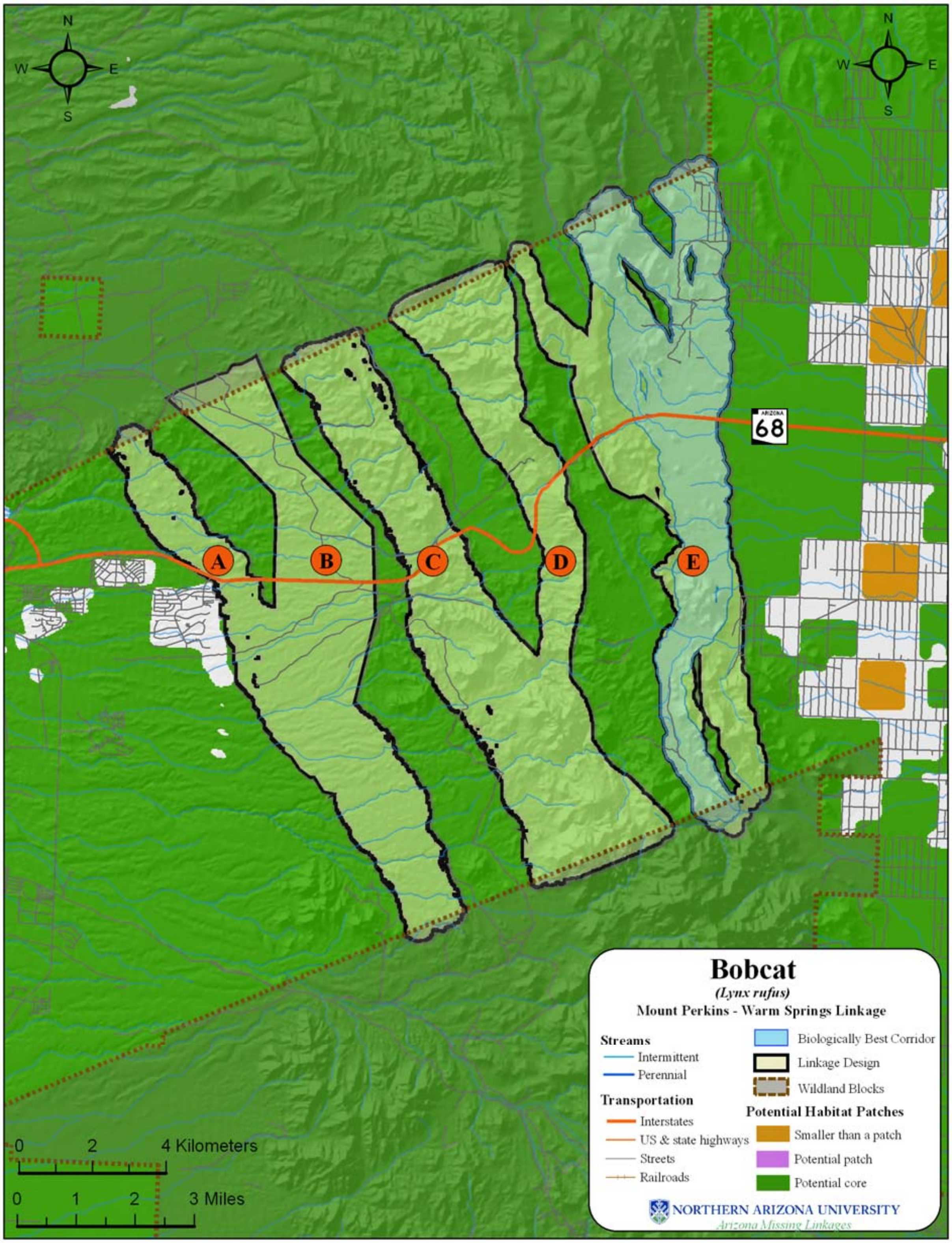

Figure 23: Potential habitat patches and cores for bobcat

Desert Bighorn Sheep (*Ovis canadensis nelsoni)*

Justification for Selection

Bighorn sheep populations have suffered massive declines in the last century, including local extinctions. Human activities such as alteration of bighorn sheep habitat, urbanization, and grazing by domestic sheep have been largely responsible for population declines (Johnson and Swift 2000; Krausman 2000). These declines, along with barriers to movement such as roads and range fences, have created small, isolated groups of bighorn sheep with a highly fragmented distribution (Singer et al. 2000; Bleich et al. 1990). Isolated bighorn populations are more susceptible to extirpation than large, contiguous populations due to climate change, fire, or disease, especially introduced diseases from domestic sheep (Gross et al. 2000; Singer et al. 2000; Epps et al. 2004). Bighorn sheep are listed as USFS Sensitive in New Mexico and Arizona (New Mexico Department of Game and Fish 2004).

Distribution

Bighorn sheep are found throughout western North America from the high elevation alpine meadows of the Rocky Mountains to low elevation desert mountain ranges of the southwestern United States and northern Mexico (Shackleton 1985). Specifically, their range extends from the mountains and river breaks of southwestern Canada south through the Rocky Mountains and Sierra Nevada, and into the desert mountains of the southwest United States and the northwestern mainland of Mexico (NatureServe 2005). In Arizona, bighorns can be found from Kanab Creek and the Grand Canyon west to Grand Wash, as well as in westernmost Arizona eastward to the Santa Catalina Mountains (Hoffmeister 1986).

Habitat Associations

Bighorn sheep habitat includes mesic to xeric grasslands found within mountains, foothills, and major river canyons (Shackleton 1985). These grasslands must also include precipitous, rocky slopes with rugged cliffs and crags for use as escape terrain (Shackleton 1985; Alvarez-Cardenas et al. 2001; Rubin et al. 2002; New Mexico Department of Game and Fish 2004). Slopes >80% are preferred by bighorn sheep, and slopes <40% are avoided (Alvarez-Cardenas et al. 2001). Dense forests and chaparral that restrict vision are also avoided (NatureServe 2005). In Arizona, the desert bighorn subspecies (*O. Canadensis nelsoni*) is associated with feeding grounds that include mesquite, ironwood, palo verde, catclaw coffeeberry, bush muhly, jojoba, brittlebrush, calliandra, and galleta (Hoffmeister 1986). Water is an important and limiting resource for desert bighorn sheep (Rubin et al. 2002). Where possible, desert bighorn will seek both water and food from such plants as cholla, prickly pear, agave, and especially saguaro fruits (Hoffmeister 1986). Bighorn sheep will also occasionally graze on shrubs such as sagebrush, mountain mahogany, cliffrose, and blackbrush (New Mexico Department of Game and Fish 2004). Elevation range for bighorn sheep varies across their range from 0 – 3660 m (New Mexico Department of Game and Fish 2004), but in Arizona the desert bighorn subspecies is found from 100 – 1000m elevation, with the best habitat found from 900 – 1000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

Home ranges for bighorn sheep vary depending upon population size, availability and connectivity of suitable habitat, and availability of water resources (Singer et al. 2001). Home ranges have been reported to range from 6.1 km^2 to 54.7 km^2 (Singer et al. 2001). One desert bighorn sheep study in Arizona reports an average home range of 16.9 ± 3.38 km^2 for ewes, and home ranges for males that increased with age from 11.7 km^2 for a one year old to 37.3 km^2 for a 6 year old (Shackleton 1985). Bighorn sheep that live in higher elevations are known to migrate between an alpine summer range to a lower elevation winter range in response to seasonal vegetation availability and snow accumulation in the higher elevations (Shackleton 1985; NatureServe 2005). Maximum distances for these seasonal movements are about 48 km (Shackleton 1985). Desert bighorns on low desert ranges do not have separate seasonal ranges (Shackleton 1985). Bighorns live in groups, but for most of the year males over 3 years of age live separate from maternal groups consisting of females and young (Shackleton 1985).

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong topographic preferences, topographic position received an importance weight of 50%, while vegetation, elevation, and distance from roads received weights of 30%, 10%, and 10%. For specific costs of classes within each of these factors used for the modeling process, see Table 4. Because bighorn sheep actively select slopes greater than 40% for escape terrain, any pixel located further than 300 meters from a slope greater than 40% was reclassified to a suitability score between 5 and 10 (see Appendix A for explanation of modeling additional critical factors).

Patch size & configuration analysis – We defined minimum potential habitat patch size as 16.9 km^2 (Shackleton 1985), and minimum potential habitat core size was defined as 84.5 km^2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species, in addition to modeling percent slope as a critical factor. In developing the final Linkage Design (Appendix D), we also considered locations of radio-tagged bighorn sheep (Figure 24, Figure 25) and documentation of sheep use of highway crossing structures (Figure 25). To reflect these data, we expanded the easternmost linkage design to include more optimal bighorn habitat corresponding to areas of high use by radio-tagged sheep.

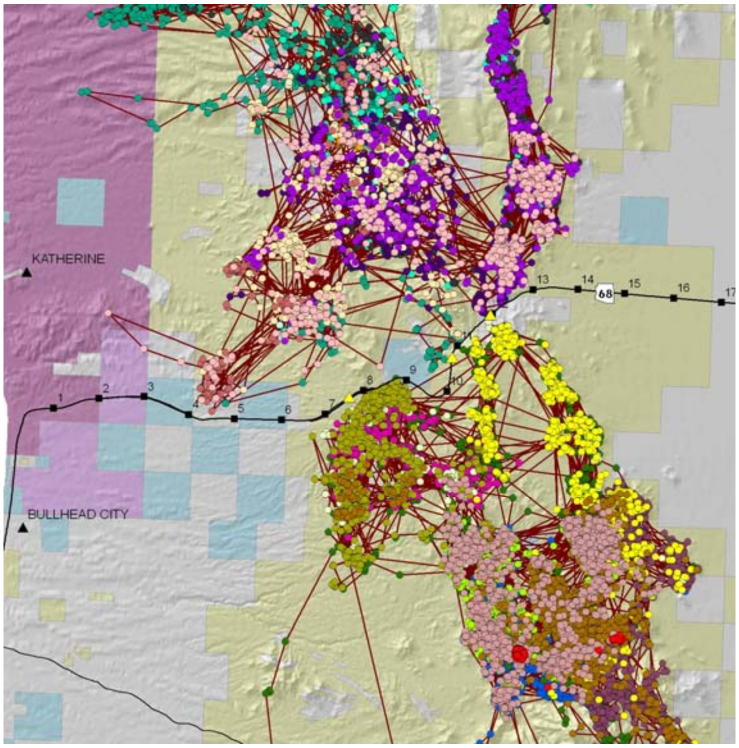

Figure 24. Locations of radio-tagged bighorn sheep that did not cross SR-68. Source: Bristow & Crabb 2008: Draft Final Report: evaluation of distribution and trans-highway movements of desert bighorn sheep near State Highway 68.

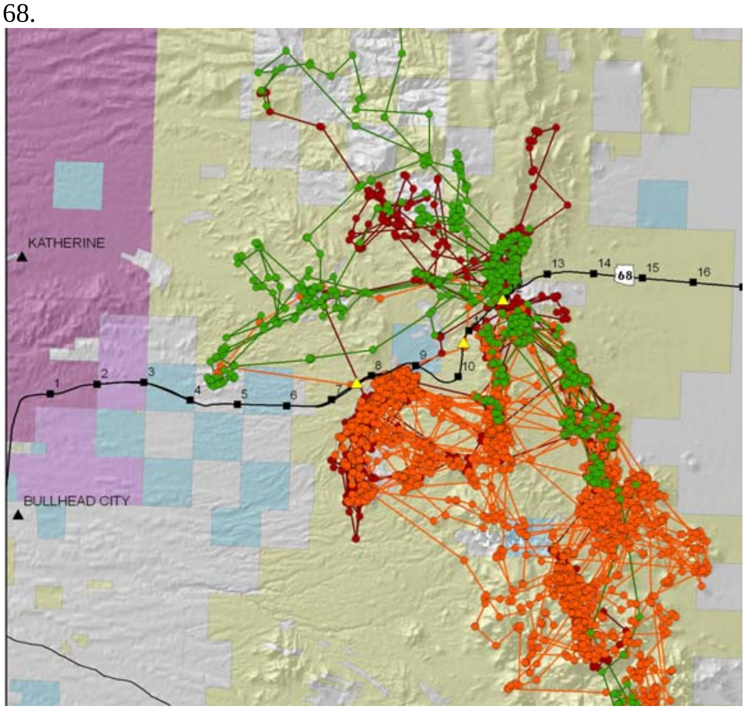

Figure 25. Locations of bighorn sheep that crossed SR-68. Crossings occurred at the bridged structures (yellow triangles) at MP 7.5 and MP 12. Camera traps documented 3 bighorn crossings at the MP 7.5 bridge, and 22 bighorn crossings at the MP 12 bridge. Bighorn did not use the crossing structure at MP 10.8. Source: Bristow & Crabb 2008: Draft Final Report: Evaluation of distribution and trans-highway movements of desert bighorn sheep near State Highway 68.

Results & Discussion

Initial biologically best corridor – Modeling results show a mixture of suitable and optimal habitat for bighorn occurring in the mountains and foothills within the potential linkage area (Figure 26). Within the BBC, habitat suitability scores range from 1.6 to 5.6, with an average suitability cost of 3.0 (S.D: 0.5). The BBC follows a continuous potential habitat core, disrupted only by SR-68 (Figure 27).

Union of biologically best corridors – Strands B and E of the Linkage Design capture a fairly continuous swath of optimal to suitable habitat that serves as a potential habitat core. Major highways and developed areas have been found to completely eliminate gene flow in bighorn sheep populations (Epps et al. 2005), so connectivity between the wildland blocks is dependent on effective crossing structures and maintenance of existing habitat.

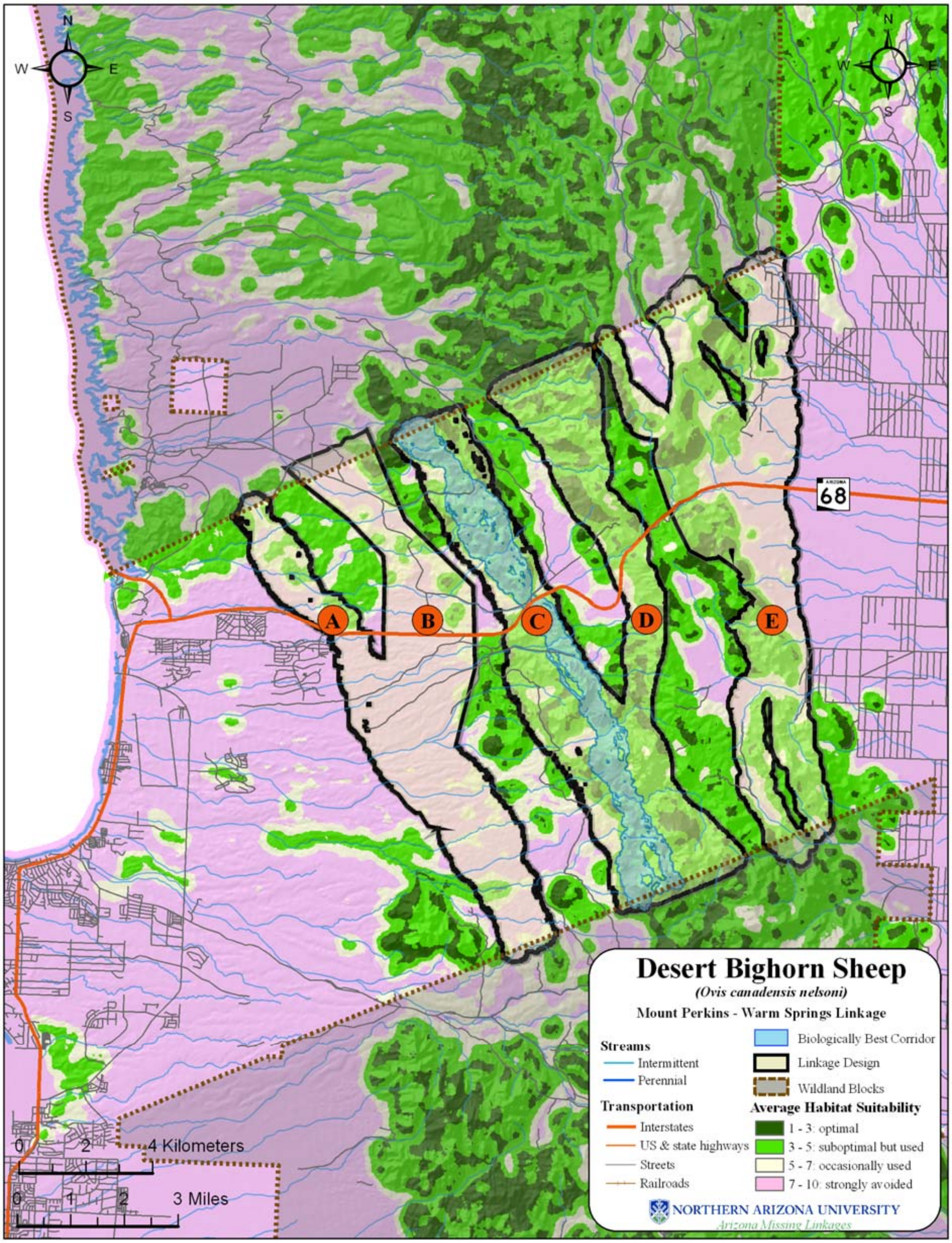

Figure 26: Modeled habitat suitability of desert bighorn sheep

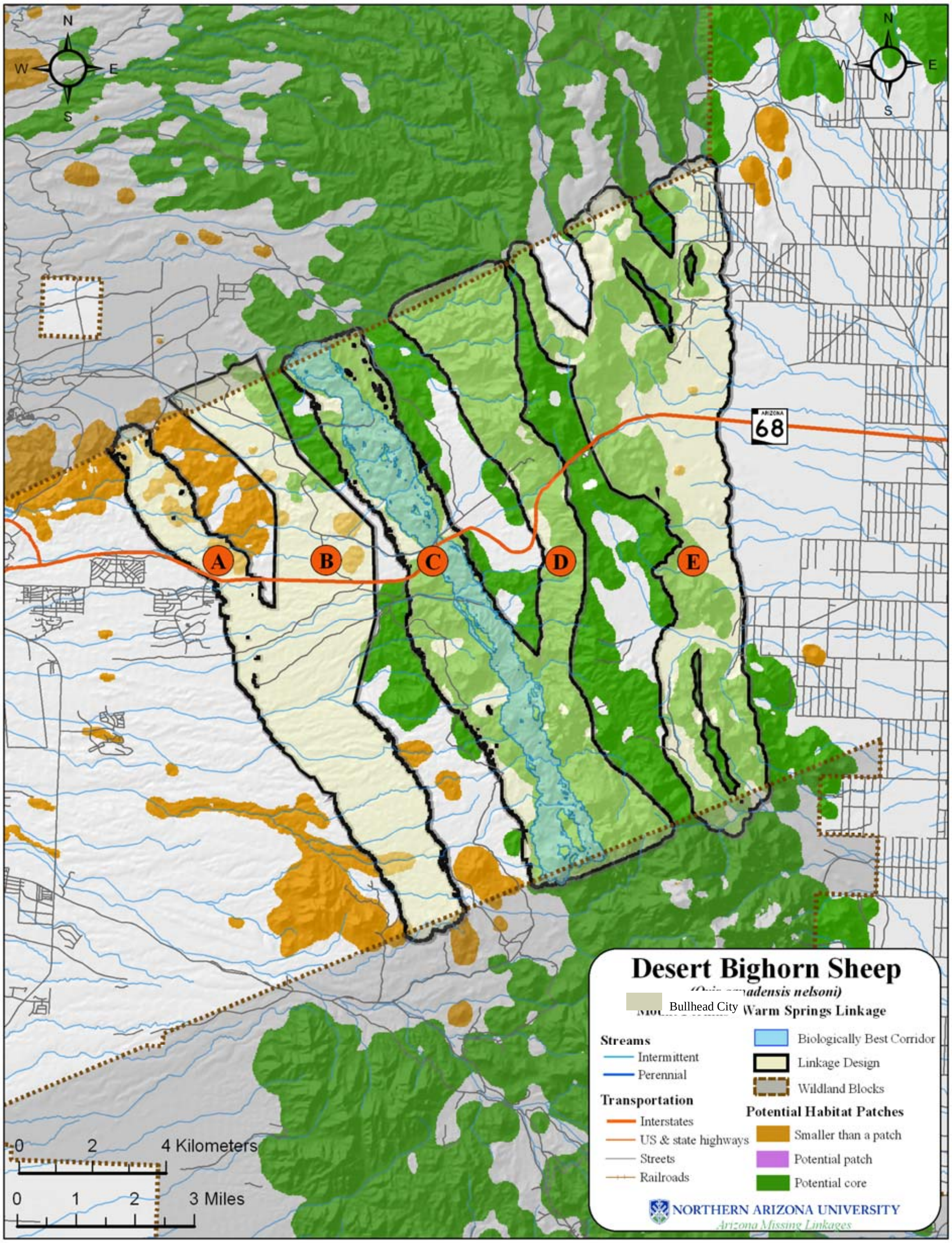

Figure 27: Potential habitat patches and cores for desert bighorn sheep

Mohave Desert Tortoise (*Gopherus agassizii*)

Justification for Selection
Although the Colorado River is generally considered the dividing line between Mohave and Sonoran desert tortoises, genetic data suggest that the population in the linkage planning area is part of the Mohave race (Lamb and McLuckie 2002). The Mojave desert tortoise is listed as Threatened under the Endangered Species Act. All desert tortoise populations are susceptible to habitat fragmentation, and need connectivity to maintain genetic diversity. Their ability to survive as an individual or population near roads is limited because of the potential for roadkill (Edwards et al. 2003).

Distribution
Desert tortoises are found in deserts throughout California, southeastern Nevada, southwestern Utah, and Arizona. Desert tortoises are divided into a Mojave Desert population and a Sonoran Desert population.

Habitat Associations
Tortoises are dependent on soil type and rock formations for shelter. Desert Tortoises are obligate herbivores (Oftedal 2002) so vegetation is an important part of their habitat. However, desert tortoises also occur over a wide range of vegetation (from Sinaloan thornscrub to Mojave Desert scrub types). Desert tortoises eat both annuals and perennials, but not generally the desert plants that characterize a vegetation type (saguaro cactus, palo verde, etc.). Unlike the Sonoran tortoises that occur in disjunct populations in rocky areas, Mohavean tortoises occur primarily in valleys and on bajadas, reaching highest densities in rockless valleys and on aridisols (van Devender 2002: p. 24; S. Goodman, AGFD, personal communication, March 2008). Mohavean tortoises are associated with creosote bush and white bursage communities.

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 25%, 40%, and 5%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the preliminary biologically best corridor for this species. However, S. Goodman (AGFD, personal communication, March 2008) indicated that this initial corridor did not match well with his observations of desert tortoises in the linkage area. The model failure probably occurred because one important driver of habitat use, namely soil type, was not included in the model because we were unable to obtain soil maps with high resolution and clearly-labeled attributes. Therefore, we use a biologically-best corridor map (Figure 28) hand-drawn by Mr. Goodman based on years of observations of tortoises by AGFD personnel in the project area.

Results & Discussion

Modeling results suggest that there are many patches of suitable habitat in the potential linkage area as suitable. Because we relied on the corridor map based on field observations instead of the map produced by our model, we do not present detailed descriptive statistics of habitat suitability for desert tortoise.

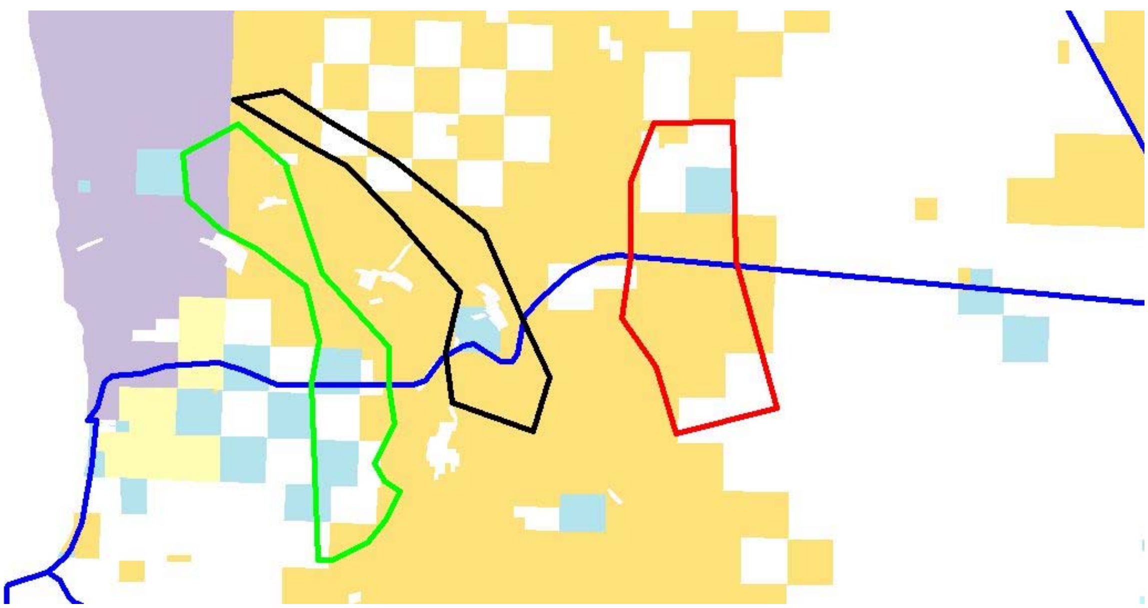

Figure 28: Potential corridors for Mohave desert tortoise in the linkage area, based on locations of tortoises observed by Arizona Game and Fish Department personnel in the linkage area. The green polygon represents the best potential corridor, and we incorporated it into the linkage design. The black and red polygons indicate potential secondary corridors; we did not include them in the linkage design. The basemap depicts land ownership (yellow = BLM; blue = ASLD). Source: Steve Goodman, AGFD.

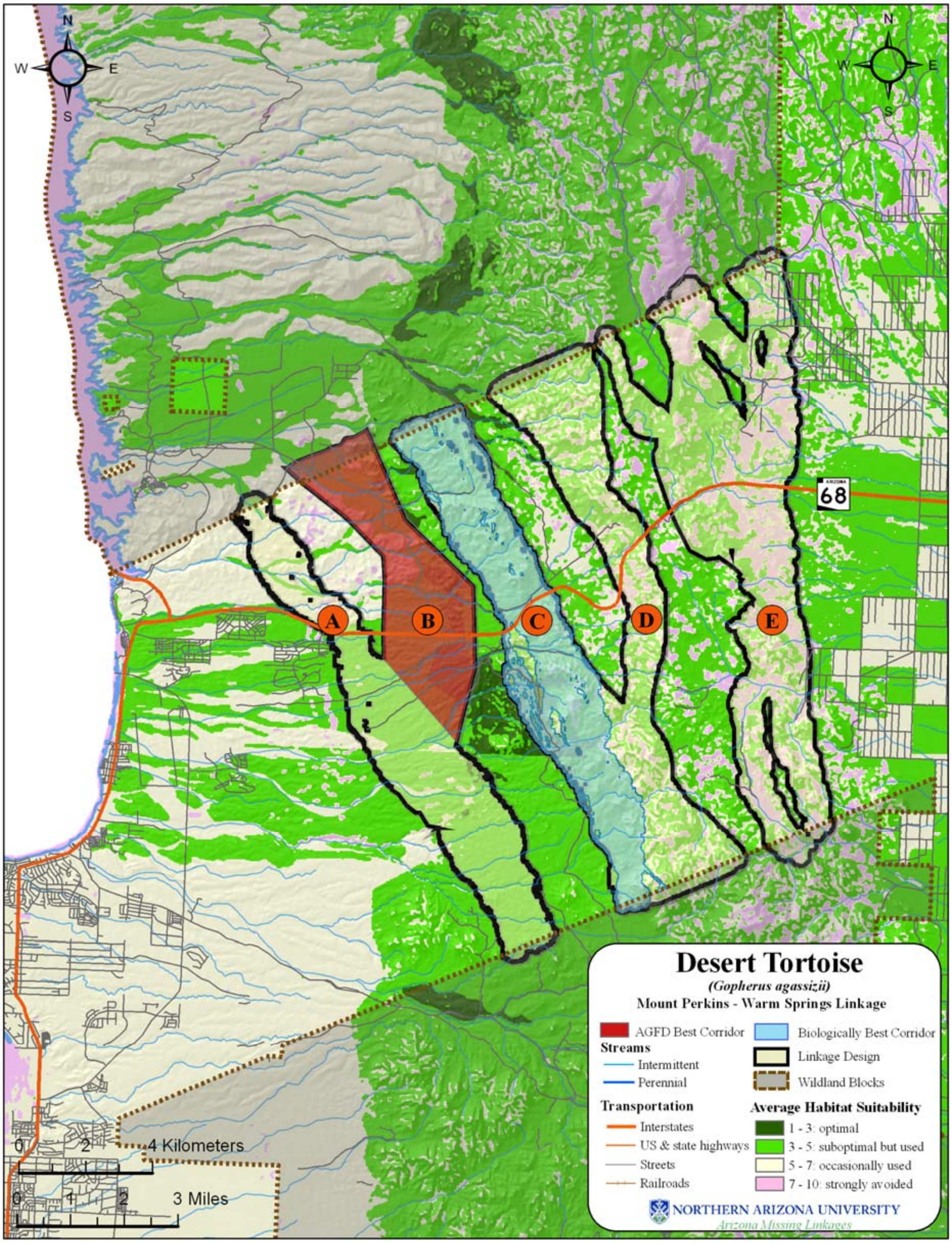

Figure 29: Modeled habitat suitability of Mohave Desert Tortoise

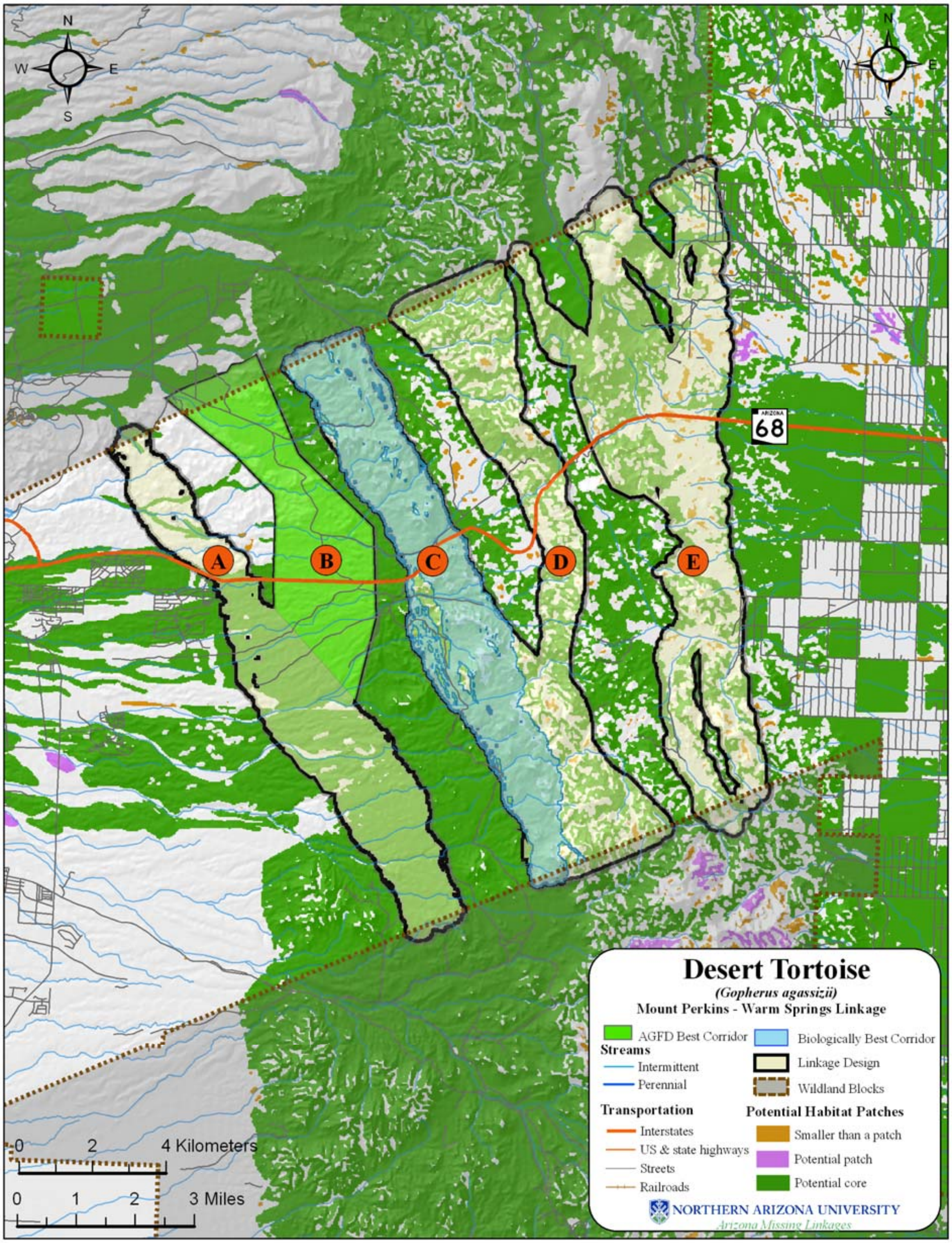

Figure 30: Potential habitat patches and cores for Mohave desert tortoise

Gila Monster (*Heloderma suspectum*)

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

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

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

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

Conceptual Basis for Model Development
Habitat suitability model – Vegetation received an importance weight of 10%, while elevation, topography, and distance from roads received weights of 35%, 45%, and 10%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

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

Results & Discussion
Initial biologically best corridor – Modeling results depict significant amounts of optimal habitat for gila monster within the potential linkage area (Figure 31). Within the BBC, habitat suitability scores ranged from 1.4 to 10.0, with an average suitability cost of 1.8 (S.D: 0.5). Almost the entire potential linkage area serves as a potential habitat core (Figure 32).

Union of biologically best corridors – The additional strands of the linkage design capture some discontinuous patches of optimal habitat, separated by suitable habitat. The entire linkage design is comprised of a potential habitat core.

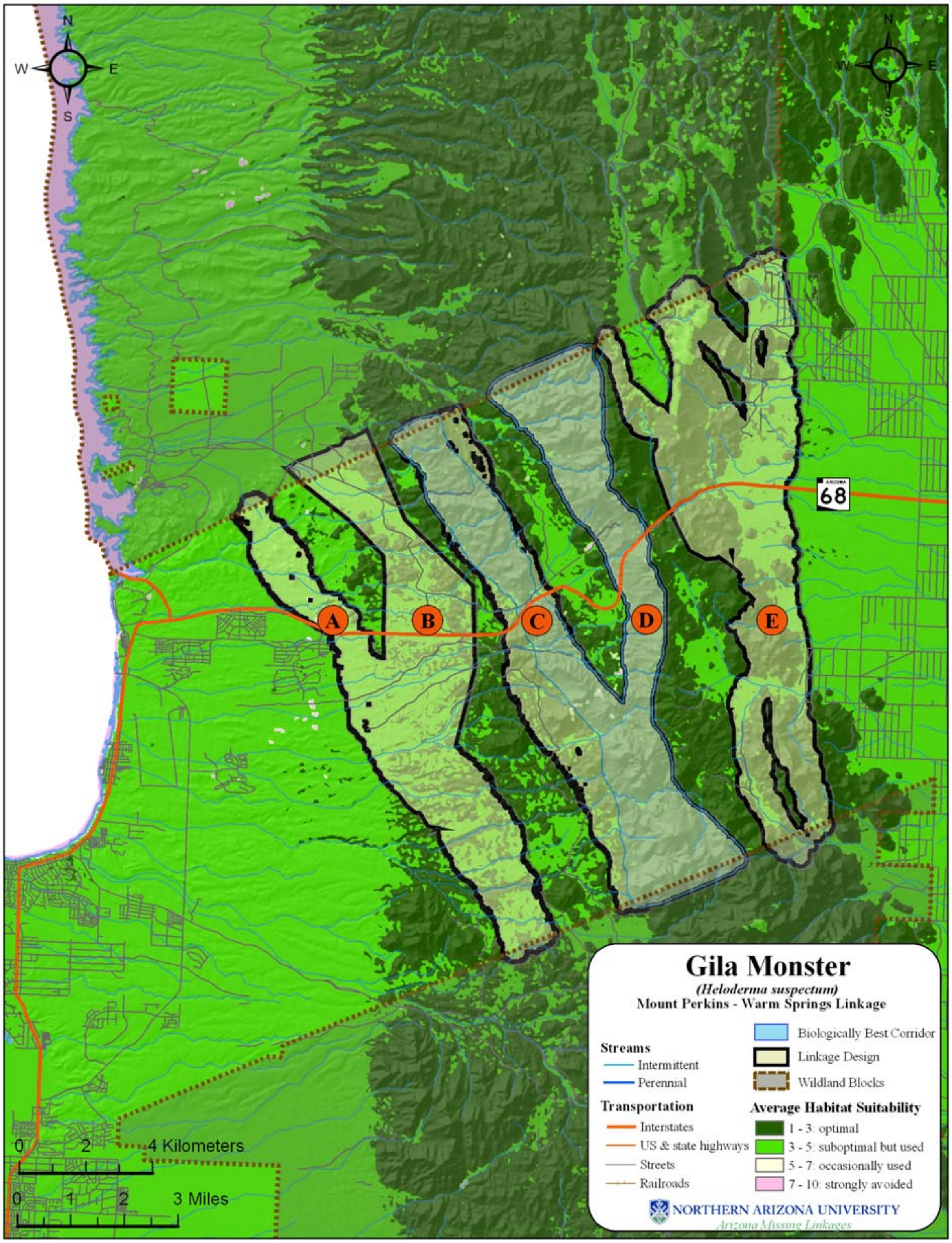

Figure 31: Modeled habitat suitability for gila monster

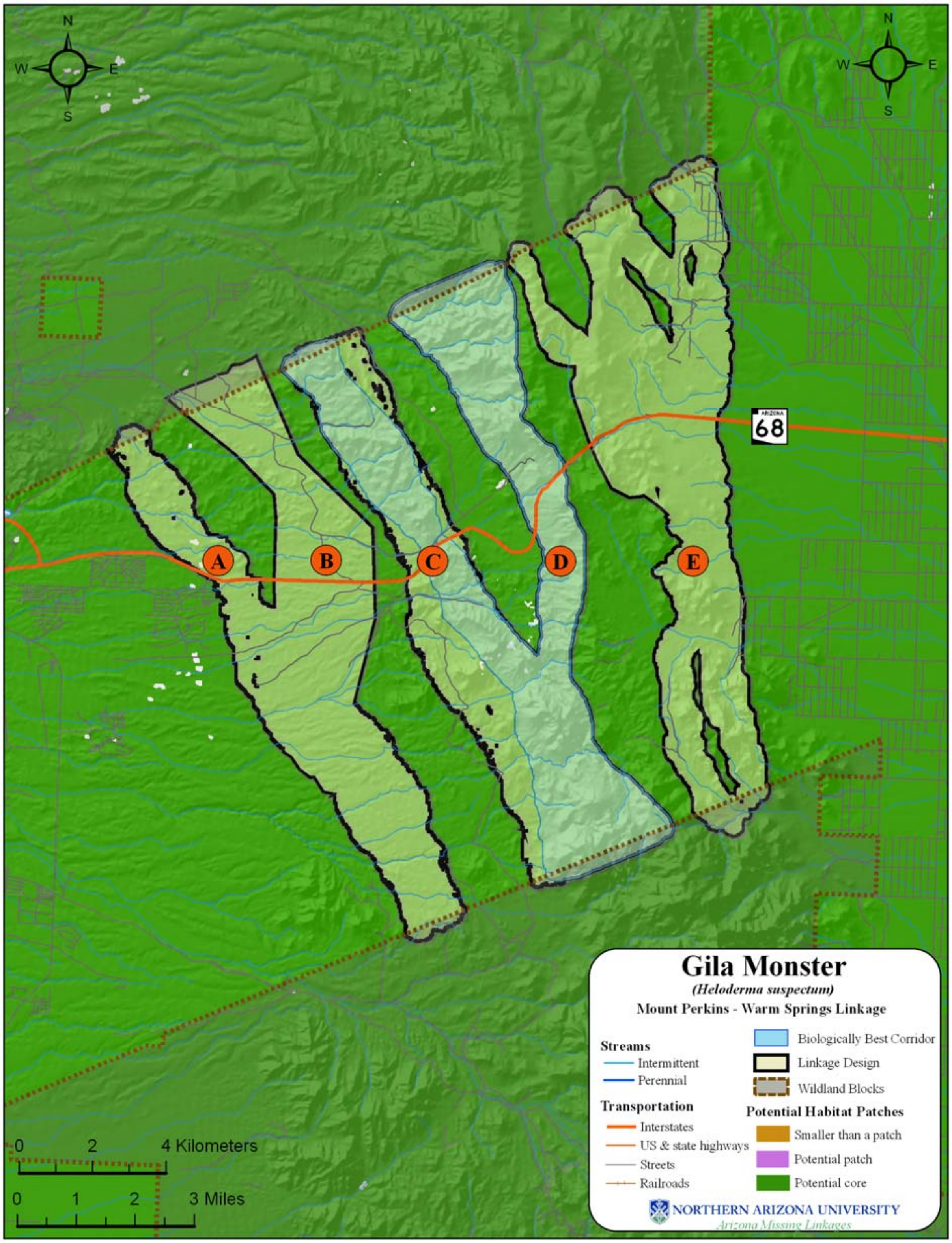

Figure 32: Potential habitat patches and cores for gila monster

Kit Fox (*Vulpes macrotis*)

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

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

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

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

Conceptual Basis for Model Development
Habitat suitability model –Vegetation received an importance weight of 75%, while topography and distance from roads received weights of 15% and 10%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

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

Results & Discussion
Initial biologically best corridor – Modeling results depict optimally-rated habitat for kit fox throughout most of the potential linkage area, with some small patches of suitable habitat and avoided habitat located in developed areas or rugged terrain (Figure 33). Within the BBC, habitat suitability scores ranged from

1.0 to 6.4, with and average of 1.4 (SD. 0.3). Nearly all of the potential linkage area serves a potential habitat core, with the exception of the areas rated as avoided (Figure 33 and Figure 29).

Union of biologically best corridors – Strand C captures additional optimally rated kit fox habitat that serves as a population core, Strand E is interspersed with avoided habitat due to its more rugged terrain.

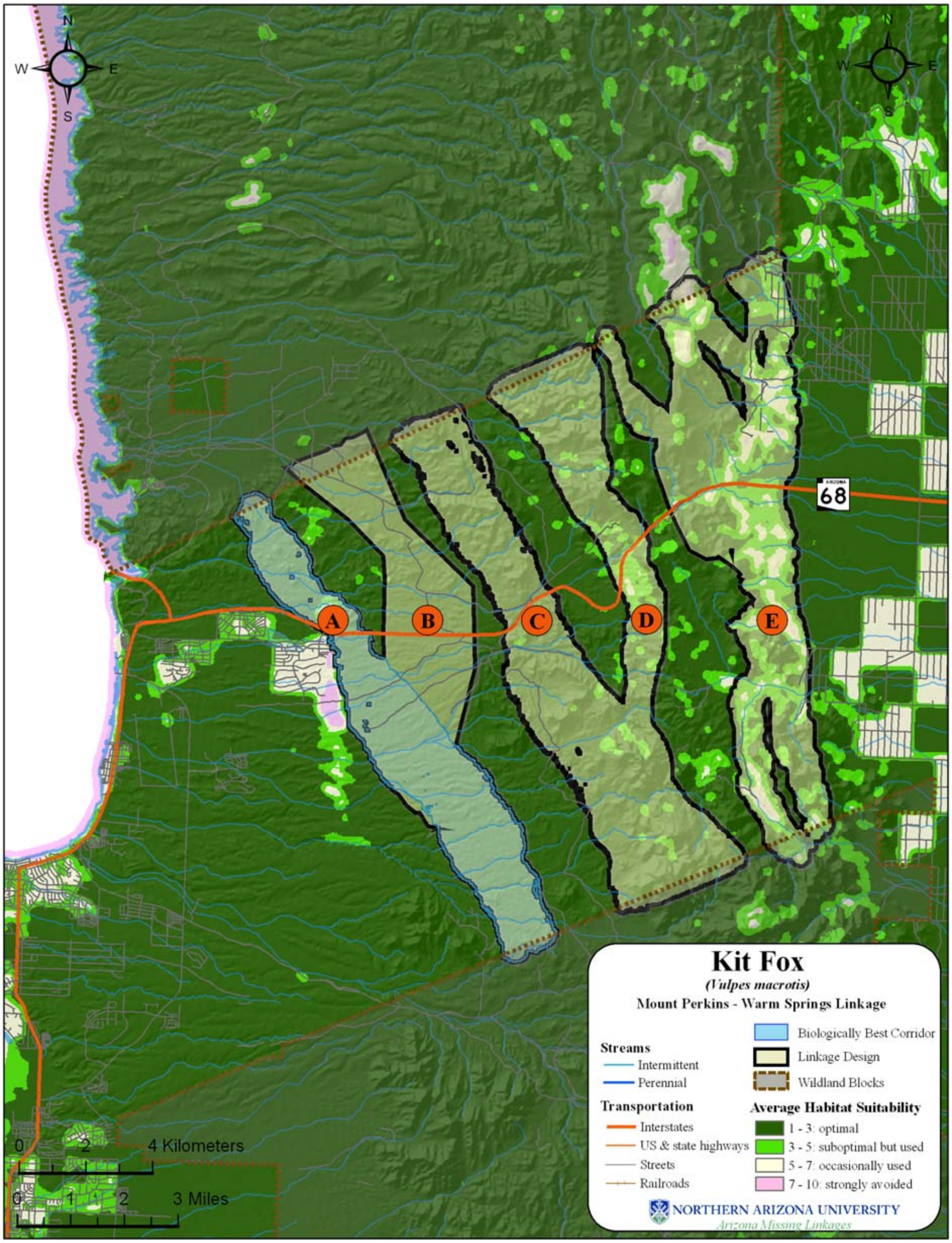

Figure 33: Modeled habitat suitability for kit fox

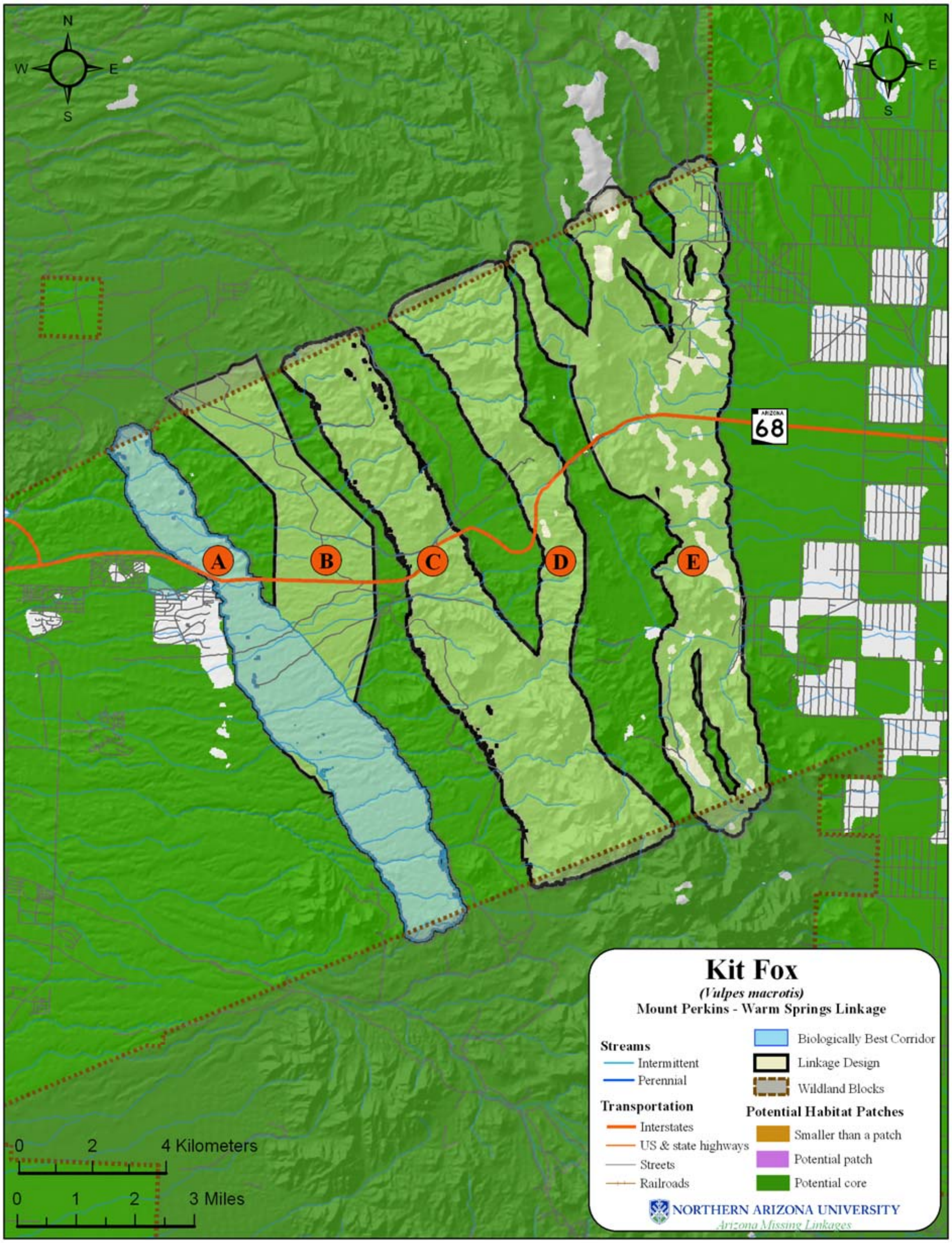

Figure 34: Potential habitat patches and cores for kit fox

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, mixed forests, shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Game and Fish Department 2004). Mountain lions are found at elevations ranging from 0 to 4,000 m (Currier 1983).

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling identified discontinuous patches of suitable habitat in the eastern portion of the linkage planning area, interspersed with a few optimally rated patches, with the majority of the potential linkage area comprised of occasionally used habitat (Figure 35). Within the BBC, habitat suitability scores ranged from 1.4 to 6.3, averaging 4.5 (SD. 1.0). Because of the large spatial requirements of mountain lions and the discontinuity of the suitable and optimal habitat, there are many small areas classified as smaller than a patch, and no potential cores were identified (Figure 36).

Union of biologically best corridors – Within Strand D, we find some additional suitable mountain lion habitat and potential habitat cores, though the remainder of the Linkage Design is comprised of less suitable or occasionally used habitat.

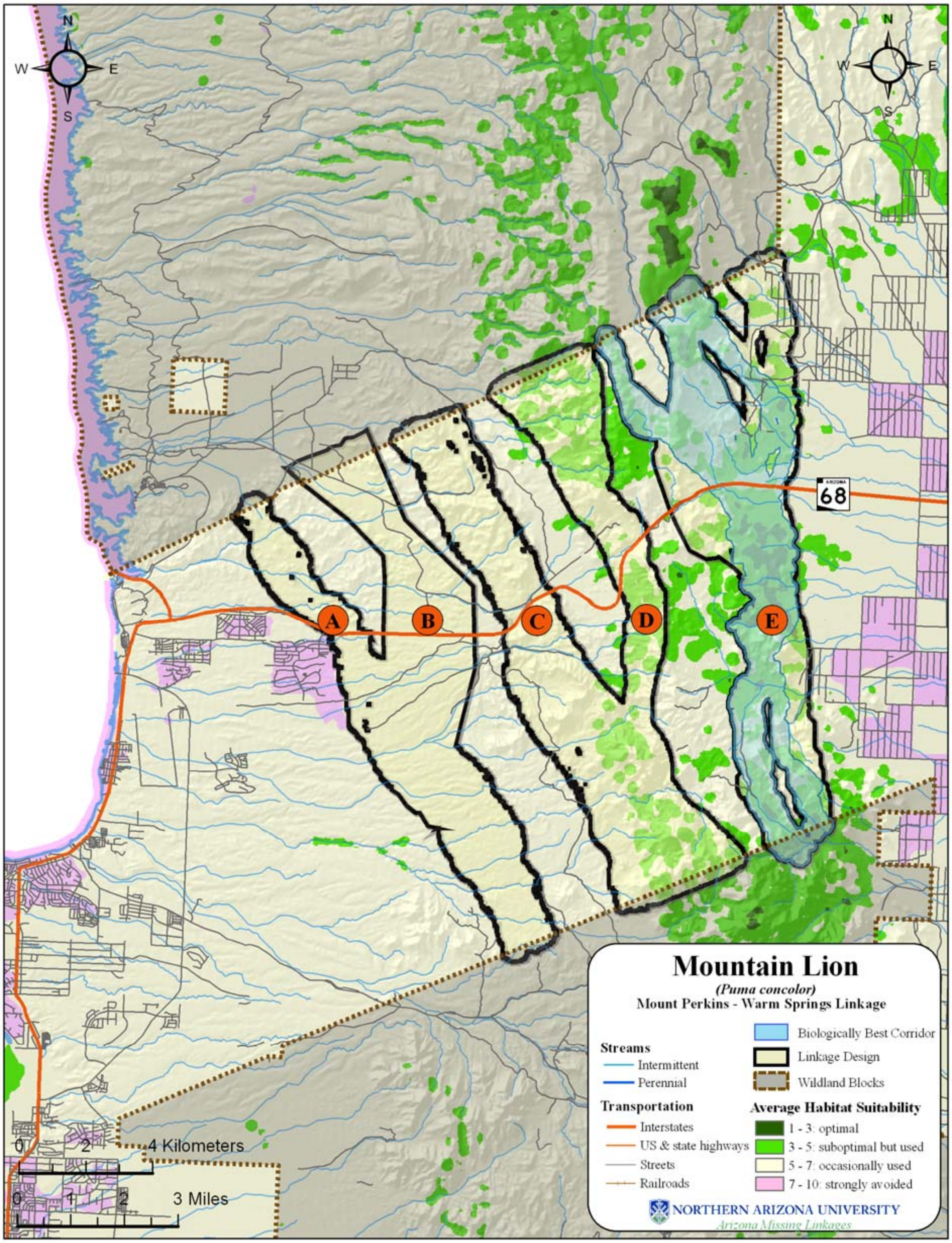

Figure 35: Modeled habitat suitability of mountain lion

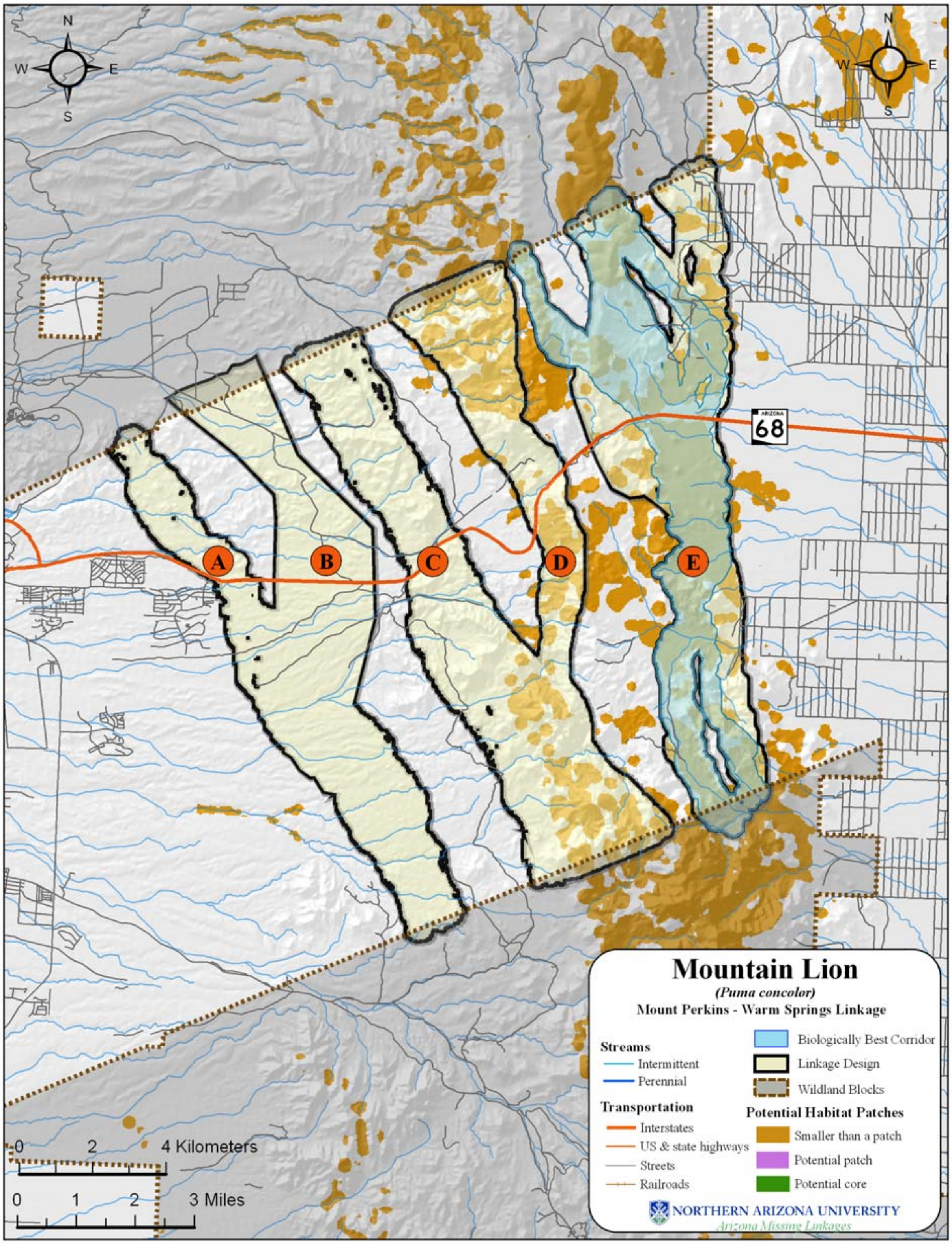

Figure 36: Potential habitat patches and cores for mountain lion

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – 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 identified very few suitably-rated patches of habitat for mule deer within the potential linkage area (Figure 37). Within the BBC, habitat scores ranged from 1.6 to 5.6 with and average of 3.0 (SD. 0.5). Because of the large spatial requirements of mule deer populations and the discontinuity of the suitable habitat, there are many small areas classified as smaller than a patch, and no potential cores were identified (Figure 38).

Union of biologically best corridors – Strand C encompasses some additional areas determined to be smaller than potential habitat patches that are comprised of suitably-rated habitat, while the remaining strainds do not capture any additional mule deer habitat.

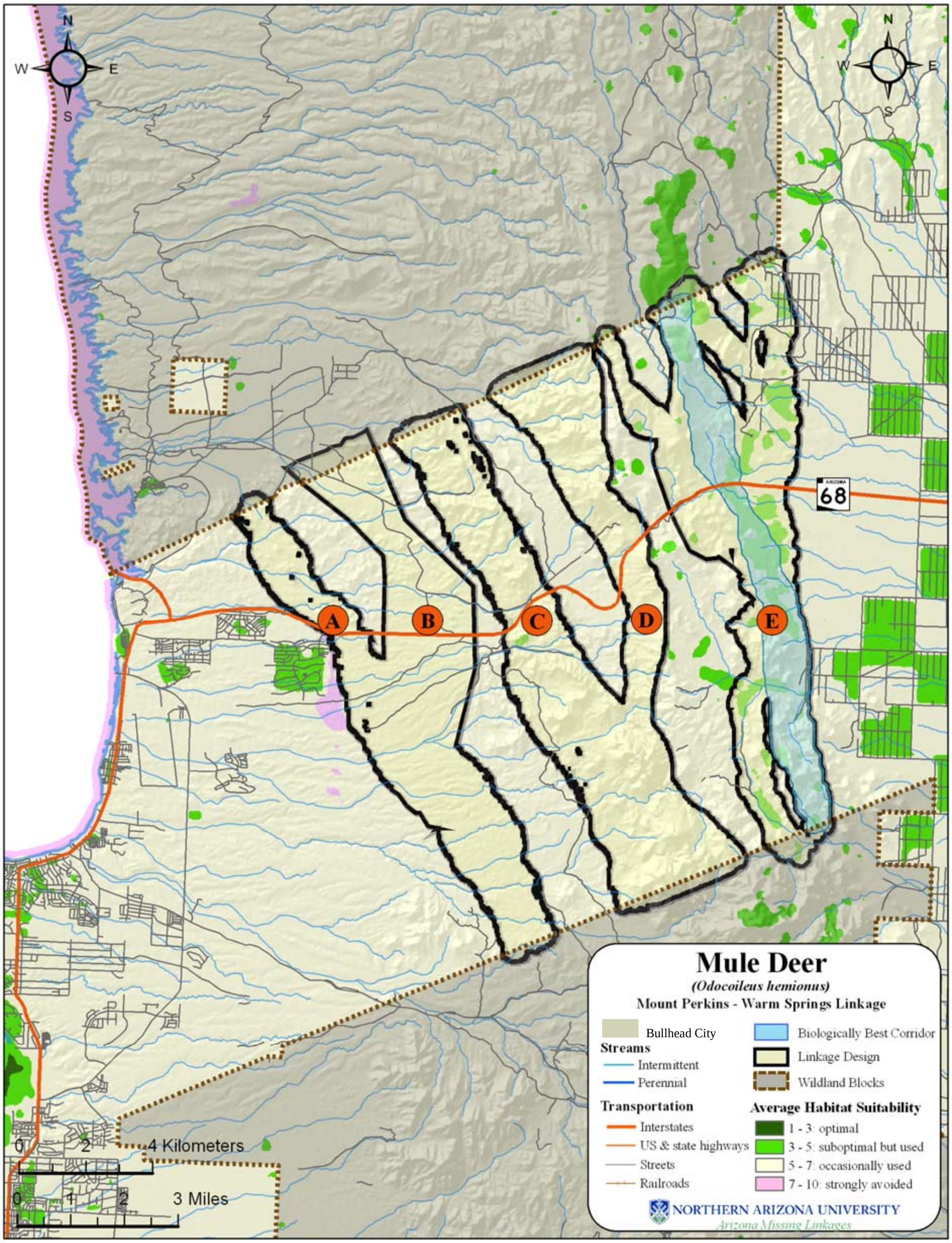

Figure 37: Modeled habitat suitability for mule deer

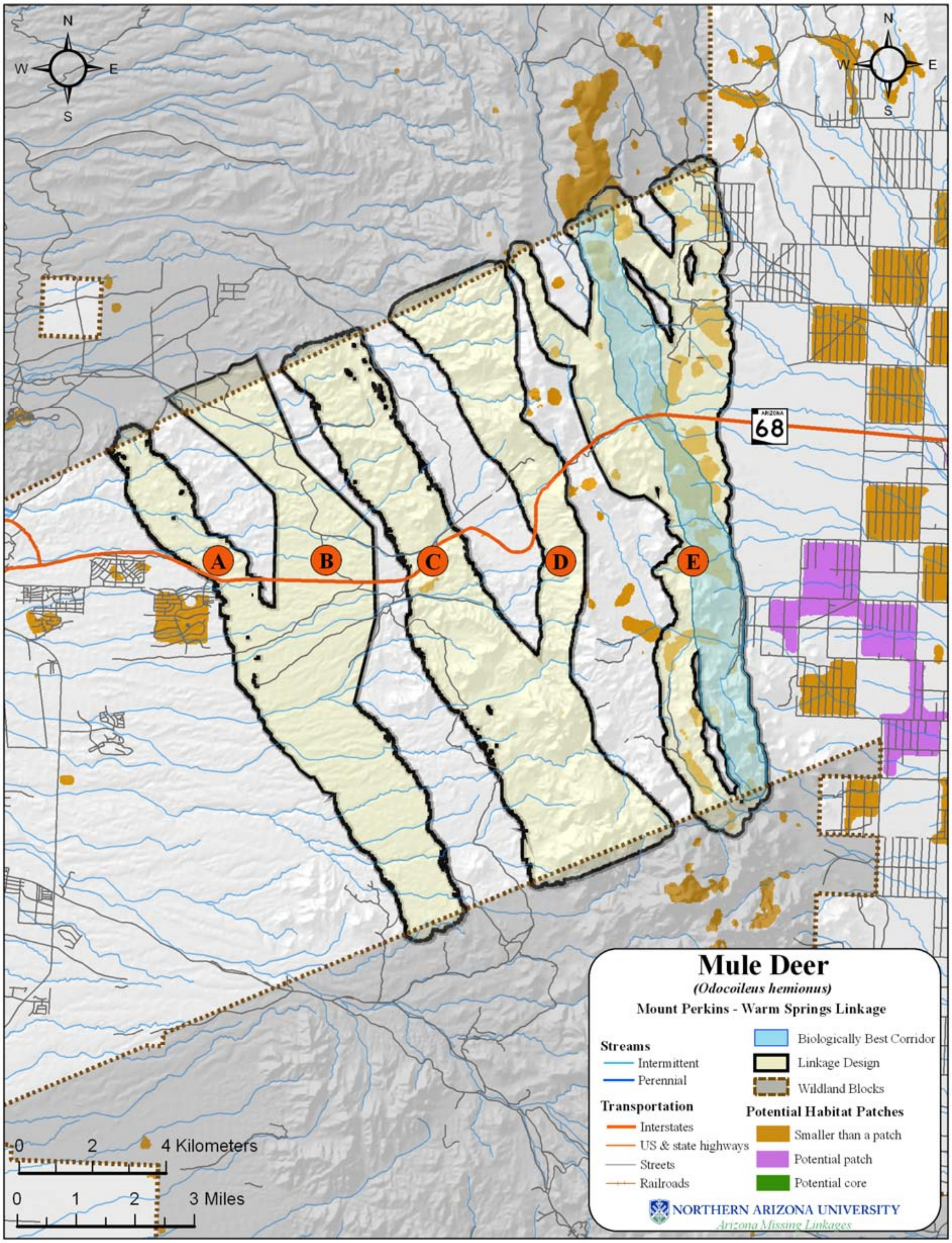

Figure 38: Potential habitat patches and cores for mule deer

Appendix C: Focal Species not Modeled

In addition to the riparian and aquatic obligate species listed above, the habitat requirements and connectivity needs of several other suggested focal species were not modeled in this study. A list of these species follows:

Mammals

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

Birds

- Peregrine Falcon (*Falco peregrinus*) – Found in Arizona wherever sufficient prey is found near cliffs though optimum peregrine habitat is generally considered to be steep, sheer cliffs overlooking woodlands, riparian areas or other habitats supporting avian prey species in abundance. In Arizona these birds utilize areas from around 400 ft (122 m) along the lower Colorado River, to 9,000 ft (2743 m) along the Mogollon Rim (AGFD 2002).

- Swainson's Hawk (*Buteo swainsoni*) – Found sparingly in central to south-central Arizona, these hawks tend to prefer semi-desert grasslands, open desertscrub, and plains (AGFD 2001).

- Western Burrowing Owl (*Athene cunicularia)* – Western burrowing owls are designated a sensitive species by the BLM. They prefer open, well-drained grasslands, steppes, deserts, and prairies (AZGFD 2001). We reasoned they would be well-covered by the remaining suite of focal species.

Reptiles

- Arizona Chuckwalla (*Sauromalus ater*) – Chuckwallas prefer large rock outcrops and crevices within desert scrub vegetation associations (NMDGF 2005). The ReGAP land cover layer does not capture small rocky outcrops which are likely to be habitat for this species (often smaller than one 30 x 30 m pixel); consequently, the habitat requirements of this species could not be adequately represented by our habitat suitability modeling process.

- Desert Rosy Boa (*Lichanura trivirgata*) – In Arizona, usually found on or near rocky mountains or hillsides in desert ranges, where they inhabit the granite rock outcroppings that absorb the suns rays providing heat and cover. They are susceptible to highway mortality, habitat alteration, and commercial collection (NMGFD 1996).

- Speckled Rattlesnake (*Crotalus mitchellii*) – This species is generally associated with rocky washes, outcrops, hills and mountain slopes. Primarily a rock dweller, but also sometimes occurs on loose soil or sandy areas, in sagebrush, creosote bush, succulent desert, thornscrub, chaparral, and pinyon-juniper woodland (Stebbins 1985).

Appendix D: The Linkage Design

To develop 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 39):

- We filled in holes that were artifacts of the modeling process.
- We created Strand B to match field observations of Mohave desert tortoise in the linkage area.
- We expanded Strand E westward to include areas heavily used by bighorn sheep, and to include the crossing structure at MP12 at which at least 22 bighorn sheep crossings have occurred.
- In Strand A, we removed a narrow arm of the UBBC on the eastern side, and widened the strand as it crosses Highway 68.
- We widened the UBBC in some locations to ensure all strands were at least 1 km wide.

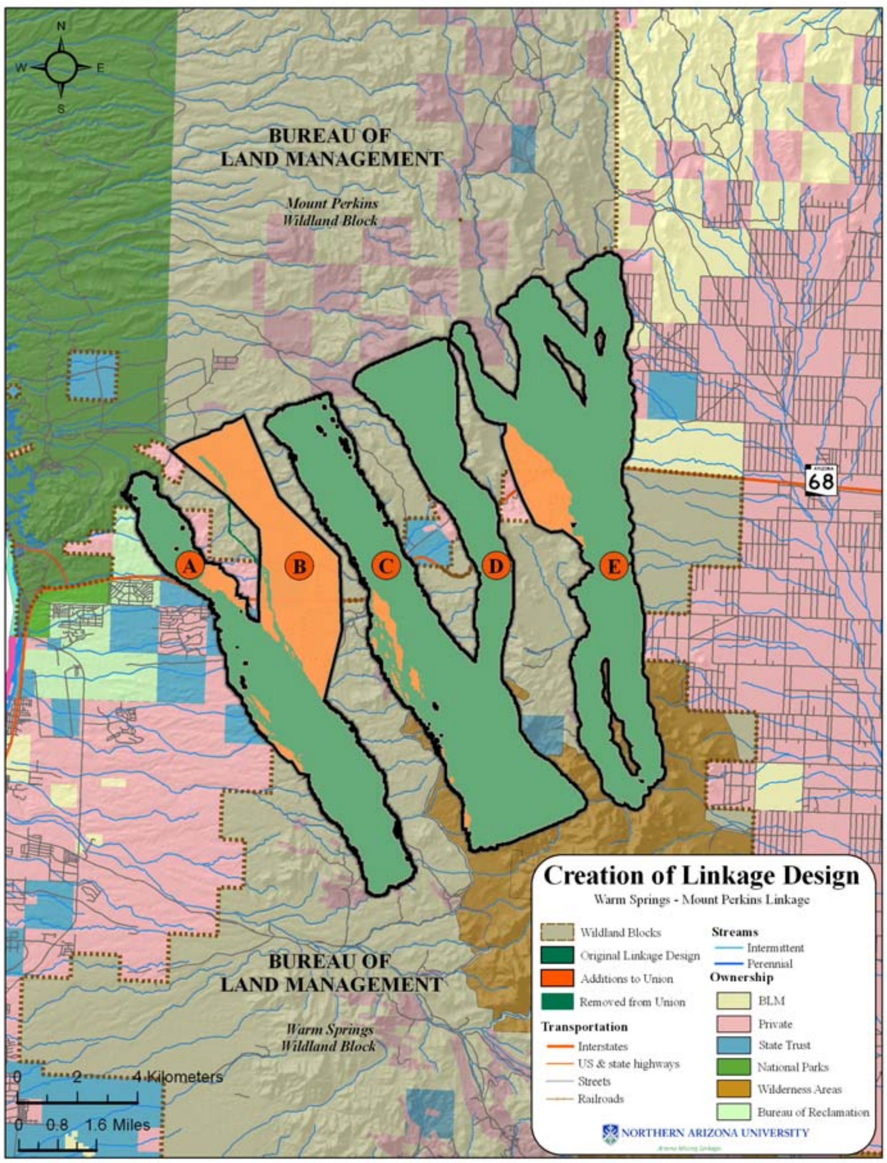

Figure 39: Adjustments to union of biologically best corridors to create the linkage design

Appendix E: Description of Land Cover Classes

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

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

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Appendix G: Database of Field Investigations

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

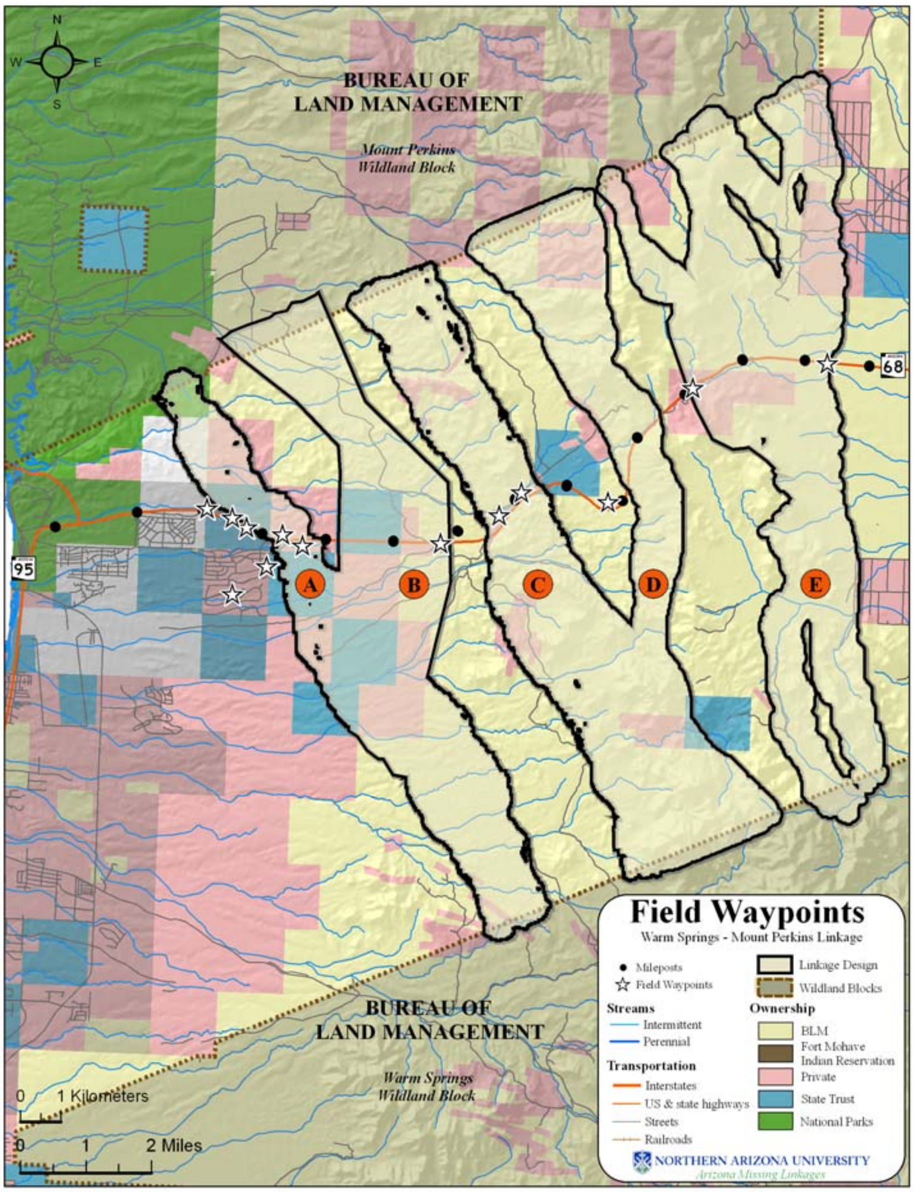
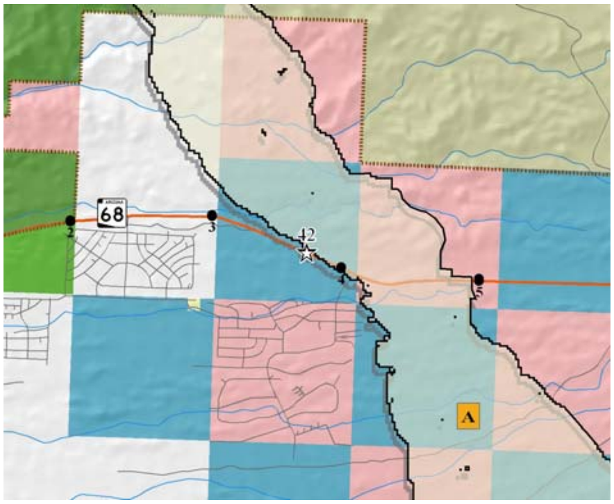


Figure 40: Field investigation waypoints in the linkage planning area

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	42		
Linkage Zone:		**Latitude:**	35.18756096	**Longitude:**	-114.50631
Observers:	Emily Garding	**UTM X:**	179283	**UTM Y:**	3900165
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

Residential development near Strand A

Site Photographs

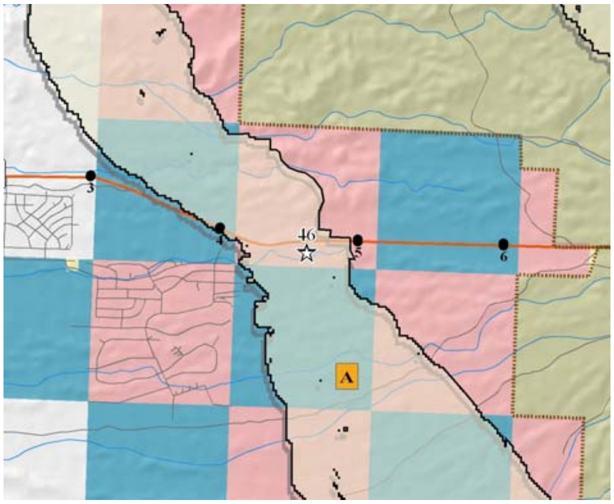
Name: IMG_1120.jpg

Azimuth: 160 **Zoom:** 1

Notes: Development near Strand A

Linkage #:	19	**Waypoint #:**	46		
Linkage Zone:		**Latitude:**	35.18396096	**Longitude:**	-114.49101
Observers:	Emily Garding	**UTM X:**	179904	**UTM Y:**	3899932
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

A wash running parralell to SR-68

Site Photographs

Name: IMG_1127.jpg

Azimuth: 260 **Zoom:** 1
Notes: An opportunity for a bridge under SR-68

Name: IMG_1128.jpg

Azimuth: 90 **Zoom:** 1
Notes: Private parcels along SR-68

Name: IMG_1129.jpg

Azimuth: 170 **Zoom:** 1
Notes: The Warm Springs Wildland Block

Name: IMG_1130.jpg

Azimuth: 240 **Zoom:** 1
Notes: Looking toward Bullhead City and outlying residential development

Appendix E: Database of Field Investigations

Linkage #: 19

Linkage Zone:

Observers: Emily Garding

Field Study Date: 8/14/2007

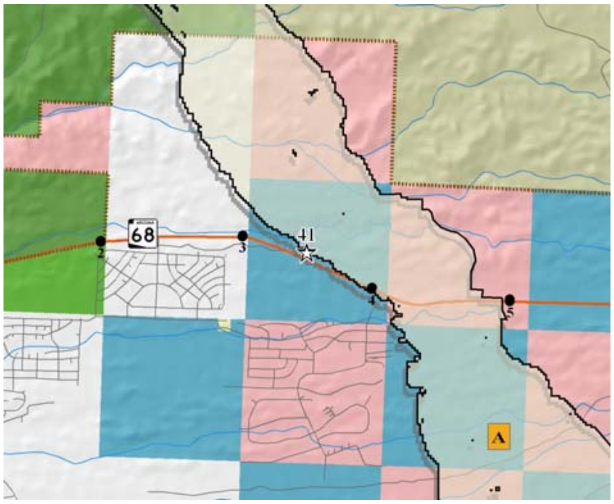
Waypoint #: 41

Latitude: 35.18956096 **Longitude:** -114.51021

UTM X: 180251 **UTM Y:** 3899698

Last Printed: 1/3/2008

Waypoint Map

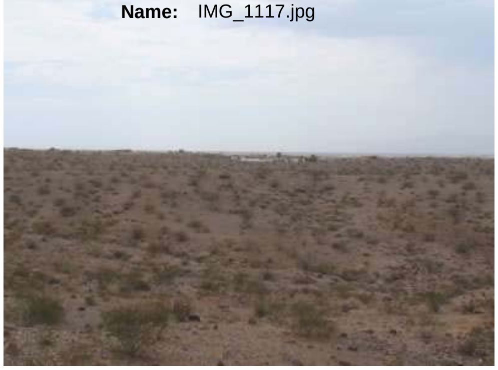


Waypoint Notes

Development to the south and east, near Strand A

Site Photographs

Name: IMG_1117.jpg



Azimuth: 190 **Zoom:** 2

Notes: A residential development visible in the south

Name: IMG_1118.jpg

Azimuth: 150 **Zoom:** 2

Notes: Residential area and Black Mountains visible in the distance

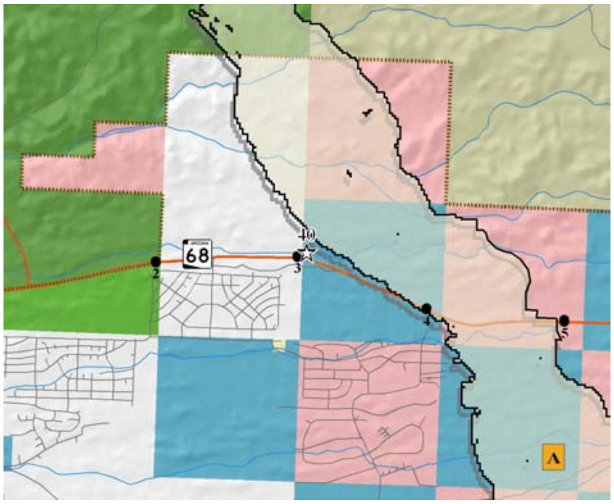
Name: IMG_1119.jpg

Azimuth: 110 **Zoom:** 1

Notes: SR-68 and the Black Mountains

Linkage #:	19	**Waypoint #:**	40		
Linkage Zone:		**Latitude:**	35.19146096	**Longitude:**	-114.51711
Observers:	Emily Garding	**UTM X:**	180966	**UTM Y:**	3899028
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map

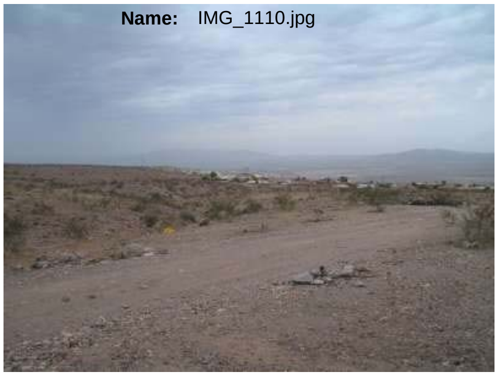


Waypoint Notes

SR-68 is a divided highway in this portion of the linkage planning area

Site Photographs

Name: IMG_1110.jpg



Azimuth: 240 **Zoom:** 1

Notes: Residential development west of the linkage design

Name: IMG_1111.jpg

Azimuth: 280 **Zoom:** 1

Notes: Toward Bullhead city and the Colorado River

Name: IMG_1112.jpg

Azimuth: 350 **Zoom:** 1

Notes: SR-68

Name: IMG_1113.jpg

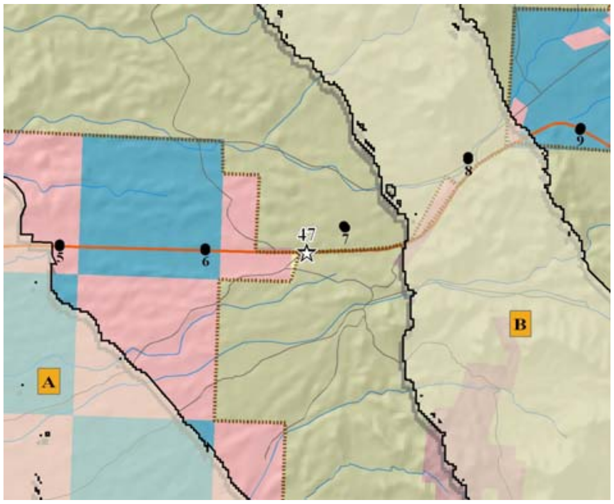
Azimuth: 90 **Zoom:** 1

Notes: SR-68 looking toward the Black Mountains

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	47		
Linkage Zone:		**Latitude:**	35.18552446	**Longitude:**	-114.453886
Observers:	Emily Garding	**UTM X:**	181227	**UTM Y:**	3899941
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

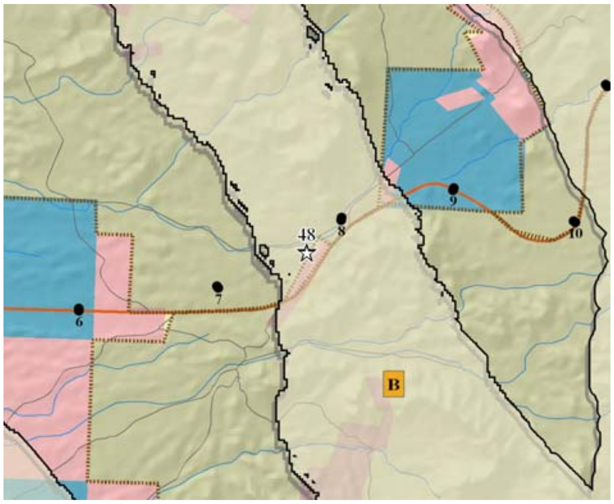
Near Mile 7 on SR-68

Site Photographs

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	48		
Linkage Zone:		**Latitude:**	35.19215496	**Longitude:**	-114.438357
Observers:	Emily Garding	**UTM X:**	179803	**UTM Y:**	3899136
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

A major wash crossing SR-68

Site Photographs

Name: IMG_1132.jpg

Azimuth: 230 **Zoom:** 1

Notes: A large bridge under SR-68, with a fence that would funnel wildlife to the bridge

Name: IMG_1133.jpg

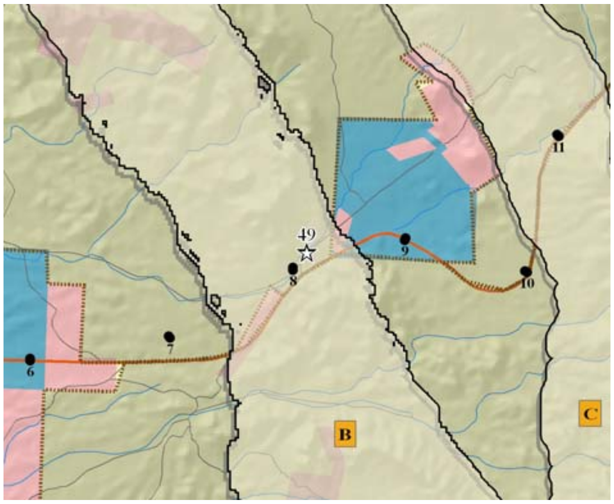
Azimuth: 80 **Zoom:** 1

Notes: Upstream toward the Black Mountains

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	49		
Linkage Zone:		**Latitude:**	35.19744773	**Longitude:**	-114.432526
Observers:	Emily Garding	**UTM X:**	181631	**UTM Y:**	3899249
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

Near Mile 8 on SR-68

Site Photographs

Name: IMG_1134.jpg

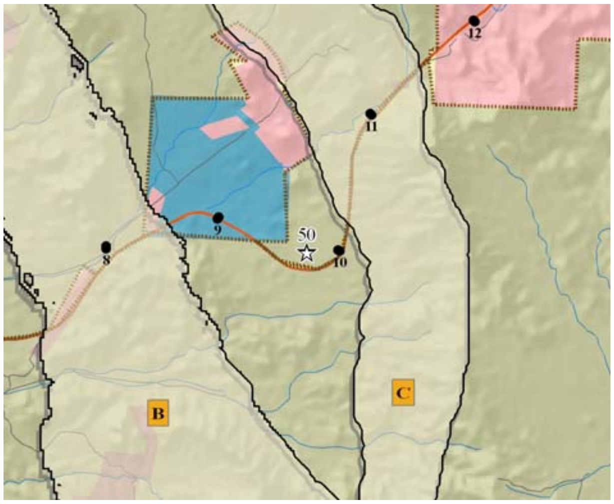
Azimuth: 30 **Zoom:** 1

Notes: Box culverts underneath SR-68

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	50		
Linkage Zone:		**Latitude:**	35.19594423	**Longitude:**	-114.409135
Observers:	Emily Garding	**UTM X:**	184939	**UTM Y:**	3899689
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

A basin near the eastern arm of Strand B

Site Photographs

Name: IMG_1135.jpg

Azimuth: 154 **Zoom:** 1

Notes: A basin in the Black Mountains

Name: IMG_1136.jpg

Azimuth: 220 **Zoom:** 1

Notes: An opportunity for a crossing under SR-68 along the basin

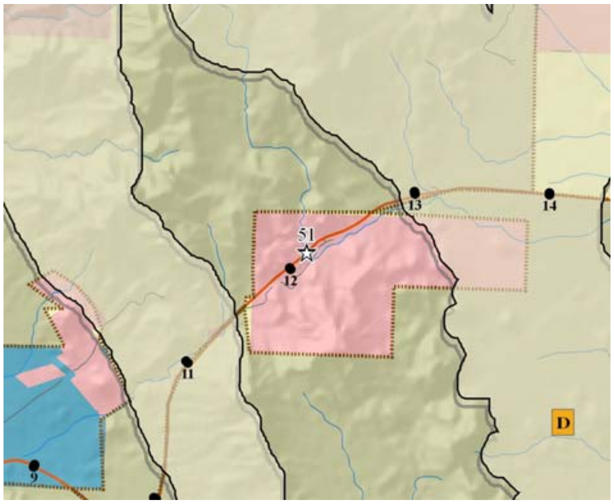
Name: IMG_1137.jpg

Azimuth: 240 **Zoom:** 1

Notes: The Mount Perkins Wildland Block across SR-68

Linkage #:	19	**Waypoint #:**	51		
Linkage Zone:		**Latitude:**	35.22198354	**Longitude:**	-114.387253
Observers:	Emily Garding	**UTM X:**	186397	**UTM Y:**	3900693
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

SR068 between Strands B and C

Site Photographs

Name: IMG_1138.jpg

Azimuth: 60 **Zoom:** 1

Notes: A jersey bariier along SR-68 impeding wildlife movement

Name: IMG_1139.jpg

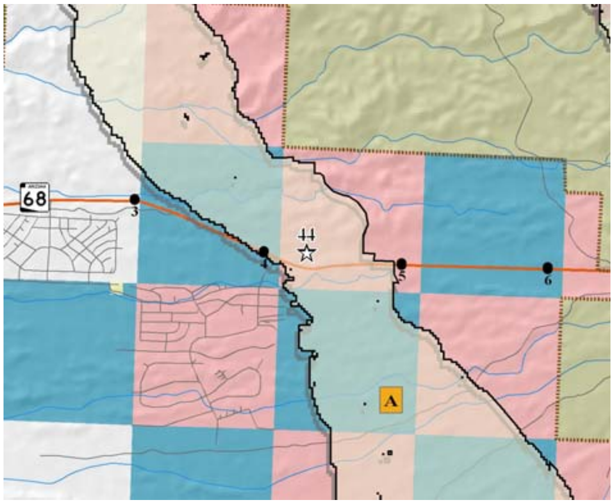
Azimuth: 260 **Zoom:** 1

Notes: SR-68 and jersey barrier

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	44		
Linkage Zone:		**Latitude:**	35.18622332	**Longitude:**	-114.496600
Observers:	Emily Garding	**UTM X:**	187390	**UTM Y:**	3900937
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

In Strand A

Site Photographs

Name: IMG_1124.jpg

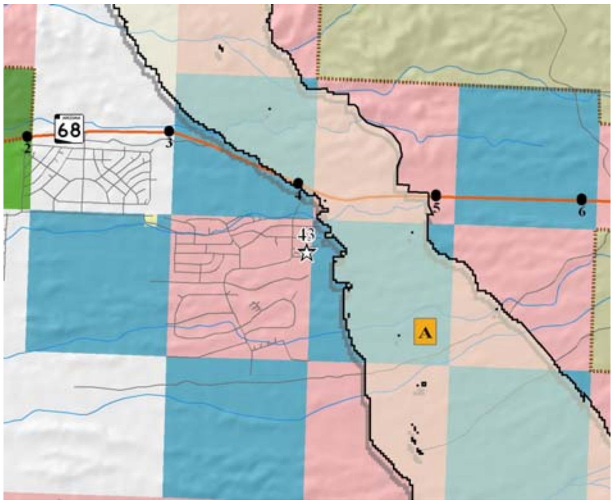
Azimuth: 230 **Zoom:** 1

Notes: Homes and associated landscaping near Strand A

Appendix E: Database of Field Investigations

Linkage #:	19	**Waypoint #:**	43		
Linkage Zone:		**Latitude:**	35.17906750	**Longitude:**	-114.500565
Observers:	Emily Garding	**UTM X:**	189307	**UTM Y:**	3900715
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

Near Strand A

Site Photographs

Name: IMG_1121.jpg

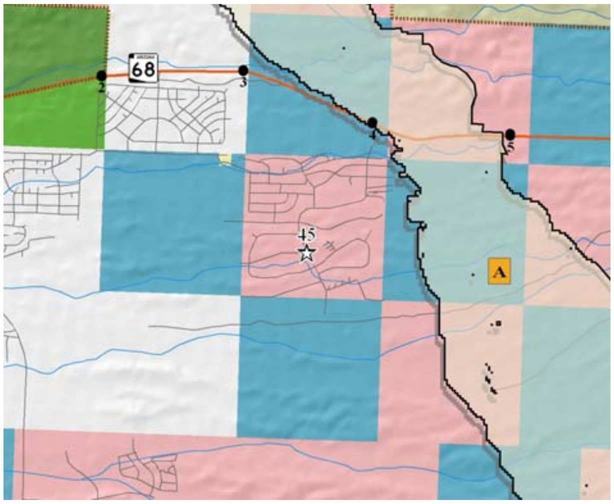
Azimuth: 180 **Zoom:** 1

Notes: Homes near Strand A

Name: IMG_1122.jpg

Linkage #:	19	**Waypoint #:**	45		
Linkage Zone:		**Latitude:**	35.17259822	**Longitude:**	-114.509553
Observers:	Emily Garding	**UTM X:**	191840	**UTM Y:**	3903595
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

Homes line the sides of a major wash that runs west to east through the linkage planning area

Site Photographs

Name: IMG_1125.jpg

Azimuth: 250 **Zoom:** 1

Notes: Downstream

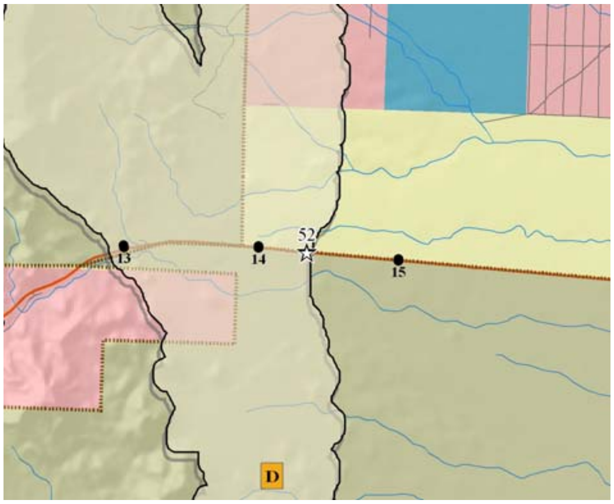
Name: IMG_1126.jpg

Azimuth: 70 **Zoom:** 1

Notes: Upstream, the Black Mountains in the background

Linkage #:	19	**Waypoint #:**	52		
Linkage Zone:		**Latitude:**	35.22846872	**Longitude:**	-114.351204
Observers:	Emily Garding	**UTM X:**	194345	**UTM Y:**	3904365
Field Study Date:	8/14/2007	**Last Printed:**	1/3/2008		

Waypoint Map



Waypoint Notes

Strand C

Site Photographs

Name: IMG_1140.jpg

Azimuth: 290 **Zoom:** 1

Notes: Toward Strand C