ARIZONA MISSING LINKAGES

Wickenburg-Hassayampa Linkage Design

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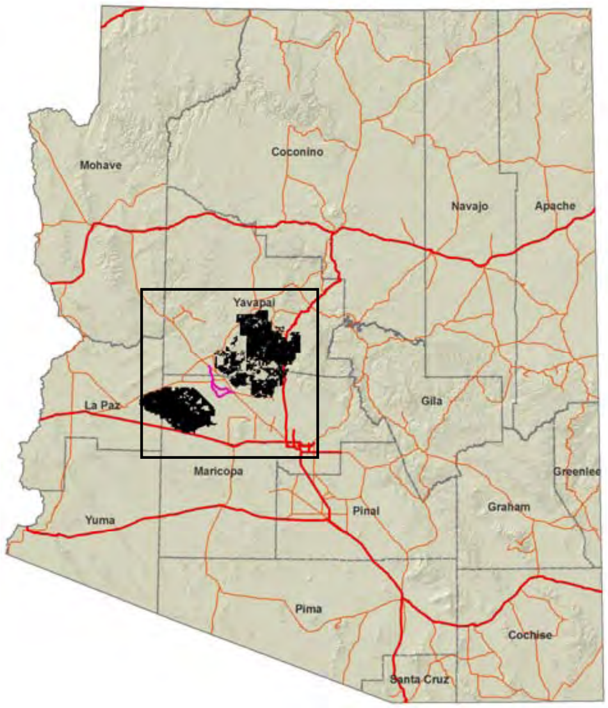
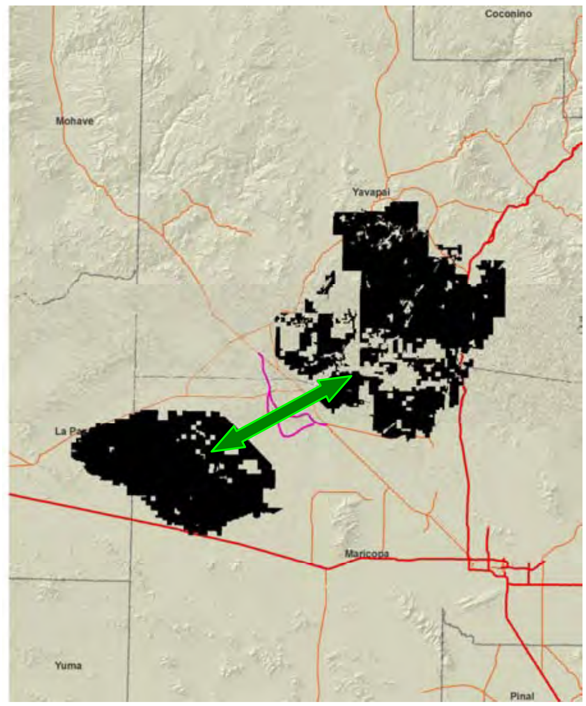
NORTHERN ARIZONA UNIVERSITY

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

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

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

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

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

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

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

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

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between two large areas of BLM-administered wildlands surrounding Wickenburg, Arizona. Running roughly northwest-southeast through this region, US 93, US 60, the Phoenix-Wickenburg Highway, the proposed Wickenburg Bypass, the Burlington Northern Santa Fe Railroad, and urban development provide an impediment to animal movement between the Vulture and Harquahala Mountains to the south, and the Wickenburg Mountains and Hassayampa River Watershed to the north. 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 22 focal species that are sensitive to habitat loss and fragmentation, including 1 amphibian, 4 reptiles, 6 birds, 5 fish, 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. badger, bighorn sheep). Some species are habitat specialists (e.g. bighorn sheep, Gila Monster), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer, desert tortoise). Some species are rare and/or endangered (desert tortoise, bonytail chub), while others like javelina are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of Sonoran Desert. Together, these 22 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing 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 three strands which together provide habitat for movement and reproduction of wildlife between the Vulture-Harquahala Mountains area on the south and the Wickenberg Mountains and upper Hassayampa River on the north. The eastern strand includes riverine habitats along the Hassayampa River that are crucial for many fishes, amphibians, reptiles, and birds. We visited priority areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

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

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

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

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

Table 1: Focal species selected for Wickenburg Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Badger	*Desert Tortoise	Black-throated Sparrow
*Bighorn Sheep	*Gila Monster	Common Black Hawk
*Black-tailed Jackrabbit	§ Gilbert's Skink	Red-shouldered Hawk
*Javelina	§ Lowland Leopard Frog	Road Runner
*Mountain Lion	Mexican Garter Snake	§ Southwestern Willow Flycatcher
*Mule Deer		§ Yellow-billed Cuckoo
		FISH
		§ Bonytail Chub
		§ Desert Pupfish
		§ Gila Topminnow
		§ Longfin Dace
		§ Razorback Sucker

* Species modeled in this report. The other species were not modeled because there were insufficient data to quantify habitat use in terms of available GIS data (e.g., species that select small rocks), or because the species probably can travel (e.g., by flying) across unsuitable habitat.
§ Species modeled as a group of "riparian obligate species."

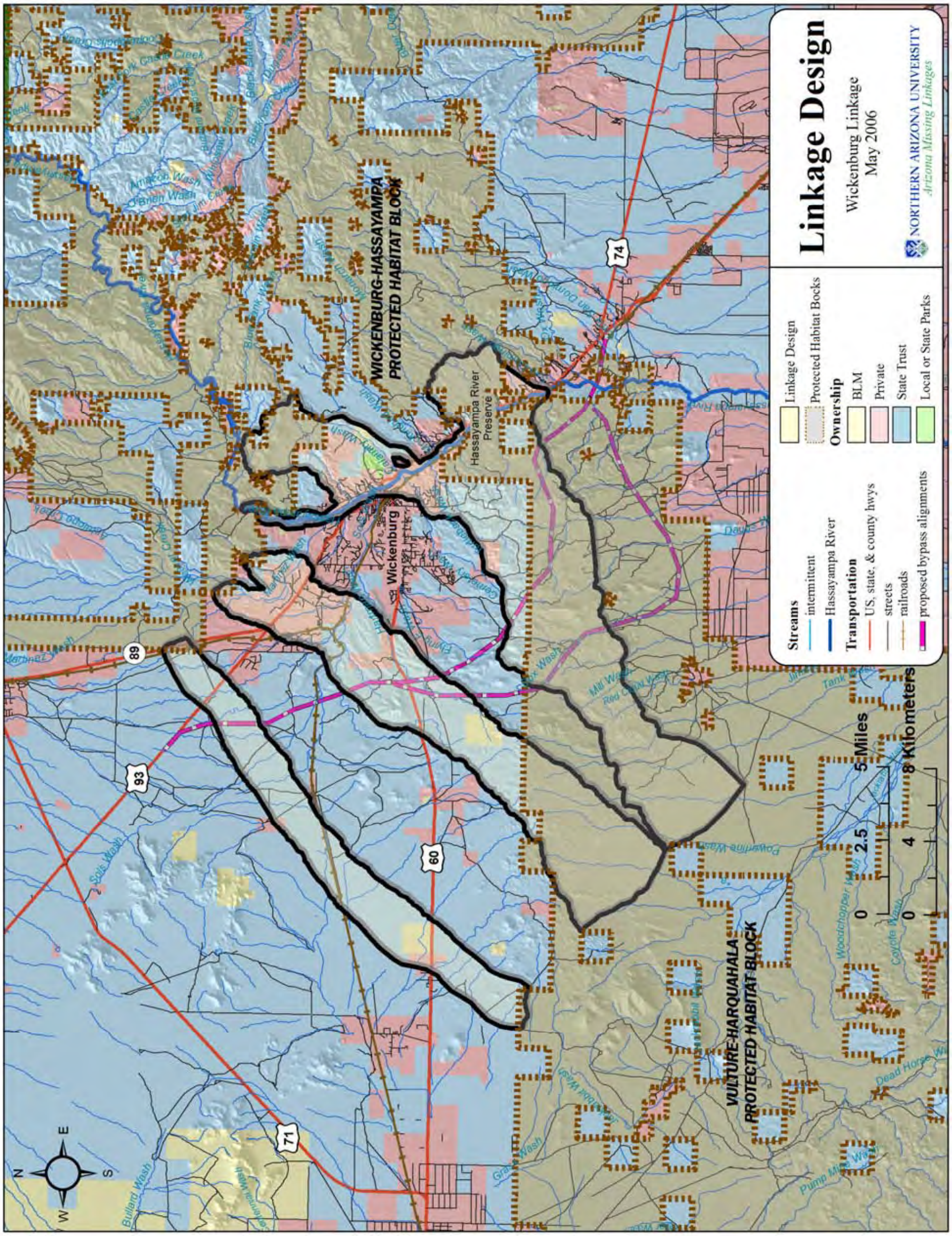

Figure 1: The Linkage Design between the Vulture-Harquahala and Wickenburg-Hassayampa wildland blocks includes three terrestrial strands, each of which is important to different species.

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, 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). The Wickenburg Linkage is one of these first 8 linkages.

Ecological Significance of the Wickenburg Linkage

The Wickenburg Linkage Planning area lies within the 55-million acre Sonoran Desert Ecoregion of southwestern Arizona, southeastern California, and northwestern Sonora, Mexico. This ecoregion is the most tropical of North America's warm deserts (Marshall et al. 2000). Bajadas sloping down from the mountains support forests of ancient saguaro cacti, paloverde, and ironwood; creosotebush and bursage desert shrub dominate the lower desert (The Nature Conservancy 2006). The Sonoran Desert Ecoregion is home to more than 200 threatened species, and its uniqueness lends to a high proportion of endemic plants, fish, and reptiles (Marshall et al. 2000; The Nature Conservancy 2006). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of 233 of the earth's most biologically valuable ecoregions.

Within the Sonoran Desert Ecoregion, the Linkage Planning Area includes two protected wildland blocks which are separated by the Phoenix-Wickenburg Highway (US 89), US 60, and a matrix of state trust and private land (Figure 2). We have named these wildland blocks the Wickenburg-Hassayampa and the Vulture-Harquahala[1]. Both areas are administered by the Bureau of Land Management.

The southern Vulture-Harquahala wildland block encompasses several desert mountain ranges including the Vulture, Harquahala, and Big Horn Mountains. These mountains support drainage systems such as Box Wash, Deadhorse Wash, Jackrabbit Wash, Tiger Wash, and Turtleback Wash. Elevation ranges from 1195 to 5691 ft, providing a geologic and topographic variability that contributes to high biological diversity.

The northern Wickenburg-Hassayampa wildland block encompasses the Wickenburg, Weaver, Hieroglyphic, Buckhorn, and Sheep Mountains, which together support drainages such as Amazon Wash, Ash Creek, Bitter Creek, Buckhorn Creek, Calamity Wash, Castle Creek, Cemetery Wash, Cottonwood Creek, French Creek, Horse Creek, Little Buckhorn Creek, Mockingbird Wash, Morgan City Wash, San Domino Wash, Spring Creek, and Weaver Creek. Elevation ranges from 1,410 to 6,150 ft.

The Linkage Planning Area is dominated by paloverde-mixed cacti desert scrub, with large amounts of creosotebush-white bursage desert scrub communities in the northwest Planning Area (Figure 3). The 6.5 miles of perennially flowing water in the Hassayampa River provides the most prominent riparian habitat in the Linkage Planning Area, including rare cottonwood-willow vegetation communities.

The varied habitat types in the Linkage Planning Area support many animal species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the desert tortoise and bighorn sheep (USFWS 2005). The Corridor Design incorporates and connects critical habitat needed for these species. The Linkage Planning Area is also home to far-ranging mammals such as mule deer, badger, and mountain lion. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as black-tailed jackrabbits, javelina, and Gila monsters also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

[1] Both blocks of BLM land have no formal designation on most maps. We named them after prominent topographic features found in each blocks: the Hassayampa River and Wickenburg Mountains in the northern block, and the Vulture and Harquahala Mountains in the southern block.

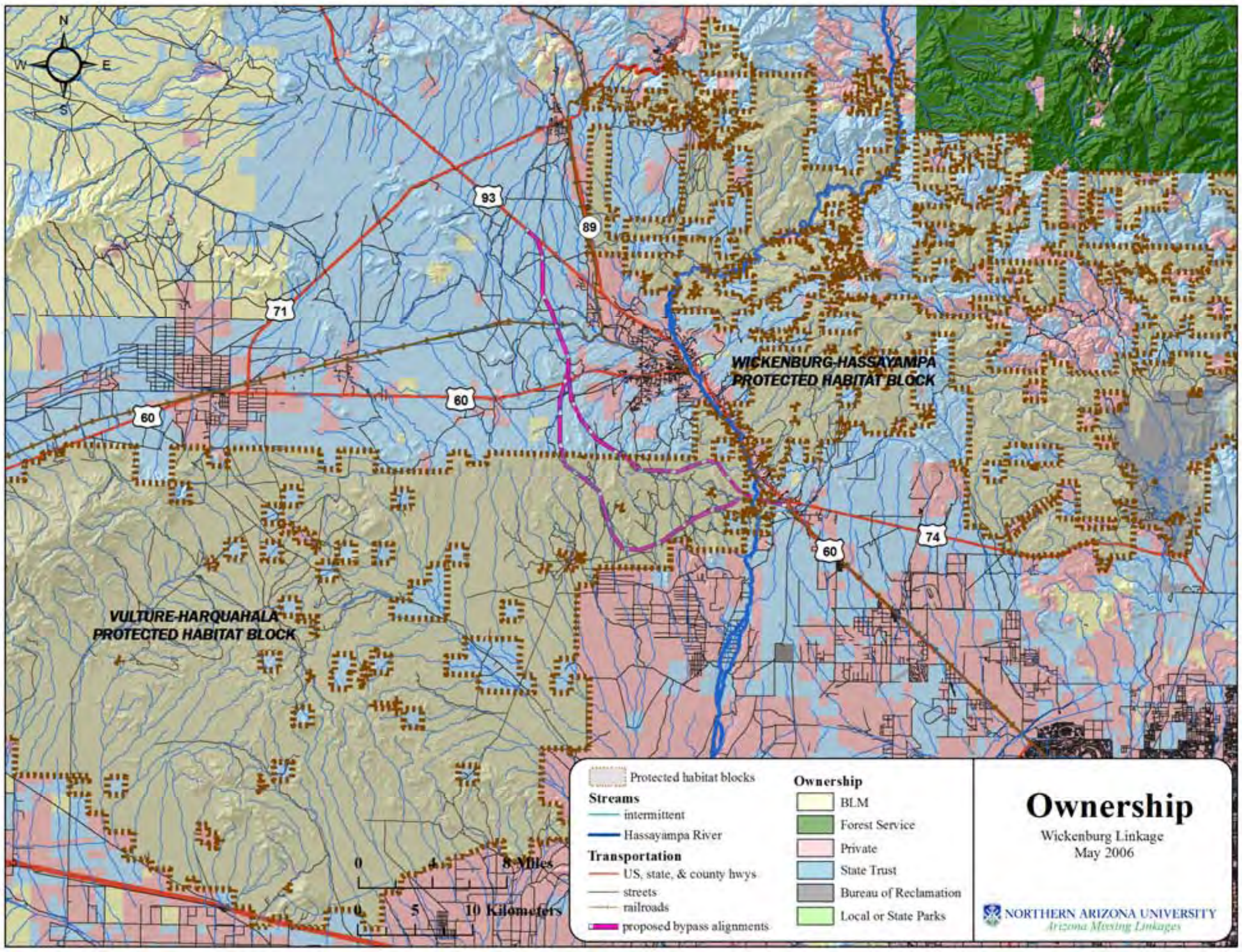

Figure 2: Land ownership within the Linkage Planning Area.

Existing Conservation Investments

The wildland blocks are comprised of land federally protected by the Bureau of Land Management. The **southern Vulture-Harquahala wildland block** consists of 510,000 protected acres of paloverde and creosotebush desert. There are 3 Wilderness Areas in this block. The 22,880-acre Harquahala Mountains Wilderness area boasts the highest point in southwest Arizona, the 5,691-foot Harquahala Peak, and supports an island of chaparral vegetation (Figure 4). Southeast of the Harquahala Wilderness, the 21,000-acre Bighorn Mountains Wilderness provides habitat for desert bighorn sheep, Gila monster, desert tortoise, kit fox, and cliff-dwelling great horned owls (BLM 2005). Adjacent to the Bighorn Mountains, the 31,200-acre Hummingbird Wilderness, dominated by paloverde, mesquite, and cacti, provides habitat for mule deer, desert tortoise, desert bighorn sheep, and Gila monsters.

The **northern Wickenburg-Hassayampa wildland block** consists of 364,000 acres of land protected by the Bureau of Land Management, the 24,000-acre Lake Pleasant Regional Park[2], and the 616,000-acre Prescott National Forest[3]. Within this wildland block is the 11,480-acre Hassayampa River Canyon Wilderness area, an important riparian habitat, and the 9,900-acre Hells Canyon Wilderness, which

[2] The park includes substantial natural areas in addition to the 10,000-acre reservoir. Most of the Park is owned by Bureau of Reclamation and managed by Maricopa County Parks.

[3] The Prescott National Forest support forest and woodlands very different from the desert lands of the southern wildland block, potential linkage area, and the rest of the northern wildland block. Because few species need to move from the southern wildland block to Prescott NF, we will not refer to the Prescott NF in the rest of this report.

includes peaks > 3,000 ft in the Hieroglyphic Mountains and which is dominated by paloverde, saguaro, ocotillo, and desert grasses (BLM 2005).

In the Potential Linkage Area (the area between the protected wildland blocks) is The Nature Conservancy's Hassayampa River Preserve. The Preserve protects 660 acres of important riparian and upland desert habitat, including the rare cottonwood-willow forests which support more than 280 species of birds, Arizona's only population of the rare Gilbert's skink (TNC 2006), and endangered fish such as bonytail chub, Gila topminnow, and longfin dace. The Tucson Audubon Society has listed the Hassayampa River as a potential Important Bird Area.

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

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include US 60, AZ 89, the Phoenix-Wickenburg Highway, US 93, the Burlington Northern Santa Fe Railroad, the proposed Wickenburg bypass, and expanding urban development in and near Wickenburg. These barriers inhibit wildlife movement between the Vulture-Harquahala and Wickenburg-Hassayampa wildland blocks. The proposed Wickenburg Bypass (Figure 3) would be a new alignment of US-93 that could present a particularly formidable barrier unless it is designed to enhance wildlife movement.

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

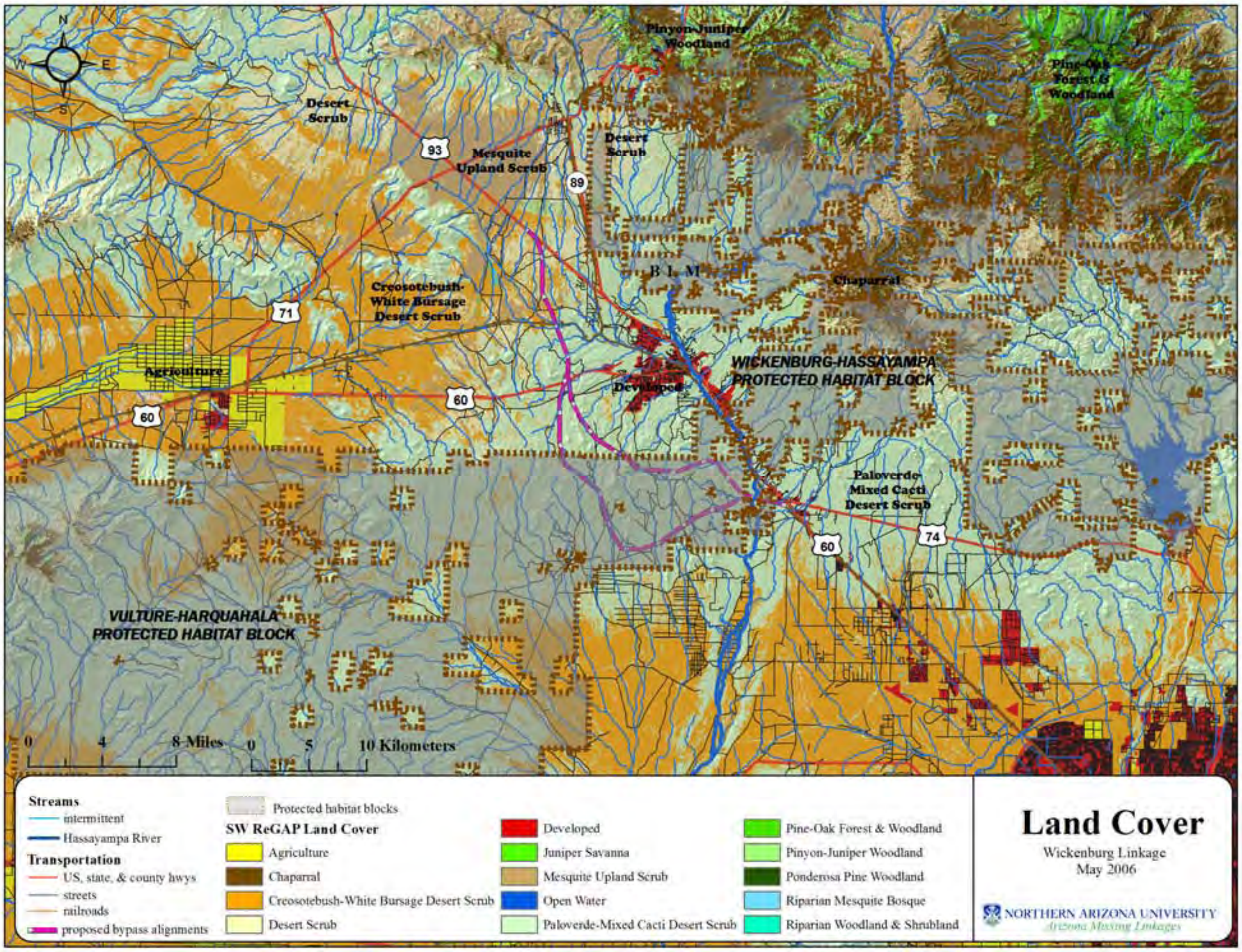

Figure 3: Land cover within the Linkage Planning Area.

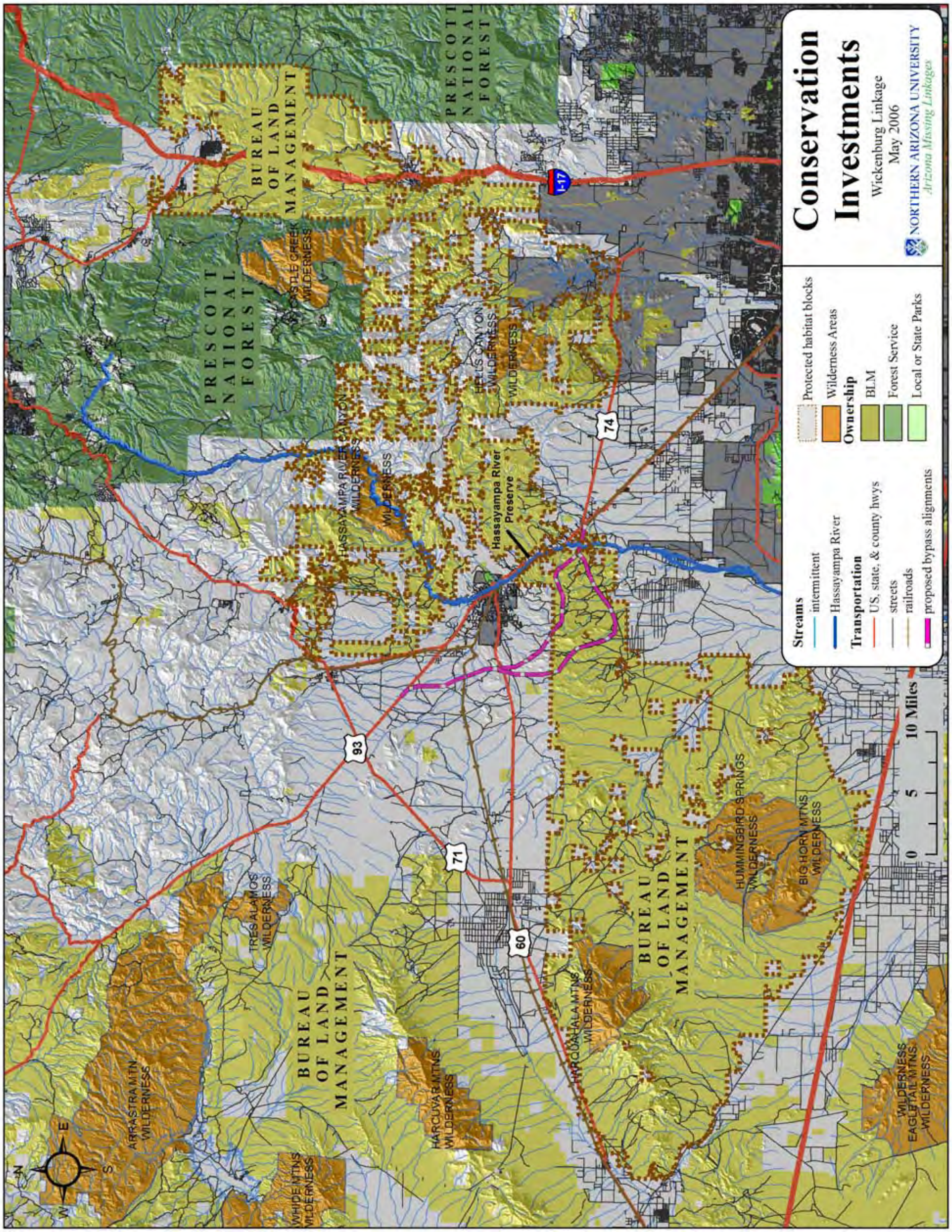

Figure 4: Existing conservation investments within the linkage planning area.

Linkage Design & Recommendations

The final Linkage Design (Figure 1, Figure 5, & Figure 6) is composed of three strands which together provide habitat for movement and reproduction of wildlife between BLM-administered lands adjacent to Wickenburg. In this section, we describe the land cover and ownership patterns in the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Three Routes Provide Connectivity Across a Diverse Landscape

The linkage design consists of three distinct strands which connect the Vulture-Harquahala and Wickenburg-Hassayampa protected wildland blocks. We describe these strands from west to east.

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

The westernmost strand of the linkage design begins west of the Vulture Mountains, runs through Aguila Valley, and captures 2.6 km of Sols Wash and many unnamed washes before joining the northern Wickenburg-Hassayampa wildland block near Martinez Creek. The strand is approximately 27 km long, and primarily composed of Creosotebush-White Bursage Desert Scrub (58%), Desert Scrub (19%), Paloverde-Mixed Cacti Desert Scrub (16%), and Mesquite Upland Scrub (5%). This strand is the flattest strand of the linkage, with an average slope of 1% (Range: 0-33%, SD: 1.8) and 99% of the area having a flat topographic position. This linkage provides live-in and pass-through habitat for species dependent on desert vegetation and/or flatter topography, such as badger, black-tailed jackrabbit, and javelina.

The middle strand of the linkage design runs through the Vulture Mountains, captures Hartman Wash and a portion of Martinez Wash, and joins the northern Wickenburg-Hassayampa wildland block near the junction of Antelope and Weaver Creeks. The strand outside of BLM-administered land is approximately 19 km long, and is primarily composed of Paloverde-Mixed Cacti Desert Scrub (88%), Creosotebush-White Bursage Desert Scrub (6%), and Desert Scrub (5%). This strand has the second greatest amount of topographic complexity, with an average slope of 7.5% (Range: 0-82%, SD: 7.2). About one-fourth (24%) of the land in this strand is classified as steep slopes, and 2% is classified as a canyon bottom or ridgetop. This linkage strand provides live-in and pass-through habitat for species dependent on desert vegetation and/or rugged topography, such as desert tortoise, black-tailed rattlesnake, desert bighorn sheep, javelina, black-tailed jackrabbit, mule deer, and Gila monster.

The easternmost strand of the linkage design begins at the Hassayampa Plain in the Vulture-Harquahala wildland block, runs through the Vulture Mountains, and encompasses Jimmie Wash, 2.4 km of Red Cloud Wash, 3.2 km of Mill Wash, Syndicate Wash, and all of Turtleback Wash to its confluence with the Hassayampa River. Over 18 km (10 miles) of the Hassayampa River are encompassed by this strand, including 11 km of perennial flow and 7.5 km of intermittent-flowing segments of the River. East of the Hassayampa River, this linkage strand splits into northern and southern segments. The northern segment joins the Wickenburg-Hassayampa wildland block near Calamity Wash and Blue Tank Wash, while the southern segment of this corridor joins BLM land at Monarch Wash. This strand is primarily composed of Paloverde-Mixed Cacti Desert Scrub (93%), with small amounts Creosotebush-White Bursage Desert

Scrub (3%), and the rare and important Riparian Mesquite Bosque and Riparian Woodland and Shrubland habitats along the Hassayampa River (0.9% and 0.6% of the southernmost strand of the linkage design, respectively). The southernmost strand of the linkage design is the most topographically complex, with an average slope of 13% (Range: 0-231%, SD: 11). Nearly half (43%) of the land within this strand is classified as steep slopes, 6% as ridegetops, and 2% as canyon bottoms. By encompassing over 10 miles of the Hassayampa River, this strand provides for species dependent on riparian or aquatic habitat, such as the southwestern willow flycatcher, yellow-billed cuckoo, Gilbert's skink, lowland leopard frog, Gila topminnow, longfin dace, razorback sucker, desert pupfish, and bonytail chub. This strand also provides live-in and pass-through habitat for species dependent on desert vegetation and/or rugged topography, such as desert tortoise, black-tailed rattlesnake, desert bighorn sheep, javelina, black-tailed jackrabbit, mule deer, and Gila monster.

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

The Linkage Design encompasses 89,800 acres (36,350 ha) of land, and is composed of 39% state trust land, 15% private land, and 46% Bureau of Land Management land, and 0.3% Local or State Parks land (Figure 5). Seven natural vegetation communities account for 95% of the land cover (Figure 6), barren lands account for 0.6%, and developed land accounts for approximately 1% of the linkage design, primarily in the eastern strand (Table 2). Natural vegetation is dominated by desert scrub-shrub associations, and has a similar composition to land cover found in each of the wildland blocks (excluding Prescott NF). Riparian vegetation accounts for 1% of the linkage design.

The Linkage Design captured a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, 66% of the land is classified as gentle slopes, 29.5% is classified as steep slopes, and 4.5% is classified as either canyon bottom or ridgetop (Figure 7). More land in the linkage had southern aspects than northern aspects (Figure 7).

Table 2: Approximate land cover found within Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (< 0.1%)			
Pinyon-Juniper Woodland	44	18	< 0.1%
Scrub-Shrub (98%)			
Creosotebush-White Bursage Desert Scrub	12326	4988	13.7%
Desert Scrub (misc)	4739	1918	5.3%
Mesquite Upland Scrub	958	388	1.1%
Paloverde-Mixed Cacti Desert Scrub	69891	28284	77.9%
Woody Wetland (0.9%)			
Riparian Mesquite Bosque	540	219	0.6%
Riparian Woodland and Shrubland	288	116	0.3%
Barren Lands (0.1%)			
Non-specific Barren Lands	131	53	0.1%
Developed and Agriculture (0.9%)			
Open Space-Low Intensity Developed	662	268	0.7%
Medium-High Intensity Developed	152	61	0.2%

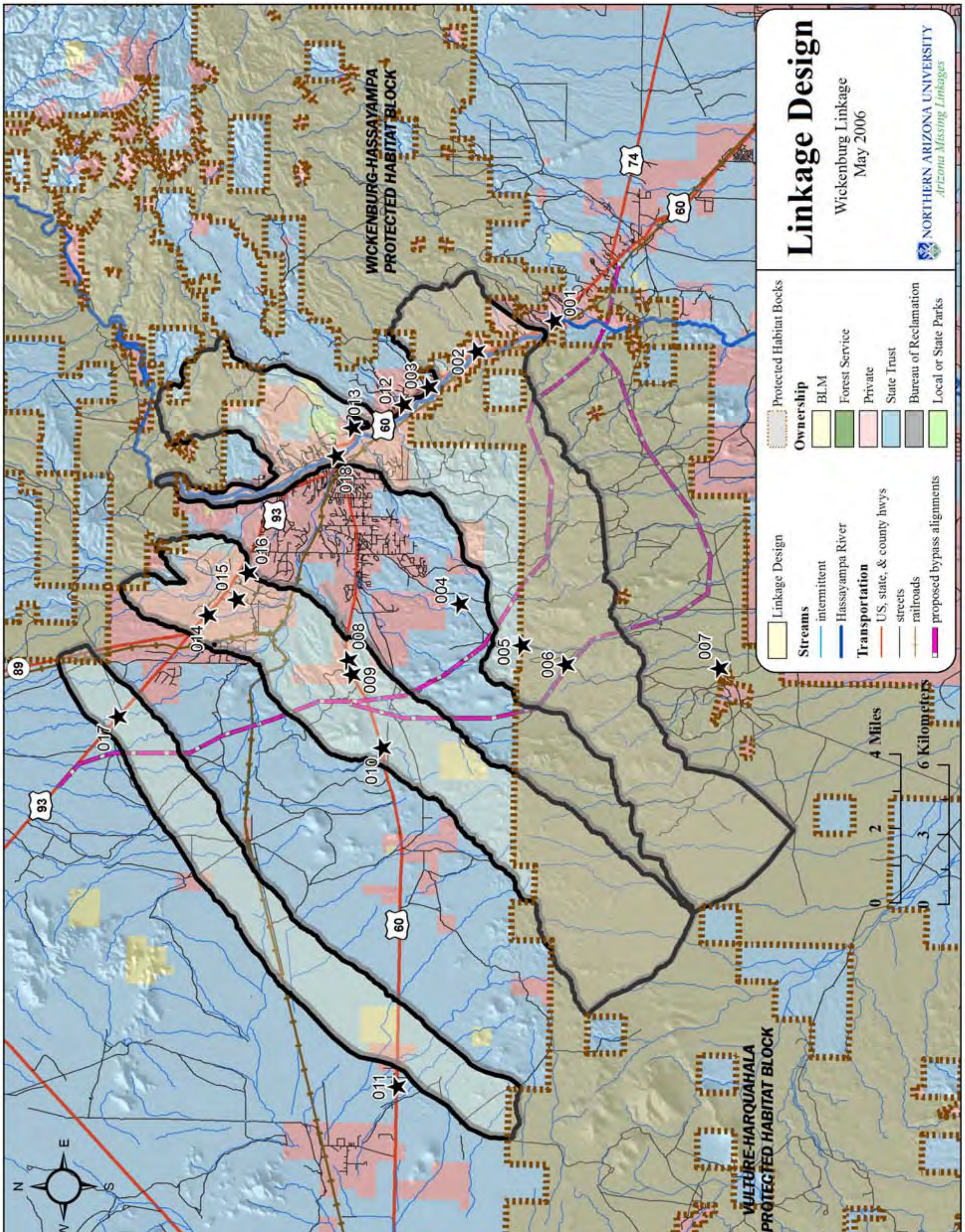

Figure 5: Property ownership and field investigation waypoints within Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.

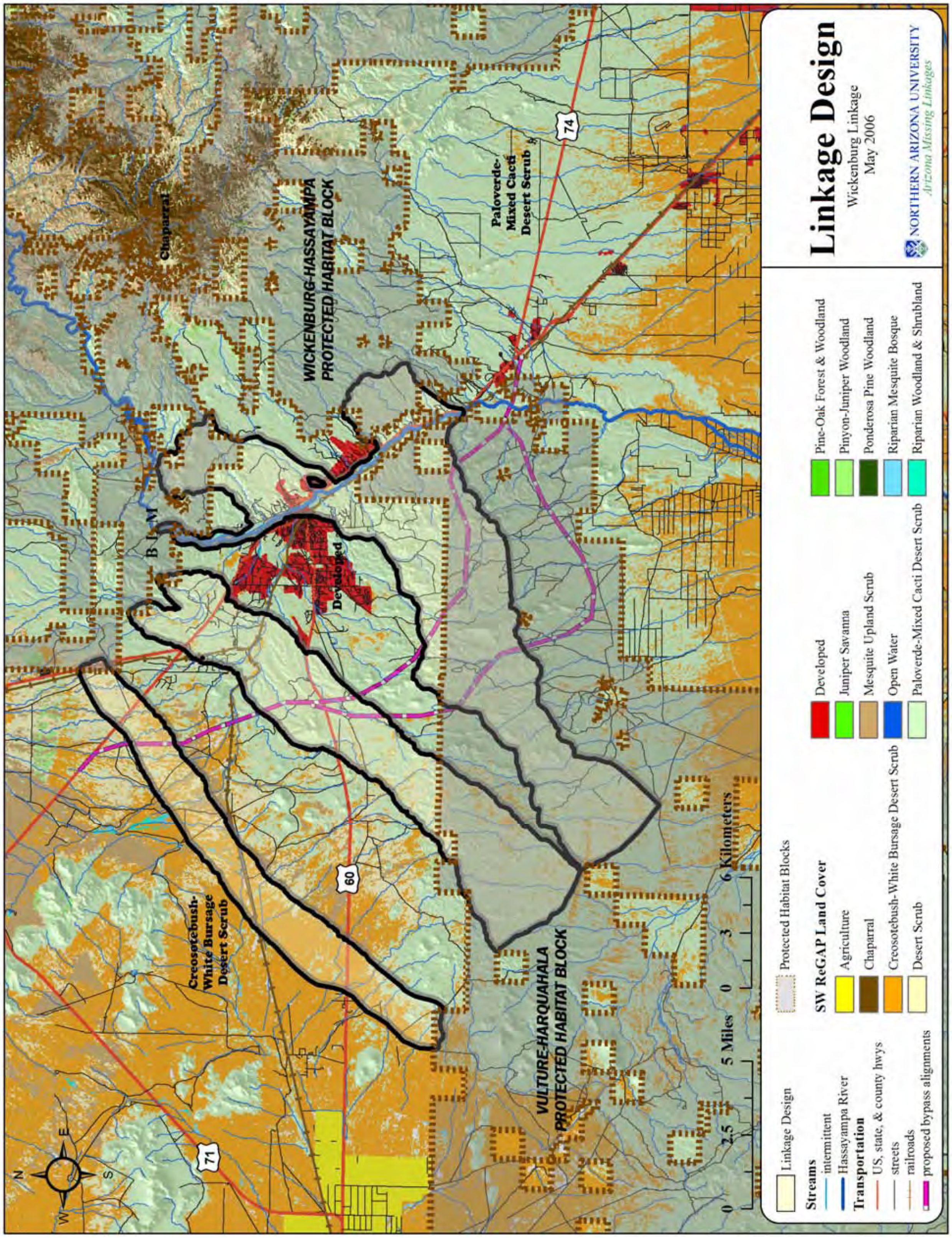

Figure 6: Land cover within Linkage Design.

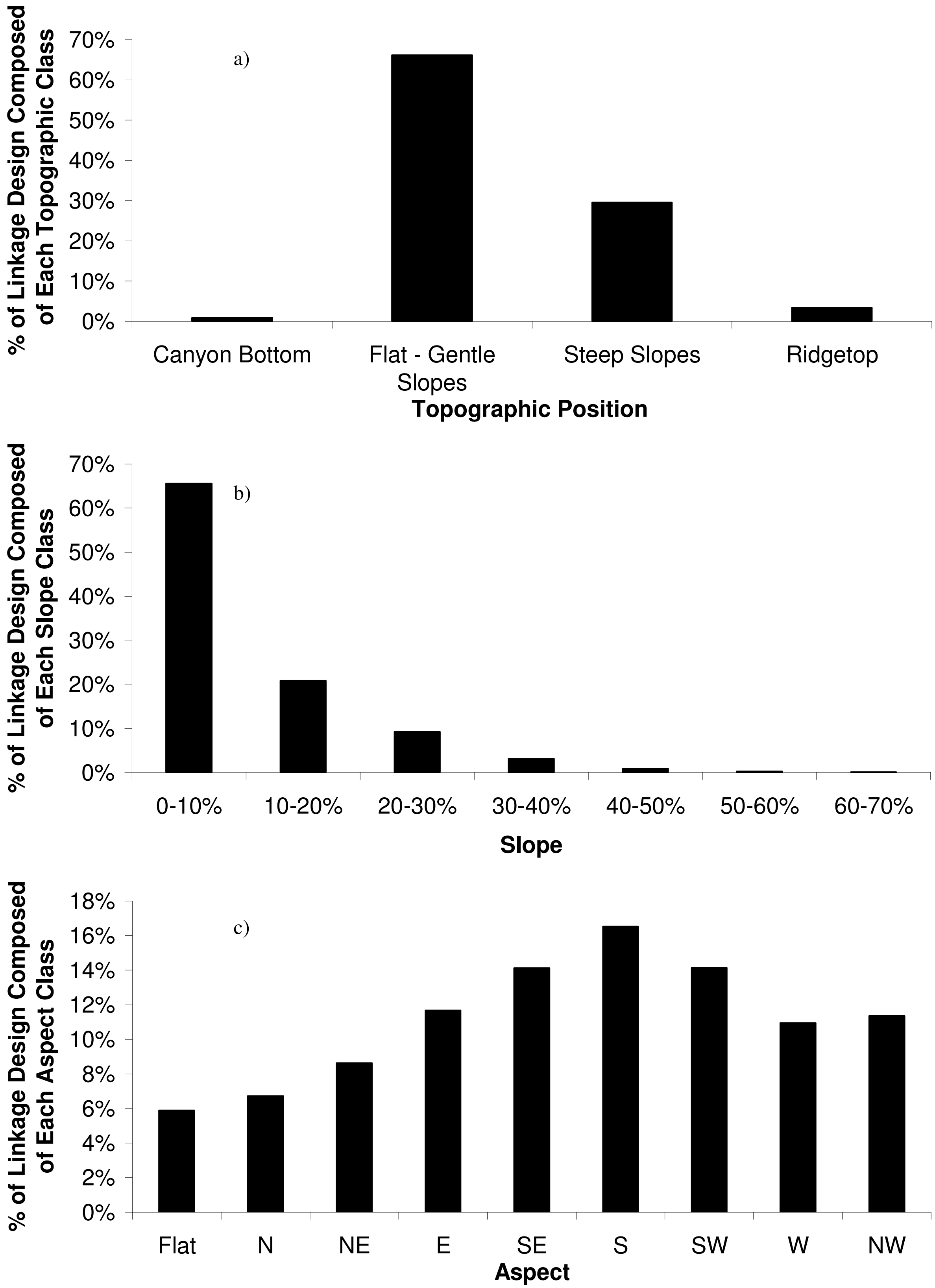

Figure 7: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect.

Removing and Mitigating Barriers to Movement

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

While roads, canals, and fences impede animal movement, and the crossing structures we recommend are important, we remind the reader that crossing structures are only part of the overall linkage design. To restore and maintain connectivity between the Vulture-Harquahala and Wickenburg-Hassayampa protected 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, habitat loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Figure 8). Direct **roadkill** affects most species, with severe documented impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the Iberian lynx (Forman et al. 2003). In a 4-year study of 15,000 km of road observations in Organ Pipe Cactus National Monument, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km per year killed due to vehicle collisions. Although we may not often think of roads as causing **habitat loss**, a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. Roads cause **habitat fragmentation** because they break large habitat areas into small, isolated habit patches which support few individuals; these small populations lose genetic diversity and are at risk of local extinction.

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

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 9). 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).

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

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

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

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

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

1) **Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area** (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald & St Clair 2004; Clevenger & Waltho 2005; Mata et al. 2005). For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and mountain lions, large box culverts with 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 and Rail Lines in the Linkage Design Area

There are approximately 296 km (184 mi) of transportation routes in the Linkage Design, including 29.1 km (18.1 mi) of the Burlington Northern Santa Fe Railroad, 25.3 km (15.7 mi) of highways, and 241 km (150 mi) of local roads (Table 3). Additionally, a new alignment of US-93 (proposed Wickenburg bypass) is expected to cross through all strands of the linkage design. We conducted field investigations of many of these roads to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 3: Major transportation routes in the Linkage Design.

ROAD NAME	KILOMETERS	MILES
Burlington Northern Santa Fe Railroad	29.1	18.1
United States Highway 60	17.1	10.5
Vulture Mine Rd	7.4	4.6
United States Highway 93	6.7	4.2
Rincon Rd	4.6	2.9
Blue Tank Rd	3.9	2.4
Jack Burden Rd	3.7	2.3
Constellation Rd	3.6	2.2
Mattie Ranch Rd	3.0	1.9
Moon Light Mesa	2.0	1.3
Stone Hedge Ranch Rd	1.9	1.2
Moonlight Mesa Rd	1.9	1.2
Scenic Loop	1.8	1.1
Vulture Peak Rd	1.8	1.1
Blue Tank Trl	1.8	1.1
State Highway 89	1.6	1.0
Named Roads < 1 mile long each	28.3	17.7
Unnamed Roads	175.7	109.2
Total length of transportation routes	296	184

Existing Crossing Structures on US 60

US 60 runs east-west through the western and middle strands of the linkage design, and northwest-southeast through the easternmost strand.

In the western strand of the linkage design, we did not find any substantial crossing structures on US-60. Apparently water drains across the road via small pipe culverts, with no larger structures.

In the middle strand of the linkage design, we noted two existing crossing structures under US 60, listed west-to-east:

- On the western edge of the middle strand, a cement culvert composed of three 6 x 8 ft boxes makes a suitable underpass for small mammals, reptiles, and amphibians (Figure 10).
- Further east, a large, open crossing structure composed of four 8 x 12 ft box culverts appeared to be a suitable underpass at first glance. However, a large pour-off creates a ledge several feet high which small species would not be able to traverse (Figure 11). The structure is probably usable for mule deer and other large animals.

In the eastern strand of the linkage design, we noted 4 crossing structures under US 60. We list them from north to south:

- In the north branch of the east strand, a large, multiple-span bridge approximately 150m in length crosses the Hassayampa River (no photo, see Figure 5–waypoint 018 to locate this structure within the linkage design). This bridge is directly adjacent to downtown Wickenburg.
- A 35-meter long bridge over Calamity Wash makes a suitable underpass for most species (no photo, see Figure 5–waypoint 013 to locate this structure within the linkage design). The area surrounding this bridge currently presents fewer obstacles to connectivity then the crossing structure over Mockingbird Wash.
- A small twin box culvert at Mockingbird Wash (Figure 12).
- A large, multiple-span bridge over Monarch Wash suitable for most species (Figure 13).

Figure 10: Looking northeast, three 6 x 8 ft box culverts provide a crossing structure under US60 for small species in the middle strand of the linkage design (waypoint 010).

Figure 11: Looking south, four 8x12 ft box culverts provide an open crossing structure under US60 (waypoint 009); however, the large pour-off makes it impermeable to small mammals, reptiles, and amphibians. See Figure 5 to locate these photos within the linkage design.

Figure 12: Looking northwest, a small twin box culvert crosses over Mockingbird Wash (waypoint 012).

Figure 13: Looking west, a large multiple-span bridge over Monarch Wash provides connectivity across the Phoenix-Wickenburg Highway for both large and small species (waypoint 002).

Existing Crossing Structures on US 93

US 93 runs northwest-southeast through the easternmost and middle strands of the linkage design, and is the primary transportation route linking Phoenix with northwestern Arizona and Las Vegas. In the middle strand of the linkage design, US-93 apparently has no crossing structures larger than a 3-ft pipe culvert. We noted one crossing structure in the center of the western strand of the linkage design, where a large, open crossing structure composed of four 8 x 6 ft box culverts makes a suitable underpass for small species (Figure 14).

Figure 14: Looking south, four 8 x 6 ft box culverts provide a crossing structure under US60 for small species in the westernmost strand of the linkage design (waypoint 017).

Recommendations for Highway Crossing Structures

The existing crossing structures are not adequate to serve the movement needs of wildlife. Because every animal moving between the Vulture-Harquahala and Wickenburg-Hassayampa protected wildland blocks must traverse at least one of the existing highways, as well as the Wickenburg bypass when it is constructed, crossing structures along these highways are crucial to success of the corridor. Although the current US-93 probably will be decommissioned as a US Highway after the bypass is constructed, the highway will continue to be an important barrier to wildlife. We recommend upgrading the crossing structures described above as follows:

- Along every paved road in each strand of the linkage, there should be at least one pipe culvert every 300m for passage by small animals. Because we did not attempt to locate small culverts, we do not know how many new culverts will need to be installed. In some dry, flat areas (e.g., where US60 and US-93 cross the western and middle strands) there are probably few to no culverts today.

- Within the western strand of the linkage design, build at least 3 large new culverts optimal for small mammals, reptiles, and amphibians under US 60 (where there are currently no large culverts), and at least 2 new culverts under existing US 93 (where 1 culvert now exists; Figure 14).

- Within the middle strand of the linkage design, build at least 2 new crossing structures along US 60 to supplement the 2 structures in this area. At least one of these structures should be a large, open bridge that will allow desert mule deer to pass under US 60. Deer prefer open crossing structures, and avoid closed structures such as the existing box culverts. All major washes in this strand of the linkage design already have crossing structures under US-60, and at least 1 of the new crossing structures should not be associated with a wash; the 4 structures should be spaced ½ to 1 mile apart. The existing structure documented in Figure 11 should be modified to eliminate the pour-off, or replaced by a larger bridge.

- Build at least three new crossing structures on US 93 in the middle strand of the linkage design, where no large structures currently exist. At least one of these structures should be suitable for mule deer. Because there are no washes which run under this portion of the highway, structures should be spaced evenly, sized to accommodate an array of species.

- There should be at least 3 underpasses under the rail line in the middle strand, to accommodate desert tortoise, bighorn sheep, and mule deer. Because we did not visit this portion of the railroad, we cannot state whether there are already 3 adequate structures here.

- Within the eastern strand of the linkage design, build 3 new large crossing structures under US 60; at least 2 of these should be bridges that mule deer and bighorn sheep could walk under. Two potential locations for these structures are labeled on Figure 15. Additionally, culverts suitable for smaller animals should be installed between the existing bridges described above.

- Crossing structures along the railroad line in the eastern strand should match (in location and size) the structures on US-60 parallel to the rail line.

- Because there are currently several proposed alignments for the proposed Wickenburg bypass, we cannot make recommendations for specific crossing structures and locations on this future highway. We recommend following the 9 guidelines above. In the westernmost strand of the linkage design (serving small animals) the bypass probably needs only culverts at intervals of 300 meters or less. In the middle and easternmost strands of the linkage design, open bridges suitable for use by deer should be constructed at least every mile, in addition to culverts at intervals of 300 meters or less. Bridges could be constructed at Hartman Wash in the middle strand, and at Cemetery Wash, Box Wash, and Syndicate Wash in the eastern strand.

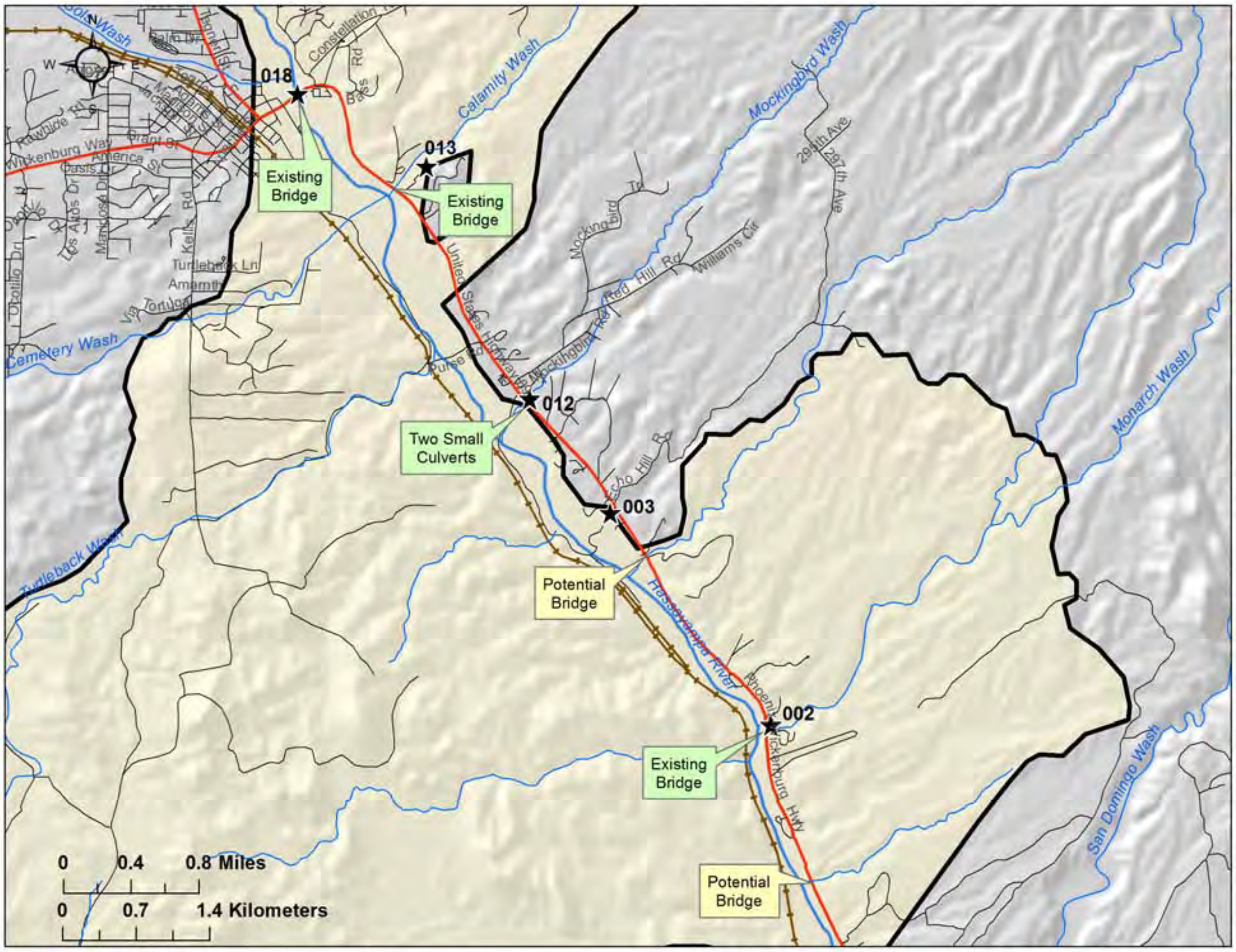

Figure 15: Potential locations for bridges in the easternmost strand of the linkage design.

Impediments to the Hassayampa River

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Hassayampa River and its associated riparian vegetation are preferred habitat for many species in the linkage area, including southwestern willow flycatcher, yellow-billed cuckoo, Gilbert's skink, lowland leopard frog, Gila topminnow, longfin dace, razorback sucker, desert pupfish, and bonytail chub.

Stream Impediments in the Linkage Design Area

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

The Hassayampa River is the only perennial flowing water in the linkage area. The river is fortunate to have no dams or diversions in or upstream from the linkage area, and few farms or road crossings in the floodplain. Furthermore, there is minimal (but growing) urban development in the watershed within or upstream from the linkage area. Therefore a functioning riparian ecosystem can be restored and maintained along the Hassayampa, especially if action is taken promptly before conditions get worse.

Mitigating Stream Impediments

We endorse the following management recommendations for riparian connectivity and habitat conservation on the Hassayampa River.

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

2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).
3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of the river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite *bosques* should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).
4) **Maintain biotic interactions within evolved tolerance ranges**. Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas

(Belsky et al. 1999), National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).

5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, with a few becoming significant problems like tamarisk and Russian olive. Removing stressors and reestablishing natural flow regimes can help bring riparian communities back into balance, however some exotics are persistent and physical eradication is necessary to restore degraded systems (Stromberg 2000, D'Antonio and Meyerson 2002, Savage 2004).
6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.
7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

Urban Development as Barriers to Movement

Urban and industrial development, unlike roads, creates barriers to movement which cannot easily be removed, restored, or otherwise mitigated. Most large carnivores, small mammals, and reptiles cannot occupy these areas for a significant period of time, although several species of lizards or small mammals may occasionally occupy residential areas. While mapped urban areas only accounted for 0.9% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

The western strand of the linkage design is currently free of urban barriers. In the middle strand of the linkage design, the development of ranchettes and homes may threaten connectivity (Figure 16). Biologically best corridors for black-tailed jackrabbit, javelina, and mule deer pass through this strand of the linkage design. In the eastern strand of the linkage design, residential and industrial development of Wickenberg may impede the movement of species such as desert bighorn sheep, mule deer, and Gila monster, particularly where this linkage strand borders Wickenburg's residential development (Figure 17). It is especially important to prevent future urban growth in the Hassyampa River and its major tributaries in the western strand, such as Calamity, Mockingbird, and Monarch Washes.

Figure 16: Residential development is a potential barrier to connectivity in the middle strand of the linkage design (view southeast from waypoint 015).

Figure 17: Residential and industrial development is a barrier to connectivity in the easternmost strand of the linkage design (view west from waypoint 013).

Mitigation for Urban Barriers

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

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

Appendix A: Linkage Design Methods

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

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[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 22 species (Table 1) that had one or more of the following characteristics:

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

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

[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.

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.

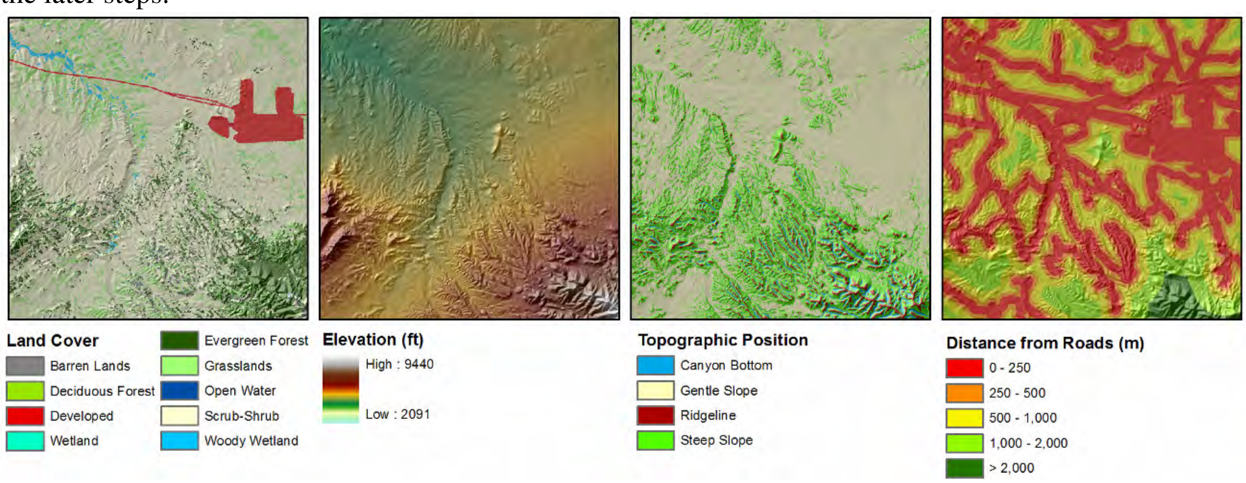

Figure 18: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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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.

Identifying Potential Breeding Patches & Potential Population Cores

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

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

To do so, we first calculated the suitability of any pixel as the average habitat suitability in a neighborhood of pixels surrounding it (Figure 19). We averaged habitat suitability within a 3x3-pixel neighborhood (0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[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.

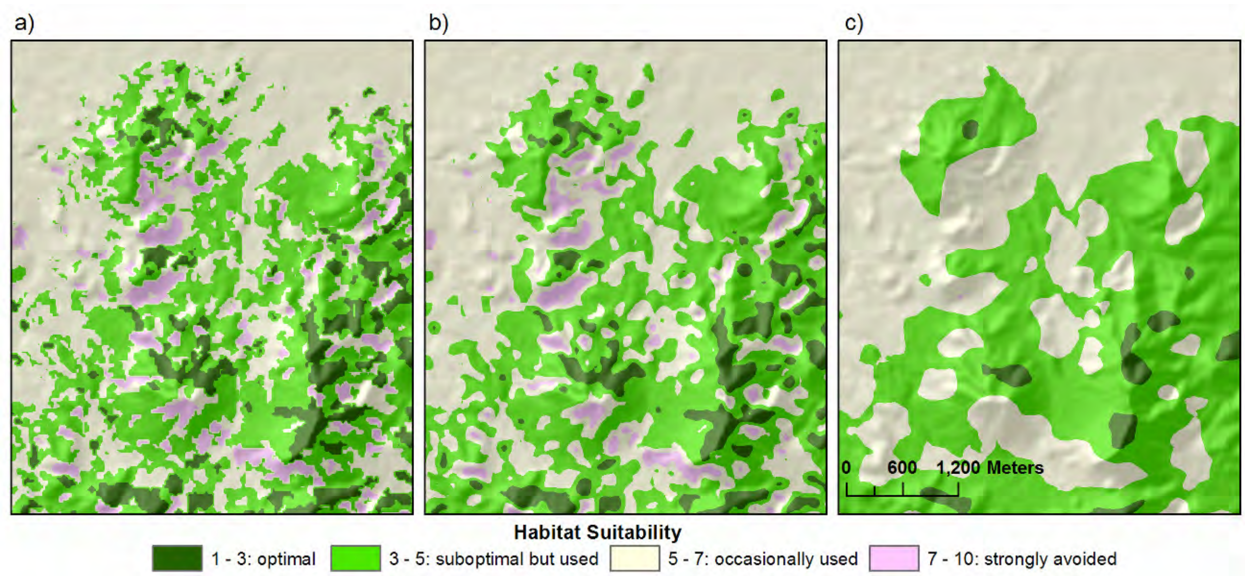

Figure 19: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

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

[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.

[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.

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

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

East of Wickenburg, the two protected wildland blocks are separated only by US-60/93 (Figure 1, Figure 2). The close proximity of the 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 3 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 wildland block. (3) It would not provide any guidance relevant to the future US-93 Wickenburg Bypass. To address these 3 problems, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks (a) were parallel to each other, (b) set back at least 3 miles from the potential Wickenberg Bypass alignments, and (c) set back at least 1 mile from any existing highway or any new or potential urban area. Thus for purposes of BBC analyses, we redefined the wildland blocks in Figure 21 through Figure 34, such that the Wickenburg-Hassayampa wildland block was 26 km (16.1 mi) from the Vulture-Harquahala wildland block.

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[10]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd protected wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 500 m (Figure 20). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the protected wildland blocks, this optimum

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

might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[11] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between protected 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*.

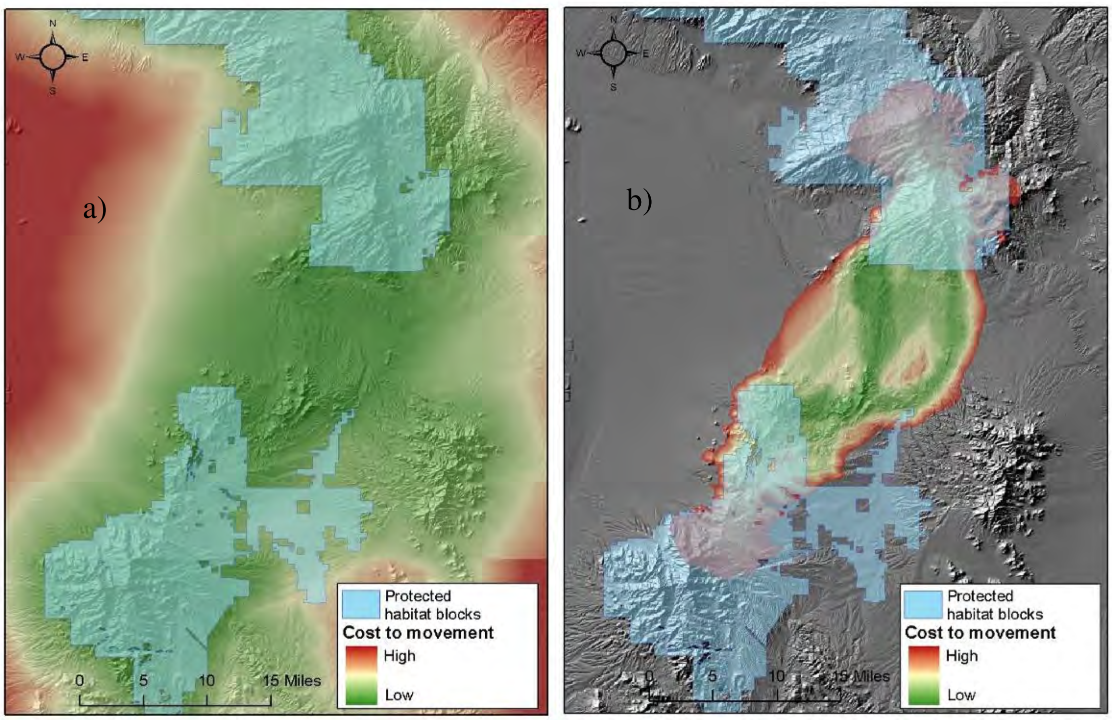

Figure 20: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

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

[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.

terrestrial branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available.

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

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

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

Field Investigations

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

	Badger	Bighorn Sheep	Black-tailed Jackrabbit	Javelina	Mule Deer
Factor Weights					
Land Cover	65	30	70	50	80
Elevation	7	10	10	30	0
Topography	15	50	10	20	15
Distance from Roads	13	10	10	0	5
Land Cover					
Pine-Oak Forest and Woodland	5	9	6	7	3
Pinyon-Juniper Woodland	4	9	4	5	5
Ponderosa Pine Woodland	5	9	6	6	5
Juniper Savanna	2	8	3	7	4
Semi-Desert Grassland and Steppe	1	5	4	2	2
Chaparral	5	9	6	3	4
Creosotebush-White Bursage Desert Scrub	2	6	2	4	6
Desert Scrub (misc)	3	2	1	2	6
Mesquite Upland Scrub	3	7	4	2	3
Paloverde-Mixed Cacti Desert Scrub	4	3	1	1	3
Riparian Mesquite Bosque	6	9	5	1	3
Riparian Woodland and Shrubland	6	9	4	2	3
Barren Lands, Non-specific	7	8	8	9	10
Volcanic Rock Land and Cinder Land	10	7	9	9	8
Recently Mined or Quarried	9	10	10	10	6
Agriculture	6	10	6	7	6
Developed, Medium - High Intensity	10	10	9	7	9
Developed, Open Space - Low Intensity	7	10	6	4	5
Open Water	9	10	9	10	10
Elevation (ft)					
Elevation range: cost	0-5500: 1 5500-8000: 3 8000-11000: 6	0-2950: 2 2950-3300: 1 3300-7000: 3 7000-11000: 7	0-6000: 1 6000-8000: 4 8000-11000: 8	0-5000: 1 5000-7000: 3 7000-11000: 10	
Topographic Position					
Canyon Bottom	5	8	3	1	2
Flat - Gentle Slopes	1	7	1	1	2
Steep Slope	8	5	4	7	4
Ridgetop	7	1	4	4	6
Distance from Roads (m)					
Distance from Roads range: cost	0-250: 6 250-1500: 1	0-1000: 6 1000-15000: 2	0-250: 9 250-500: 6 500-1000: 3 1000-15000: 1		0-250: 7 250-1000: 3 1000-15000: 1

	Desert Tortoise	Gila Monster
Factor Weights		
Land Cover	30	10
Elevation	25	35
Topography	40	45
Distance from Roads	5	10
Land Cover		
Pine-Oak Forest and Woodland	10	10
Pinyon-Juniper Woodland	10	6
Ponderosa Pine Woodland	10	10
Juniper Savanna	10	10
Semi-Desert Grassland and Steppe	8	5
Chaparral	10	6
Creosotebush-White Bursage Desert Scrub	5	3
Desert Scrub (misc)	4	3
Mesquite Upland Scrub	7	4
Paloverde-Mixed Cacti Desert Scrub	1	1
Riparian Mesquite Bosque	5	5
Riparian Woodland and Shrubland	10	5
Barren Lands, Non-specific	10	10
Volcanic Rock Land and Cinder Land	10	1
Recently Mined or Quarried	10	10
Agriculture	10	10
Developed, Medium - High Intensity	10	9
Developed, Open Space - Low Intensity	7	1
Open Water	10	10
Elevation (ft)		
Elevation range: cost	0-5000: 1 5000-7000: 7 7000-11000: 10	0-1700: 4 1700-4000: 1 4000-4800: 4 4800:5700: 7 5700-11000:10
Topographic Position		
Canyon Bottom	8	1
Flat - Gentle Slopes	5	5
Steep Slope	3	1
Ridgetop	7	1
Distance from Roads (m)		
Distance from Roads range: cost	0-250: 5 250-500: 4 500-1000: 3 1000-15000: 1	0-1000: 5 1000-3000: 3 3000-15000: 1

Badger (*Taxidea taxus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area (Figure 21). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.7 to 6.0, with an average suitability cost of 2.3 (S.D: 0.8). Within the corridor, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 22).

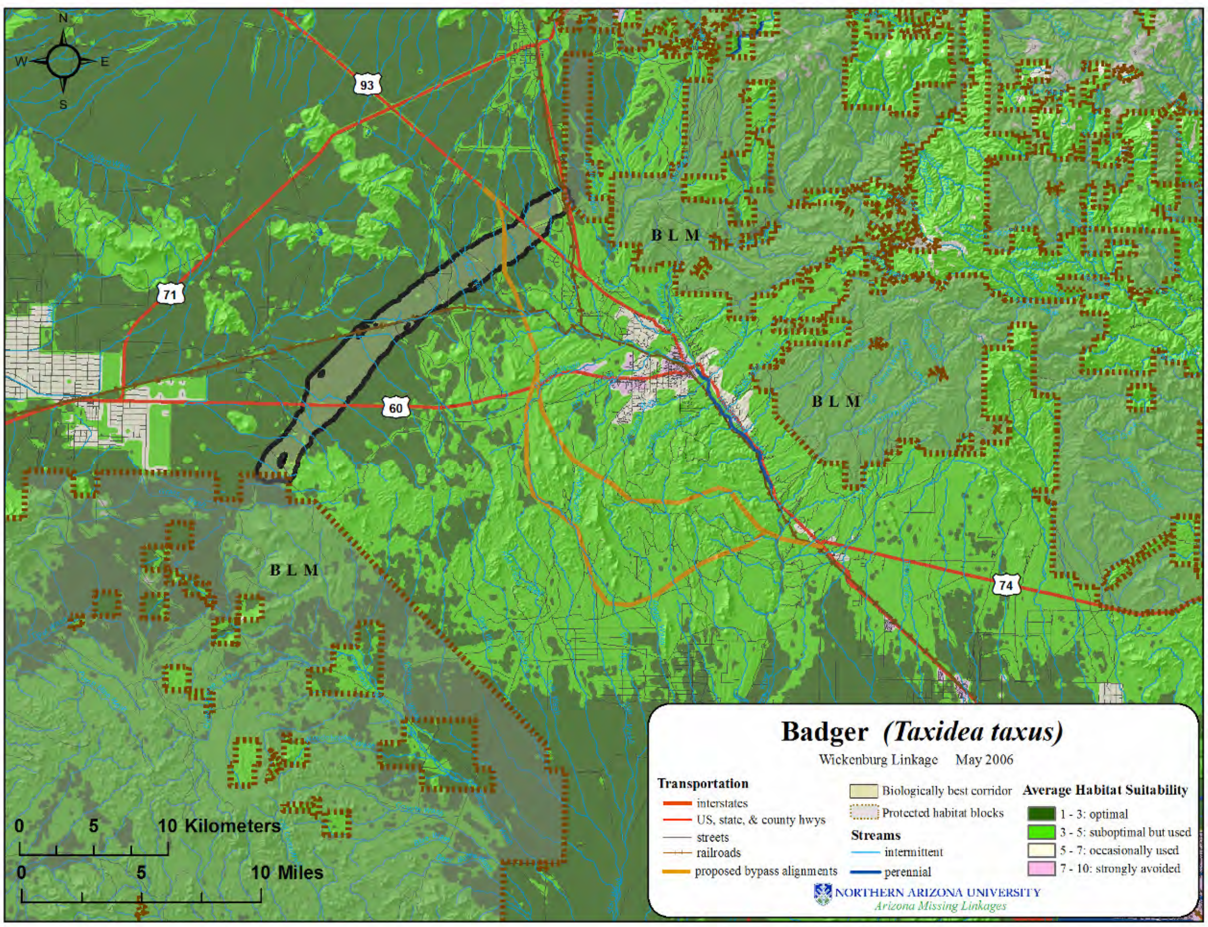

Figure 21: Modeled habitat suitability of badger.

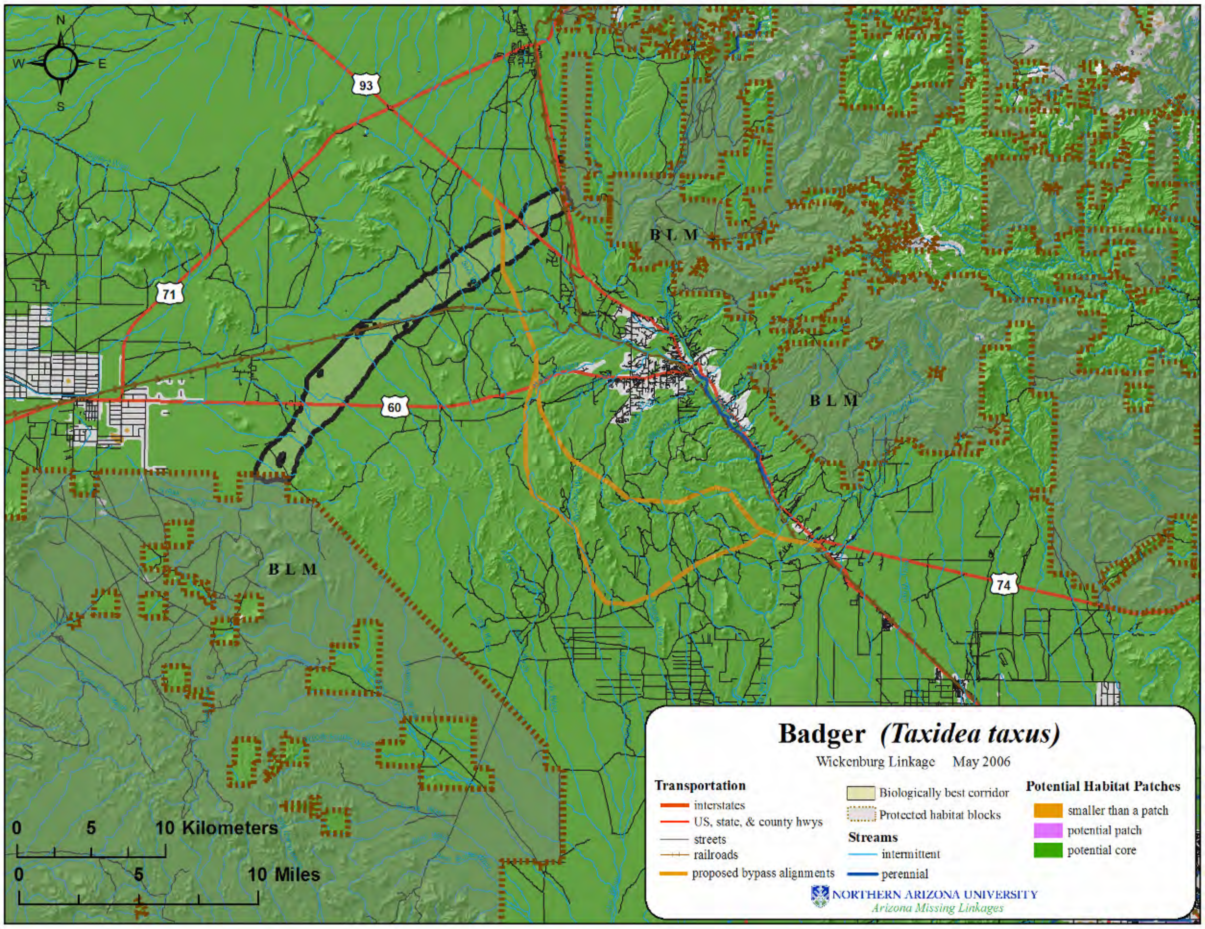

Figure 22: Potential habitat patches and cores for badger.

Union of biologically best corridors – The two additional eastward strands of the UBBC increase potential habitat for badger. While these strands are comprised mostly of paloverde vegetation associations and complex topography which is less suitable than the biologically-best corridor for this species, badger may still occasionally use habitat within these corridors. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US60 & US 93, and habitat fragmentation.

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 km² to 54.7 km² (Singer et al. 2001). One desert bighorn sheep study in Arizona reports an average home range of 16.9 ± 3.38 km² for ewes, and home ranges for males that increased with age from 11.7 km² for a one year old to 37.3 km² 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.

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 – The standard geometric habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a fair amount of potentially suitable habitat for this species within the potential linkage area (Figure 23). The biologically best corridor for this species runs from the Belmont Mountains in the southern wildland block northward through the Vulture Mountains, before ending near the Black Hills and Wickenburg Mountains in the northern wildland block. Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.4 to 10.0, with an average suitability cost of 6.1 (S.D: 2.3). The largest gap between potentially suitable habitat patches is approximately 16 kilometers, between the Belmont and Vulture Mountains (Figure 24).

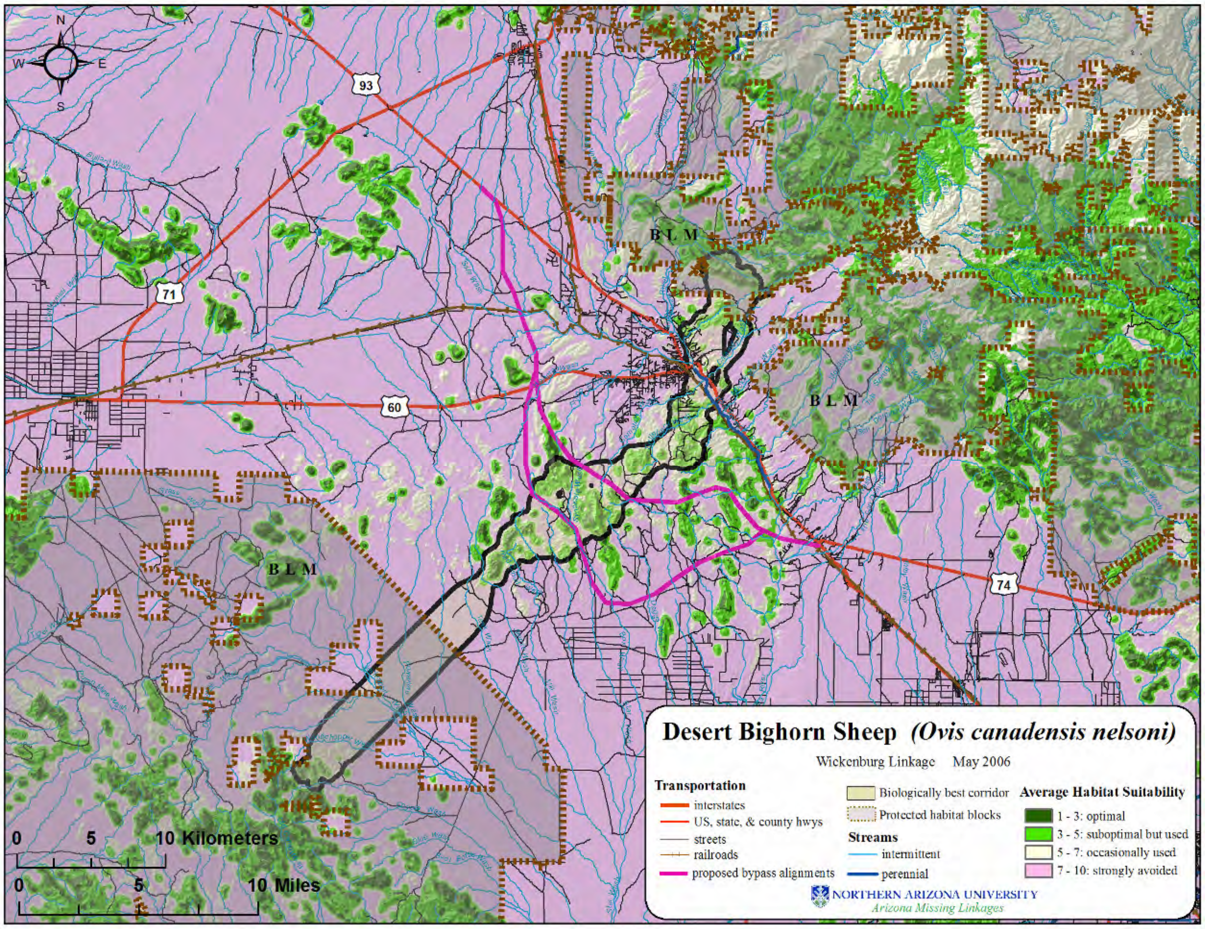

Figure 23: Modeled habitat suitability of desert bighorn sheep.

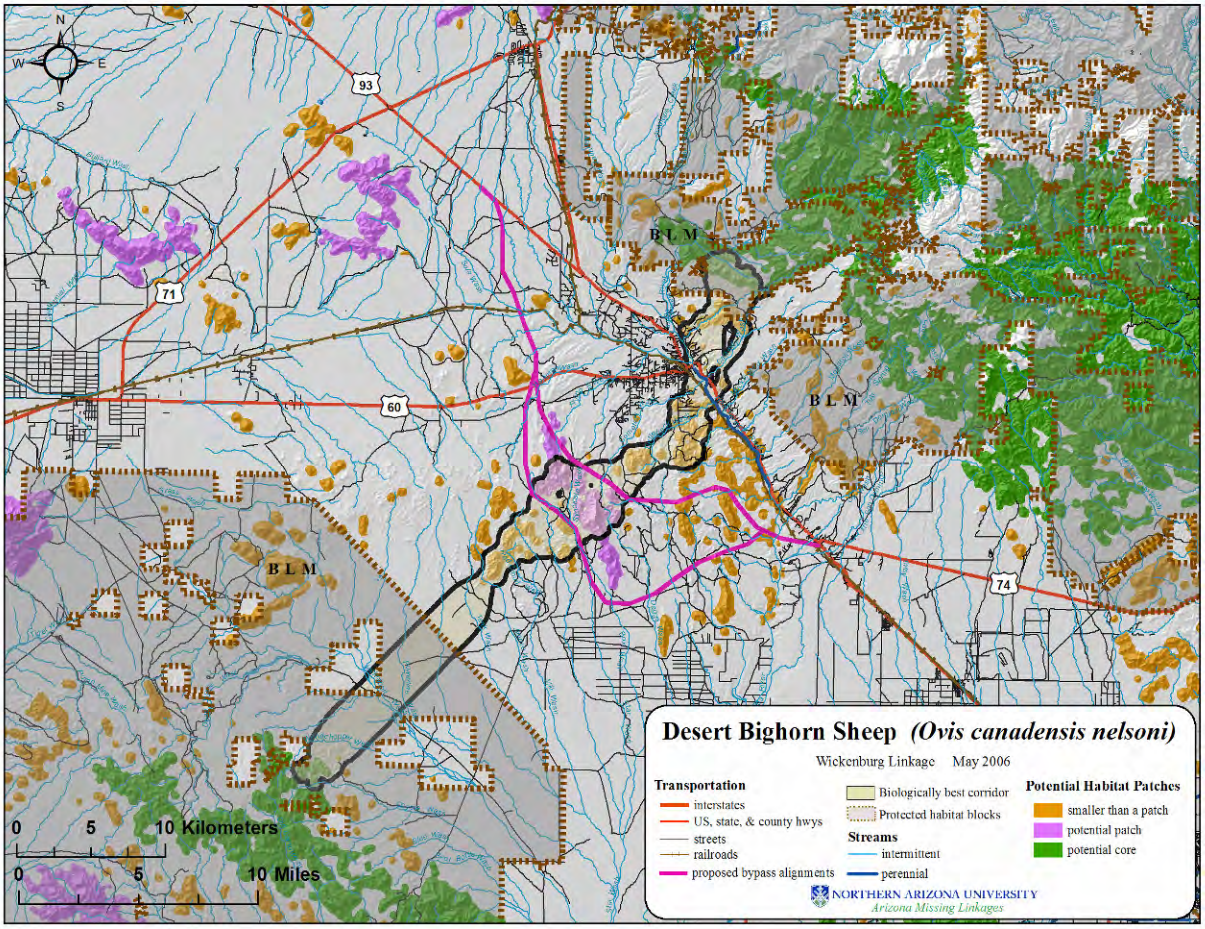

Figure 24: Potential habitat patches and cores for desert bighorn sheep.

Union of biologically best corridors – The UBBC provides very little additional habitat for the desert bighorn sheep. The only additional habitat afforded by the UBBC is Black Mountain in the middle strand of the linkage design. This small patch is only approximately 2 km^2, and not large enough to sustain the home range of one sheep. Bighorn sheep have been found to make seasonal movements up to 48 km (Shackleton 1985), and disperse up to 70 km (Witham & Smith 1979), and therefore could possibly move between the larger mountain ranges which it currently inhabits in the Vulture-Harquahala wildland block (namely the Harquahala Mountains) and the larger mountain ranges such as the Buckhorn, Hieroglyphic, and Wickenburg Mountains in the northern Wickenburg-Hassayampa wildland block. However, major highways, and developed areas have been found to completely eliminate gene flow in bighorn sheep populations (Epps et al. 2005), so connectivity between these blocks is dependent on effective crossing structures and maintenance of existing habitat.

Black-tailed Jackrabbit (*Lepus californicus*)

Justification for Selection

Black-tailed jackrabbits are important seed dispersers (Best 1996) and are frequently killed by roads (Adams & Adams 1959). They also serve as prey for predators such as hawks, eagles, owls, coyotes, badgers, foxes, and bobcats (Hoffmeister 1986; Best 1996).

Distribution

Black-tailed jackrabbits are common through western North America. They range from western Arkansas and Missouri to the Pacific Coast, and from Mexico northward to Washington and Idaho (Best 1996). They are found throughout the lower elevations of Arizona (Lowe 1978).

Habitat Associations

This species primarily prefers open country, and will typically avoid areas of tall grass or forest where visibility is low (Best 1996). In Arizona, black-tailed jackrabbits prefer mesquite, sagebrush, pinyon juniper, and desert scrub (Hoffmeister 1986). They are also found in sycamore, cottonwood, and rabbitbrush habitats (New Mexico Department of Fish and Game 2004). Dense grass and/or shrub cover is necessary for resting (New Mexico Department of Fish and Game 2004). Black-tailed jackrabbits are known to avoid standing water, making large canals and rivers possible population barriers (Best 1996).

Spatial Patterns

Home range size varies considerably for black-tailed jackrabbits depending upon distances between feeding and resting areas. Home ranges have been reported from less than 1 sq km to 3 sq km in northern Utah (NatureServe 2005); however, daily movements of several miles to find suitable forage may be common in southern Arizona, with round trips of up to 10 miles each day possible (Hoffmeister 1986). Best (1993) estimated home range size to be approximately 100 ha.

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong vegetation preferences, vegetation received an importance weight of 70%, while elevation, topography, and distance from roads each received weights of 10%. For specific costs of classes within each of these factors used for the modeling process, see Table 4.

Patch size & configuration analysis – We defined minimum potential habitat patch size as 100 hectares (Best 1993), and minimum potential habitat core size was defined as 500 ha, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area (Figure 25). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.0 to 8.5, with an average suitability cost of 1.5 (S.D: 0.6). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 26).

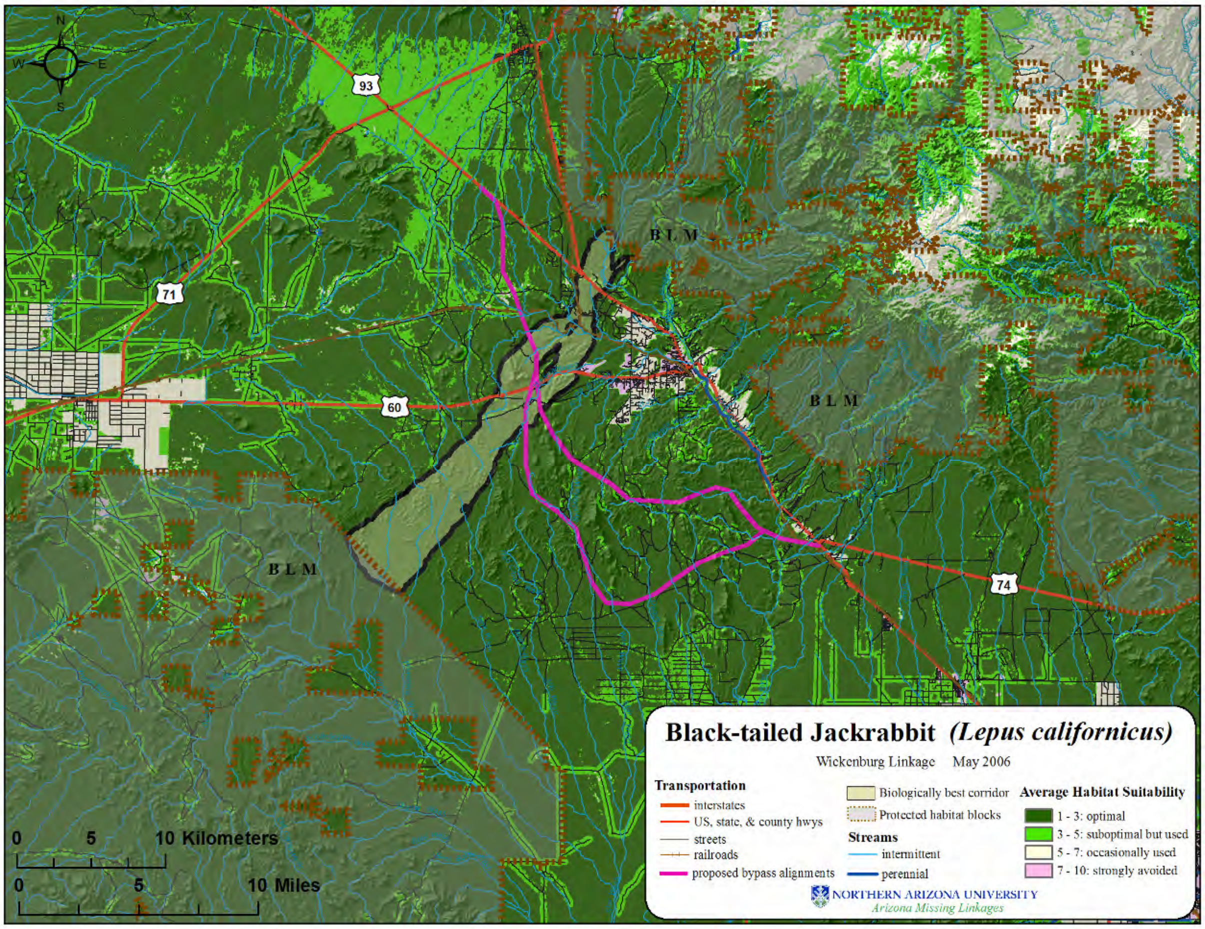

Figure 25: Modeled habitat suitability of black-tailed jackrabbit.

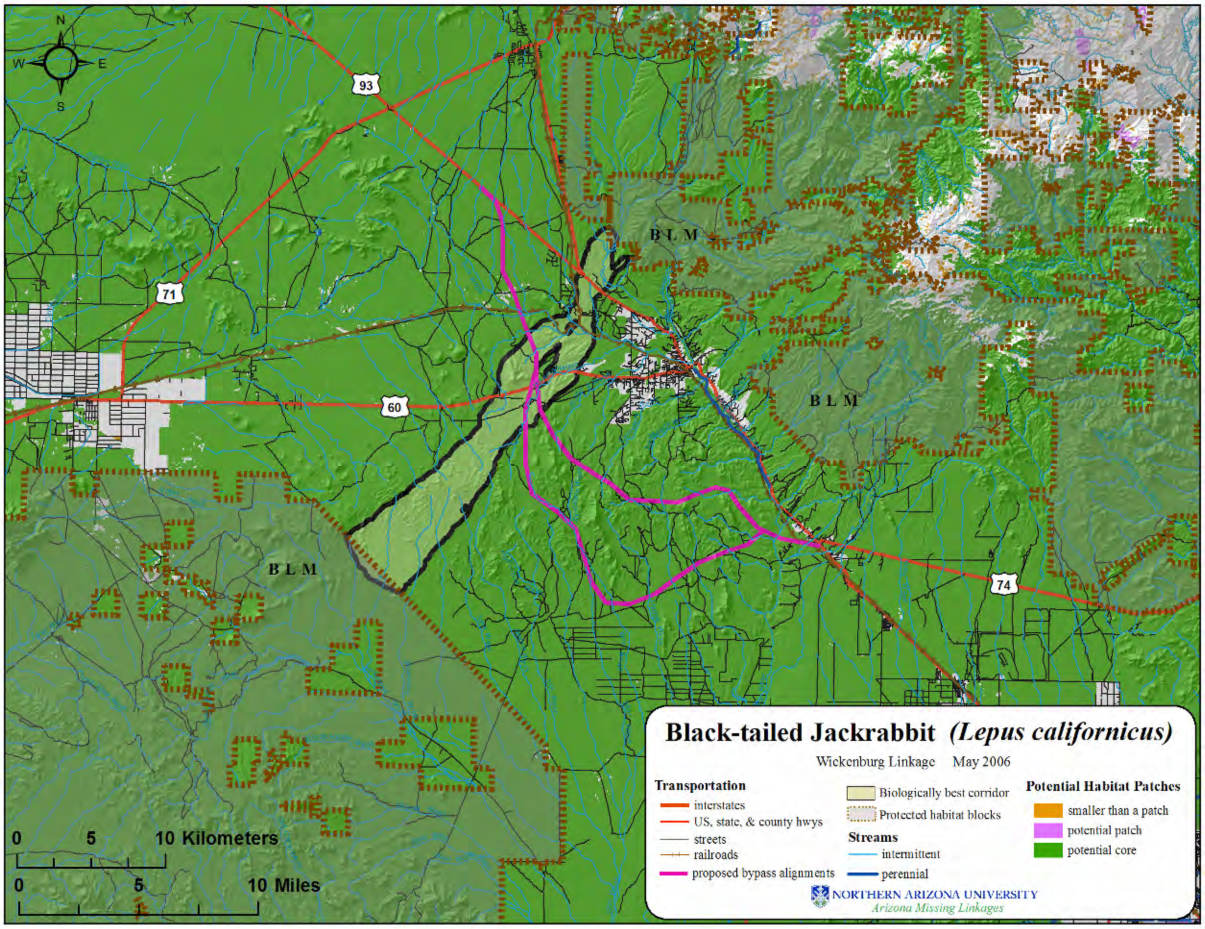

Figure 26: Potential habitat patches and cores for black-tailed jackrabbit.

Union of biologically best corridors – The additional western and eastern strands of the UBBC significantly increase potential habitat for black-tailed jackrabbit. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US 60 & US 93, and habitat fragmentation.

Javelina (*Tayassu tajacu*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation as it relates to both forage and cover requirements is very important for javelina. Sowls (1997) lists climate, vegetation, and topography as important factors in javelina habitat use. For this species', vegetation received an importance weight of 50%, while elevation and topography received weights of 30% and 20%, respectively. For specific scores of classes within each of these factors, see Table 4.

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant suitable habitat for this species within the potential linkage area (Figure 27). Within the biologically best corridor for this species, habitat suitability ranged from 1.0 to 7.0, with an average suitability cost of 1.5 (S.D: 0.8). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 28).

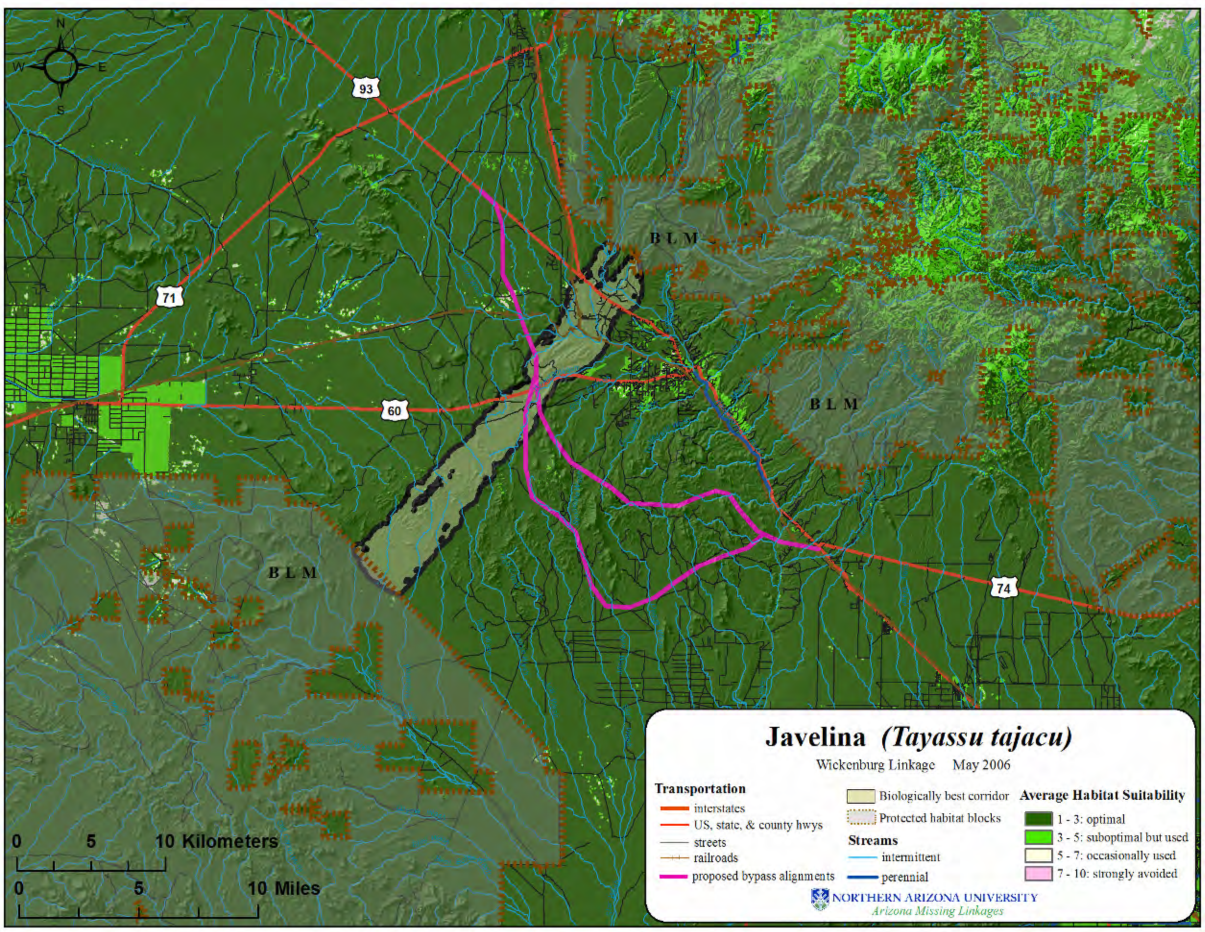

Figure 27: Modeled habitat suitability of javelina.

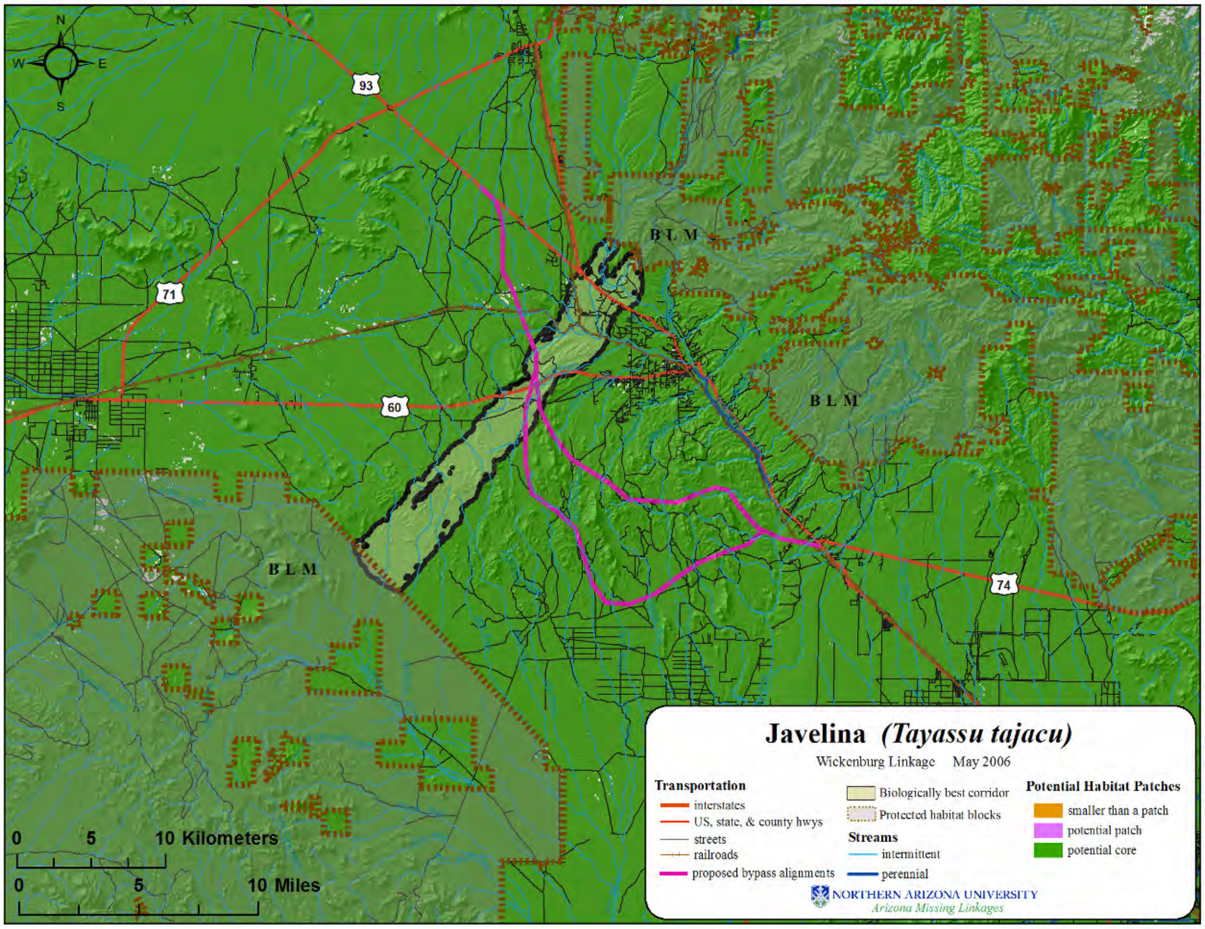

Figure 28: Potential habitat patches and cores for javelina.

Union of biologically best corridors – The additional western and eastern strands of the UBBC significantly increase potential habitat for javelina. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US60 & US 93, and habitat fragmentation.

Mule Deer (*Odocoileus hemionus*)

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

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

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

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

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for this species within the potential linkage area (Figure 29). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 2.8 to 8.7, with an average suitability cost of 3.1 (S.D: 0.6). Both corridors for this species contain nearly equal habitat quality. Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core. (Figure 30).

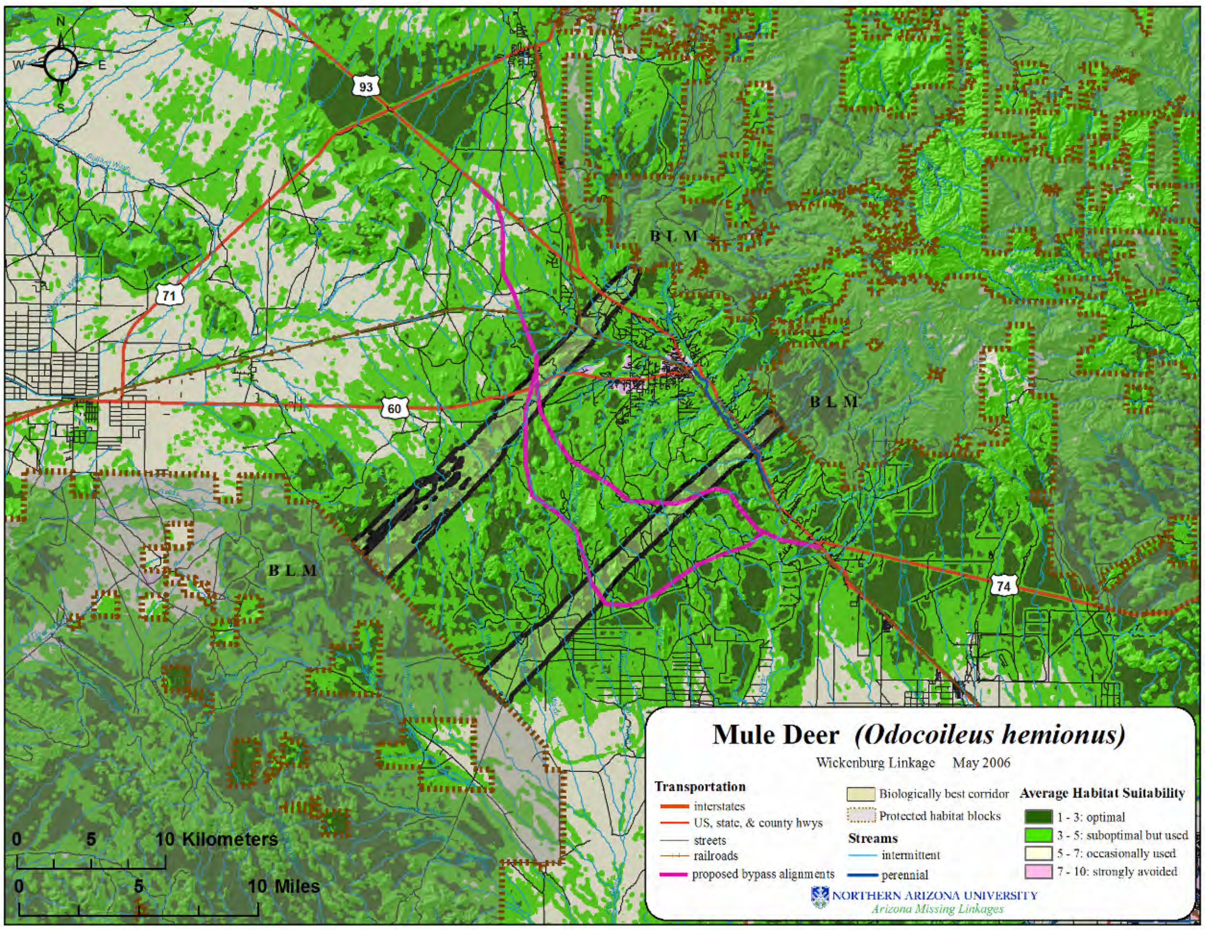

Figure 29: Modeled habitat suitability of mule deer.

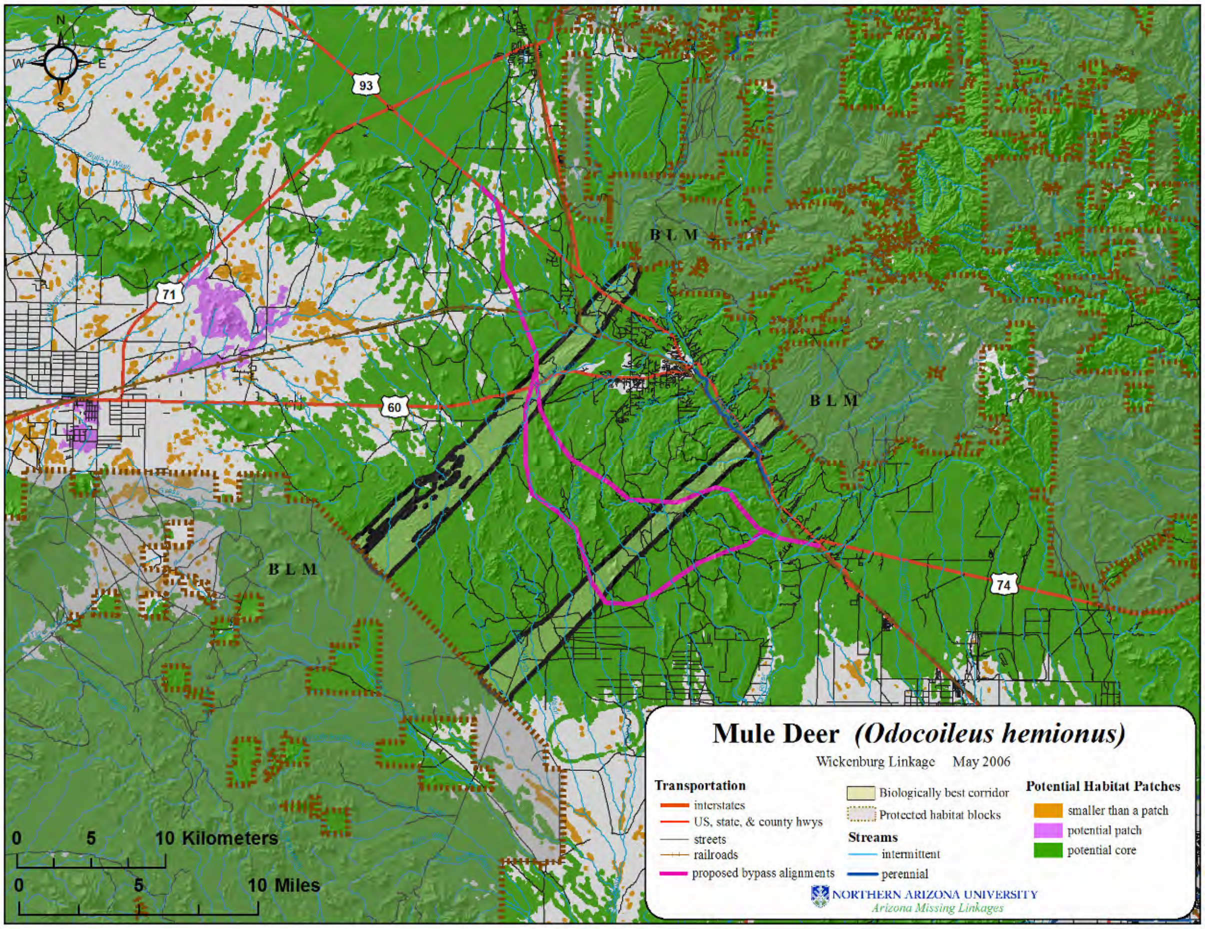

Figure 30: Potential habitat patches and cores for mule deer.

Union of biologically best corridors – The expanded middle and easternmost strands of the UBBC significantly increase potential habitat for mule deer, while the westernmost strand of creosotebush plains offers only negligible amounts of suitable habitat. Because there is ample habitat for this species, and much of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US 60 & US 93, and habitat fragmentation.

Desert Tortoise (*Gopherus agassizii*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 25%, 40%, and 5%, respectively. For specific scores of classes within each of these factors, see Table 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 – The standard geometric habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for this species within the potential linkage area (Figure 31). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.0 to 10.0, with an average suitability cost of 2.3 (S.D: 1.2). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 32).

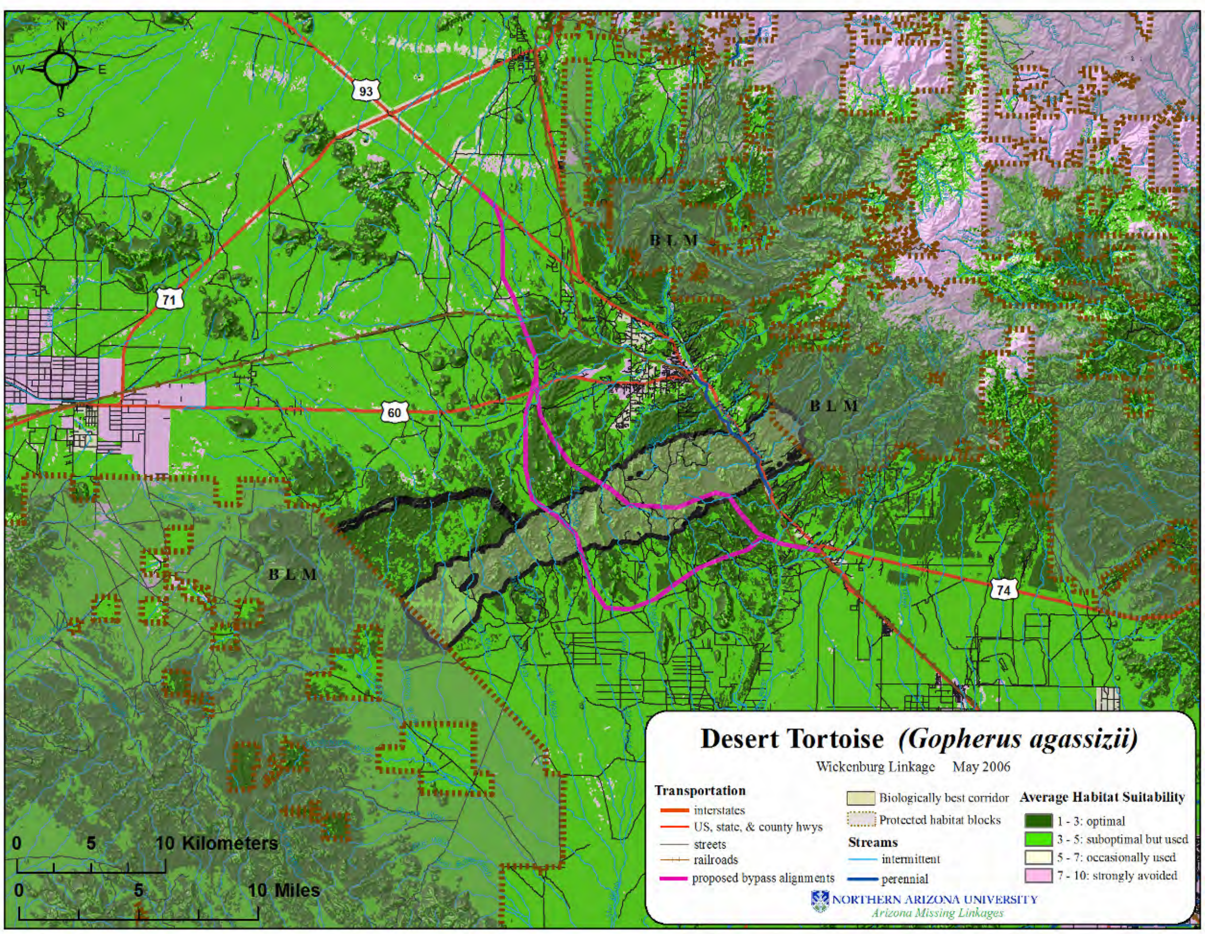

Figure 31: Modeled habitat suitability of desert tortoise.

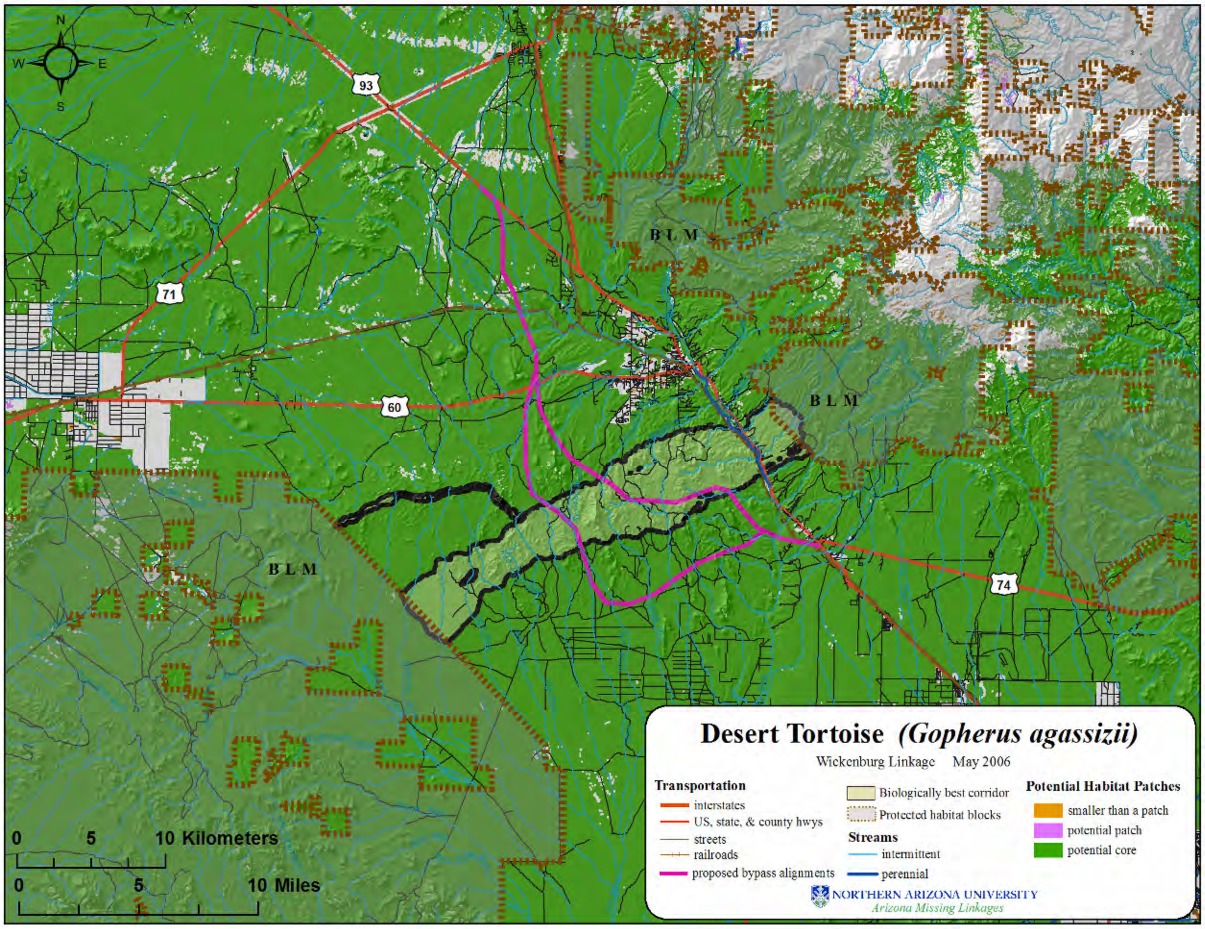

Figure 32: Potential habitat patches and cores for desert tortoise.

Union of biologically best corridors – The middle strand of the UBBC significantly increase potentially optimal habitat for desert tortoise, while the westernmost strand of the UBBC is composed of creosote flats which would mainly only be used during inter-population movements (T. Edwards, personal comm.). Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US 60 & US 93, and habitat fragmentation.

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 1,700 and 4,000 ft.

Spatial Patterns

Home ranges from 13 to 70 ha have been recorded (Beck 2005). Home ranges 3-4 km long have been recorded. Gila Monsters are widely foraging, and 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 – The standard geometric habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area (Figure 33). Within the biologically best corridor linking the wildland blocks, habitat suitability ranged from 1.2 to 4.2, with an average suitability cost of 2.3 (S.D: 1.0). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 34).

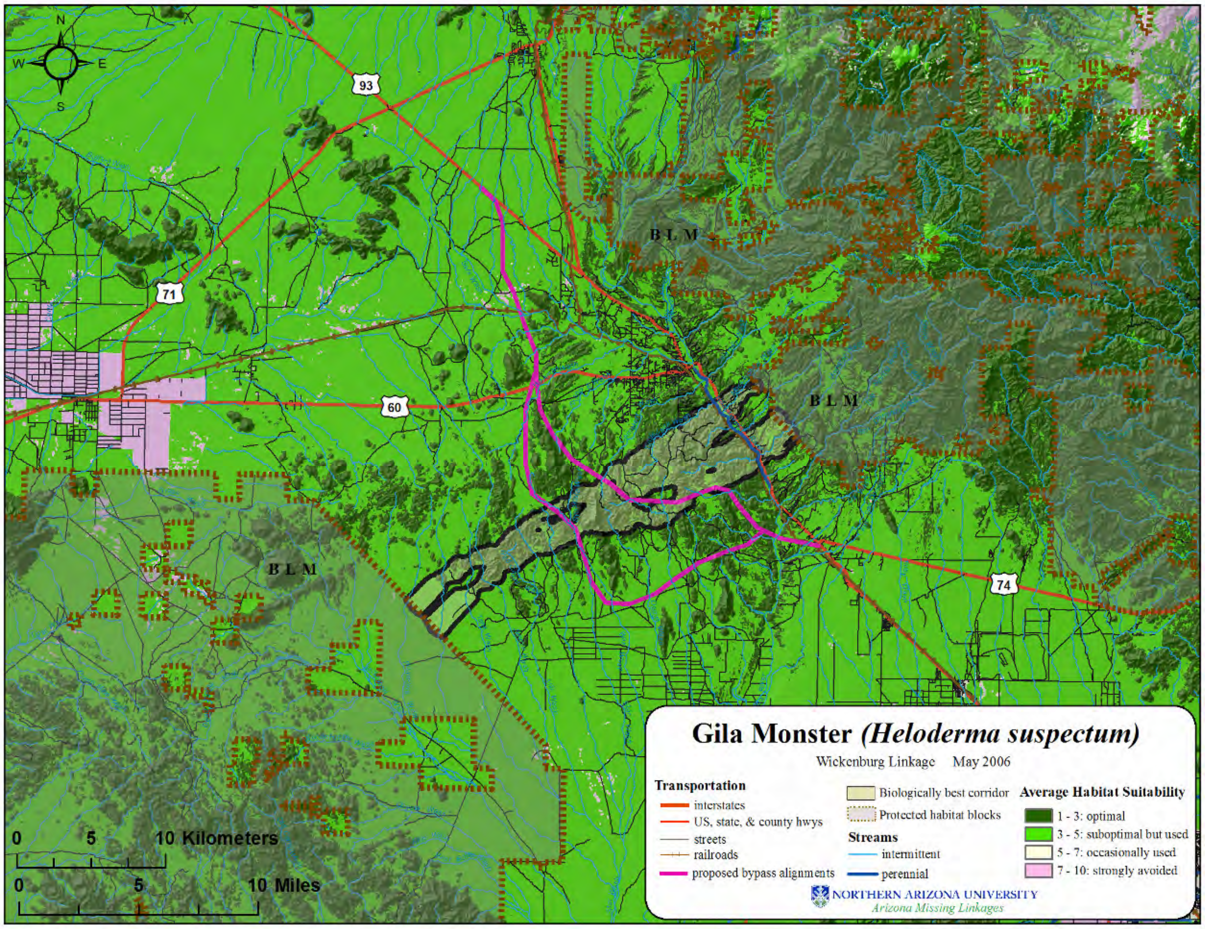

Figure 33: Modeled habitat suitability of Gila monster.

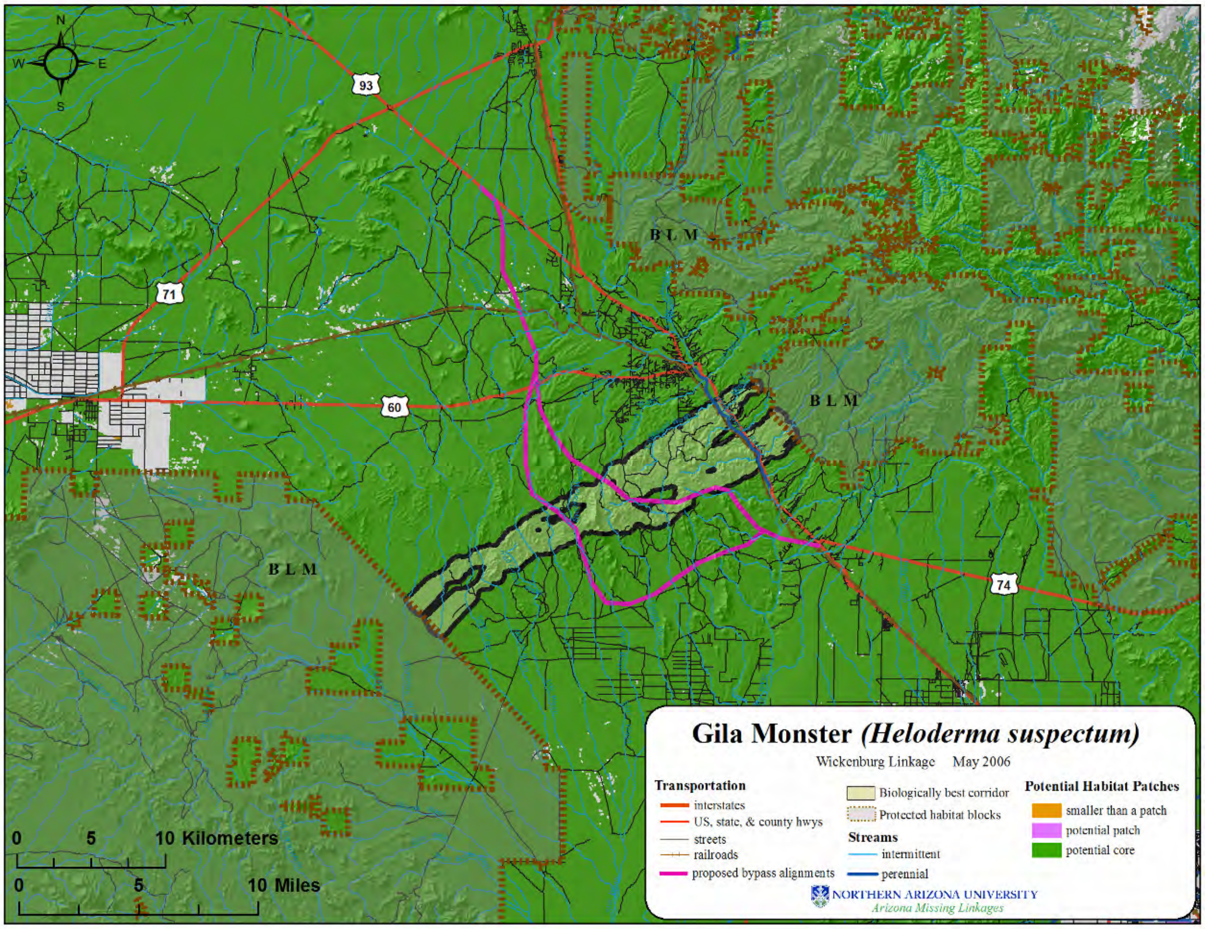

Figure 34: Potential habitat patches and cores for Gila monster.

Union of biologically best corridors – The middle strand of the UBBC significantly increases optimal potential suitable habitat for Gila Monster, while the westernmost strand of the UBBC is composed of creosote flats. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as US 60 & US 93, and habitat fragmentation.

Riparian and Aquatic Obligates

Several fish, amphibians, reptiles, and birds associated with riparian or aquatic habitats were suggested as focal species for this linkage design. Although we could not model their habitat requirements using the same analyses employed for terrestrial species, we ensured that the riparian and aquatic habitats in the linkage design along the Hassayampa River were adequately incorporated in the linkage design (Figure 35). The linkage design was expanded to include all perennial flowing waters of the Hassayampa in the linkage planning area, as well as riparian woodland and riparian mesquite bosque habitats along the river. A list of important riparian and aquatic obligate species follows:

Fish

- Bonytail Chub (*Gila elegans*) – The bonytail chub is listed as federally endangered by the U.S. Fish and Wildlife Service. While it no longer occurs on the Hassayampa River, the Hassayampa River Preserve's Palm Lake holds a reintroduced population of the species.
- Desert pupfish (*Cyprinodon macularius*) – The desert pupfish is listed as federally endangered by the U.S. Fish and Wildlife Service. It historically occurred on the Hassayampa River, and has been reintroduced to the Hassayampa River Preserve's Palm Lake
- Gila topminnow (*Poeciliopsis occidentalis occidentalis*) – The Gila topminnow is listed as federally endangered by the U.S. Fish and Wildlife Service, and is a Wildlife Species of Special Concern in Arizona. It is being held and bred at Hassayampa River Preserve.
- Longfin dace (*Agosia chrysogaster*) – The longfin dace is listed as BLM Sensitive, threatened in Mexico, and considered a Species of Concern by the U.S. Fish and Wildlife Service. (Arizona Game and Fish Department 2002). It is found on perennial reaches of the Hassayampa River.
- Razorback sucker (*Xyrauchen texanus*) – The razorback sucker is listed as federally endangered with critical habitat by the U.S. Fish and Wildlife Service. The Hassayampa River Preserve's Palm Lake holds a reintroduced population of the species.

Herpetofauna

- Gilbert's skink (*Eumeces gilberti rubricaudatus*) – Gilbert's skink is a Wildlife Species of Special Concern in Arizona, and considered a "Species of Concern" by the U.S. Fish and Wildlife Service. It is found in riparian woodland habitats along the Hassayampa River (AZGFD 2003).
- Lowland leopard frog (*Rana yavapaiensis*) – Lowland leopard frog is considered a Species of Concern by the U.S. Fish and Wildlife Service, is USFS Sensitive, and a Wildlife Species of Special Concern in Arizona. It occurs along the perennial reaches of the Hassayampa River.

Birds

- Southwestern willow flycatcher (*Empidonax traillii extimus*) – Southwestern willow flycatchers are listed as endangered by the U.S. Fish and Wildlife Service, Forest Service Sensitive, and a Species of Special Concern in Arizona. They occur in dense riparian habitats along rivers, streams, and wetlands where cottonwood, willow, boxelder, tamarisk, Russian olive, arrowweed, and buttonbrush are present.
- Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) – The yellow-billed cuckoo is listed as a candidate for endangered species by the USFWS and is a Wildlife Species of Special Concern in Arizona. They occur in riparian cottonwood-willow forests such as those surrounding the Hassayampa River.

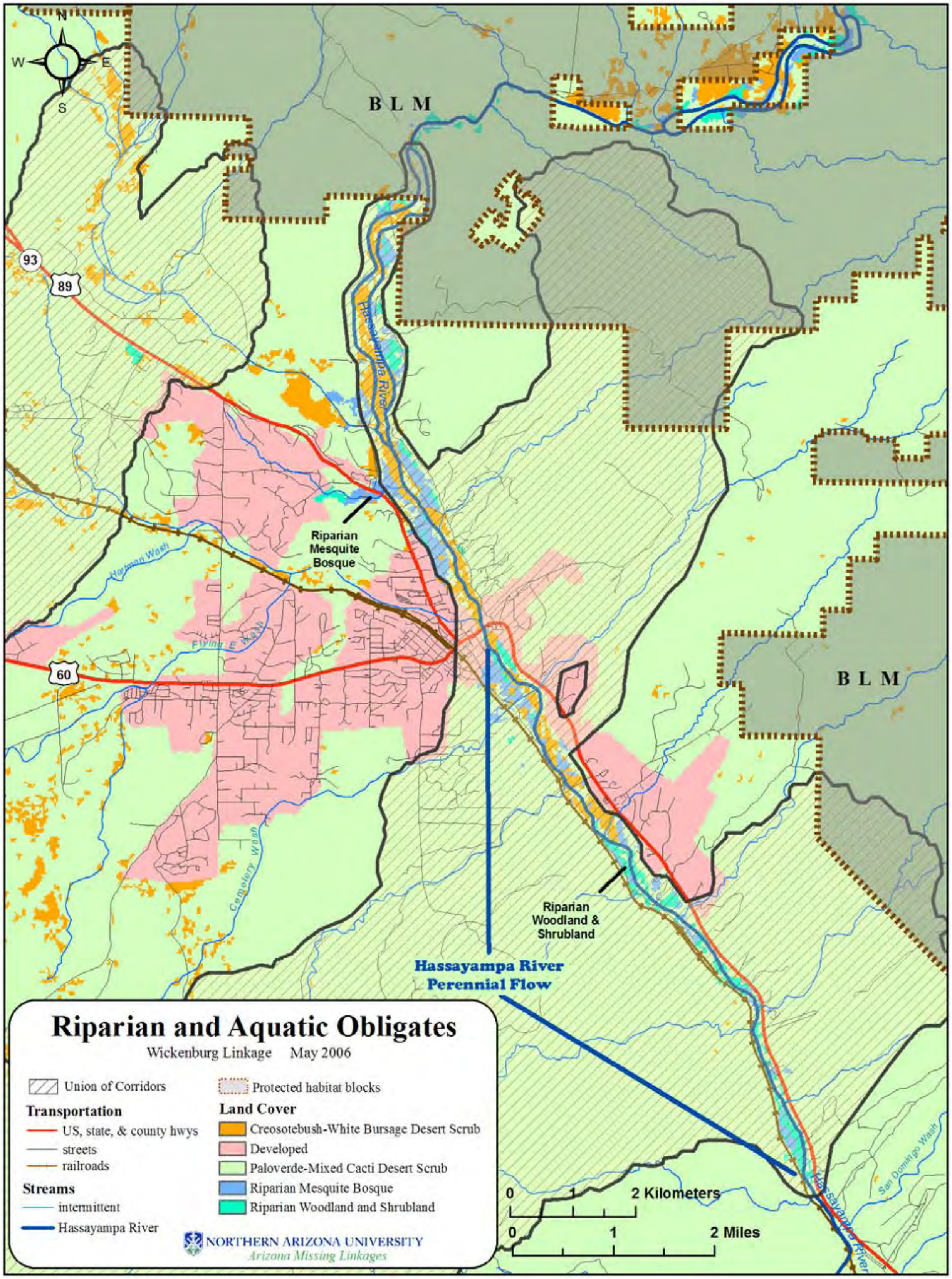

Figure 35: Important riparian habitat for fish, herpetofauna, and birds along the Hassayampa River was incorporated into the linkage design.

Appendix C: Suggested 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.
- Black Bear (*Ursus americanus*) – While black bears occur in the Prescott Forest to the north of the Wickenburg-Hassayampa wildland block, and may forage on desert vegetation such as prickly pear in Fall, there is no evidence that they have historically occured in the southern Vulture-Harquahala wildland block (Hoffmeister 1986). Two unauthenticated sightings of black bears were recorded in the 1950’s (Halloran & Blanchard 1954); however, this is not strong enough evidence for use of black bear as a focal species.
- Mountain Lion (*Puma concolor*) – Preliminary analyses indicated little habitat for mountain lions in the southern Vulture-Harquahala wildland block. The only significant suitable habitat in the southern block for this species was a small patch of chaparral in the Harquahala Mountains that was not large enough to sustain a breeding pair. While this species likely ranges throughout the southern linkage planning area, as well as the Hassayampa River and northern wildland block, we felt its habitat needs would be adequately served by the modeled focal species.
- Ringtail (*Bassariscus astutus*) – Ringtails are most often associated with rocky habitats, which cannot be adequately modeled using the available GIS layers.

Birds

- Black-throated sparrow (*Amphispiza bilineata*) – Black throated sparrows occur in a range of desert habitat dominated by shrubs, including paloverde and creosotebush vegetation associations (NMDGF 2005). They are also highly mobile. We reasoned they would be well-covered by the remaining suite of focal species.
- Common black-hawk (*Buteogallus anthracinus anthracinus*) – Common black-hawks occur in riparian woodlands, especially cottonwood forests (NMDGF 2005). They are also highly mobile. We reasoned they would be well-covered by buffering the riparian habitat surrounded the Hassayampa River, described above.
- Red shouldered hawk (*Buteo lineatus*) – The red-shouldered Hawk prefers riparian woodlands, and is found in the riparian habitat along the Hassayampa River. They are also highly mobile, and we reasoned they would be well-covered by buffering the riparian habitat surrounded the Hassayampa River, described above.
- Road runner (*Geococcyx californianus*) – Road runners occur in a range of desert habitat dominated by shrubs, including paloverde and creosotebush vegetation associations (NMDGF 2005). We reasoned they would be well-covered by the remaining suite of focal species.

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor edits to the union of biologically best corridors (Figure 36):

- We removed the straight-line strand jutting out from the easternmost strand of the linkage design. This strand was one of the two biologically best corridors for mule deer which were equal in habitat quality. We removed this strand because the remaining UBBC provided more adequately for mule deer than this strand.
- We removed the portion of the desert bighorn sheep's corridor model which runs to the Belmont Mountains, because this portion of the linkage design was encompassed by the Vulture-Harquahala protected wildland block.
- North of US 60 in the easternmost strand of the linkage design, we removed a portion of the UBBC near Mockingbird Wash.
- We widened the UBBC in several locations to ensure all strands were at least 2 km wide, and buffered the Hassayampa River approximately 200 m north of US 93.

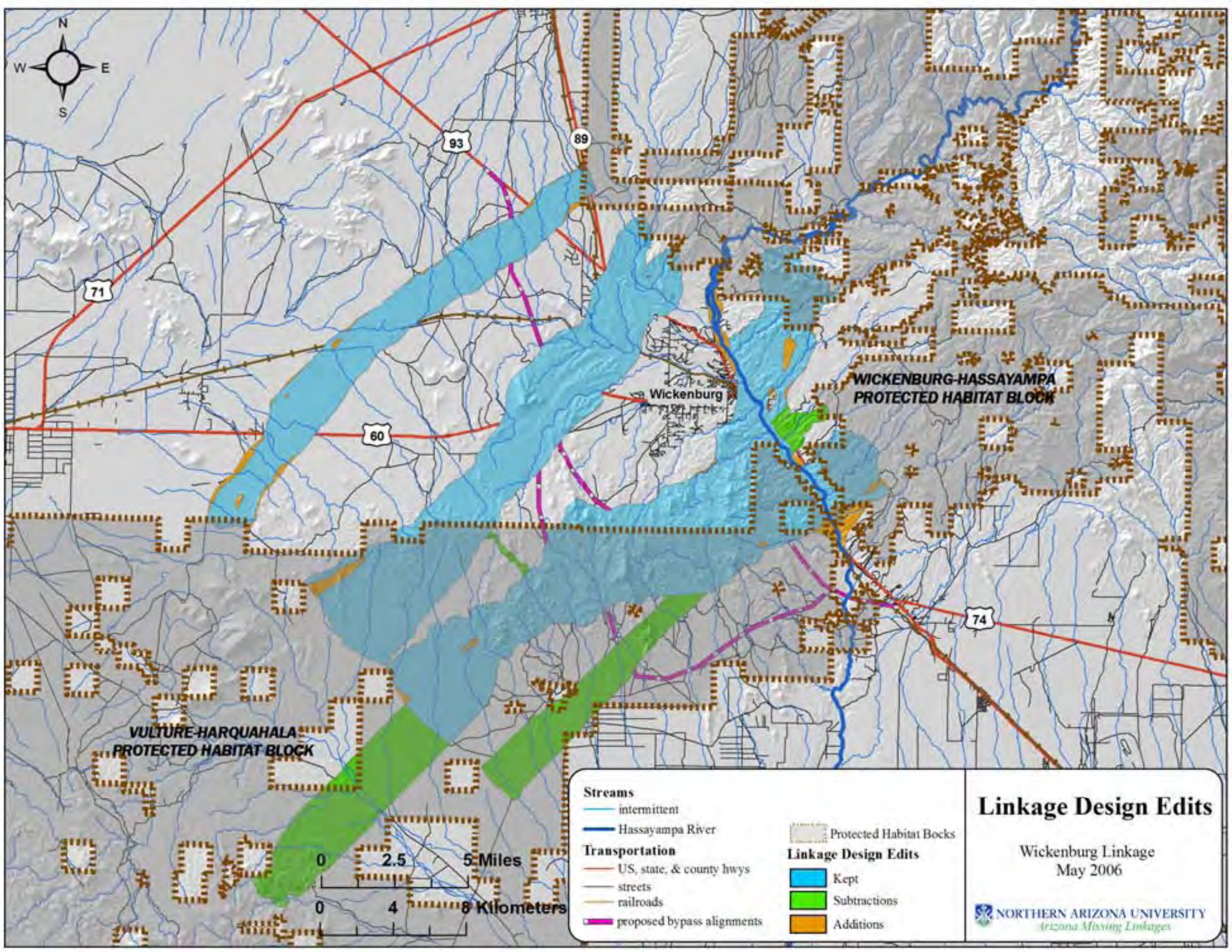

Figure 36: Edits made to union of biologically best corridors to create final linkage design.

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.

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

<u>Agriculture</u>

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

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

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

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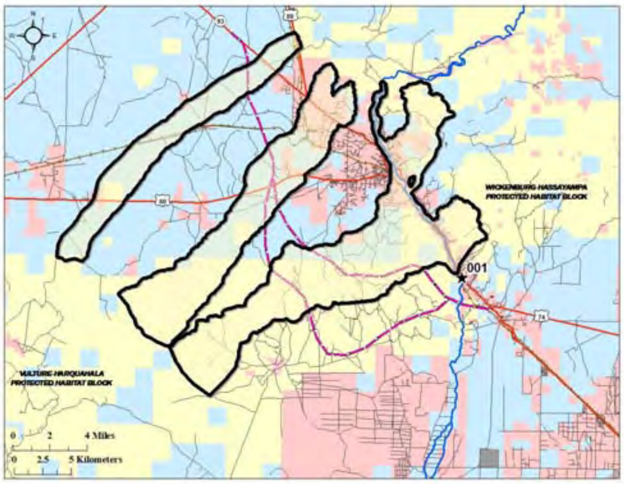
Appendix G: Database of Field Investigations

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

Appendix G: Database of Field Investigations

Linkage #:	51	**Waypoint #:**	001		
Linkage Zone:	Wickenburg	**Latitude:**	33.88741761	**Longitude:**	-112.661579
Observers:	Paul Beier, Dan Majka	**UTM X:**	346346.3916	**UTM Y:**	3750915.628
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

A medium-sized bridge is over San Domingo Wash at US60. North of this crossing is a very-active gravel mine.

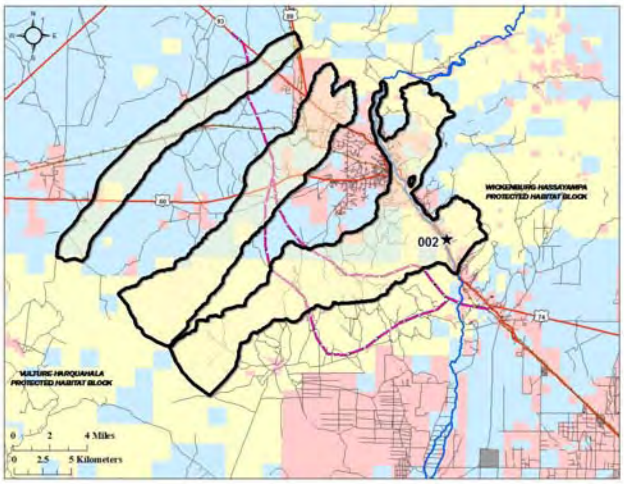
Site Photographs

Name: DSCF0001.jpg

Azimuth: 224 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	002		
Linkage Zone:	Wickenburg	**Latitude:**	33.91732517	**Longitude:**	-112.676457
Observers:	Paul Beier, Dan Majka	**UTM X:**	345024.6330	**UTM Y:**	3754254.56
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

A large bridge over Monarch Wash at US60.

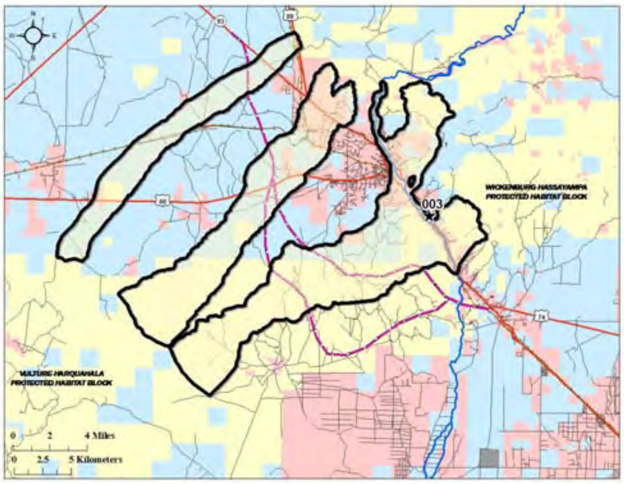
Site Photographs

Name: DSCF0002.jpg

Azimuth: 312 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	003		
Linkage Zone:	Wickenburg	**Latitude:**	33.93532388	**Longitude:**	-112.693364
Observers:	Paul Beier, Dan Majka	**UTM X:**	343494.4537	**UTM Y:**	3756276.185
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

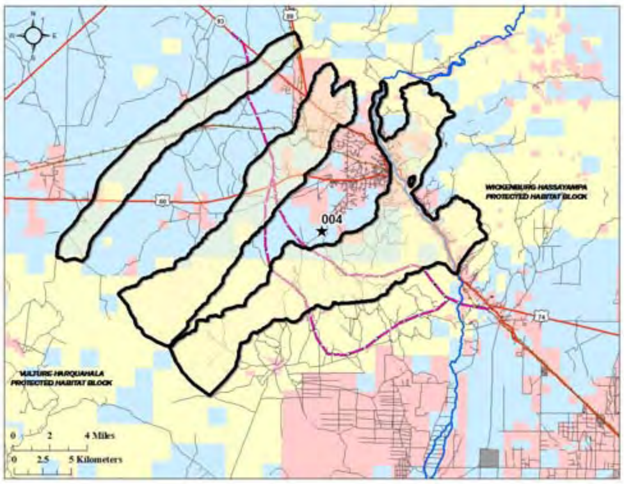
This waypoint marks the entrance to the Nature Conservancy's Hassayampa River Preserve. NO PHOTO FOR THIS WAYPOINT.

Site Photographs

Appendix G: Database of Field Investigations

Linkage #:	51	**Waypoint #:**	004		
Linkage Zone:	Wickenburg	**Latitude:**	33.92202767	**Longitude:**	-112.794211
Observers:	Paul Beier, Dan Majka	**UTM X:**	334146.9362	**UTM Y:**	3754960.100
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

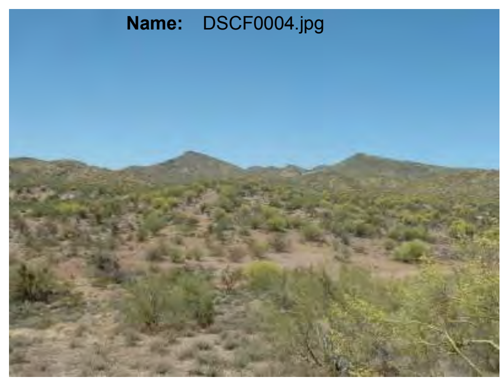
This photo shows the uplands south of the linkage area.

Site Photographs

Name: DSCF0003.jpg

Azimuth: 180 **Zoom:** 1x

Notes: Photo taken off Vulture Mine Rd.



Name: DSCF0004.jpg

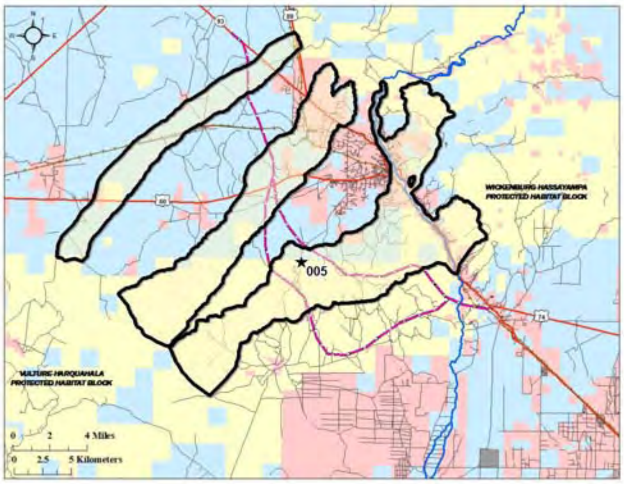
Azimuth: 240 **Zoom:** 1x

Name: DSCF0005.jpg

Azimuth: 316 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	005		
Linkage Zone:	Wickenburg	**Latitude:**	33.89768084	**Longitude:**	-112.813009
Observers:	Paul Beier, Dan Majka	**UTM X:**	332361.389	**UTM Y:**	3752290.637
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Proposed US93 realignment/Wickenburg bypass passes through this area. Photo taken from BLM/ASLD transition on Vulture Mine Rd. at Syndicate Wash.

Site Photographs

Name: DSCF0006.jpg

Azimuth: 166 **Zoom:** 1x

Name: DSCF0007.jpg

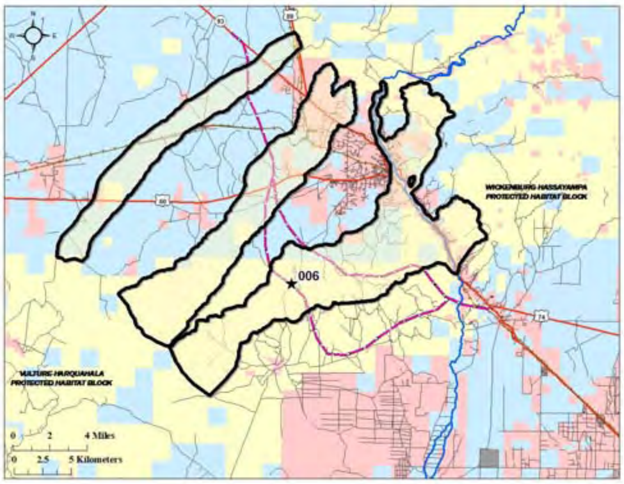
Azimuth: 224 **Zoom:** 1x

Name: DSCF0008.jpg

Azimuth: 56 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	006		
Linkage Zone:	Wickenburg	**Latitude:**	33.88047857	**Longitude:**	-112.821692
Observers:	Paul Beier, Dan Majka	**UTM X:**	331524.5976	**UTM Y:**	3750397.159
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken off Vulture Mine Rd.

Site Photographs

Name: DSCF0009.jpg

Azimuth: 166 **Zoom:** 1x

Notes: Box Wash

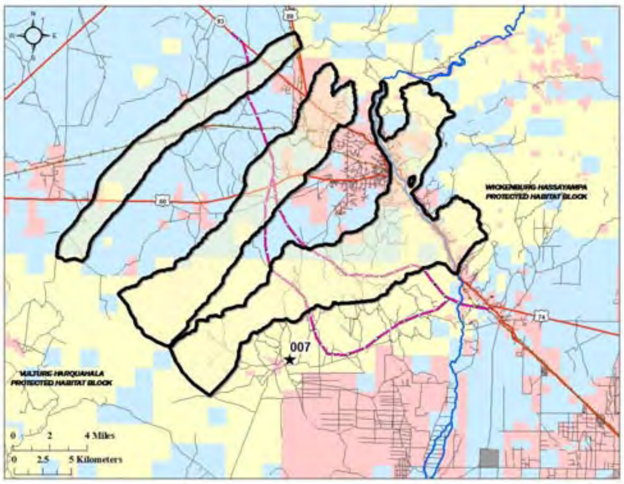
Name: DSCF0010.jpg

Azimuth: 316 **Zoom:** 1x

Notes: Facing west, Box Wash crosses Vulture Mine Rd.

Linkage #:	51	**Waypoint #:**	007		
Linkage Zone:	Wickenburg	**Latitude:**	33.82106798	**Longitude:**	-112.822141
Observers:	Paul Beier, Dan Majka	**UTM X:**	331366.3426	**UTM Y:**	3743809.453
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken from south edge of BLM land.

Site Photographs

Name: DSCF0011.jpg

Azimuth: 30 **Zoom:** 1x

Notes: Low Flats in Linkage area. Vulture Mine in distance.

Name: DSCF0012.jpg

Azimuth: 30 **Zoom:** 4x

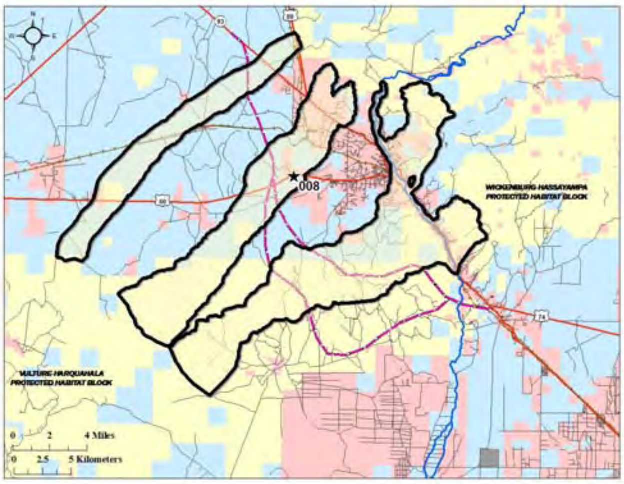
Notes: Low Flats in Linkage area. Vulture Mine in distance.

Name: DSCF0013.jpg

Azimuth: 232 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	008		
Linkage Zone:	Wickenburg	**Latitude:**	33.96465425	**Longitude:**	-112.821536
Observers:	Paul Beier, Dan Majka	**UTM X:**	331704.7022	**UTM Y:**	3759731.812
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

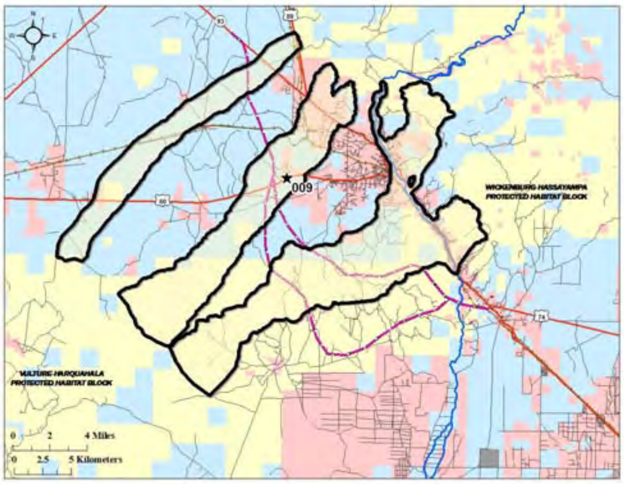
Hartman Wash crosses waypoint. Airport & transfer station are east of waypoint. NO PHOTOS FOR THIS WAYPOINT.

Site Photographs

Appendix G: Database of Field Investigations

Linkage #:	51	**Waypoint #:**	009		
Linkage Zone:	Wickenburg	**Latitude:**	33.96320335	**Longitude:**	-112.828048
Observers:	Paul Beier, Dan Majka	**UTM X:**	331100.1014	**UTM Y:**	3759581.619
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

This crossing structure would be sufficient for most animals; however, there is a large pour-off which would prevent most small animals from using the structure.

Site Photographs

Name: DSCF0016.jpg

Azimuth: 186 **Zoom:** 1x

Notes: Four 8 x 12 ft box culverts provide an open crossing structure under US60.

Name: DSCF0017.jpg

Azimuth: 20 **Zoom:** 1x

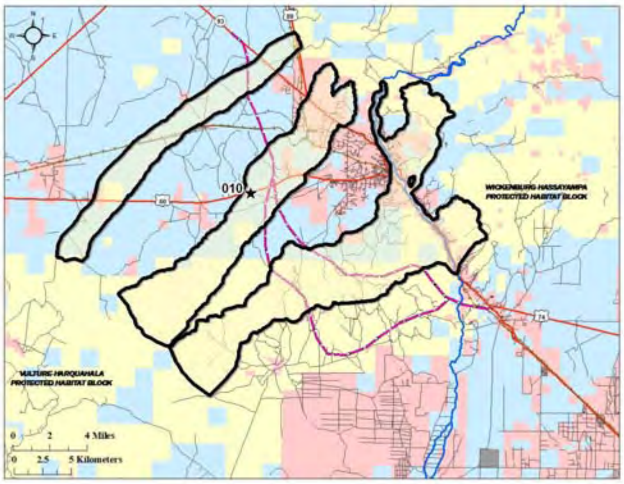
Notes: Looking down wash.

Name: DSCF0018.jpg

Notes: Close-up of pour-off

Linkage #:	51	**Waypoint #:**	010		
Linkage Zone:	Wickenburg	**Latitude:**	33.95104917	**Longitude:**	-112.862144
Observers:	Paul Beier, Dan Majka	**UTM X:**	327924.9335	**UTM Y:**	3758290.43
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Box culvert

Site Photographs

Name: DSCF0019.jpg

Azimuth: 36 **Zoom:** 1x

Notes: 3-span box culvert under US60 (each approx. 6 x8 ft)

Name: DSCF0020.jpg

Azimuth: 144 **Zoom:** 1x

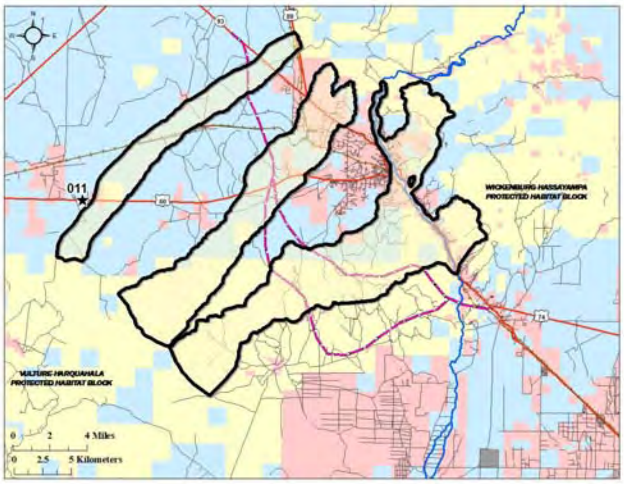
Notes: Looking up wash

Name: DSCF0021.jpg

Azimuth: 320 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	011		
Linkage Zone:	Wickenburg	**Latitude:**	33.94283121	**Longitude:**	-113.020001
Observers:	Paul Beier, Dan Majka	**UTM X:**	313317.7786	**UTM Y:**	3757655.172
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

These photos show the creosote flats in the westernmost strand of the linkage design. Photos taken from US60. Could probably shift the western corridor to this area from the private parcel to the east.

Site Photographs

Name: DSCF0022.jpg

Azimuth: 20 **Zoom:** 1x

Name: DSCF0023.jpg

Azimuth: 1x **Zoom:** 150

Name: DSCF0024.jpg

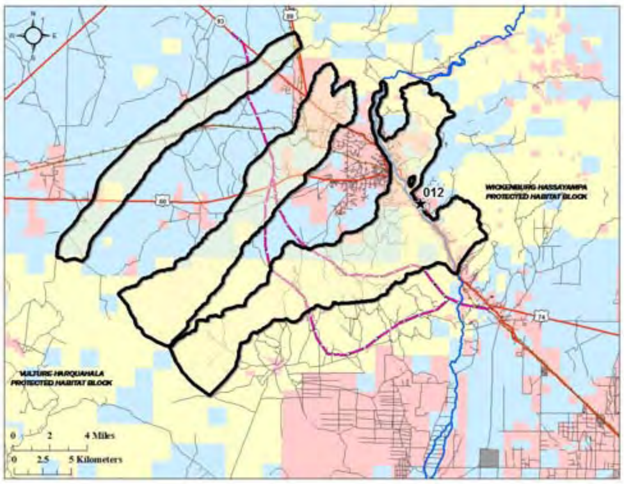
Azimuth: 234 **Zoom:** 1x

Name: DSCF0025.jpg

Azimuth: 330 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	012		
Linkage Zone:	Wickenburg	**Latitude:**	33.94502216	**Longitude:**	-112.701851
Observers:	Paul Beier, Dan Majka	**UTM X:**	342727.8054	**UTM Y:**	3757364.661
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos show Mockingbird Wash & vicinity. There are a few spaced 1-story houses along north side of highway in this corridor, and a couple businesses on south side, along wash. Photos taken from US60 at Mockingbird Wash.

Site Photographs

Name: DSCF0028.jpg

Azimuth: 314 **Zoom:** 1x

Name: DSCF0029.jpg

Azimuth: 294 **Zoom:** 1x

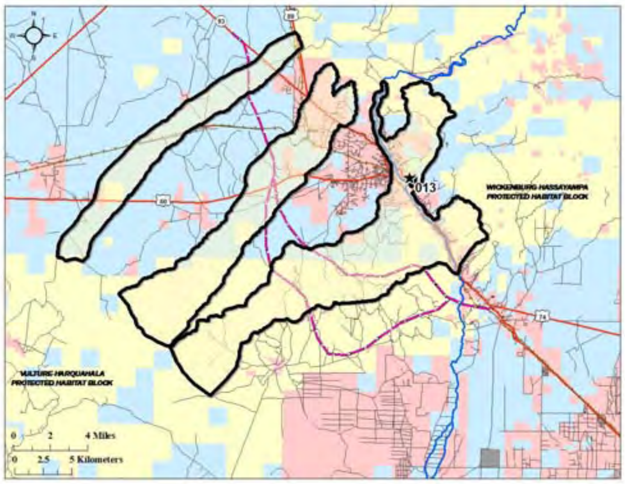
Name: DSCF0030.jpg

Azimuth: 130 **Zoom:** 1x

Appendix G: Database of Field Investigations

Linkage #:	51	**Waypoint #:**	013		
Linkage Zone:	Wickenburg	**Latitude:**	33.96482105	**Longitude:**	-112.712897
Observers:	Paul Beier, Dan Majka	**UTM X:**	341743.5602	**UTM Y:**	3759577.271
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken from bank of calamiyty canyon, approx. 1/4 mile north of US60. There a few homes in the flood plain. There seems to be less barriers here than at Mockingbird Wash.

Site Photographs

Name: DSCF0031.jpg

Azimuth: 254 **Zoom:** 1x

Notes: US60 bridge over Calamity Wash/Canyon.

Name: DSCF0032.jpg

Azimuth: 0 **Zoom:** 1x

Notes: Looking up Calimity Wash/Canyon

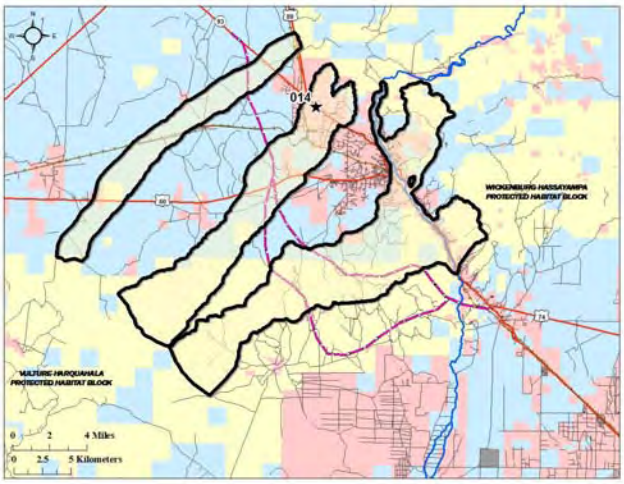
Name: DSCF0033.jpg

Azimuth: 290 **Zoom:** 3x

Notes: Zoomed view looking towards city of Wickenburg

Linkage #:	51	**Waypoint #:**	014		
Linkage Zone:	Wickenburg	**Latitude:**	34.01961255	**Longitude:**	-112.801584
Observers:	Paul Beier, Dan Majka	**UTM X:**	333655.5279	**UTM Y:**	3765794.032
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

Photos taken from US93 East of Jct. 89. Photos show middle branch of linkage. Western area of this branch has little urbanization.

Site Photographs

Name: DSCF0034.jpg

Azimuth: 184 **Zoom:** 1x

Name: DSCF0035.jpg

Azimuth: 32 **Zoom:** 1x

Name: DSCF0036.jpg

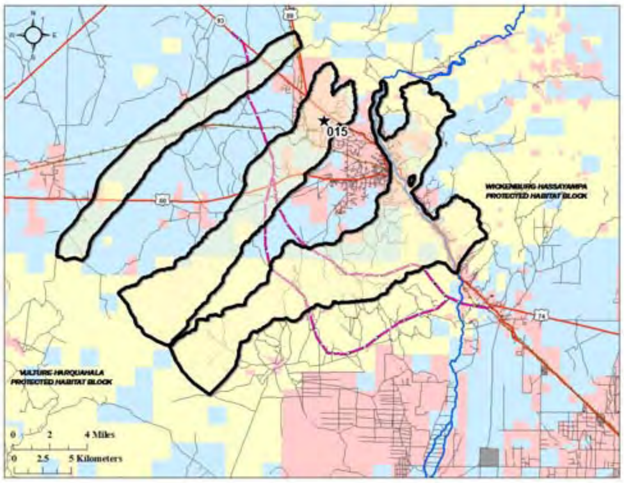
Azimuth: 74 **Zoom:** 1x

Name: DSCF0037.jpg

Azimuth: 230 **Zoom:** 1x

Linkage #:	51	**Waypoint #:**	015		
Linkage Zone:	Wickenburg	**Latitude:**	34.00850711	**Longitude:**	-112.794001
Observers:	Paul Beier, Dan Majka	**UTM X:**	334334.2324	**UTM Y:**	3764550.155
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

A fair amount of development (ranchettes & homes) is in the center strand of the linkage design. Photos taken from Quail Rd., south of US93.

Site Photographs

Name: DSCF0038.jpg

Azimuth: 28 **Zoom:** 1x

Name: DSCF0039.jpg

Azimuth: 96 **Zoom:** 1x

Name: DSCF0040.jpg

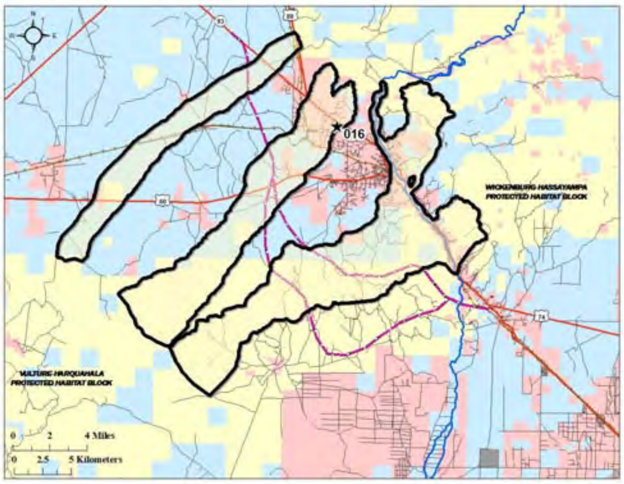
Azimuth: 120 **Zoom:** 3x

Name: DSCF0041.jpg

Azimuth: 142 **Zoom:** 6x

Linkage #:	51	**Waypoint #:**	016		
Linkage Zone:	Wickenburg	**Latitude:**	34.00428599	**Longitude:**	-112.78147
Observers:	Paul Beier, Dan Majka	**UTM X:**	335483.3927	**UTM Y:**	3764061.836
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map

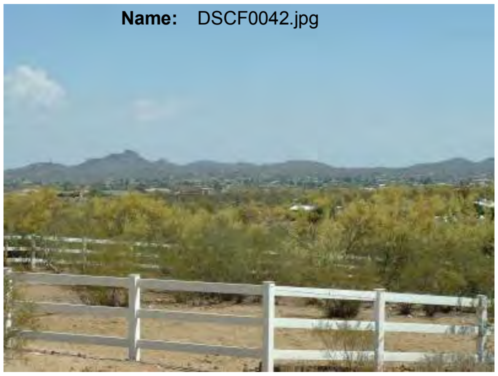


Waypoint Notes

Ranchette development in center corridor of linkage design. Denser housing is in distance, beyond the likely linkage design. Photos taken from Camino Blanco Rd., off US93.

Site Photographs

Name: DSCF0042.jpg



Azimuth: 166 **Zoom:** 3x

Name: DSCF0043.jpg

Azimuth: 188 **Zoom:** 2x

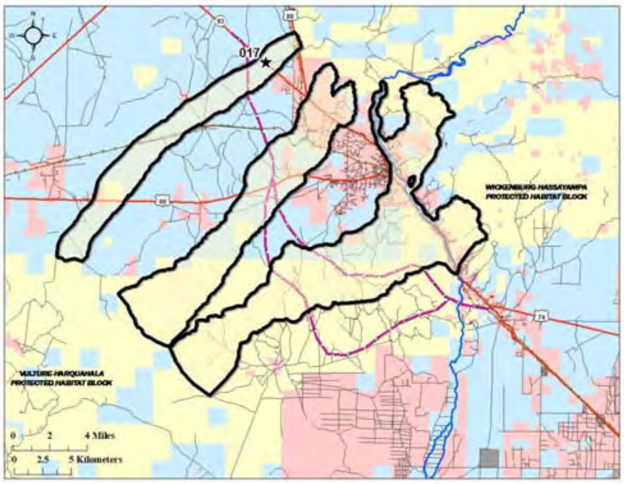
Name: DSCF0044.jpg

Azimuth: 170 **Zoom:** 1x

Appendix G: Database of Field Investigations

Linkage #:	51	**Waypoint #:**	017		
Linkage Zone:	Wickenburg	**Latitude:**	34.05364785	**Longitude:**	-112.849919
Observers:	Paul Beier, Dan Majka	**UTM X:**	329260.2967	**UTM Y:**	3769648.163
Field Study Date:	5/17/2006	**Last Printed:**	9/21/2006		

Waypoint Map



Waypoint Notes

A 4-span culvert, with 4 approx. 8x6 ft boxes, is over a wash at the western branch of the linkage design. Photo taken off US93, west of Wickenburg.

Site Photographs

Name: DSCF0045.jpg

Azimuth: 160 **Zoom:** 1x