ARIZONA MISSING LINKAGES

Bradshaw Mountains to Agua Fria Linkage Design

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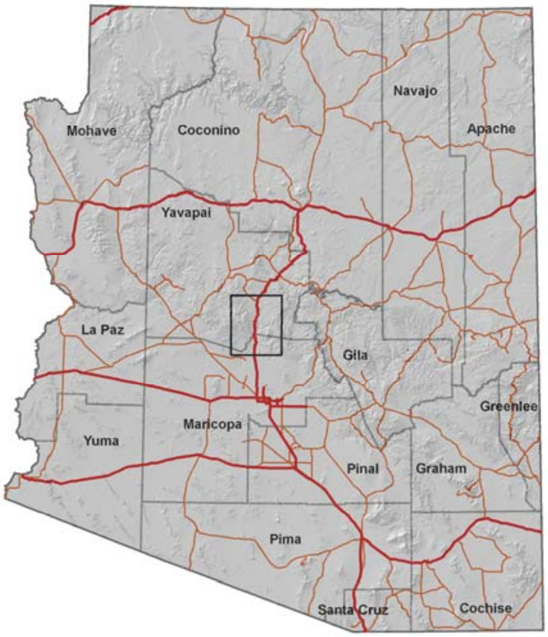
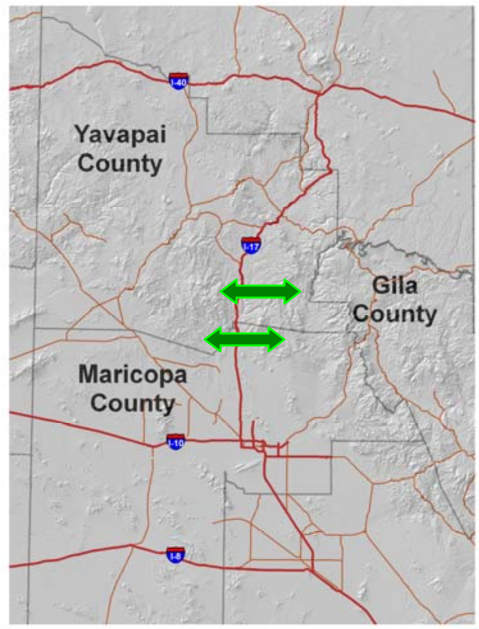
2008

BRADSHAW MOUNTAINS TO AGUA FRIA LINKAGE DESIGN





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Terminology

Key terminology used throughout the report includes:

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

Habitat Suitability: The quality of food resources, suitable cover, and other resources, as predicted from available GIS layers. We use the word "optimal" to indicate habitat where survival and reproduction of a species is expected to be close to their highest possible levels, and "suitable" for habitat in which survival and reproduction are lower, but that will support breeding by the species.

Linkage Design: A set of recommendations intended to restore or maintain the ability of wildlife to move across potential barriers between the wildland blocks. The Linkage Design in this report differs from the other 7 reports produced in 2007, which focused on identifying lands to secure biologically best corridors for individual focal species.

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

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 that may be affected by future alignments of I-17, future urbanization, and other human activities in a way that could prevent wildlife movement between the wildland blocks, or isolate large areas of wildlife habitat.

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we provide recommendations that will help conserve and enhance wildlife movement between public wildlands east and west of Interstate 17 from the Bradshaw Mountains to Agua Fria National Monument. Over 90% of the planning area is publicly owned and predominantly natural. Interstate 17 is the only major impediment to wildlife movement. Interstate17 will be undergoing major improvements to add capacity between Mileposts 232 and 262, a length of approximately 30 miles. A design concept report and environmental study of the area are expected in 2008, creating an opportunity to improve permeability compared to current conditions.

We refer to this linkage as the Bradshaw Mountains to Agua Fria Linkage in reference to two major public land investments west and east of I-17. To the west are BLM lands and the Prescott National Forest; the Bradshaw Mountains are the dominant landscape feature in this part of the Prescott National Forest. To the east lie the Agua Fria National Monument, the Tonto National Forest, and large blocks of BLM and Arizona State Lands. These areas represent an invaluable public investment in biological diversity, and this report provides 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 28 focal species that are sensitive to habitat loss and fragmentation, including 1 amphibian, 4 reptiles, 7 birds, 6 fish, and 10 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. elk and mountain lions). Some species are habitat specialists, 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 (Gila Chub, River otter), 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 and Apache Highlands. Together, these 28 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.

We used GIS methods to model habitat suitability for each focal species to identify areas important to movement for each one. We also analyzed the size and configuration of suitable habitat patches to identify live-in and move-through habitat for each focal species. We provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The ecological, educational, recreational, archeological, and spiritual values of the wildlands in this area 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 wildlands. If implemented, our plan would not only permit movement of individuals and genes across this stretch of I-17, 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 the Bradshaw Mountains to Agua Fria Linkage.

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
Bats	*Desert Tortoise	Bald Eagle
*Black Bear	§Black-necked Garter Snake	Cassin's Sparrow
*Coues White-Tailed Deer	§Lowland Leopard Frog	Common Black Hawk
*Elk	§Mexican Garter Snake	Gambel's Quail
*Javelina	§Narrow-headed Garter Snake	Northern Goshawk
*Mountain Lion		§Southwestern Willow Flycatcher
*Mule Deer		§Yellow-billed Cuckoo
*Pronghorn		**FISH**
Ringtail		§Longfin Dace
§River Otter		§Gila Mountain Sucker
		§Gila Chub
		§Speckled Dace
		§Spikedace
		§Gila Topminnow

* 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."

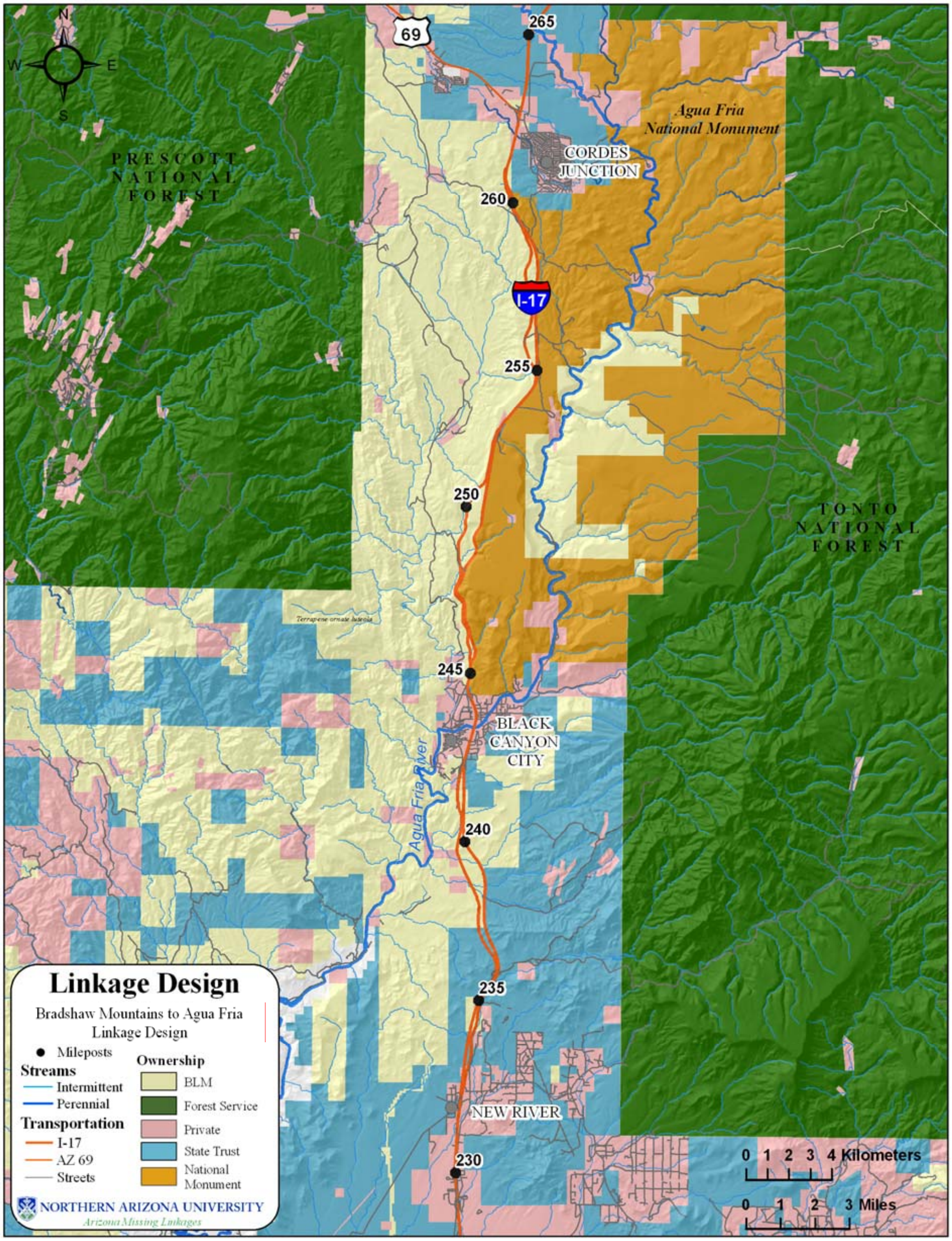

Figure 1: The Linkage Design addresses opportunities to enhance permeability of I-17 from milepost 230 to 265.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

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

Ecological Significance of the Bradshaw Mountains to Agua Fria Linkage

The Bradshaw Mountains to Agua Fria Linkage planning area includes I-17 and adjacent lands from Cordes Junction at State Highway 69 to New River, from mileposts 265 to 230 (Figure 1). This area is largely within the Sonoran Desert Ecoregion, near its transition to the Apache Highlands Ecoregion. The Sonoran Desert Ecoregion consists of 55 million acres within southern Arizona, southeastern California, northern Baja, California, and northwestern Sonora (Marshall et al. 2000). 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, whose conservation is critical for maintaining the earth's biodiversity.

The heart of the Linkage Area is a large BLM-administered area spanning I-17, including the Agua Fria National Monument on the east side of I-17 (Figure 2). This area boasts high-elevation deserts, canyons, mesas, and riparian canyons, while forests and chaparral communities bound it to the east in the Tonto National Forest, and to the west in the Prescott National Forest.

The southern end of the Linkage Area is dominated by paloverde-mixed cacti desert scrub that gives way to mesquite upland habitat and semi-desert grasslands near Cordes Junction (Figure 3). The Agua Fria River Valley runs parallel to I-17, crossing the Interstate near Black Canyon City. Its perennially flowing waters provide the most prominent riparian habitat in the Linkage Area.

The varied habitat types in the Linkage Planning Area support a variety of wildlife. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include the river otter and southwestern willow flycatcher (USFWS 2005). The Linkage Area is also home to far-ranging mammals such as mule deer, elk, and mountain lions. These animals move long distances to gain access to suitable foraging or breeding sites, and require connectivity between large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as javelina also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

Existing Conservation Investments

The Bradshaw Mountains to Agua Fria Linkage is designed to protect connectivity and promote wildlife movement in an area boasting significant public investments in conservation. The Linkage Area lies between the Prescott and Tonto National Forests along the Mogollon Rim. Protected areas in the region include the Agua Fria National Monument, and the Castle Creek, Pine Mountain, Mazatzal, and Cedar Bench Wilderness Areas (Figure 4).

The Agua Fria National Monument covers over 70,000 acres of semi-desert mesas and valleys; the dominant feature is the Agua Fria River canyon which provides rare riparian habitat and rugged topography. This canyon is home to a wide array of wildlife including the lowland leopard frog, the Mexican garter snake, the common black hawk, and the desert tortoise. Four species of native fish, including the longfin dace, the Gila mountain sucker, the Gila chub, and the speckled dace, exist in the Agua Fria River and its tributaries. Elevations within the monument range from 2,150 feet along the river canyon to roughly 4,600 feet in the adjacent hills.

Further east, the Agua Fria National Monument abuts the Tonto National Forest, the fifth largest National Forest, embracing almost 3 million acres of a rugged and varied landscape. A diversity of vegetative communities boasts saguaro cactus deserts in the lower elevations and cool pine forests in the mountains. The elevation ranges from 1,300 to 7,900 feet. Three wilderness areas lie in or adjacent to the Tonto. The Pine Mountain Wilderness Area includes over 29,000 acres of mountains, mesas, and canyons, appropriately named for the pine forests covering the mountains. The Cedar Bench Wilderness lies just a few miles to the north along the Verde Rim. Chaparral and pinyon forests cover the 16,000 acre wilderness landscape. Tonto National Forest is also home to the expansive Mazatzal Wilderness Area, over 252,500 acres of rugged desert mountains, foothills, and deep canyons that form one of the original Wilderness Areas designated in 1964. The wilderness spans several life zones, as the elevation ranges from 2,100 feet near the Sheep Bridge up to 7,903 feet at Mazatzal Peak. Sonoran desert scrub gives way to semi-desert grasslands in the low to mid-elevations. The higher elevations support stands of ponderosa pine. The Verde River snakes through vertical canyons, providing rare riparian habitat in the area.

To the west of I-17, the Prescott National Forest encompasses roughly 1.25 million acres including the Juniper, Santa Maria, Sierra Prieta, and Bradshaw Mountains, and the headwaters of the Verde and Santa Maria Rivers. The landcover is primarily Sonoran desert scrub in the lower elevations chaparral and forest communities dominate the higher reaches of the landscape. The Prescott borders three other National Forests, and contains several Wilderness Areas. One of these, the Castle Creek Wilderness, forms much of the western skyline for motorists on I-17 and contains 29,000 acres of desert and forest. The lower elevations support saguaro cactus, paloverde, and mesquite. The elevation climbs as granite peaks top off at 7,000 feet on Juniper Ridge, overlooking the Agua Fria River valley. The higher elevations include chaparral communities of scrubby live oak, mountain mahogany, and manzanita with pinyon and juniper on southern slopes. Dense populations of mule deer and javelina inhabit this area, along with mountain lions, black bears, and elk.

Threats to Connectivity

I-17 is the only significant barrier to animal movement in this area (Figure 1), although urbanization extending from Cordes Junction, Black Canyon City, and New River may increasingly threaten connectivity. The Arizona Department of Transportation has initiated a Design Concept Study and related environmental studies regarding the proposed widening of, and other improvements to, I-17 from milepost 232 to milepost 262. This segment of I-17 is the primary transportation corridor between Phoenix and northern Arizona. The existing roadway is a four-lane, divided interstate.

The New River area, at mile 232, is at the southern end of the Linkage Planning Area. This community is included in the General Plan for Phoenix, a rapidly growing metropolitan area. Cordes Junction is at the northern end of the Linkage Planning Area, at the interchange of I-17 and State Route 69, near mile 262. Plans for a new Interchange at this junction are in the development phase. Many communities in Yavapai County anticipate rapid population growth, which would be facilitated by an expanded I-17. Improvements to I-17 provide an opportunity to improve wildlife crossings, promote wildlife habitat connectivity, and decrease wildlife-vehicle collisions.

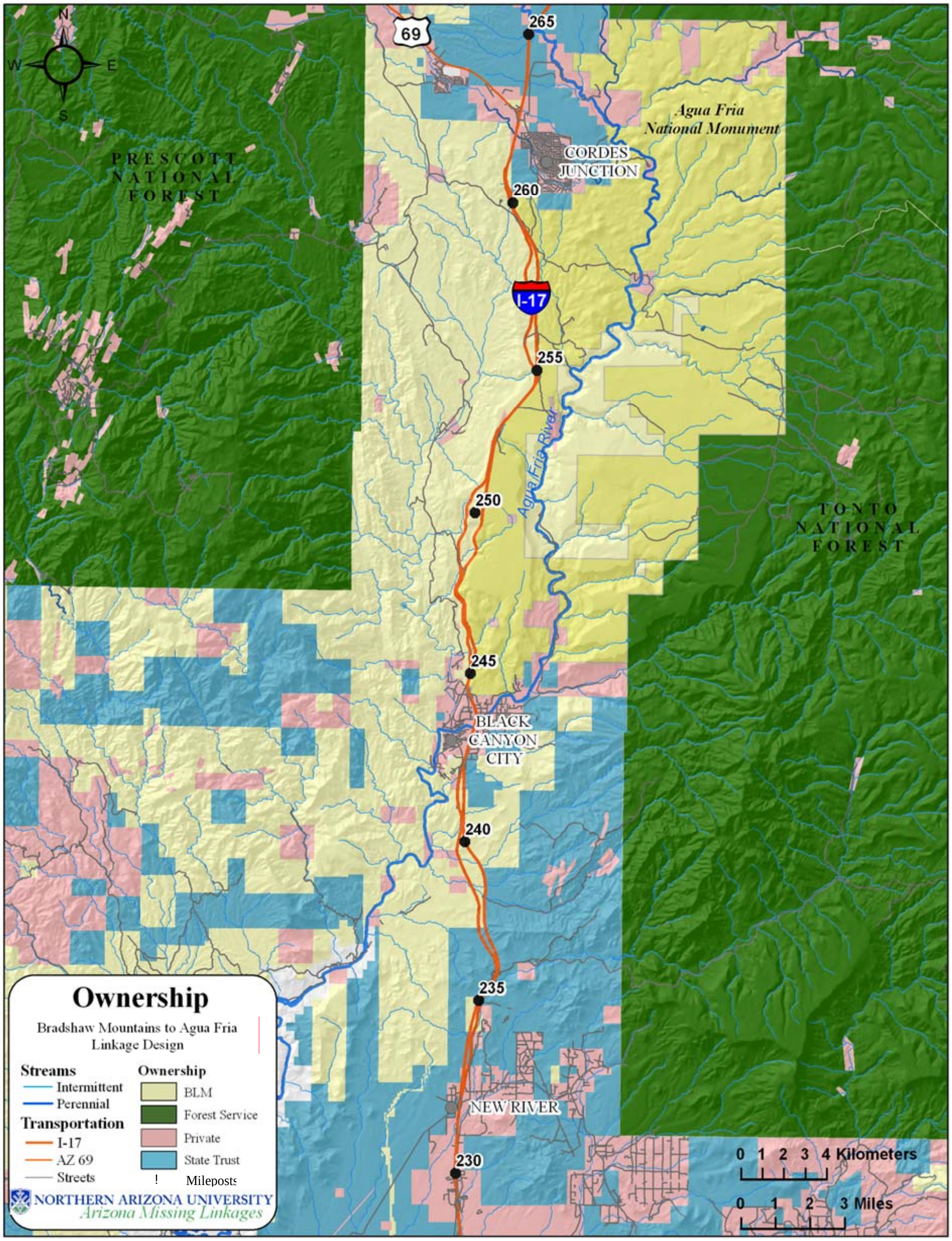

Figure 2: Land ownership in the Linkage Planning Area.

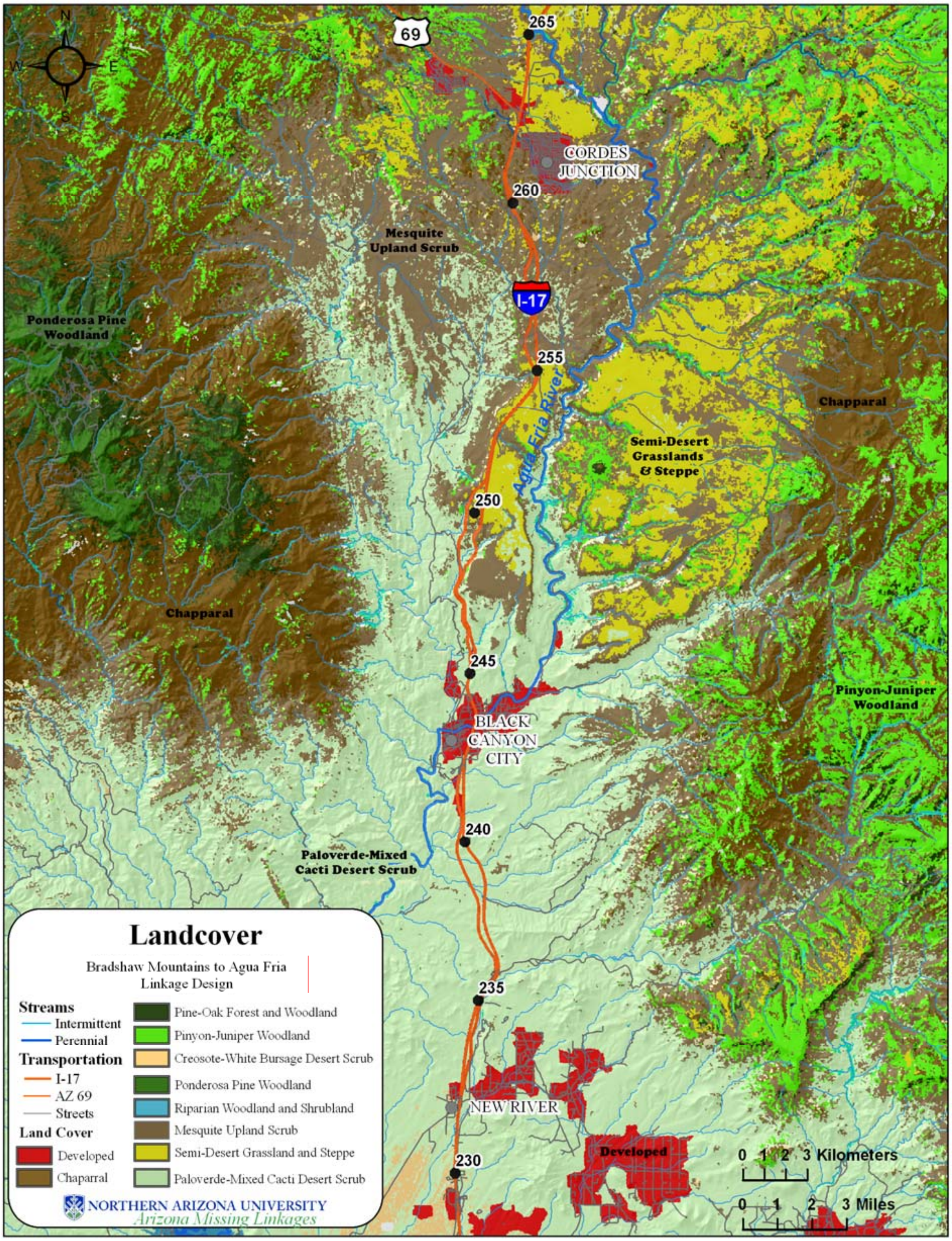

Figure 3: Land cover in the Linkage Planning Area. At about Milepost 253, I-17 occupies almost 100% of a narrow isthmus of grasslands connecting the two major grassland blocks of the Agua Fria National Monument.

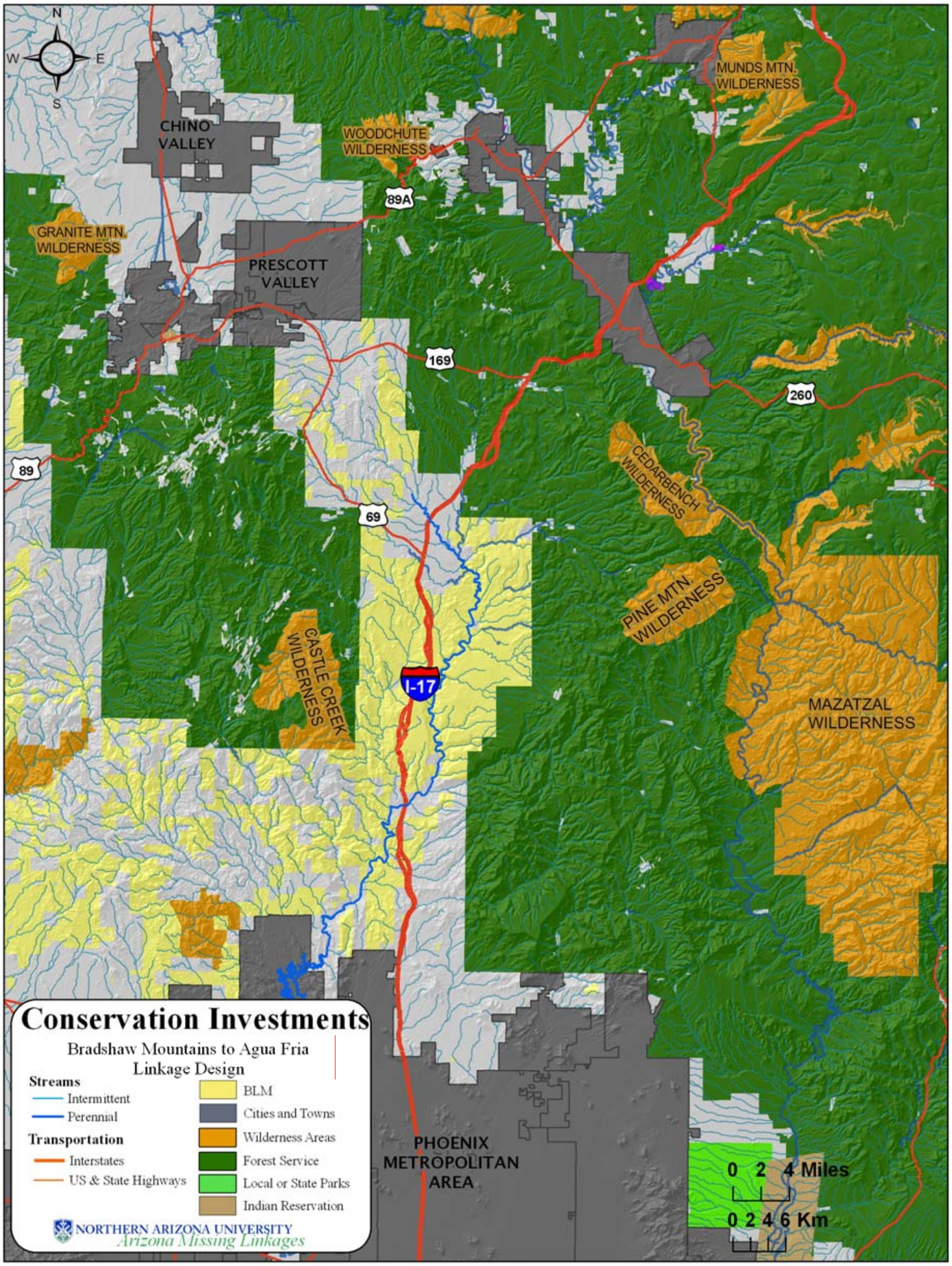

Figure 4: Existing conservation investments within the Linkage Planning Area.

Linkage Design & Recommendations

Because design alternatives for improvements to I-17 are in the development phase, we cannot make recommendations for specific crossing structures in the linkage area. Instead, this Linkage Design provides maps of potential habitat for focal species, describes barriers to movement, and recommends mitigation measures to maintain or improve wildlife movement.

Land Cover and Habitat by Five-Mile Segment

For each of seven 5-mile segments between mileposts 230 and 265, we first describe the land cover patterns (Table 2) and wildlife habitat (Table 3) surrounding I-17, from south to north.

The area surrounding **mileposts 230-235** provides potential live-in and pass-through habitat for javelina, and suitable habitat for desert tortoise, mule deer, and pronghorn. Landcover is mainly paloverde-mixed cacti desert scrub, interspersed with some creosotebush mixed desert and thornscrub. The New River, a seasonal wash, and the community of New River are located here.

Table 2. Percentage composition of land cover classes within ½ mile (800 m) of US-93.

Land Cover	I-17 Mileposts							
	230-235	**235-240**	**240-245**	**245-250**	**250-255**	**255-260**	**260-265**	**Total**
Chaparral	0	0	0	0	0	2	12	2
Creosotebush, Mixed Desert & Thornscrub	3	0	0	0	0	0	< 1	0
Desert Scrub	<1	<1	<1	1	1	2	1	1
Developed	14	11	47	10	8	9	1	14
Encinal	0	0	0	0	0	1	18	3
Juniper Savanna	0	0	0	0	<1	0	<1	0
Mesquite Upland Scrub	1	1	0	20	40	66	41	24
Paloverde-Mixed Cacti Desert Scrub	80	88	53	64	2	9	<1	42
Pine-Oak Forest and Woodland	0	0	0	0	0	1	<1	0
Pinyon-Juniper Woodland	0	0	0	1	2	9	2	2
Ponderosa Pine Woodland	0	0	<1	<1	0	0	0	0
Riparian Woodland and Shrubland	<1	0	0	<1	<1	<1	<1	0
Semi-Desert Grassland and Steppe	0	0	0	4	45	0	25	11

Table 3: Distribution of optimal and suitable habitat of focal species along Interstate 17. "Optimal" habitat is associated with the highest survival and reproduction of the species; "suitable" habitat is good enough to support breeding, but is not as good as optimal habitat.

Focal Species	Mileposts that intercept large areas of **suitable habitat**	Mileposts that intercept large areas of **optimal habitat**
Black Bear	245-250, 260-262	260-262
Coues White-tailed Deer	247-265	none
Desert Tortoise	230-255	240-242, 245-250
Elk	260-262	260-262
Javelina	230-265	230-255
Mountain Lion	247-265	260-262

The area from **mileposts 235-240** provides potential live-in and pass-through habitat for javelina, and suitable habitat for desert tortoise, mule deer, and pronghorn. The landcover is mainly paloverde-mixed cacti desert scrub.

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

Developed land dominates the area between **mileposts 240 to 245**, where Black Canyon City (Figure 25) is situated. Outside of the developed areas, there is optimal live-in and pass-through habitat for javelina, and suitable habitat for desert tortoise, mule deer, and pronghorn. The Agua Fria River also crosses I-17 here, providing important habitat for riparian species (Appendix B). Land cover is mainly paloverde-mixed cacti desert scrub.

Between **mileposts 245 and 250**, there is potentially optimal live-in and pass-through habitat for javelina and desert tortoise, whereas miles 247 to 250 contain potentially optimal habitat for mule deer and pronghorn. In addition, this is the southernmost habitat in the linkage suitable for black bear, Coues white-tailed deer, and mountain lion. The landcover is mostly paloverde-mixed-cacti desert scrub in the south. Scattered mesquite upland scrub and small patches of semi-desert grassland and steppe appear in the northern portion. The Agua Fria National Monument abuts the east side of I-17 from Milepost 245 to Milepost 260. The gentle topography from Milepost 230 to 245 begins to transition to mountainous terrain. There are steep grades, curves, and a shortened field of view for motorists on I-17. The area from Black Canyon City to the Bumble Bee Interchange (Milepost 248.4) is noted for a high rate of wildlife-vehicle collisions (AGFD 2006).

From **mileposts 250-255**, there is potentially optimal live-in and pass-through habitat for Coues white-tailed deer, javelina, mule deer, and mountain lion. The land cover is a mix of mesquite upland scrub and semi-desert grassland scrub. The Sunset Point Interchange is located at Milepost 252.5. Arizona Game and Fish Department (2006) identified this area as a critical corridor for pronghorn. The problem is that at the Sunset Point Interchange, I-17 occupies almost 100% of a narrow isthmus of grasslands connecting the two major grassland blocks of the Agua Fria National Monument (Figure 3).

Between **mileposts 255 and 260** there is potentially optimal live-in and pass-through habitat for desert tortoise, Coues white-tailed deer, javelina, mule deer, and mountain lion. The landcover is dominated by mesquite upland scrub, with small amounts of pinyon-juniper and paloverde vegetation associations. The Badger Springs Interchange is located at Milepost 256.1, another area that has been identified as a critical corridor for pronghorn (AGFD 2006).

Big Bug Creek crosses I-17 at Milepost 262, providing rugged topography that is potentially optimal or suitable for several of the focal species including black bear, Coues white-tailed deer, desert tortoise, javelina, mule deer, and mountain lion. This is the only segment containing potential elk habitat in the linkage. The gentler steppe lands north of Big Bug Creek are suitable for pronghorn. The land cover surrounding **mileposts 260-265** is largely mesquite upland scrub, interspersed with semi-desert grassland steppe.

Removing and Mitigating Barriers to Movement

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

While roads 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 in the Linkage Planning Area, it is essential to consider the *entire* linkage design, including conserving land within the linkage planning area. Indeed, investment in a crossing structure would be futile if the associated habitat is lost.

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Table 1). 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 5). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

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

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

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

Table 4: 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 5: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

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

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

5) **Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement.** Small mammals, carnivores, and reptiles avoid crossing structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004).

In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches, Russian thistle, sand, or garbage that impede animal movement (Beier, personal observation). Bridged undercrossings rarely have similar problems.

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

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

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

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

10) **Crossing structures for pronghorn must have high openness ratio, at-grade location, and special fencing.** Sawyer and Rudd (2005) recommend underpasses for pronghorn should have natural substrate, minimum height of 18 ft and minimum width of 60 feet. For a typical 4-lane highway this corresponds to an openness ratio (opening length x opening width/ width of road) of about 7 or more. Because pronghorn prefer gentle topography, crossings structures should be at the grade of the surrounding terrain; thus the roadway should be either elevated (to provide a wildife underpass) as in Figure 5, row 2, right photos, or built into a trench (to provide an at-grade wildlife overpass (Sawyer and Rudd 2005) as in Figure 5, top row. Pronghorn have been known to walk across bridges to cross streams and rivers (H. Sawyer, WEST, Inc., unpublished data). Highway fencing should be as far as possible from the right-of-way (AGFD 2006a). Near crossing structures, woven wire fencing can help funnel pronghorn to the structure. If a fence is intended to be permeable to pronghorn (e.g., to allow pronghorn to escape the right of way, or where suitable crossing structures are not available), use wire strands for roadside fencing, with a smooth bottom wire >18” above the ground (Yoakum 2004).

Existing Roads and Crossing Structures on Interstate 17

We noted 11 crossing structures (locations shown in Figure 13) between Mileposts 232 and 265. Some of these could serve medium or large animals after appropriate modifications.

- Milepost 232, large (159’ and 149’ long) bridges over the New River
- Milepost 238.8, Waypoint 024, large bridges span Moore’s Gulch.

- Milepost 239.6, Waypoint 025, large (315’ and 179’) bridges over Little Squaw Creek (Figure 6).
- Milepost 243.3, a 363’ bridge over the Agua Fria River.
- Milepost 249.5, large (about 160’) underpass (northbound I-17) and overpass (southbound I-17) for Bumble Bee Road (Figure 7).
- Milepost 251, Waypoint 015, a box culvert approximately 5x9’, the entrance is blocked by a barbed-wire fence (Figure 9)
- Milepost 252.5, Waypoints 013 and 014, 107’ bridges over the access road to the Sunset Point Rest Area. The undercrossing is paved.
- Milepost 256, Waypoint 010, 89’ bridges over Badger Point Road (Figure 10).
- Milepost 259.4, Waypoint 007, 89’ bridges over Bloody Basin Road.
- Milepost 262, Waypoint 001. The 215’ bridges over Big Bug Creek (Figure 11) have limited usefulness for wildlife because residential development dominates Big Bug Creek in this area.
- Milepost 265, Waypoint 006, large bridges (232’ and 274’ ft) over the Agua Fria River (Figure 12).

Figure 6: Bridge over southbound lane of Little Squaw Creek provides a good wildlife crossing structure for species that use Sonoran habitat, Milepost 239.6, Waypoint 025.

Figure 7: The Bumble Bee Interchange was not designed to facilitate animal movement (Waypoint 017, MP 249). Bumblebee Road crosses under the northbound lanes (background) where the steep cut bank impedes animal access to the underpass. The road crosses over the southbound lanes (foreground). A vegetated wildlife overpass is a good option in places like this where the main highway is cut deep below the natural surface of the land.

Figure 8: Site recommended for a new wildlife underpass (Milepost 249.5, Waypoint 016). Replacing the fill slope with a bridge would create an excellent wildlife underpass.

Figure 9: Milepost 251 (Waypoint 015), a box culvert blocked by a fence could be upgraded to a larger, more accessible wildlife crossing.

Figure 10: A bridge at Badger Point Interchange could provide a good crossing opportunity if native vegetation were restored and pavement removed, Milepost 256, Waypoint 010.

Figure 11: Bridge over Big Bug Creek appears wildlife-friendly, but it leads into a developed area, Milepost 262, Waypoint 001.

Figure 12: A large bridge makes a good crossing structure at the Agua Fria River, Milepost 265, Waypoint 006.

Recommendations for Highway Crossing Structures on the Current I-17 Alignment

The primary highway connecting Phoenix to northern Arizona, I-17 is the single most important threat to wildlife movement in this area. Although several crossing structures existing on I-17 allow for some animal movement, the area needs more large crossing structures. Wildlife-automobile collisions occur throughout this area, with highest collision rates in four areas (1) just north of New River, (2) from Black Canyon City to Bumble Bee Road, (3) from the Sunset Point Interchange to Bloody Basin Road, and (4) near riparian areas such as Moore's Gulch and the Agua Fria River (Figure 13) (Arizona Game and Fish Department 2006). Most documented collisions involve deer, elk, and bears; collisions with small mammals, reptiles, and amphibians are much more common but are not systematically recorded (Arizona Game and Fish Department 2006). In addition to *Standards and Guidelines for Wildlife Crossing Structures* above, we offer these recommendations to reduce collisions with large mammals and improve connectivity on the current I-17 alignment.

Create new bridges or large, open culverts in seven locations (Figure 13):

- Milepost 240.9
- Milepost 246
- Milepost 249.5 (Figure 8)
- Milepost 250.2
- Milepost 252.5: The current interchange here should be removed (it can be replaced by an interchange closer to the Sunset Point Rest Area), and a high, long bridge should be built in this location to allow pronghorn and other grassland animals to easily move in a continuous swath of restored grassland underneath the bridge.
- Milepost 255
- Somewhere between mileposts 260-262, build a bridged underpass suitable for use by elk, black bear, and mule deer to supplement the bridged crossing at Big Bug Creek. Urban development threatens to block wildlife movement to and from the existing bridge at Big Bug Creek.

Upgrade 3 existing structures for use by large mammals (Figure 13):

- Mileposts 249 Southbound and 248.4 Northbound, Bumble Bee Interchange (Figure 7). Crossing structures should be aligned and should funnel wildlife off of the roadways. A vegetated wildlife overpass would be a good choice at this location. Alternatively, a new underpass at MP 249.5 (Figure 8) nearby might be a cheaper option.
- The box culvert at Milepost 251. Upgrade to a more open crossing structure
- Milepost 256, Waypoint 010, Badger Point Interchange. Remove the pavement from the underpass and restore native vegetation (Figure 10).

Improve permeability for small animals:

- Remove wire fences across entrances to existing structures, and use fencing to guide animals towards crossing structures.
- Build small or midsized crossing structures to provide connectivity across the highway for species such as javelina.
- Install reptile and amphibian fencing (such as a lipped concrete wall) along all portions of I-17 which are adjacent to rock outcrops and steep slopes.
- Install culverts suitable for smaller animals every 300 meters as described in the Standards and Guidelines above.

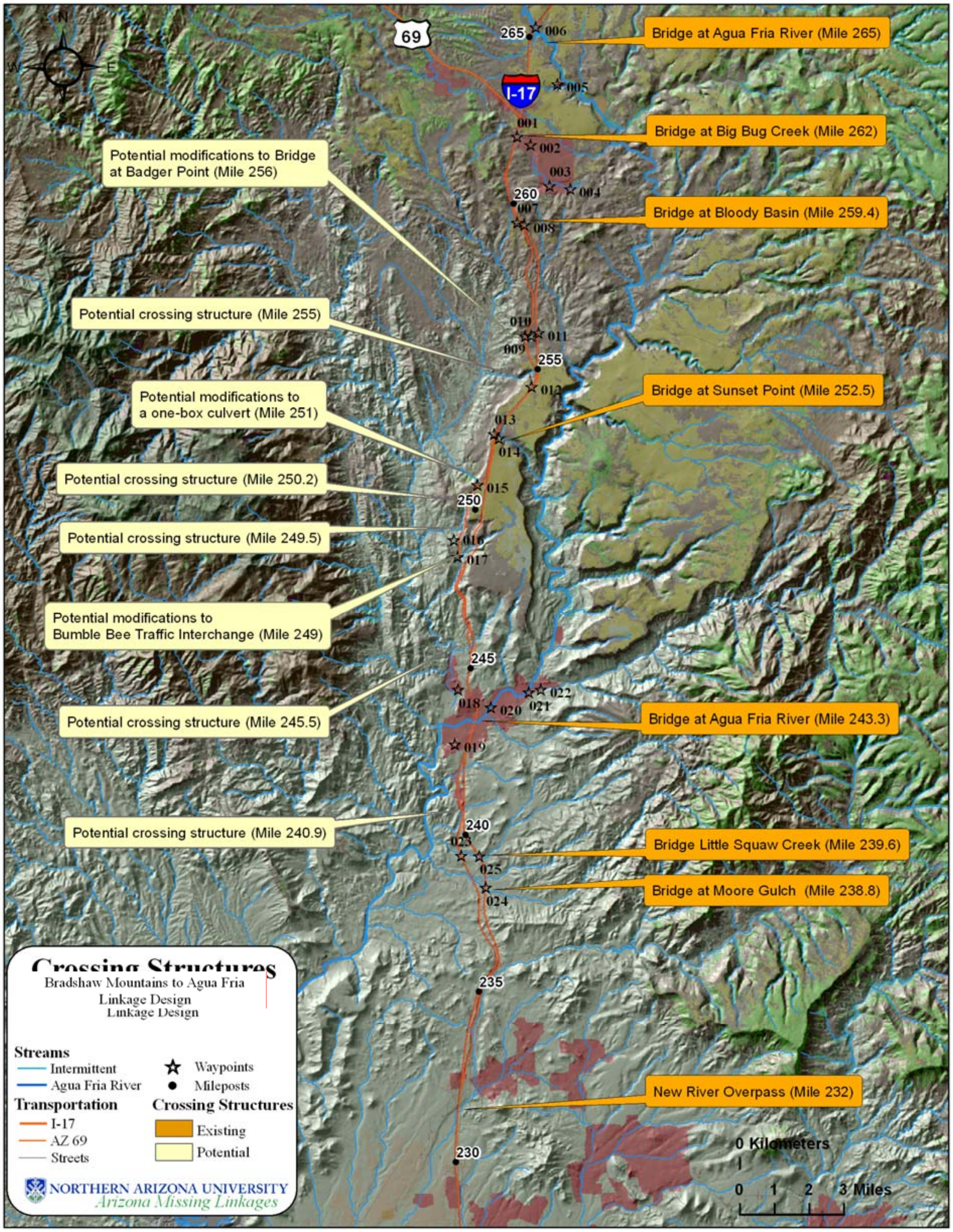

Figure 13: Existing bridges (yellow labels) and locations for recommended new crossing structures (white labels) on the current alignment of I-17. Stars indicate waypoints at which photographs (Figures 7-12, Figures 23-27) were taken. The bridge at MP 252.5 contains a vehicle underpass that makes it unusable by pronghorn; this should be replaced by a pronghorn-friendly crossing structure.

Recommendations for Highway Crossing Structures along Proposed Alternative Routes

ADOT's 2006 Design Concept includes nine potential alternative alignments (A – H) for widening Interstate 17 between Cordes Junction and Black Canyon City (Figure 14). At the time this report is being written, ADOT recommends four alignments for further study (A, D, E and G.) Alternative A would widen the existing alignment. The current road would remain operational even if another alignment is built, potentially creating a new habitat island between the old and new highways. In this section, we discuss each of the proposed alignments. From the perspective of wildland integrity, the main issues are:

1. Impacts to the area's only large wildland with a primary mandate for conservation, namely the Agua Fria National Monument. Large protected ecosystems are important as places where natural processes (fire, predator-prey interactions, hydrologic regimes, inter-species competition, evolutionary selection) operate under near-natural conditions. These places also provide humans with a sense of place, solitude, and renewal; smaller wildlands cannot provide similar cultural benefits to people. Because these ecological and cultural values are largely independent of species diversity and species rarity, such large intact systems are sometime called "coldspots" to recognize conservation importance distinct from that offered by "hotspots" that may conserve rare species.

2. Impacts to grasslands (a highly threatened vegetation type in Arizona) and pronghorn (a state species of concern). The Agua Fria National Monument protects high desert grasslands on its flats and mesas – which are also the easiest places to build roads. This pronghorn herd is isolated from nearby populations by habitat loss and highways, is susceptible to predation, fencing, and urban expansion, and currently has low fawn recruitment and survival rates (AGFD 2006). Maintaining and restoring connectivity is a priority for this herd.

3. Isolation of wildlife habitat in a "habitat island" between the old and new highway alignments, potentially isolating optimal and suitable habitat for many wildlife species (Table 6). Although crossing structures can mitigate isolation effects, avoidance of impacts involves less risk.

Table 5. Acres of optimal and suitable habitat for each focal species that would fall inside an "island" of land between each alternative alignment (B through H) and the existing I-17, based on habitat models in Appendix B. "Optimal" habitat is associated with the highest survival and reproduction of the species; "suitable" habitat is good enough to support breeding, but is not as good as optimal habitat.

Species	B (MP 244-251)		C (MP 245-251		D (MP 245-262)		E (MP 246-251)		F (MP 245-215		G (MP 245-257)		H (MP 245-260)	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S
Black Bear	0	11	0	6	0	8	0	1.5	0	7	0	22	0	29
Coues' White-tailed	0.1	16	0.1	12	0	2	2	0.4	0	1	0.9	24	1	39
Desert tortoise	14	10	6	5	125	145	3	1	9	4	26	23	35	35
Elk	0.2	0.1	0.2	0.1	0	0	0.1	0.1	0.1	0.2	1	0.4	2	0.5
Javelina	38	5	21	4	417	190	5	1	14	1	49	17	68	26
Lion	0.2	18	0.2	13	0	19	0.1	1.8	0.1	1	1	21	2	35
Mule Deer	21	21	13	11	102	445	1	5	0.9	14	14	50	25	66
Pronghorn	8	15	4	10	61	86	0.2	1	0.3	3	5	14	10	21

Alternatives B and C would cross Agua Fria National Monument, and would bisect the largest grasslands and largest pronghorn habitat in the region. Thus with respect to all three of the above criteria, Alternatives B and C are far worse than any other alternative. From the perspective of wildland connectivity and wildland integrity, we agree with ADOT's recommendation that Alternatives B and C should not be further investigated. Nonetheless, we do include relevant crossing structure recommendations for these alternatives.

Alternatives G and H have markedly greater potential to isolate habitat for black bear, desert tortoise, Coues white-tailed deer, elk, javelina, mountain lion, mule deer, and pronghorn. If one of these alignments is selected, it will be important to construct crossing structures suitable both on the new alignment as well as along the current alignment.

Although we could not visit all potential alignments, we documented existing crossing structures along the existing I-17 route, and identified areas that would be suitable for building additional crossings (Figure 13 above). In this section, we identify washes that would be suitable for additional large crossing structures along each alternative route. For the purposes of this discussion, we reference these washes to the nearest corresponding milepost on the existing I-17 route. Based on habitat suitability maps for each focal species (Appendix B), Table 2, Table 3, and Table 5 indicate how each alternative alignment would impact vegetation communities and wildlife species.

- Alternative A would widen the existing alignment without constructing new routes for I-17. Sites for new or upgraded wildlife crossing structures on the existing alignment are identified in Figure 13. Alternative A would not create habitat islands between alignments, and would not result in increased fragmentation and isolation of wildlife habitat. Because the current road will remain open if an alternative alignment is built, we recommend new and upgraded wildlife crossings on the existing alignment (Figure 13 and text above) regardless of which additional alignment(s) may be implemented. Alternative A is clearly the optimum alternative from the perspective of wildlife connectivity. The cost of new and upgraded crossing structures is also far lower for Alternative A, because each other alternative would require new structures both on the old and new alignments.

- Alternative B (12 km of alternative route) could isolate large areas of optimal habitat for desert tortoise (about 1400 acres), javelina (3700 acres), and mule deer (2100 acres). Most dramatically, this alternative would create an island of pronghorn habitat between the two freeways, consisting of about 780 acres of optimal pronghorn habitat and about 1500 acres of suitable pronghorn habitat (Table 6). In accordance with the Standards and Guidelines for Wildlife Crossing Structures (above), we recommend building at least 8 crossings suitable for large mammals and ungulates, and 40 smaller crossings suitable for small mammals in this 12 km of roadway. Suitable sites for large crossing structures include Arrastre Creek, near Milepost 250, and an unnamed stream near Milepost 245 (Figure 15).

- Alternative C (10 km of alternative route) fragments optimal habitat for desert tortoise, javelina, mule deer, and pronghorn, and suitable habitat for black bear, Coues white-tailed deer, and mountain lion. This alternative would potentially isolate approximately 400 acres of optimal pronghorn habitat and nearly 1000 acres of suitable pronghorn habitat. We recommend building at least 7 crossings suitable for large mammals and ungulates, and 33 smaller crossings suitable for small mammals along this 10 km roadway. Suitable sites for large crossing structures include Arrastre Creek near Milepost 249, and an unnamed stream near Milepost 247 (Figure 16).

- Alternative D (10 km of alternative route) would include a new alignment within the median area between existing roadways. It would bisect an existing island between the roadways where there is optimal habitat for desert tortoise, javelina, mule deer, and pronghorn, and suitable habitat for black bear, Coues white-tailed deer, and mountain lion. We recommend building at least 7 crossings suitable for large mammals and ungulates, and 33 smaller crossings suitable for small mammals. We recommend one of the large crossing structures should be at Arrastre Creek, near Milepost 249 (Figure 18).

- Alternative D1 (9 km of alternative route) includes a series of underground tunnels. Without knowing what portion of the route would be made up of tunnels, we cannot analyze the areas of habitat that would be impacted. Assuming tunnels are a substantial fraction of the 9 km of road length, this alternative would not significantly fragment wildlife habitat. We recommend providing fencing to funnel wildlife away from the tunnel entrances and toward any wildlife crossings on existing or new alignments. A tunneled road creates wildlife overpasses that should facilitate movement by all wildlife species.

- Alternative E (11 km of alternative route) isolates a smaller quantity of optimal habitat than Alternatives B, C, F, G, and H. Nonetheless it could isolate > 200 acres of optimal habitat for desert tortoise, javelina, and Coues white-tailed deer (Table 6). We recommend building at least 7 crossings suitable for large mammals and ungulates, and 37 smaller crossings suitable for small mammals. Suitable sites for large crossing structures include an unnamed stream near Milepost 251, and unnamed stream near Milepost 249, and Arrastre Creek near Milepost 248 (Figure 19).

- Alternative F (11 km of alternative route) could isolate about 950 acres of optimal habitat for desert tortoise, about 1400 acres of optimal javelina habitat, and about 1400 acres of habitat suitable for mule deer. We recommend building at least 7 crossings suitable for large mammals and ungulates, and 37 smaller crossings suitable for small mammals. Suitable sites for large crossing structures include an unnamed stream near Milepost 251, an unnamed stream near Milepost 249.5, Arrastre Creek near Milepost 248, and an unnamed stream near Milepost 245 (Figure 20).

- Alternative G (19 km of alternative route) could isolate over 2500 acres of optimal habitat for desert tortoise, over 500 acres of optimal pronghorn habitat, and additional 1400 acres of suitable pronghorn habitat, about 4900 acres of optimal javelina habitat, and about 1400 acres of optimal mule deer habitat. It could isolate large patches of suitable habitat of all focal species except elk. We recommend building at least 13 crossings suitable for large mammals and ungulates, and 63 smaller crossings suitable for small mammals. Suitable sites for large crossing structures include an unnamed stream near Milepost 249.5, Bumble Bee Creek near Milepost 252, an unnamed stream near Milepost 249, Arrastre Creek near Milepost 248, and an unnamed stream near Milepost 245 (Figure 21).

- Alternative H (23.7 km of alternative route) fragments optimal habitat for desert tortoise, javelina, mule deer, and pronghorn. This is the only area where suitable and optimal elk habitat abut I-17, making it the most critical area for locating elk crossings. This alignment potentially isolates over 9000 acres of mule deer habitat (optimal and suitable combined), 4000 acres of Coues white-tailed deer habitat, 3700 acres of mountain lion habitat, and 3000 acres of pronghorn habitat. To avoid isolating such large areas, it is particularly important that crossing structures on this alignment be designed for maximum permeability. We recommend building at least 14 crossings suitable for large mammals and ungulates, and 65 smaller crossings suitable for small mammals. Suitable sites for large crossing structures include an unnamed stream near Milepost 260, Bumble Bee Creak near Milepost 258, Government Springs Wash near Milepost 256, Bumble Bee Creek near Milepost 252, an unnamed stream near Milepost 249, Arrastre Creek near Milepost 247, and an unnamed stream near Milepost 246 (Figure 22).

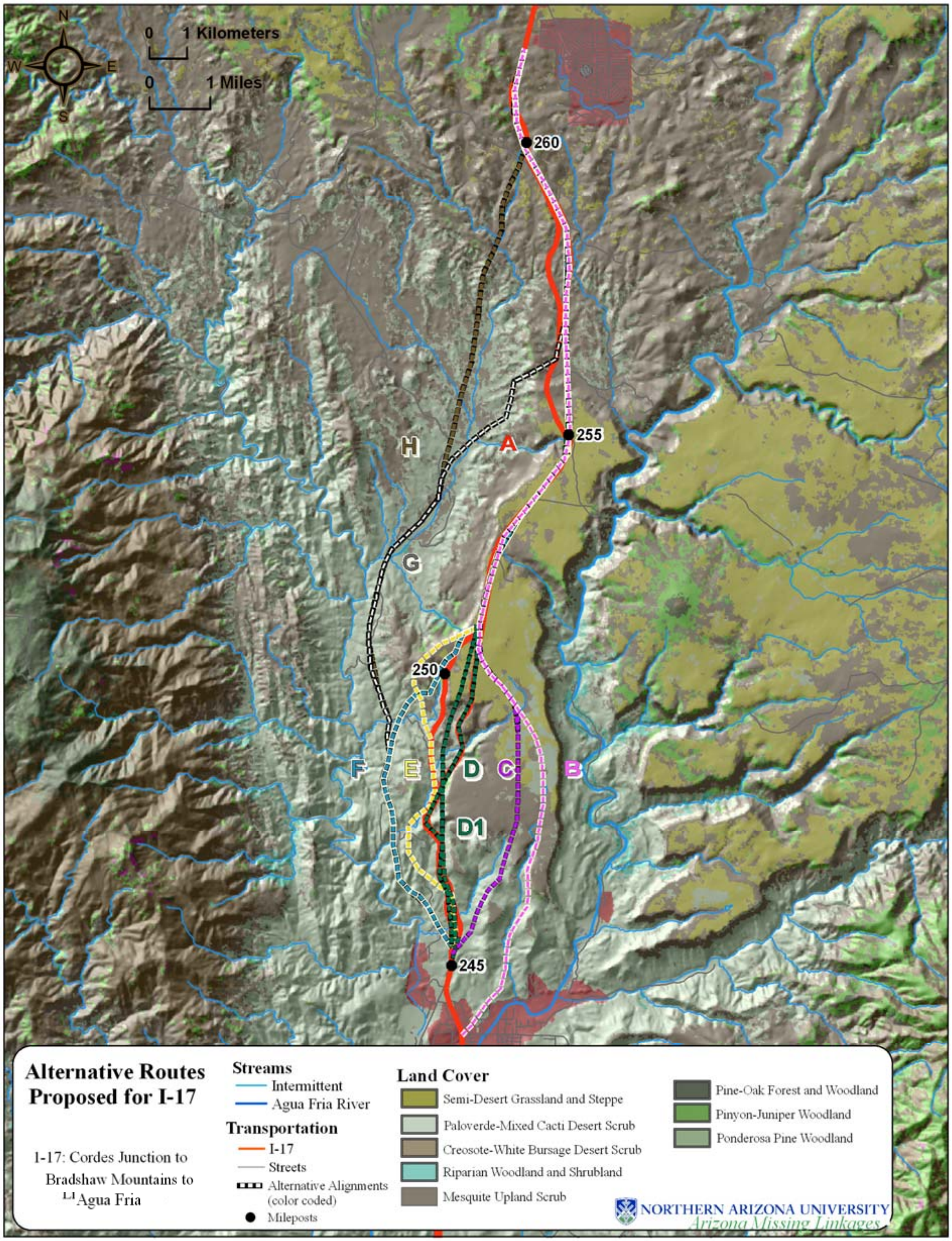

Figure 14: Proposed alternative alignments A through H. Alternative A is to add lanes to the existing alignment.

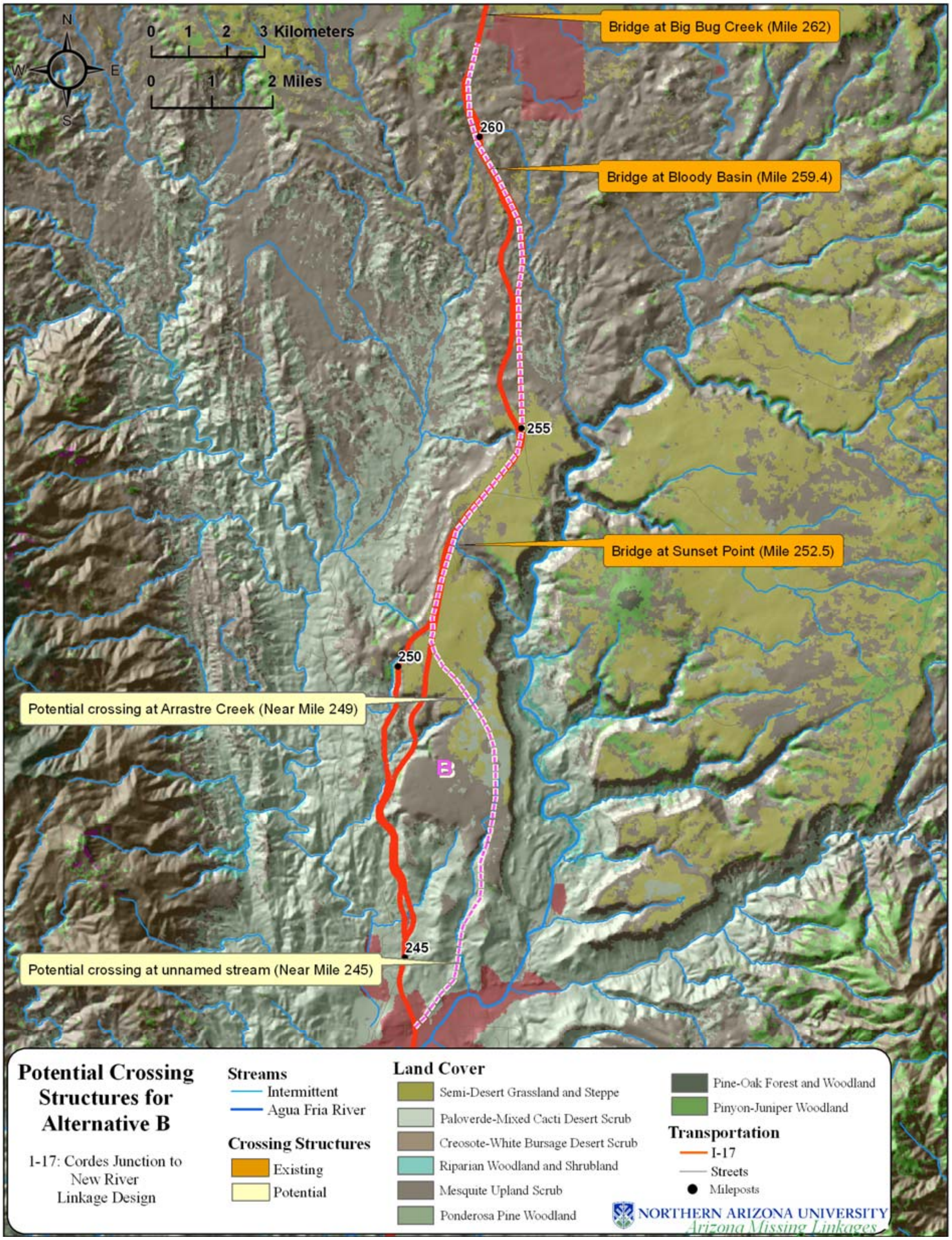

Figure 15: Additional potential crossings identified for the alternative route B. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

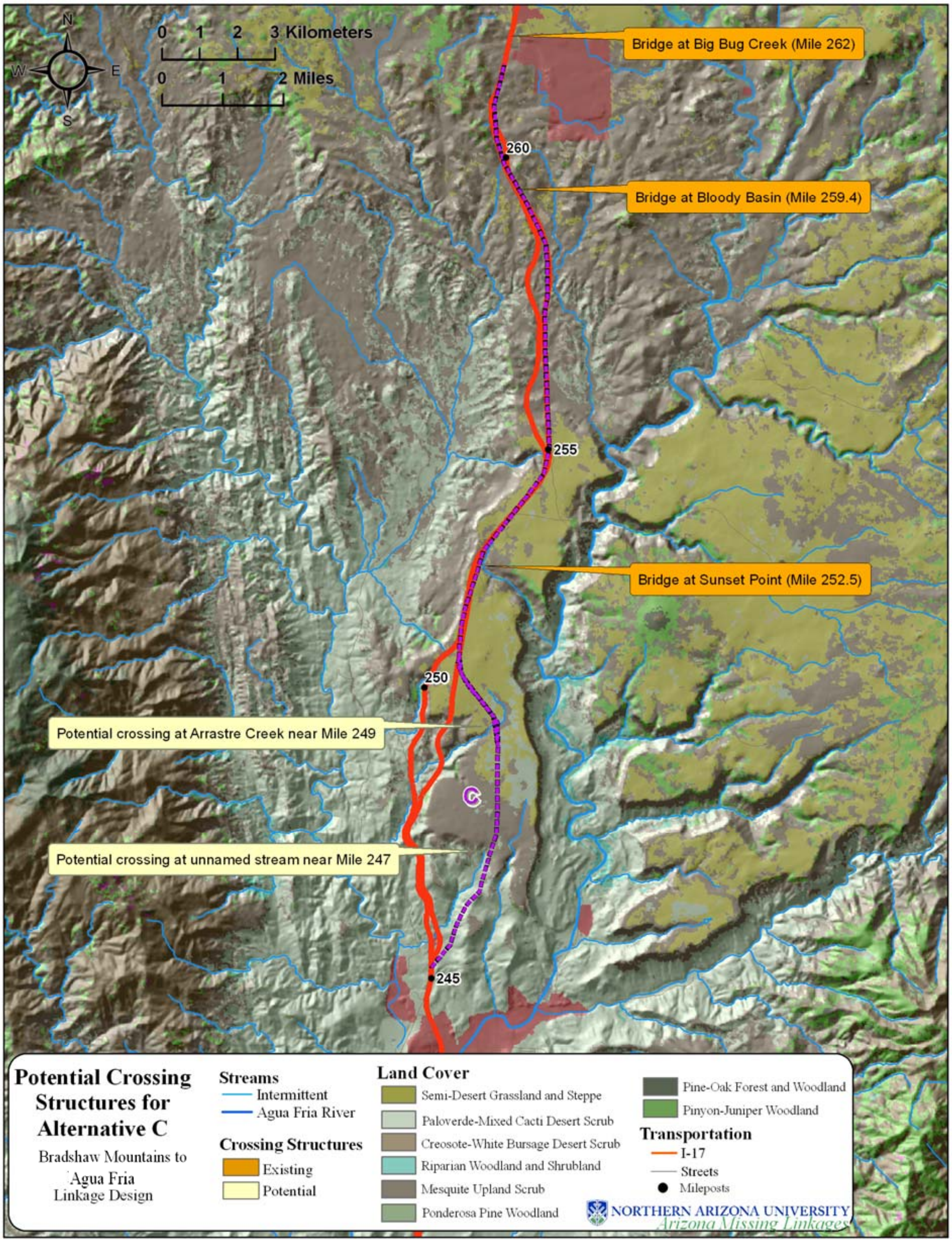

Figure 16: Additional potential crossings identified for the alternative route C. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

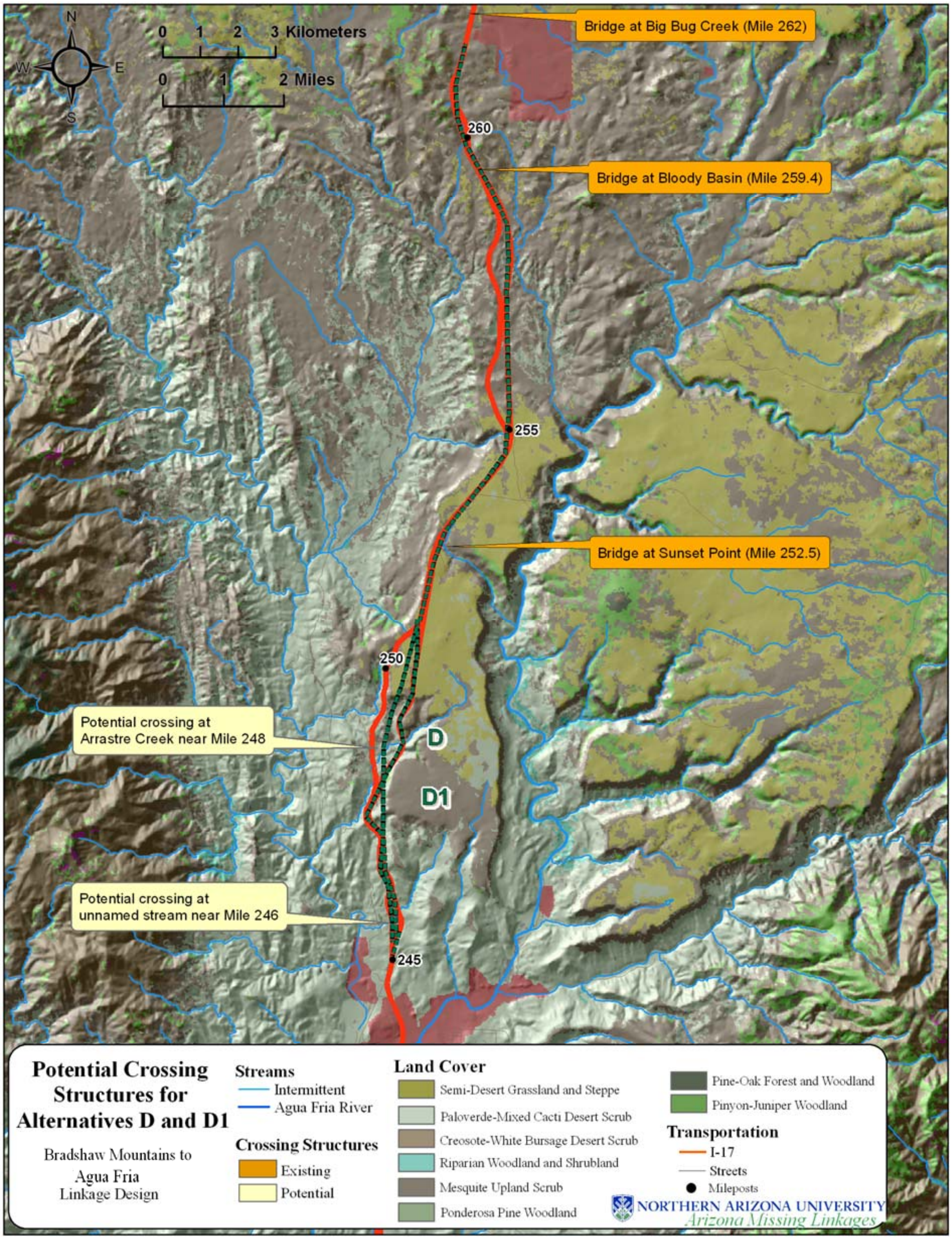

Figure 17: Additional potential crossings identified for the alternative routes D and D1. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

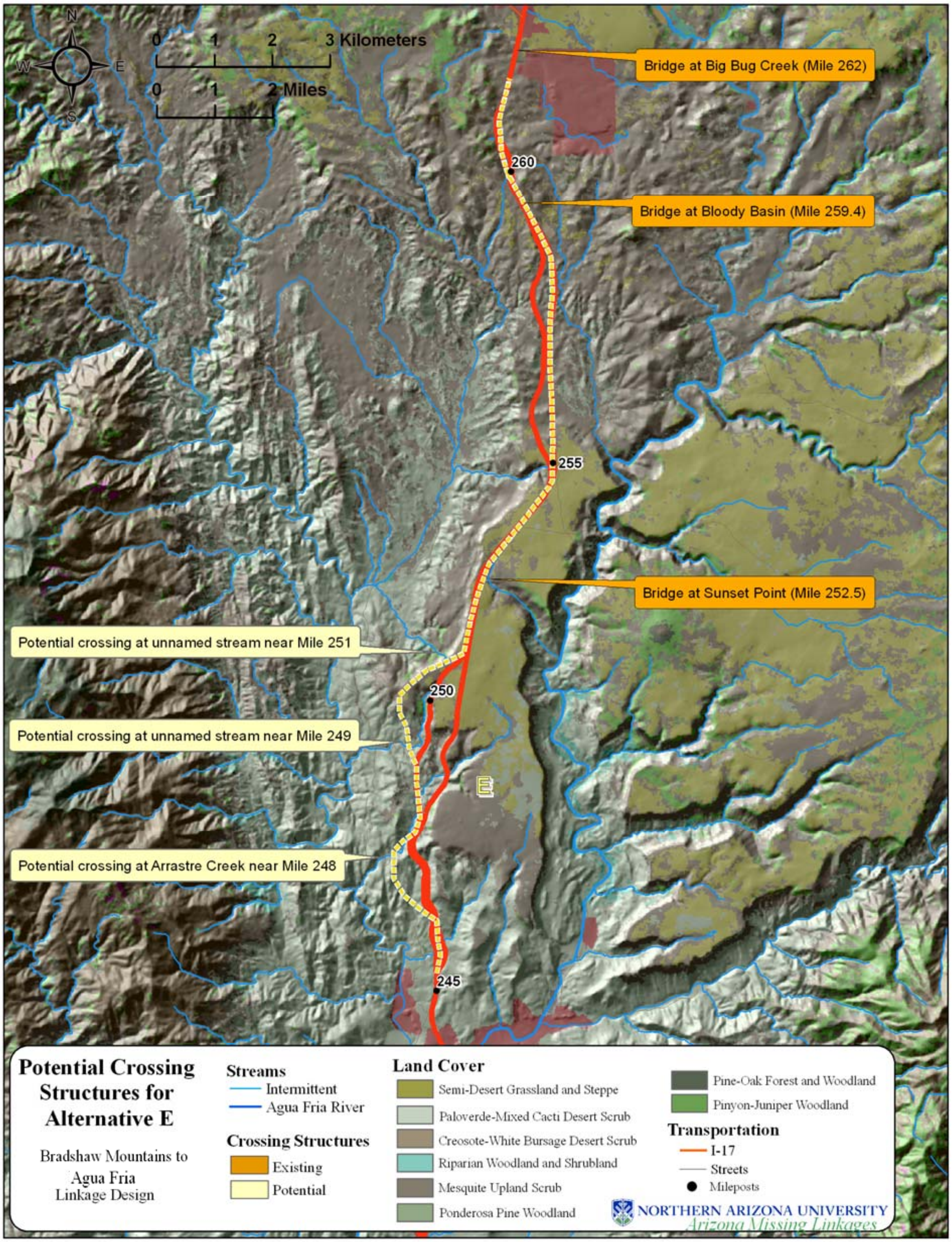

Figure 18: Additional potential crossings identified for the alternative route E. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

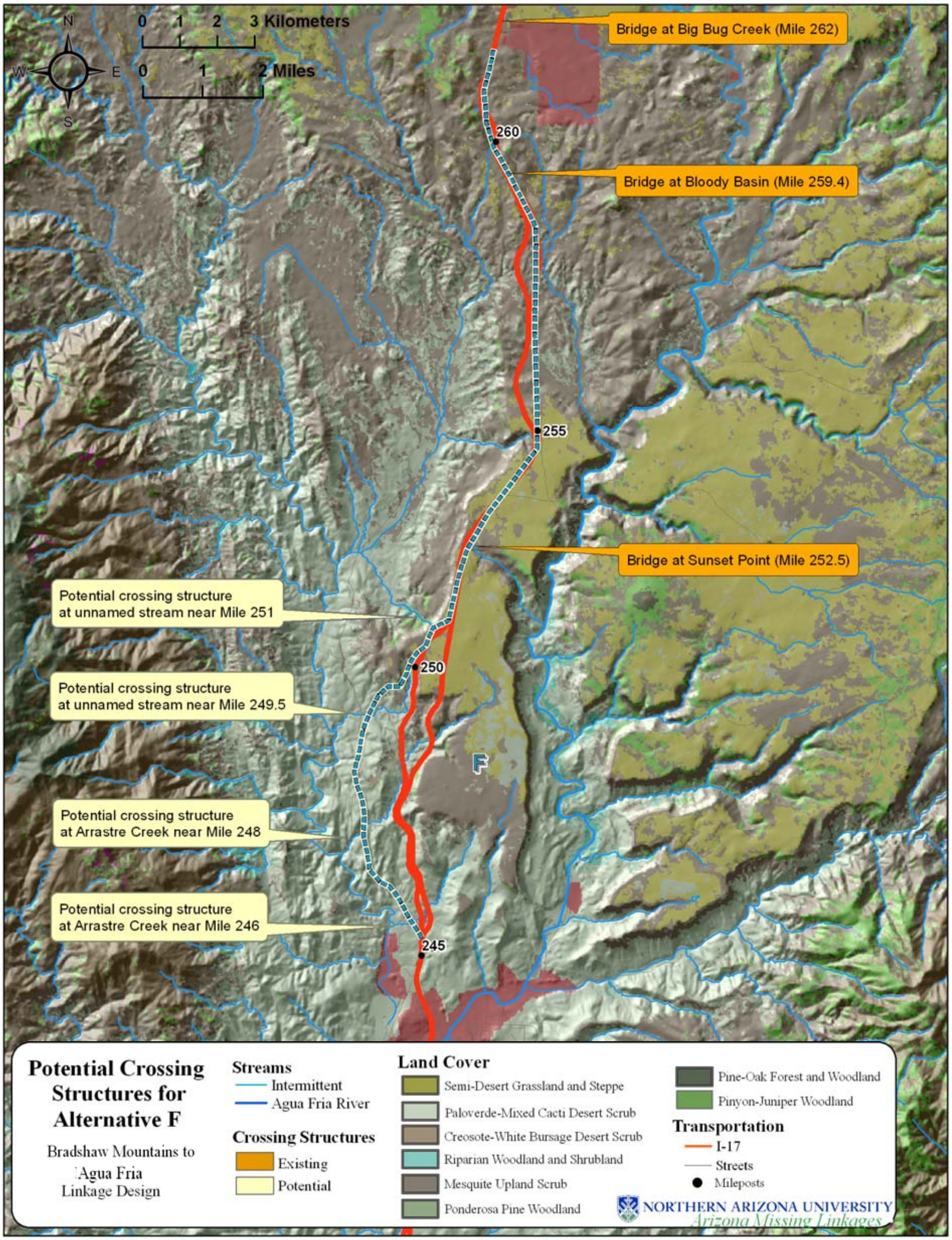

Figure 19: Additional potential crossings identified for the alternative route F. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

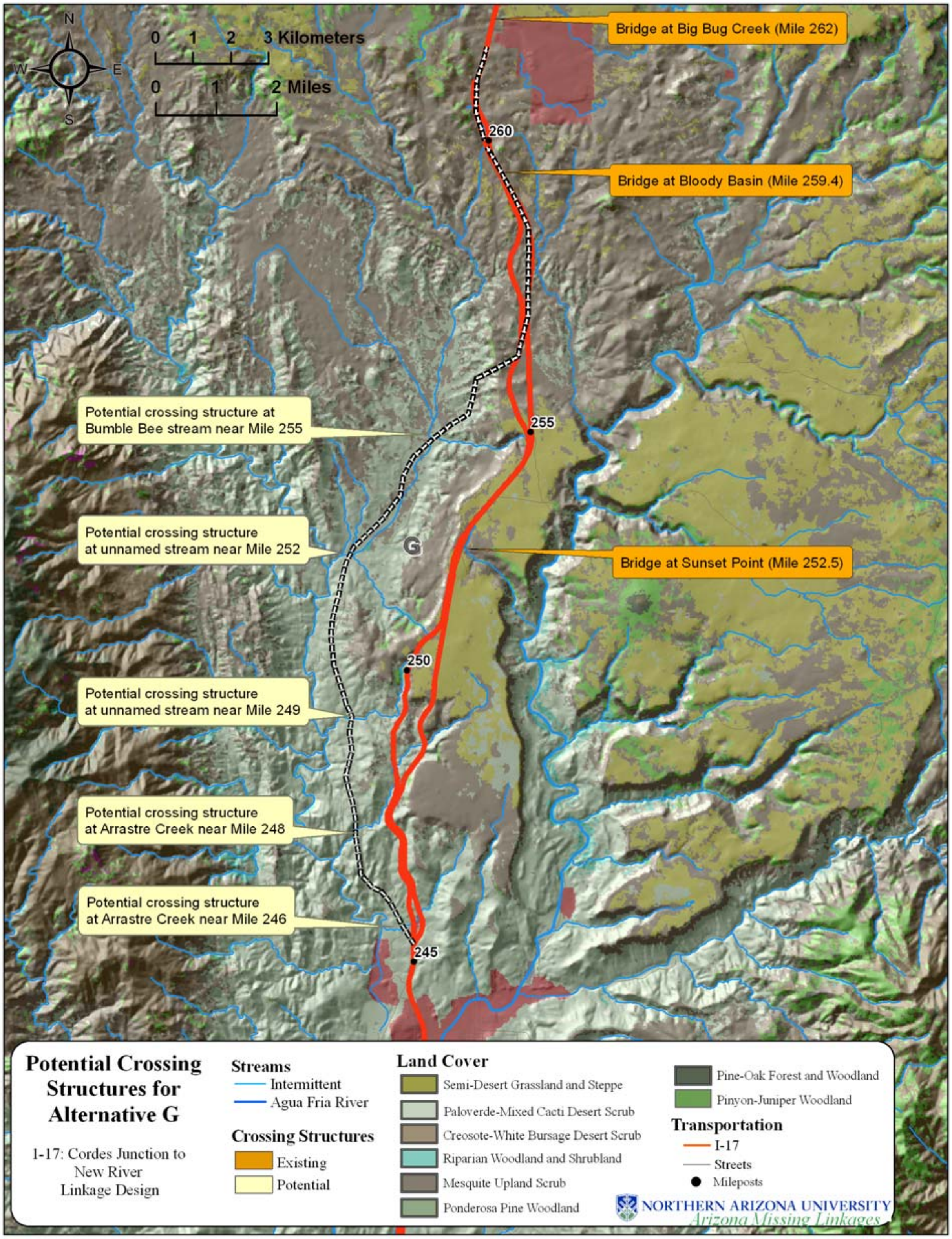

Figure 20: Additional potential crossings identified for the alternative route G. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

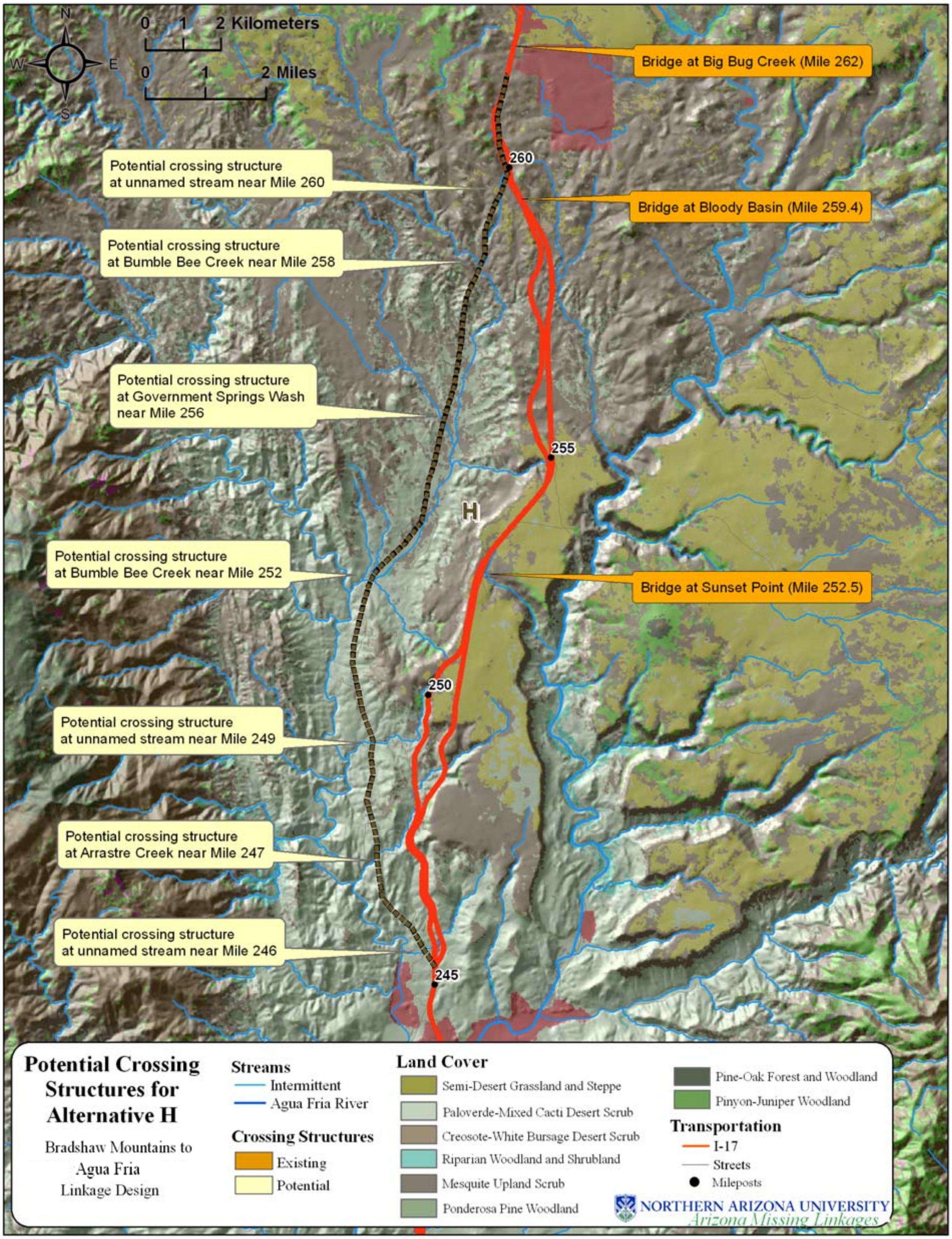

Figure 21: Additional potential crossings identified for the alternative route H. The existing bridge at MP 252.5 occurs at a bottleneck in grassland habitat for pronghorn, and is not suitable for pronghorn crossing. It should be replaced with a pronghorn-friendly crossing structure.

Impediments to the Agua Fria 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). Both the Agua Fria and New Rivers and their associated riparian vegetation are preferred habitat for many species in the linkage area, including the southwestern willow flycatcher, yellow-billed cuckoo, lowland leopard frog, Gila topminnow, longfin dace, razorback sucker, desert pupfish, and river otter.

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 Agua Fria provides important perennial flowing waters in the linkage area. It is fed by several tributaries including the Big Bug, Ash, Sycamore, Black Canyon, Silver, and Yellow Jacket Creeks. The river valley supports a unique riparian system that is home to water-dependent species including the lowland leopard frog.

The Agua Fria watershed faces severe impacts from various human activities along its course. Future urban development upstream from the linkage area, could have major impacts downstream. Already, the river suffers effects from historic dams upstream. Further, the river exhibits heavy metal contamination and turbidity caused by abandoned mines and sand and gravel operations (Arizona Department of Environmental Quality, 1990). In the linkage area, the banks of the river bed are a popular ORV recreation site.

Maintaining the integrity of the Agua Fria River for the future requires addressing the cumulative impacts of all of these anthropogenic activities throughout the watershed. We provide some recommendations below that could reduce adverse impacts to the river.

Mitigating Stream Impediments

We endorse the following management recommendations for riparian connectivity and habitat conservation on the Agua Fria and associated tributaries.

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 Agua Fria 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

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

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure 22). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

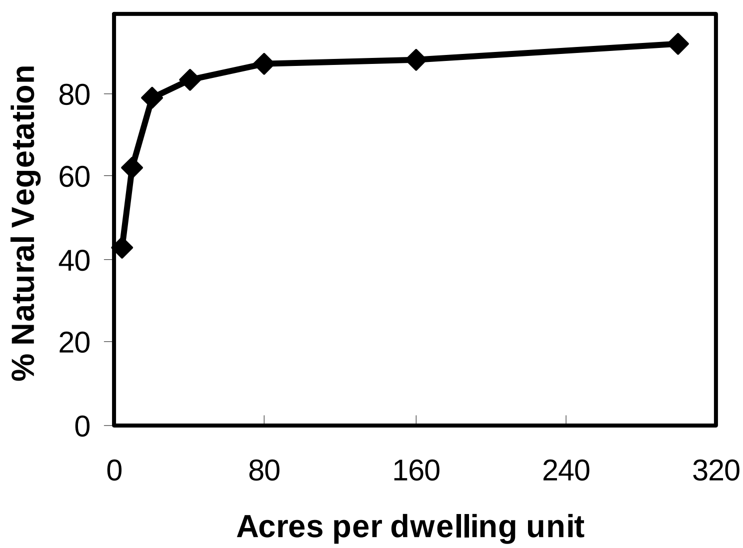

Figure 22: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

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

- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized "suburban native predators" such as raccoons, foxes, and crows, that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).
- mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).
- artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas currently accounts for over 14% (Figure 3) of the land cover, residential development may increase rapidly in parts of the linkage planning area.

Urban Barriers in the Linkage Design Area

Cordes Junction is at the interchange of I-17 and State Route 69 in Yavapai County. The outlying communities in the county are expecting rapid growth in the future. Further south, the New River area is included in the General Plan for Phoenix, a rapidly growing metropolitan area. Urban growth should be carefully planned to provide for conservation of natural resources. It is especially important to prevent future urban growth along the Agua Fria River and its major tributaries.

Figure 23: A brush lot, road, and stables adjacent to the Big Bug Creek floodplain (waypoint 003).

Figure 24: Homes located in the Big Bug Creek floodplain (waypoint 004).

Figure 25: Overlooking Black Canyon City (waypoint 019).

Figure 26: The Agua Fria River on the outskirts of Black Canyon City (waypoint 020).

Figure 27: An auto salvage yard adjacent to the Agua Fria River (waypoint 022).

Mitigation for Urban Barriers

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

1) Integrate this Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the linkage planning area.
2) Where development is permitted within the linkage planning area, encourage small building footprints on large (> 40 acre) parcels with a minimal road network.
3) Integrate this Linkage Design into county general plans, and conservation plans of governments and nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the linkage planning area. Recognizing that there may never be enough money to buy easements or land for the entire area, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as recreation and protection of water quality.
6) Trail systems should be carefully planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.
7) Where human residences or other low-density urban development occurs within the linkage planning area, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept

depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area.

8) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.
9) Develop a public education campaign to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.
10) Discourage residents and visitors from feeding or providing water for wild mammals, or otherwise allowing wildlife to lose their fear of people.
11) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.
12) Do not install artificial night lighting on rural roads that pass through the linkage planning area. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
13) Encourage the use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.
14) Discourage the killing of ‘threat’ species such as rattlesnakes.
15) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.
16) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.

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

- Limit urbanization along the important riparian areas and floodplains, including Big Bug Creek, the New River, and the Agua Fria River. We documented residential and industrial developments along both Big Bug Creek and the Agua Fria River (Figure 23, Figure 24, Figure 26, and Figure 27). Where possible, a continuous strip of native vegetation at least 200 m wide along each side of river and stream channels should be restored (see Mitigating Stream Impediments, recommendation number 6).
- Discourage development of private land near existing and potential wildlife crossing structures in the linkage planning area.
- Work with homeowners and residents to manage the residential areas for wildlife permeability, especially at Black Canyon City, which contains the highest density development adjacent to I-17 (Figure 25).
- Discourage further residential development and subdivision of large parcels in the linkage planning area.

Appendix A: Linkage Design Methods

Our goal was to provide information to help transportation agencies to identify important areas for constructing crossing structures along I-17, and reduce the impacts in association with its potential improvement. These structures will conserve and enhance wildlife movement through the existing habitat surrounding the highway.

To create the Linkage Design, we used GIS approaches to estimate potential habitat suitability for focal species representing the ecological community in the area[1]. By carefully selecting a diverse group of focal species, the Linkage Design should ensure the long-term viability of all species in the protected areas. Our approach included four 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) Carry out field visits to identify barriers to movement and suggest locations for underpasses or overpasses within Linkage Design area.

During 2005-2007, we are producing 16 linkage designs under contract to Arizona Game and Fish Department. In most cases, our analyses focus on a "Potential Linkage Area" – a swath of private and state land between publicly-owned wildland blocks. For this report, we are focusing on the impacts of I-17 as it borders public and private lands. In this case, the Potential Linkage Area (or Linkage Planning Area) we modeled includes land roughly 20 kilometers on each side of I-17 along the segment designated for improvement (mileposts 230-265).

Because we defined the Linkage Planning Area differently than in our other reports, we cannot conduct the same wildlife corridor analyses that we use in our other reports. Instead we map the distribution of potential habitat, breeding patches, and population cores for each focal species within the linkage planning area. We use these maps and literature on how wildlife crosses highways to provide general recommendations for accommodating movement by these species in future highway realignments.

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 28 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

[1] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute "truth" but rather an estimate or prediction of wildlife habitat. 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 a particular landscape) 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.

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.

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 28):
- *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[2].

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 1 and 10. We then weighted each of the by 4 factors by a weight between 0% and 100%, subject to the constraint that the 4 weights must sum to 100%. We calculated a weighted geometric mean[3] 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.

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

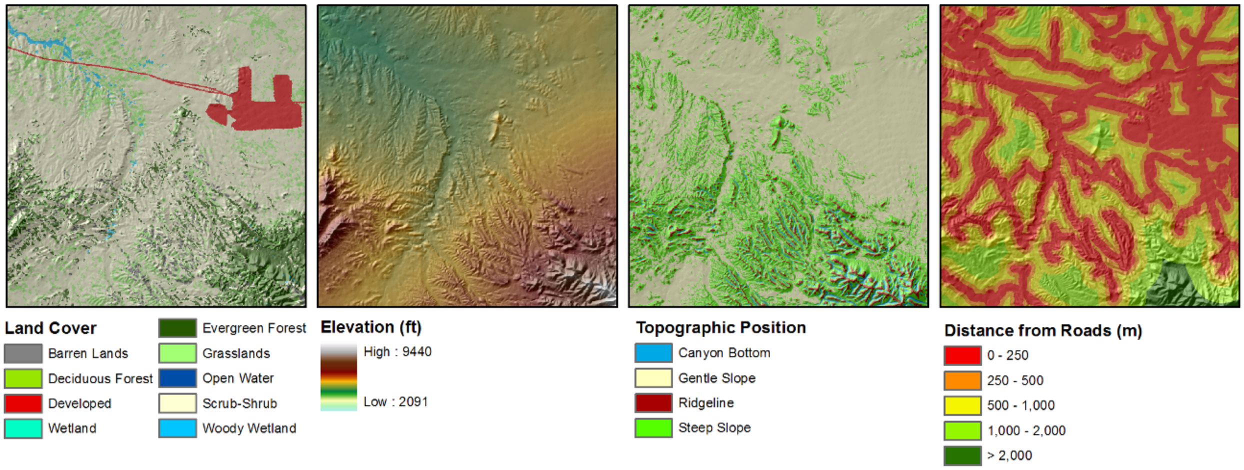


Figure 28: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

Identifying Potential Breeding Patches & Potential Population Cores

The habitat suitability map provides scores for each 30x30-m pixel. For our analyses, we also needed to identify – both in the 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 28). We averaged habitat suitability within a 3x3-pixel neighborhood (90 x 90 m^2, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[4]. 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.

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

[4] 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.

or exotic plant species. A database of field notes, GPS coordinates, and photos of our field investigations can be found in Appendix F, as well as in a MS Access database on the CD-ROM accompanying this report.

Appendix B: Individual Species Analyses

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

	Black Bear	Coues White-tailed Deer	Desert Tortoise	Elk	Javelina
Factor weights					
Land Cover	75	65	30	75	50
Elevation	10	5	25	0	30
Topography	10	15	40	0	20
Distance from Roads	5	15	5	25	0
Land Cover					
Encinal	1	1	7	2	4
Pine-Oak Forest and Woodland	1	2	10	1	7
Pinyon-Juniper Woodland	6	3	10	1	5
Ponderosa Pine Woodland	4	5	10	1	6
Juniper Savanna	7	3	10	1	7
Semi-Desert Grassland and Steppe	5	6	8	7	2
Chaparral	3	3	10	4	3
Creosotebush, Mixed Desert and Thorn Scrub	6	5	6	9	3
Creosotebush-White Bursage Desert Scrub	9	7	5	9	4
Desert Scrub (misc)	5	6	4	8	2
Mesquite Upland Scrub	6	4	7	7	2
Paloverde-Mixed Cacti Desert Scrub	5	8	1	8	1
Riparian Mesquite Bosque	5	3	5	3	1
Riparian Woodland and Shrubland	5	2	10	2	2
Barren Lands, Non-specific	10	10	10	10	9
Mixed Bedrock Canyon and Tableland	10	9	10	9	10
Agriculture	6	7	10	7	7
Developed, Medium - High Intensity	10	10	10	10	7
Developed, Open Space - Low Intensity	10	9	7	7	4
Open Water	10	7	10	10	10
Elevation (ft)					
	0-2500: 8	0-2000: 7	0-5000: 1		0-5000: 1
	2500-4000: 6	2000-3000: 6	5000-7000: 7		5000-7000: 3
	4000-6500: 2	3000-4000: 2	000-11000: 10		7000-11000: 10
	6500-8500: 3	4000-6000: 1			
	8500-11000: 4	6000-8000: 3			
		8000-11000: 7			
Topographic Position					
Canyon Bottom	3	1	8		1
Flat - Gentle Slopes	6	5	5		1
Steep Slope	3	2	3		7
Ridgetop	4	4	7		4
Distance from Roads (m)					
	0-100: 10	0-250: 8	0-250: 5	0-100: 9	
	100-500: 4	250-500: 6	250-500: 4	100-200: 8	
	500-15000: 1	500-750: 2	500-1000: 3	200-400: 6	
		750-15000: 1	1000-15000: 1	400-1000: 5	
				1000-2000: 2	
				2000-15000: 1	

	Mountain Lion	Mule Deer	Pronghorn
Factor weights			
Land Cover	70	80	45
Elevation	0	0	0
Topography	10	15	37
Distance from Roads	20	5	18
Land Cover			
Encinal	1	3	7
Pine-Oak Forest and Woodland	1	3	8
Pinyon-Juniper Woodland	1	5	6
Ponderosa Pine Woodland	4	5	7
Juniper Savanna	4	4	4
Semi-Desert Grassland and Steppe	5	2	1
Chaparral	3	4	8
Creosotebush, Mixed Desert and Thorn Scrub	6	6	2
Creosotebush-White Bursage Desert Scrub	6	6	2
Desert Scrub (misc)	6	6	3
Mesquite Upland Scrub	4	3	7
Paloverde-Mixed Cacti Desert Scrub	7	3	3
Riparian Mesquite Bosque	4	3	8
Riparian Woodland and Shrubland	2	3	8
Barren Lands, Non-specific	8	10	7
Mixed Bedrock Canyon and Tableland	6	7	8
Agriculture	10	6	8
Developed, Medium - High Intensity	10	9	10
Developed, Open Space - Low Intensity	8	5	8
Open Water	9	10	7
Elevation (ft)			
Topographic Position			
Canyon Bottom	1	2	7
Flat - Gentle Slopes	3	2	1
Steep Slope	3	4	8
Ridgetop	4	6	6
Distance from Roads (m)			
	0-200: 8	0-250: 7	0-100: 10
	200-500: 6	250-1000: 3	100-250: 6
	600-1000: 5	1000-15000: 1	250-1000: 3
	1000-1500: 2		1000-15000: 1
	1500-15000: 1		

Black Bear (*Ursus americanus*)

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

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

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

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

Conceptual Basis for Model Development
Habitat suitability model – Cover is the most important factor for black bears, so vegetation was assigned an importance weight of 75%. Elevation and topography each received a weight of 10%, and distance from roads received a weight of 5%. For specific scores of classes within each of these factors, see Table 6 for habitat suitability scores.

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

Potential Habitat Suitability

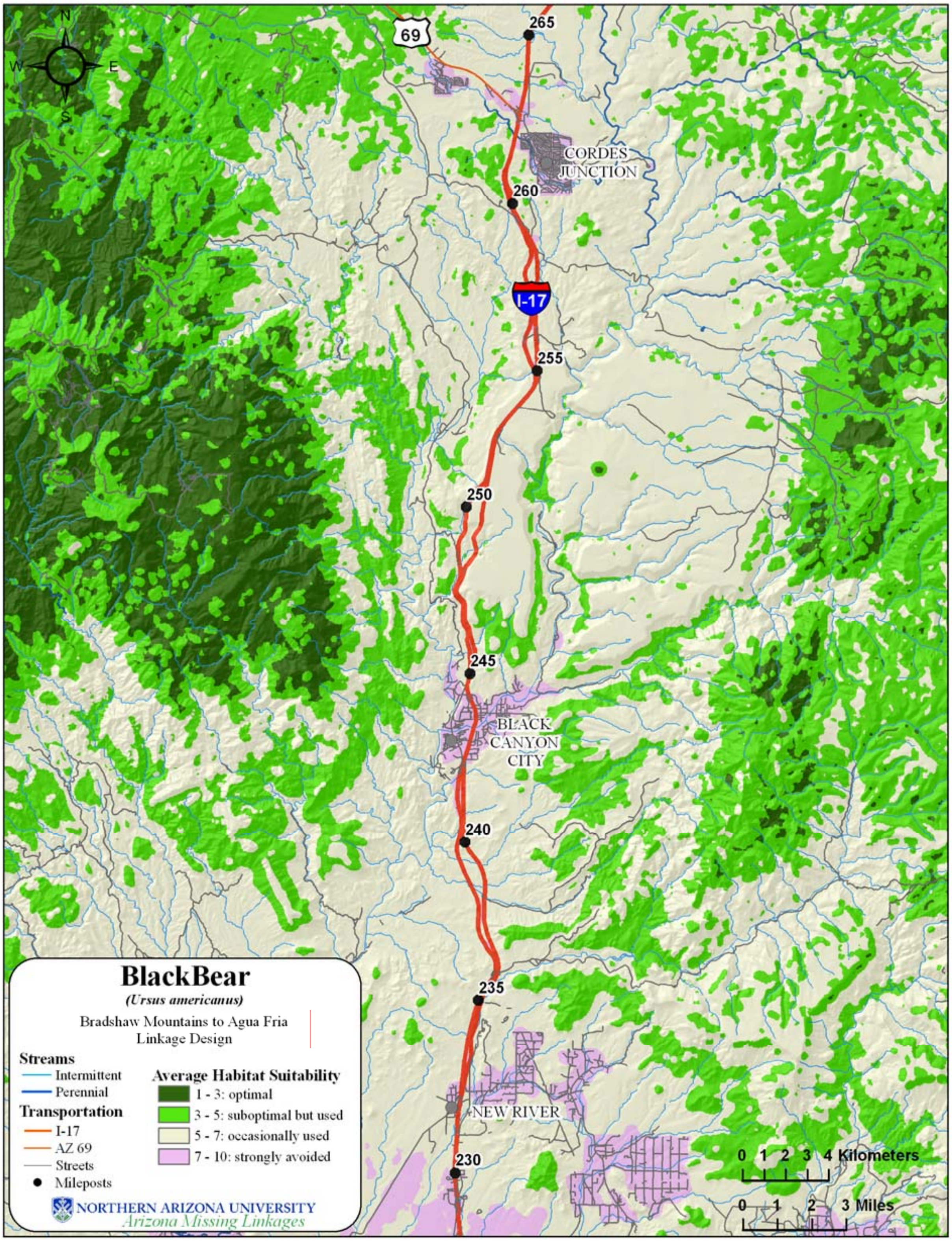


Figure 29: Modeled habitat suitability for black bear.

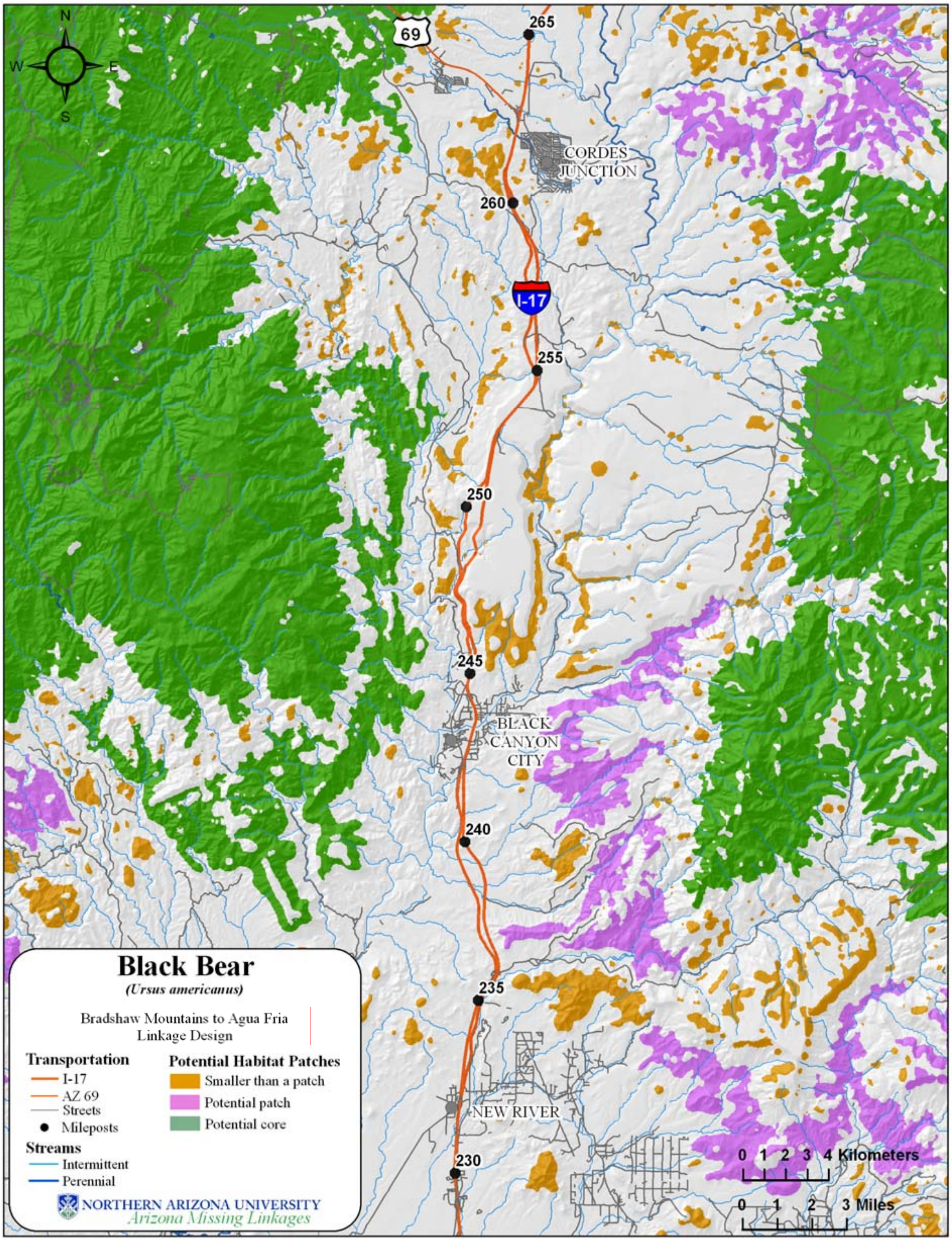


Figure 30: Potential habitat patches and cores for black bear.

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

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong preferences for woodlands and shrubs, vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received a weight of 5%, 15%, and 15%, respectively. For specific scores of classes within each of these factors, see Table 6.

Patch size & configuration analysis – We defined minimum patch size for Coues white-tailed deer as 5.2 km2, the average home range for females in the Santa Rita Mountains (Ockenfels 1991). While this species exhibits high home range overlap, we defined minimum core size as 26 km2, or five times minimum patch size, to ensure potential cores could account for seasonal movements and use of different habitats. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Potential Habitat Suitability

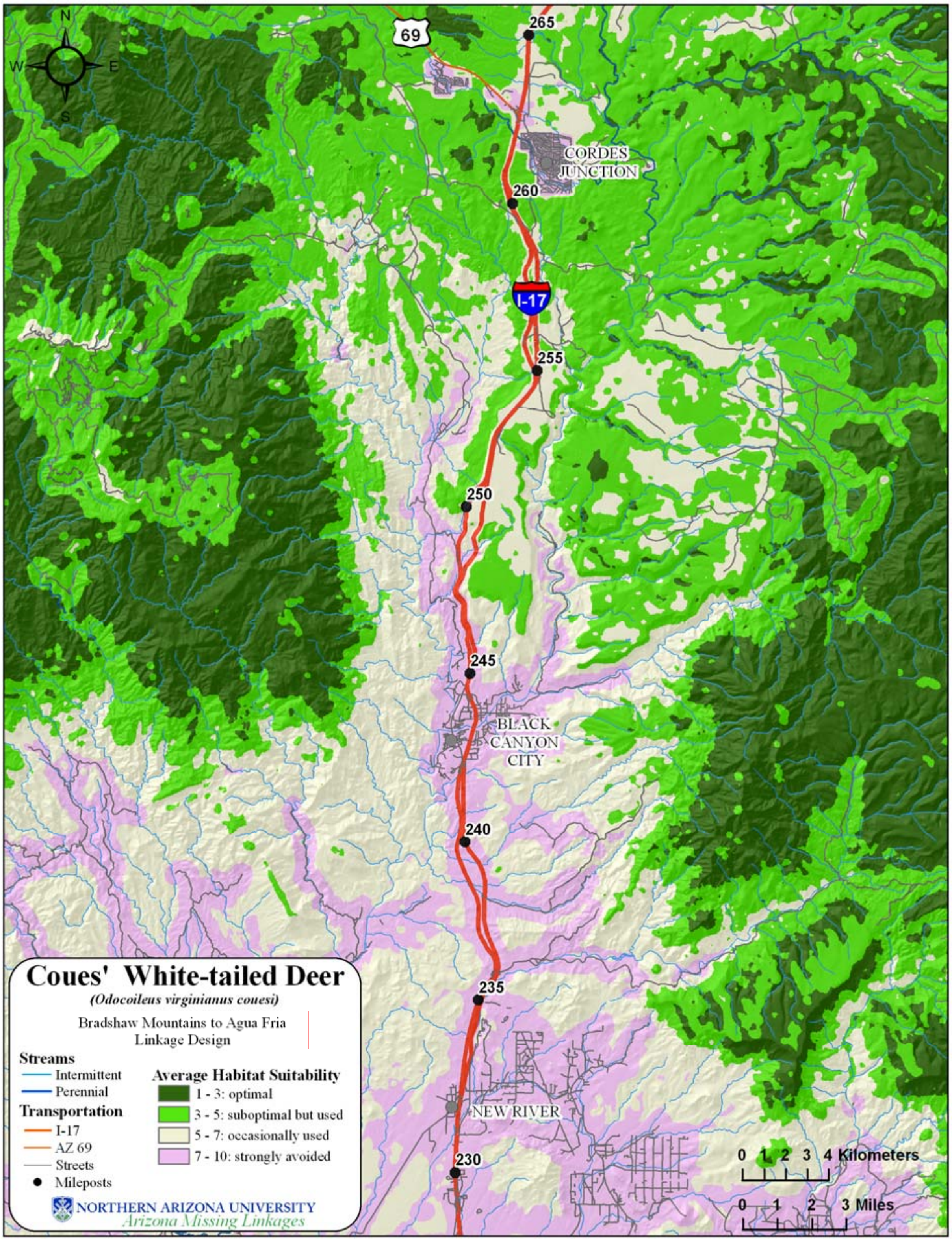


Figure 31: Modeled habitat suitability for Coues white-tailed deer.

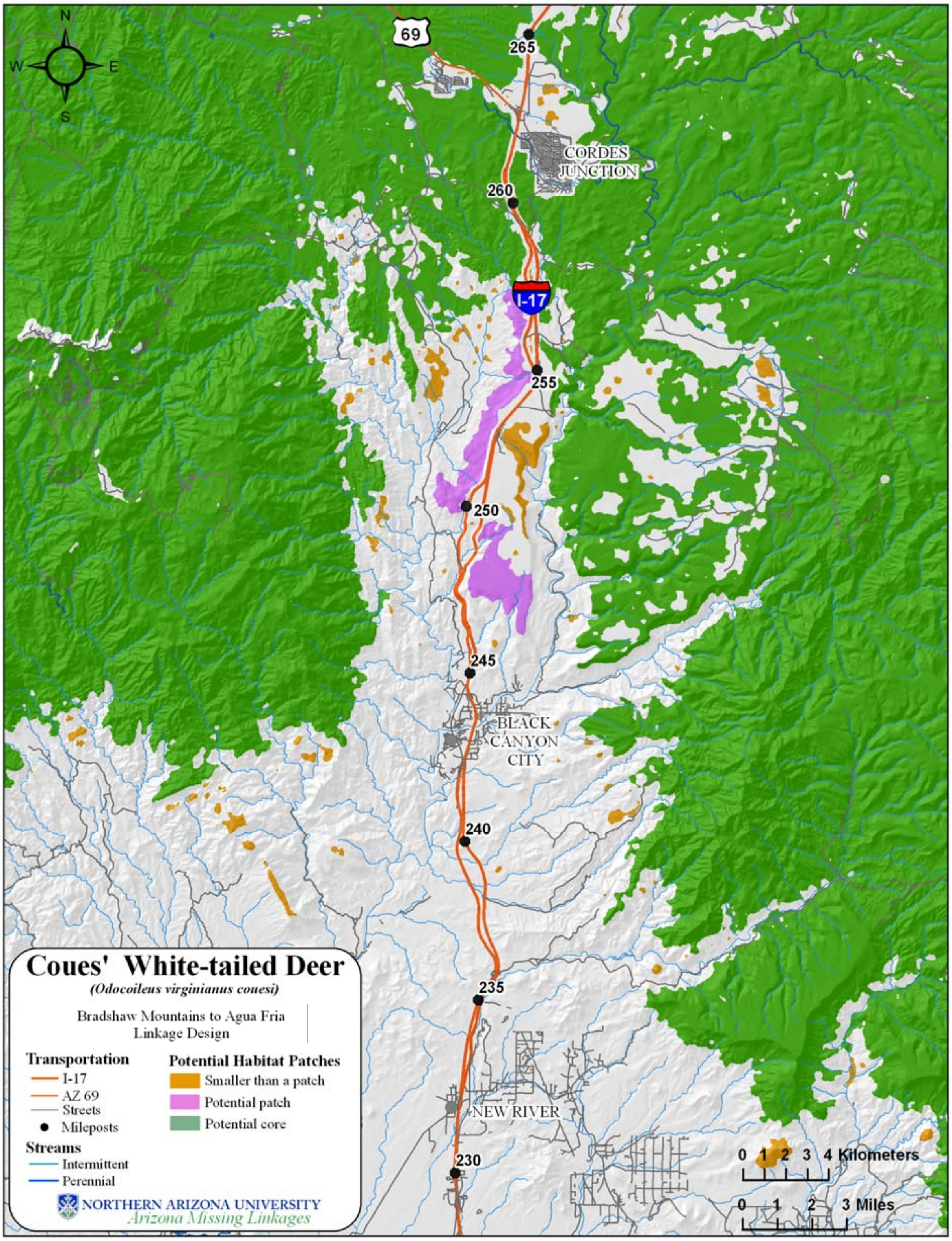


Figure 32: Potential habitat patches and cores for Coues white-tailed deer.

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, which occurs north and west of the Colorado River, and the Sonoran Desert population which 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 across the Sonoran Desert are between 7 and 23 ha (Averill-Murray et al. 2002). Density of tortoise populations ranges from 20 to upwards of 150 individuals per square mile (from 23 Sonoran Desert populations; Averill-Murray et al. 2002). Tortoises have overlapping home ranges, so the estimated space needed for roughly 20 adults is approximately 50 hectares, which is the size of the Tumamoc Hill population near Tucson (Edwards et al. 2003). Desert tortoises are a long-lived species (well exceeding 40 years; Germano 1992) with a long generation time (estimated at 25 years; USFWS 1994). A 5-10 year time frame for a desert tortoise population is relatively insignificant, 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 6.

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.

Potential Habitat Suitability

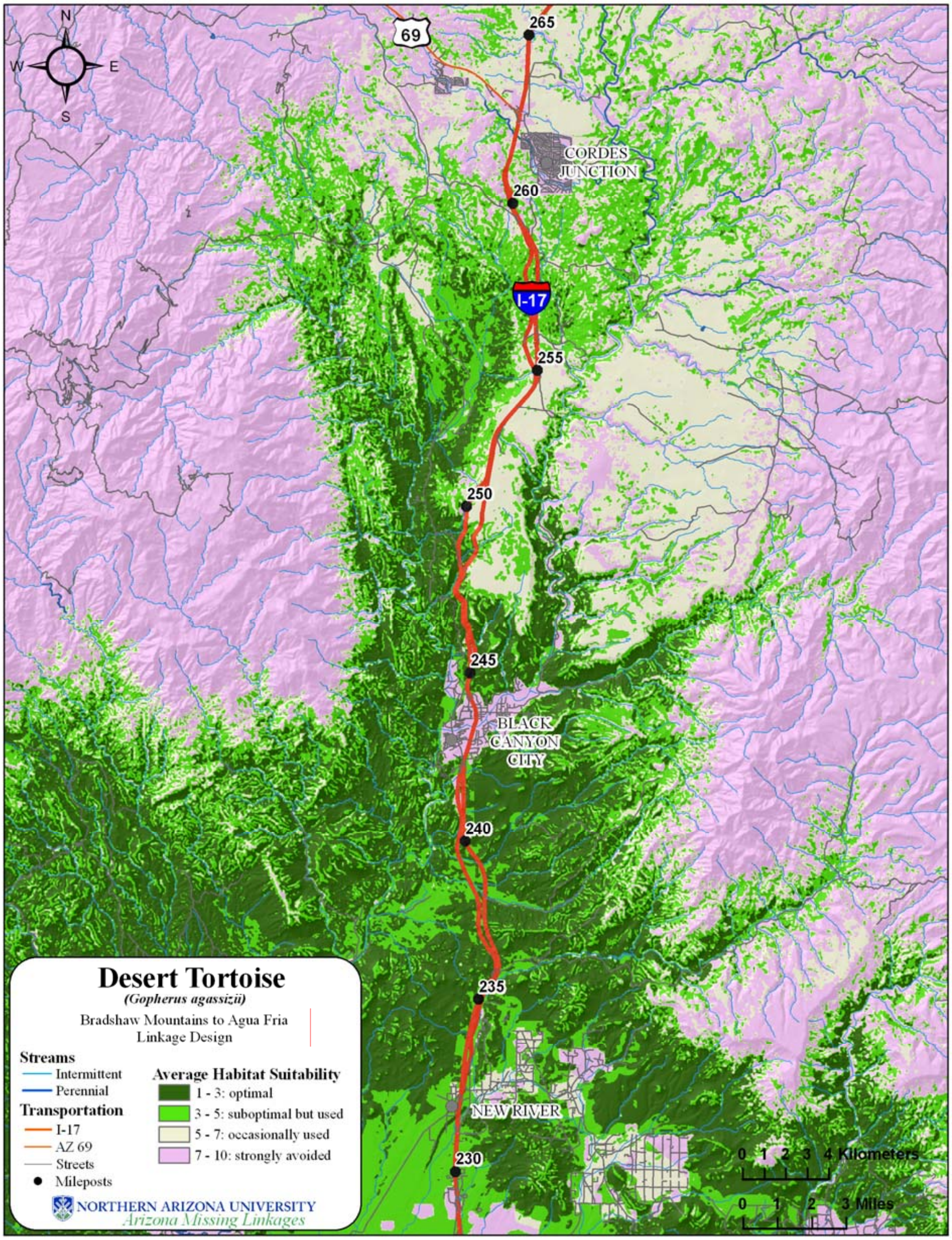


Figure 33: Modeled habitat suitability of desert tortoise.

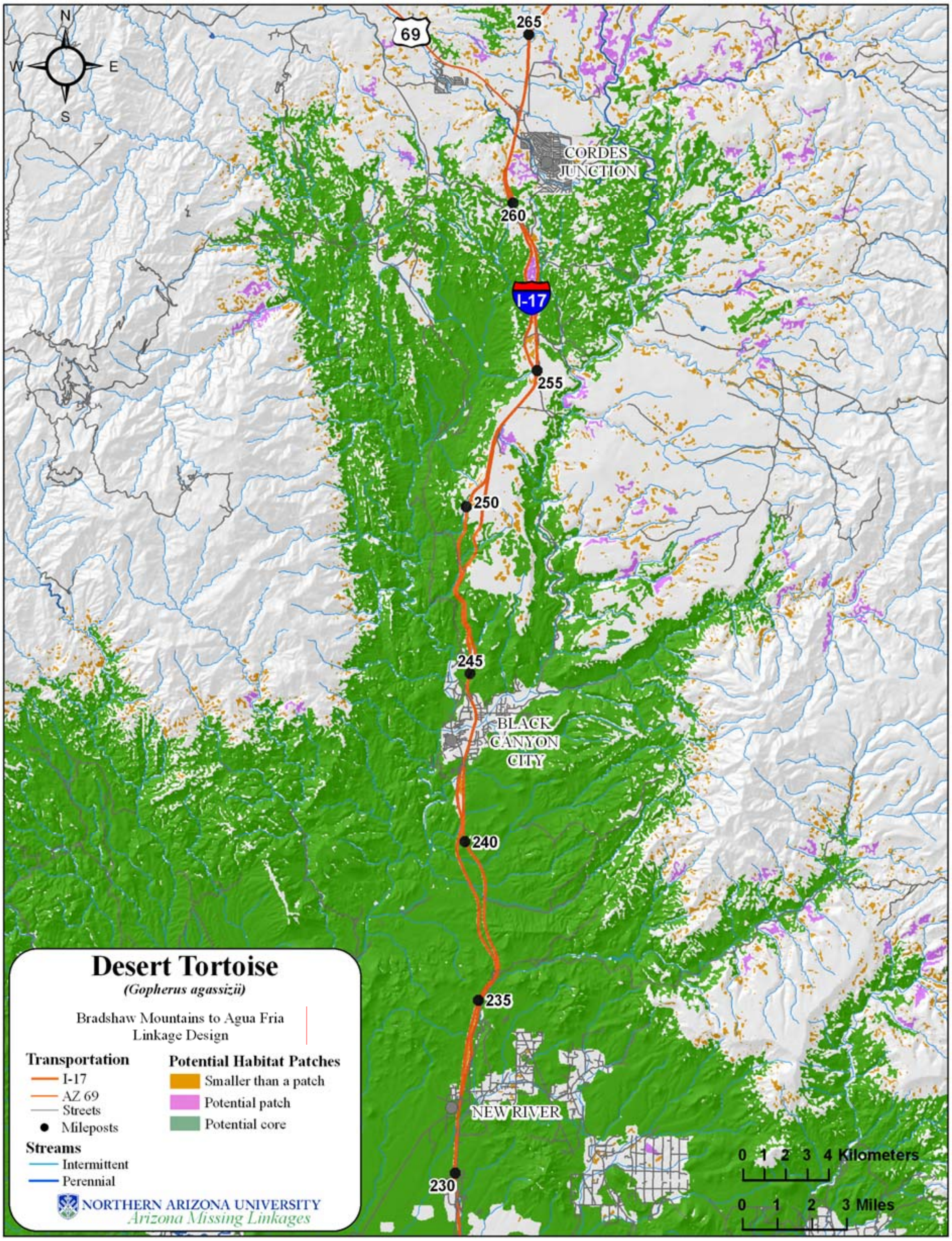


Figure 34: Potential habitat patches and cores for desert tortoise.

Elk (*Cervus elaphus*)

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

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

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

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

Conceptual Basis for Model Development
Habitat suitability model –Vegetation received an importance weight of 75%, while distance from roads received a weights of 25%. For specific scores of classes within each of these factors, see Table 6.

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

Potential Habitat Suitability

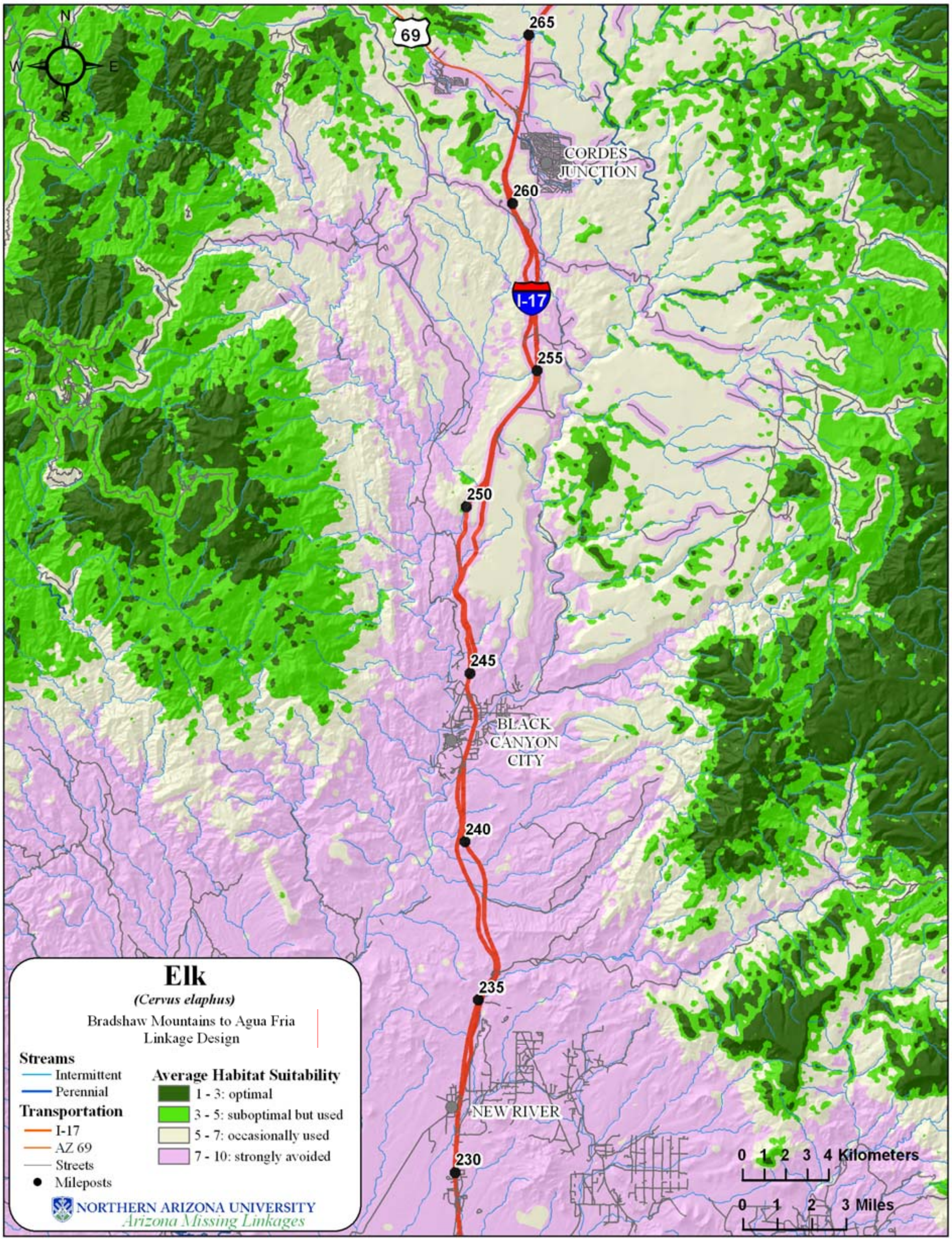


Figure 35: Modeled habitat suitability for elk.

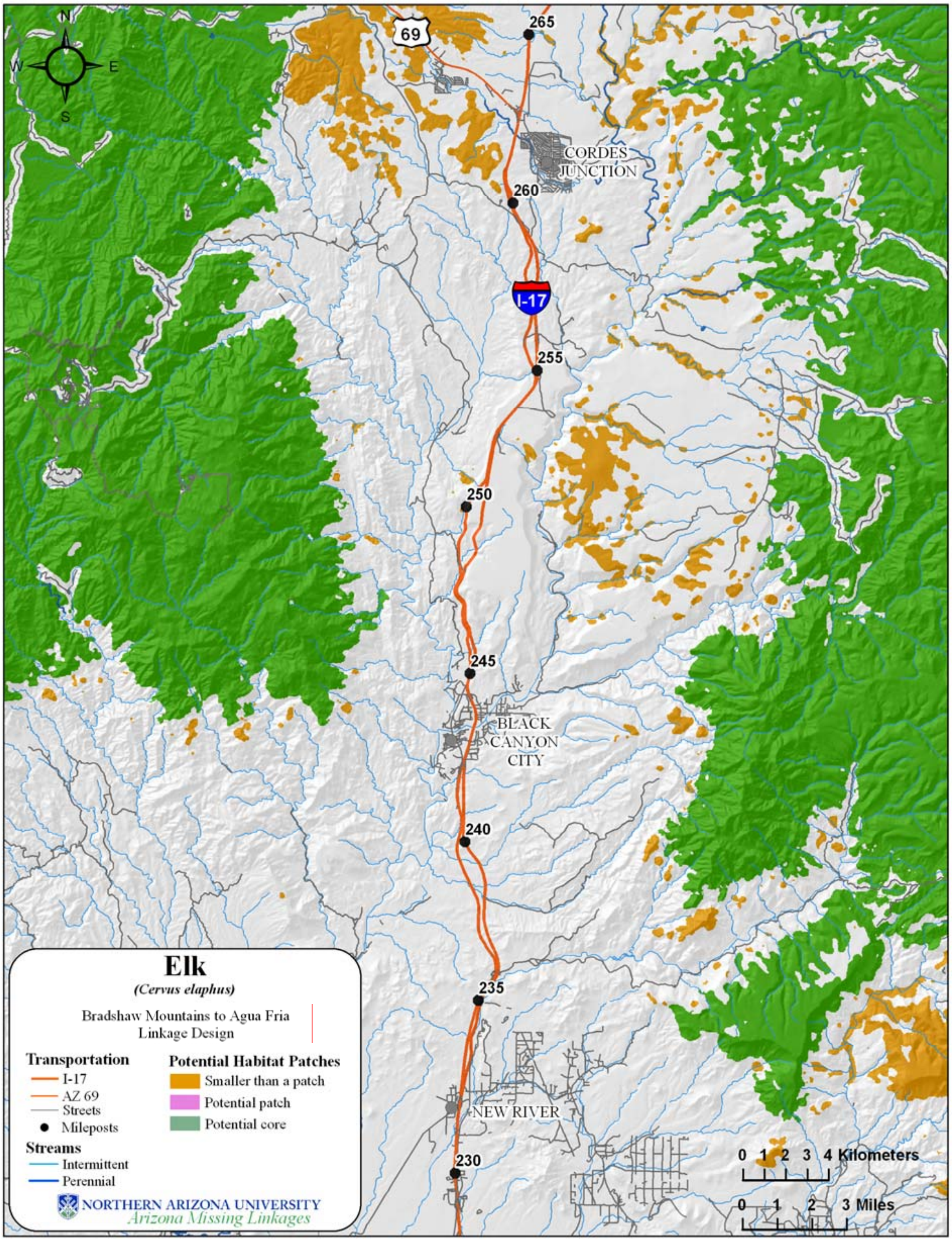


Figure 36: Potential habitat patches and cores for elk.

Javelina (*Tayassu tajacu*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

Javelina live in stable herds, though occasionally some individuals may move out of the herd to join another or establish their own (Hoffmeister 1986). Home ranges for herds have been reported as 4.7 km^2 in the Tortolita Mountains (Bigler 1974), 4.93 km^2 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 6.

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.

Potential Habitat Suitability

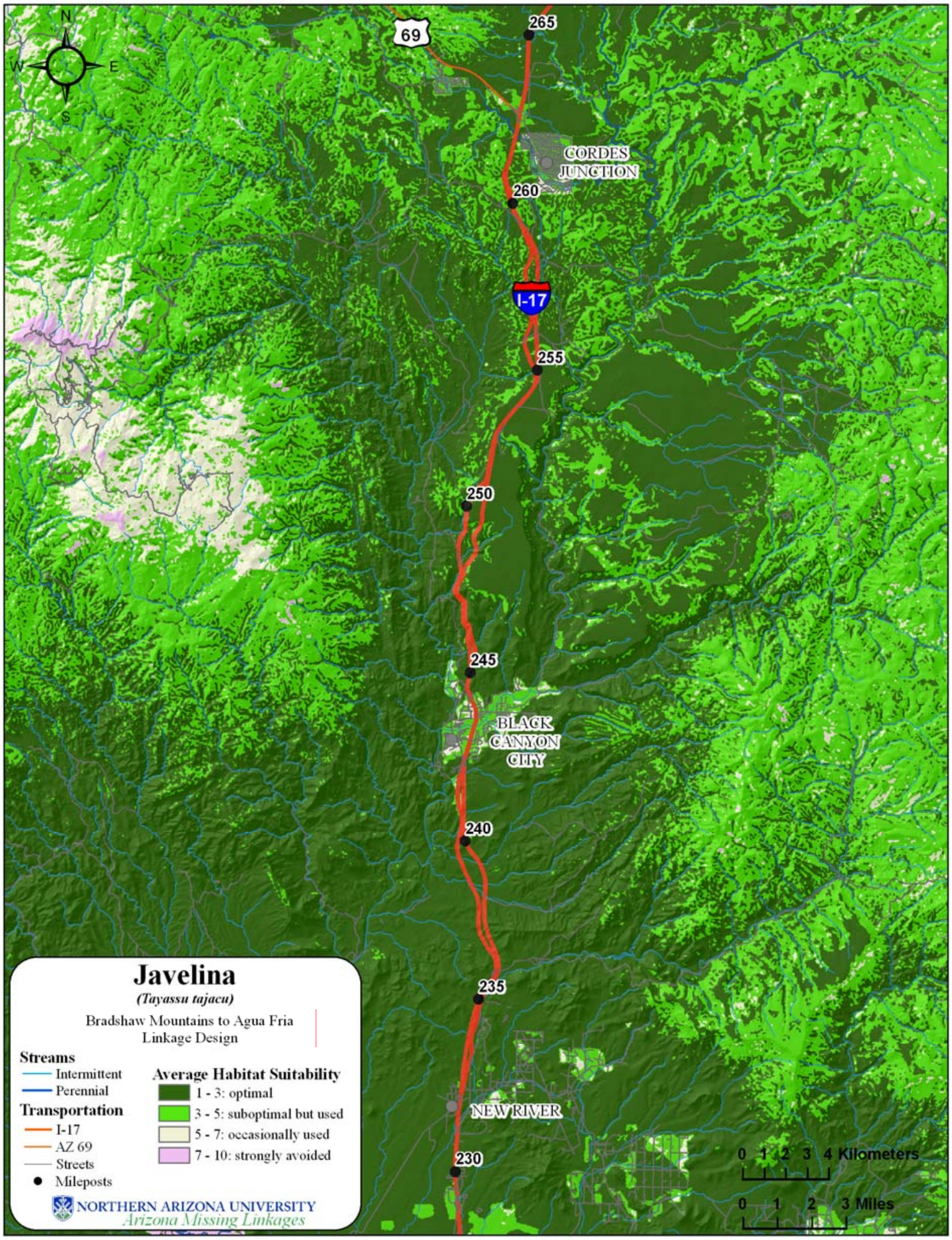


Figure 37: Modeled habitat suitability of javelina.

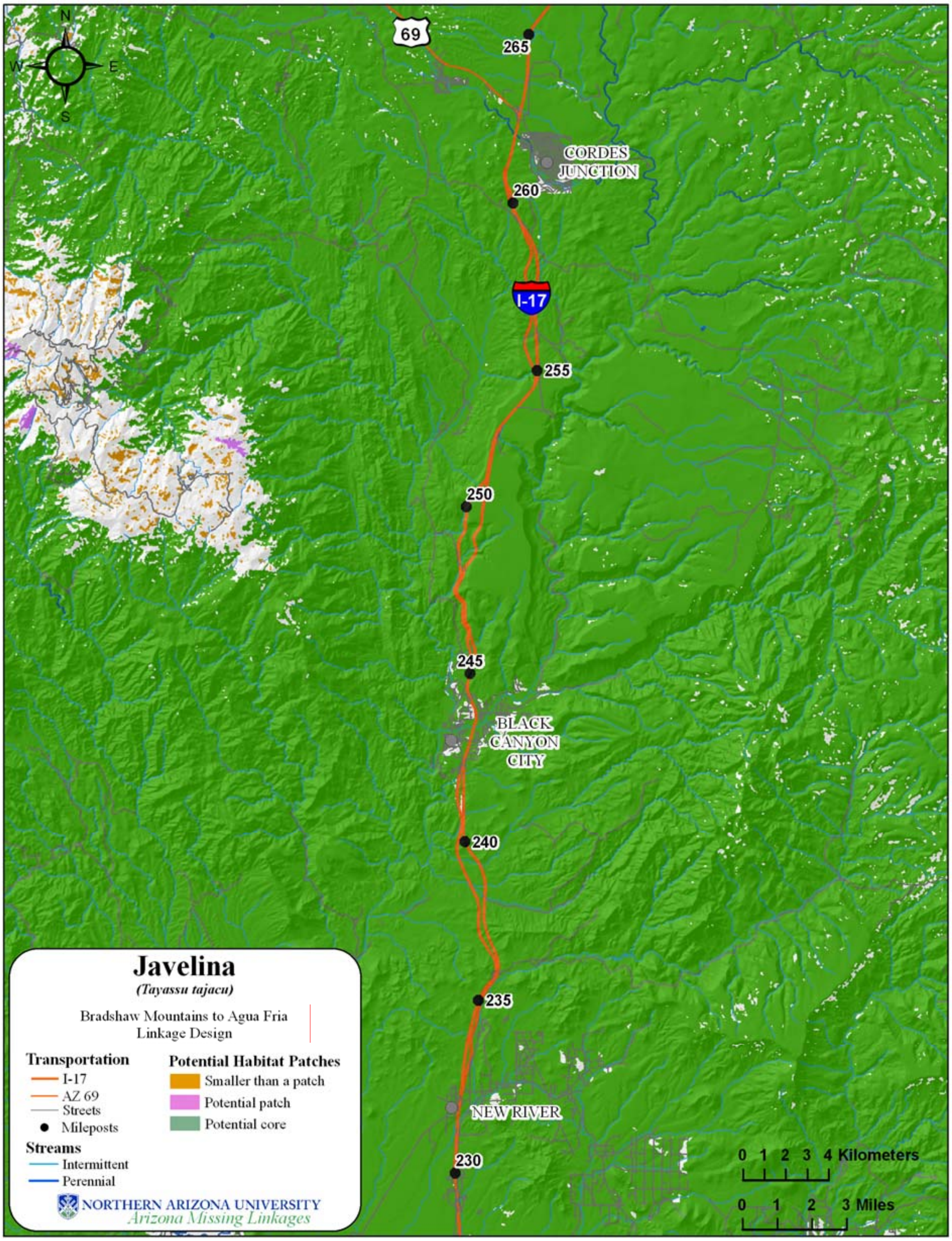


Figure 38: Potential habitat patches and cores for javelina.

Mountain Lion (*Puma concolor*)

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

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

Habitat Associations
Mountain lions are associated with mountainous areas with rocky cliffs and bluffs (Hoffmeister 1986; New Mexico Game and Fish Department 2004). They use a diverse range of habitats, including conifer, hardwood, mixed forests, shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Game and Fish Department 2004). Mountain lions are found at elevations ranging from 0 to 4000 m (Currier 1983).

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

Conceptual Basis for Model Development
Habitat suitability model – While mountain lions can be considered habitat generalists, vegetation is still the most important factor accounting for habitat suitability, so it received an importance weight of 70%, while topography received a weight of 10%, and distance from roads received a weight of 20%. For specific scores of classes within each of these factors, see Table 6.

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

Potential Habitat Suitability

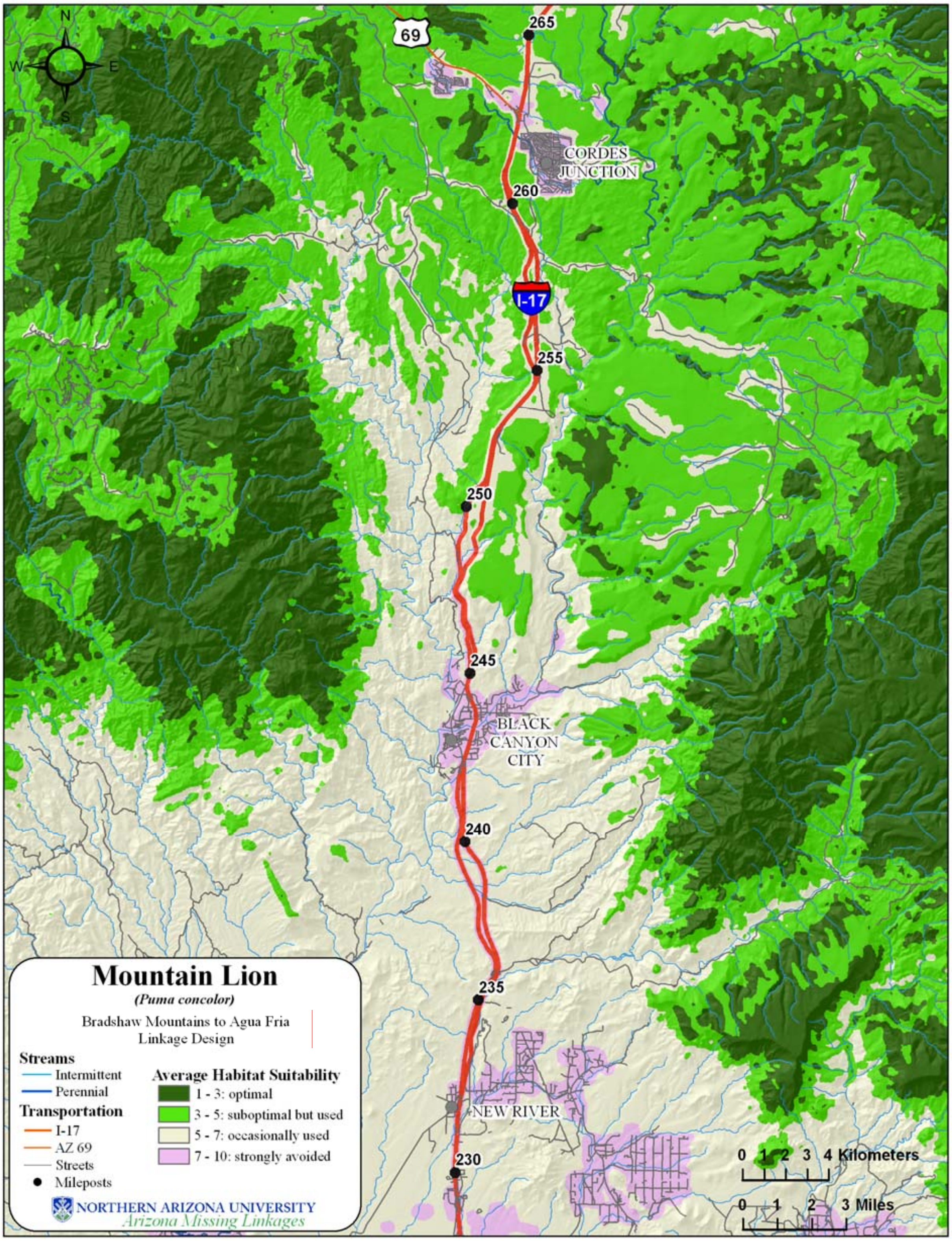


Figure 39: Modeled habitat suitability of mountain lion.

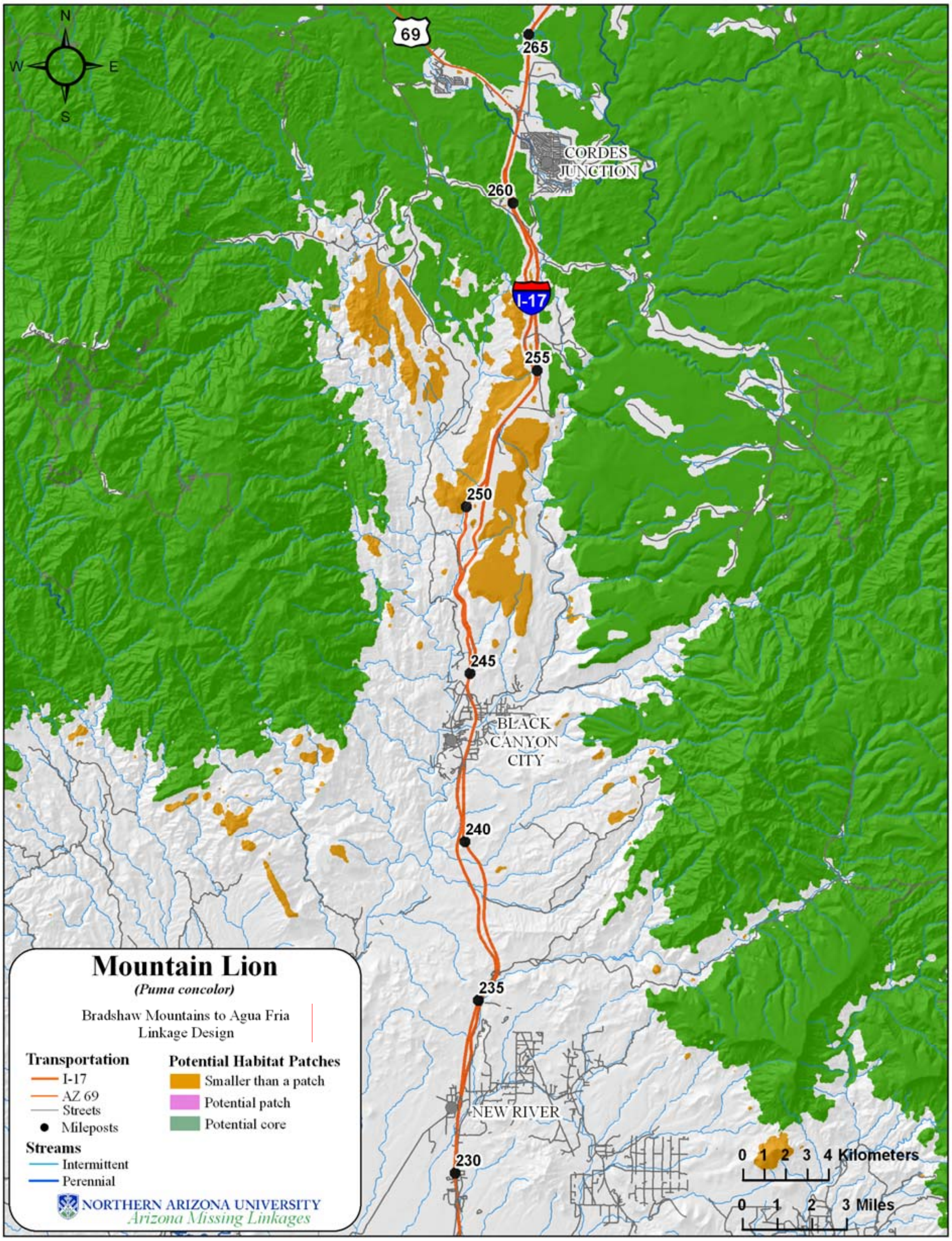


Figure 40: Potential habitat patches and cores for mountain lion.

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation has the greatest role in determining deer distributions in desert systems, followed by topography (Jason Marshal, personal comm.). For this reason, vegetation received an importance weight of 80%, while topography and distance from roads received weights of 15% and 5%, respectively. For specific scores of classes within each of these factors, see Table 6.

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.

Potential Habitat Suitability

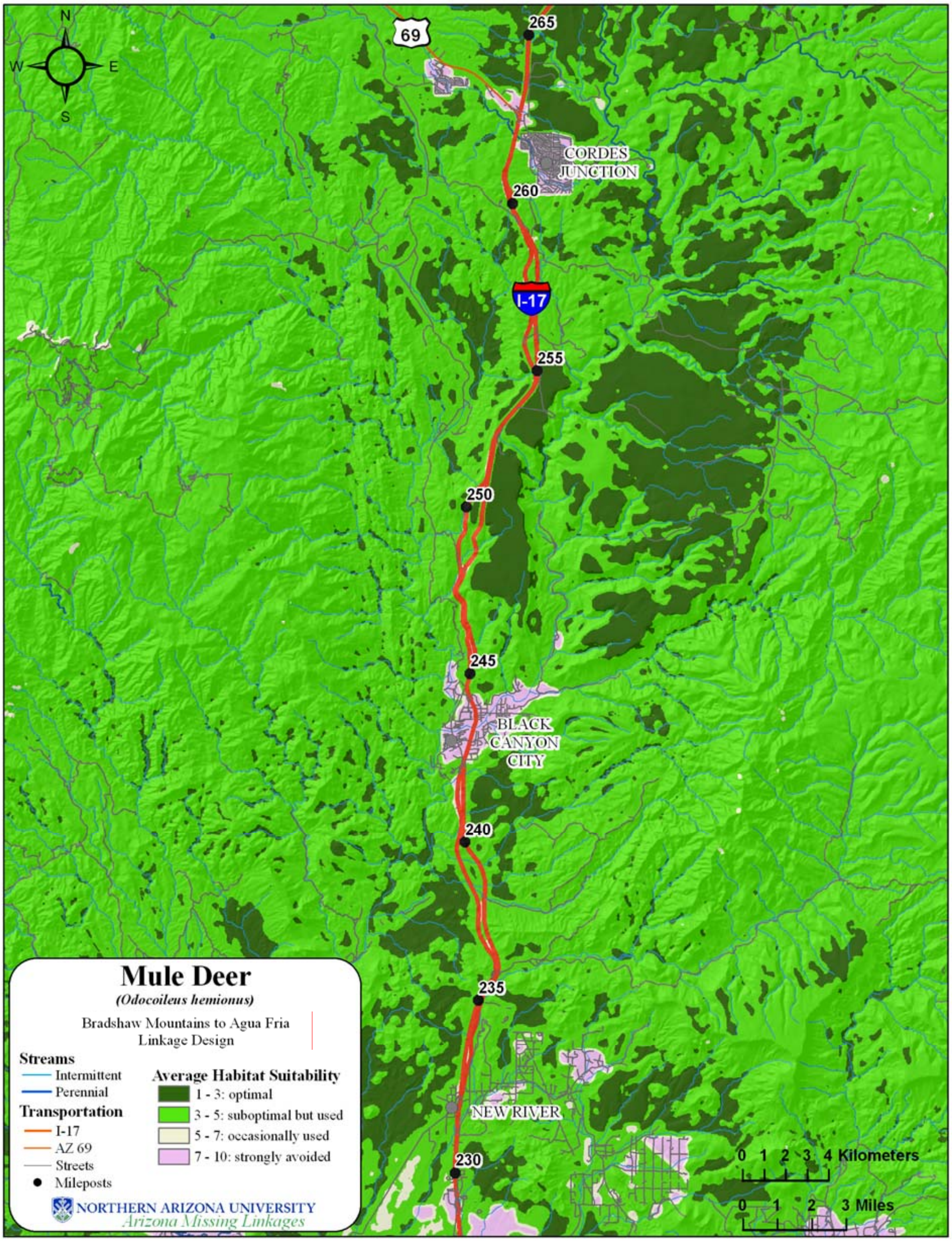


Figure 41: Modeled habitat suitability of mule deer.

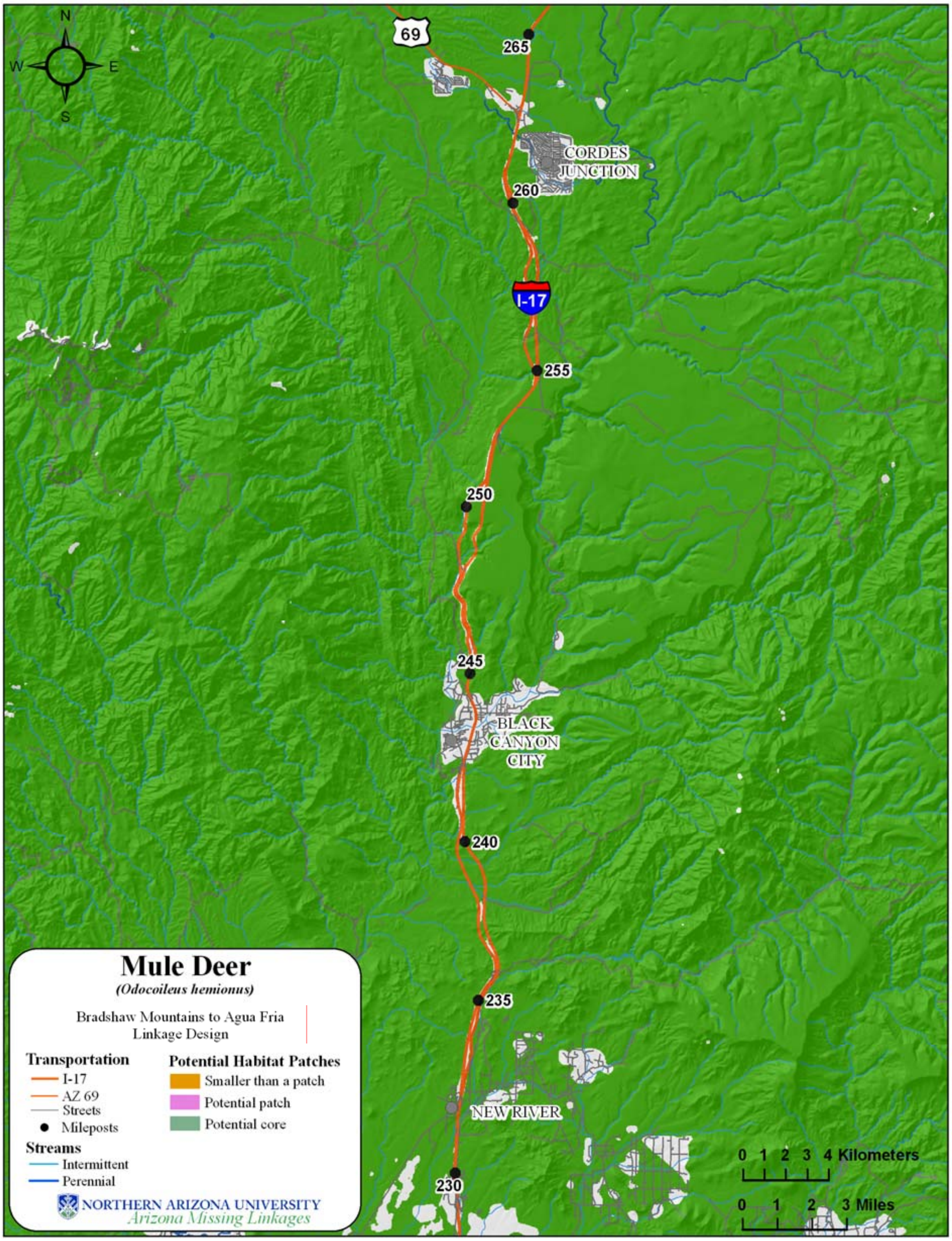


Figure 42: Potential habitat patches and cores for mule deer.

Pronghorn (*Antilocapra americana*)

Justification for Selection
Pronghorn are known to be susceptible to habitat degradation and human development (AZGFD 2002a). One example of harmful development is right of way fences for highways and railroads, which are the major factor affecting pronghorn movements across their range (Ockenfels et al. 1997). Existence of migration corridors is critical to pronghorn survival for allowing movement to lower elevation winter ranges away from high snowfall amounts (Ockenfels et al. 2002).

Distribution
Pronghorn range through much of the western United States, and are found throughout the grasslands of Arizona, except in the southeastern part of the state (Hoffmeister 1986).

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

Spatial Patterns
In northern populations, home range has been estimated to range from 0.2 to 5.2 km^2, depending on season, terrain, and available resources (O'Gara 1978). However, large variation in sizes of home and seasonal ranges due to habitat quality and weather conditions make it difficult to apply data from other studies (O'Gara 1978). Other studies report home ranges that average 88 km^2 (Ockenfels et al. 1994) and 170 km^2 in central Arizona (Bright & Van Riper III 2000), and in the 75 – 125 km^2 range (n=37) in northern Arizona (Ockenfels et al. 1997). One key element in pronghorn movement is distance to water. One study found that 84% of locations were less than 6 km from water sources (Bright & Van Riper III 2000), and another reports collared pronghorn locations from 1.5 – 6.5 km of a water source (Yoakum et al. 1996). Habitats within 1 km of water appear to be key fawn bedsite areas for neonate fawns (Ockenfels et al. 1992).

Conceptual Basis for Model Development
Habitat suitability model – Vegetation received an importance weight of 45%, while topography and distance from roads received weights of 37% and 18%, respectively. For specific scores of classes within each of these factors, see Table 6.

Patch size & configuration analysis **–** Minimum patch size for pronghorn was defined as 50 km^2 and minimum core size as 250 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Potential Habitat Suitability

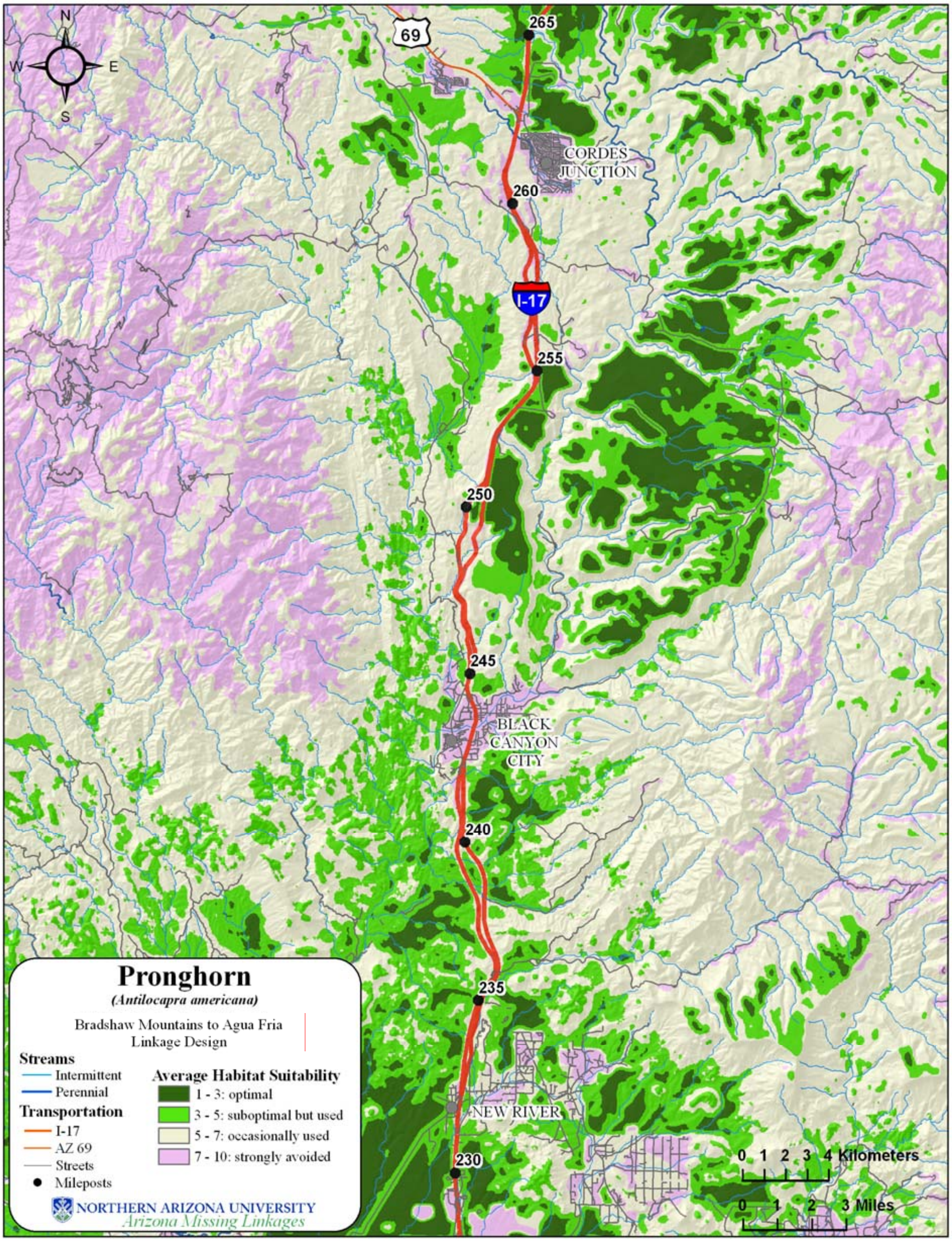


Figure 43: Modeled habitat suitability of pronghorn.

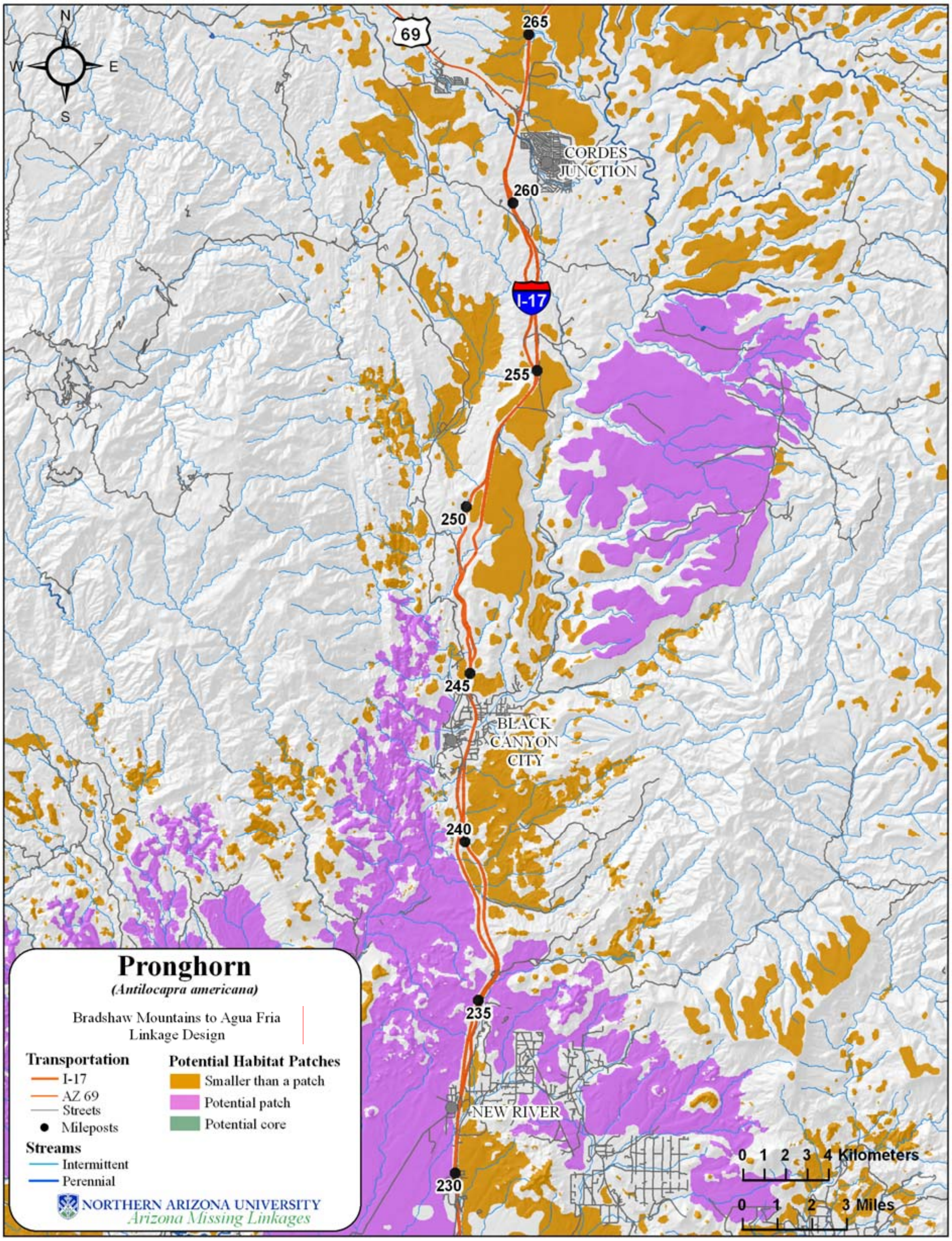


Figure 44: Potential habitat patches and cores for pronghorn.

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 area along the Agua Fria River were adequately incorporated in the linkage design (Figure 45). A list of important riparian and aquatic obligate species follows:

Mammals

- Southwestern River Otter (Lontra canadensis sonora) – this very rare species is listed as a Species of Concern by the U.S. Fish and Wildlife Service and a Species of Special Concern in Arizona. They appear to have been extirpated in Arizona (New Mexico Game and Fish Department 2006). Another species (Lontra canadensis laxatina) from Louisiana was introduced into the Verde River in the early 1980's, though it is also appears to be very rare (New Mexico Game and Fish Department 2006).

Fish

- Desert Sucker (*Catostomus clarki*) – listed as sensitive by the BLM and considered a Species of Concern by the U.S. Fish and Wildlife Service, though it is thought to be fairly common in Arizona (New Mexico Game and Fish Department 2006).
- Gila Chub – listed as a federally endangered species, USFS and BLM Sensitive, and a Species of Special Concern in Arizona, it is commonly found in association with the Gila topminnow, desert and sonora sucker and longfin and speckled dace. It is highly secretive, seeking out deeper waters near cover. It is associated with broadleaf riparian vegetation (Arizona Game and Fish Department 2002).
- Gila Topminnow (*Poeciliopsis occidentalis occidentalis*) – listed as federally endangered by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It has been documented in the Badger Springs wash (Arizona Game and Fish Department 2006).
- Longfin Dace (*Agosia chrysogaster*) – listed as Sensitive by the BLM, threatened in Mexico, and a Species of Concern by the U.S. Fish and Wildlife Service (Arizona Game and Fish Department 2002).
- Speckled Dace (*Rhinichthys osculus*) – listed as endangered in Mexico, the federal register describes its an overall declining population trend, and its disappearance was documented along the main channels of the Gila drainage (New Mexico Game and Fish Department 2006).
- Spikedace (*Meda fulgida*) – listed as threatened in Arizona and by the U.S. Fish and Wildlife Service, with critical habitat designated. Once abundant in Arizona, it is now found in the reaches of 3 waterways in the state, including the upper Verde River (New Mexico Game and Fish Department 2006).

Herpetofauna

- Black-neck Gartersnake (*Thanmophis cyrtopsis*) – the western black-necked gartersnake, as it is commonly referred to, is known to occupy riparian areas and rocky slopes of the Tonto National Forest, and may be associated with pinyon-juniper woodlands (New Mexico Game and Fish Department 2006).
- Mexican Gartersnake (*Thamnophis eques megalops*) – considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It is associated with riparian, marsh, and riverine habitats in middle elevations (New Mexico Game and Fish Department 2006).
- Narrow-headed Gartersnake (*Thamnophis rufipunctatus rufipunctatus*) – considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It is

an almost strictly aquatic species known to occur in permanent streams draining the Mogollon Rim (New Mexico Game and Fish Department 2006).

- Lowland Leopard Frog (*Rana yavapaiensis*) – 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. Since nearly 60 % of all localities occur in Gila, Maricopa and Yavapai counties, occurrences in this part of the state are considered to be important (Arizona Game and Fish Department 2006).

Birds

- Southwestern Willow flycatcher (*Empidonax traillii extimus*) – listed as endangered by the U.S. Fish and Wildlife Service, Sensitive by the Forest Service, 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. It is known to occur in Bumble Bee Creek (Arizona Game and Fish Department 2006).
- Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) – listed as a candidate for endangered species by the USFWS and a Wildlife Species of Special Concern in Arizona. In the West, cuckoos are closely associated with broadleaf riparian forests.

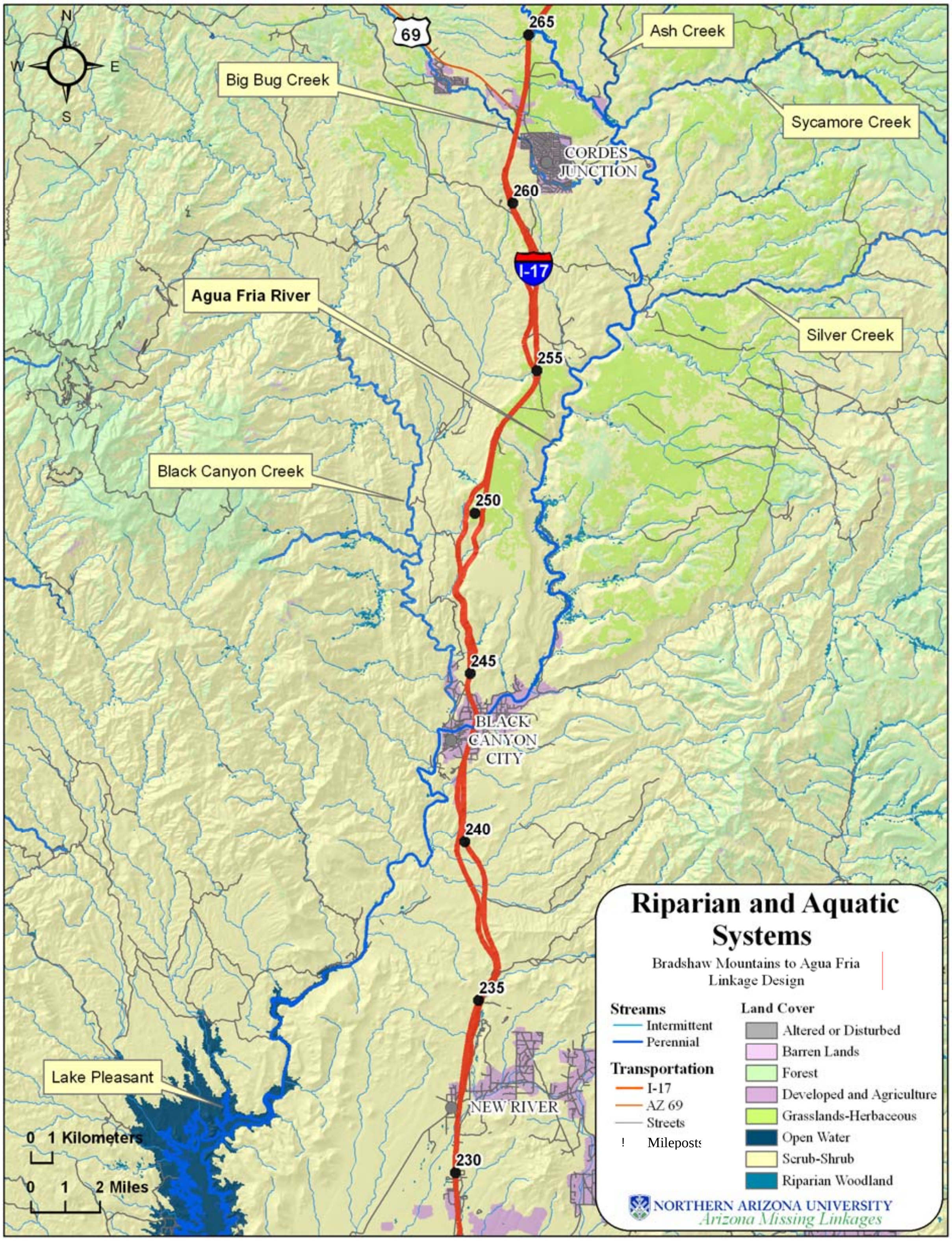


Figure 45: Riparian habitat for fish, herpetofauna, and birds along the Agua Fria River is important to the Linkage Design.

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. Bridges, culverts and tunnels often serve as roost sites since they moderate ambient temperature extremes and provide shelter.
- Ringtail (*Bassariscus astutus*) – Ringtails are most often associated with rocky habitats, which cannot be adequately modeled using the available GIS layers.

Birds

- Bald Eagle (*Haliaeetus leucocephalus*) – listed as threatened by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. In order for the bald eagle population to recover, these require ongoing protection and management of their habitat, population monitoring, and re-establishment of breeding populations throughout their historic range.
- Cassin's Sparrow (*Aimophila cassinii*) – a neotropical migrant that winters and builds groundnests in the mixed grass and shrublands of the southwest, populations are apparently secure in Arizona (New Mexico Game and Fish Department 2006).
- Common Black-hawk (*Buteogallus anthracinus anthracinus*) –occur in riparian woodlands, especially cottonwood forests (New Mexico Game and Fish Department 2006). They are also highly mobile.
- Gambel's Quail (*Callipepla gambelii*) – prefer xeric habitats dominated by shrubs, and populations appear to be secure in Arizona (New Mexico Game and Fish Department 2006).
- Northern Goshawk (*Accipter gentilis*) – listed as a Species of Special Concern both by the State of Arizona and the U.S. Fish and Wildlife Service, goshawks appear to be uncommon or restricted in Arizona, where they nest in the coniferous forests of the mountains and mesas of northeastern and northcentral parts of the state (New Mexico Game and Fish Department 2006).

Appendix D: Description of Land Cover Classes

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

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

Appendix E: Literature Cited

Adams, H.B., and L. Adams. 1959. Black-tailed jackrabbit carcasses on the highways in Nevada, Idaho, and California. Ecology 40: 718-720.

Alvarez-Cardenas, S., I. Guerrero-Cardenas, S. Diaz, P. Calina-Tessaro, and S. Gallina. 2001. The variables of physical habitat selection by the desert bighorn sheep (*Ovis Canadensis weemsi*) in the Sierra del Mechudo, Baja California Sur, Mexico. Journal of Arid Environments 49: 357-374.

Anderson, A.E., and O.C. Wallmo. 1984. Mammalian Species 219: 1-9. Mule deer.

Apps, C.D., N.J. Newhouse, and T.A. Kinley. 2002. Habitat associations of American badgers in southeastern British Columbia. Canadian Journal of Zoology 80: 1228-1239.

Arizona Game and Fish Department. 2001. *Cenidophorus burti stictigrammus*. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 5 pp.

Arizona Game and Fish Department. 2001. *Rana chiricahuensis*. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 5 pp.

Arizona Game and Fish Department. 2002. *Heloderma suspectum cinctum.* Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 5 pp.

Arizona Game and Fish Department. 2002a. Antilocapra americana mexicana. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 6 pp.

Arizona Game and Fish Department. 2002b. Antilocapra americana sonoriensis. Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 6 pp.

Arizona Game and Fish Department. 2003. *Eumeces gilberti rubricaudatus.* Unpublished abstract compiled and edited by the Heritage Data Management System, Arizona Game and Fish Department, Phoenix, AZ. 4 pp.

Arizona Game and Fish Department. 2006. Arizona Statewide Pronghorn Operational Plan. Arizona Game and Fish Department, Phoenix, AZ. 192 pp.

Welch, J.M. 1960. A study of seasonal movements of white-tailed deer (Odocoileus virginianus Couesi) in the Cave Creek Basin of the Chiricahua Mountains. M.S. Thesis, Univ. Arizona, Tucson, 79 pp.

Aslan, C.E., A. Schaeffer, and D.E. Swann. 2003. Gopherus agassizii (desert tortoise) elevational range. Herpetological Review 34:57.

Averill-Murray, R.C., A.P. Woodman, and J.M. Howland. 2002. Population ecology of the Sonoran desert tortoise in Arizona. Pages 109-134 in Van Devender, T.R., editor. University of Arizona Press, Tucson, Arizona, USA. 388pp

Baily, S.J. C.R. Schwalbe, and C.H. Lowe. 1995. Hibernaculum use by a population of desert tortoises (Gopherus agassizii) in the Sonoran Desert. Journal of Herpetology 29:361-369.

Barnes, T. and Adams, L. 1999. A Guide to Urban Habitat Conservation Planning: University of Kentucky Cooperative Extension Service.

Barnum, S.A. 2003. Identifying the best locations along highways to provide safe crossing opportunities for wildlife: a handbook for highway planners and designers. Colorado Department of Transportation.

Beck, D.D. 1995. Ecology and energetics of three sympatric rattlesnake species in the Sonoran Desert. Journal of Herpetology 29: 211-223.

Beck, D.E. 2005. Biology of Gila Monsters and Beaded Lizards. University of California Press, Berkeley.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology 7: 94-108.

Beier, P., and S. Loe. 1992. A checklist for evaluating impacts to wildlife corridors. Wildlife Society Bulletin 20: 434-40.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Best, T. 1996. Lepus californicus. Mammalian Species 530: 1-10.

Blair, R.B. 1996. Land use and avian species diversity along an urban gradient. Ecological Applications 6:506-519.

Blair, R.B. 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity? Ecological Applications 9:164-170.

Blair, R.B. and A.E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. Biological Conservation 80:113-125.

Boyce, M.S. 1991. Migratory behavior and management of elk (Cervus elaphus). Applied Animal Beahviour Science 29: 239-250.

Bright, J.L., and C. Van Riper III. 2000. Habitat selection by pronghorn antelope at Wupatki National Monument.

Arizona. Proceedings of Pronghorn Workshop 17: 77-85.
Britt, T.L. and D.P. Theobald, eds. 1982. Provincial, reservation and state status reports. Proceedings of the Western States Elk Workshop. Western Association of Fish and Wildlife Agencies. Phoenix, AZ. 166 p.
Brooks, M.L., and B. Lair. 2005. Ecological effects of vehicular routes in a desert ecosystem. Report prepared for the United States Geological Survey, Recoverability and Vulnerability of Desert Ecosystems Program.
Brown, C.F., and P.R. Krausman. 2003. Habitat characteristics of three leporid species in southeastern Arizona. Journal of Wildlife Management 67: 83-89.
Brown, G. et al.. 1980 Elk habitat: timber management relations. Central Zone, Northern Region. USDA Forest Service, Montana Dept. of Fish, Wildlife & Parks, Confederated Salish and Kootenai Tribes.
Brudin III, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. ICOET 2003.
Bunnell, F.L., and D.E.N. Tait. 1981. Population dynamics of bears-implications. Pages 75 - 98 in C. W. Fowler and T. D Smith, Eds. Dynamics of Large Mammal Populations. John Wiley and Sons, New York, New York. USA.
Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114: 189-197.
Clevenger, A.P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.
Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121: 453-464.
Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38: 1340-1349.
Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109: 15-26.
Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503-514.
Colby, B., and S. Wishart. 2002. Riparian areas generate property value premium for landowners. Agiculatural and Resource Economics, Arizona State University, Tucson, AZ. 15p. Available online: http://ag.arizona.edu/arec/pubs/riparianreportweb.pdf.
Conservation Biology Institute. 2005. Analysis of General Plan-2020 San Diego County. Encinitas, Ca. 27pp.
Cunningham, S.C., and W. Ballard. 2004. Effects of wildfire on black bear demographics in cetral Arizona. Wildlife Society Bulletin 32: 928-937.
Currier, M.P. 1983. Felis Concolor. Mammalian Species 200: 1-7.
D'Antonio, C. and L.A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology 10: 703-713.
Degenhardt, W.G., C.W. Painter, and A.H. Price. 1996. Amphibians and Reptiles of New Mexico. UNM Press, Albuquerque, NM. 431 pp.
DeVos, James C. and William H. Miller. 2005. Habitat use and survival of Sonoran pronghorn in years with above-average rainfall. Wildlife Society Bulletin 33(1): 35-42.
Dickson, B.G., and P. Beier. 2002. Home range and habitat selection by adult cougars in southern California. Journal of Wildlife Management 66:1235-1245.
Dodd, C.K, W.J. Barichivich, and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.
Donnelly, R., and J.M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. Conservation Biology 18:733-745.
Edwards, T., E.W. Stitt, C.R. Schwalbe, and D.E. Swann. 2004. Natural History Notes: Gopherus Agassizii (Desert Tortoise). Movement. Herpetological Review 35:381-382
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Washington D.C. Available from www.elistore.org
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Environmental Law Institute. Washington D.C. Available online: www.elistore.org.
Epps, C.W., D.R. McCullough, J.D. Wenausen, V.C. Bleich, and J.L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18: 102-113.
Evink, G.L. 2002. Interaction between roadways and wildlife ecology. National Academy Press, Washington, D.C.
Fisher, R. A. and J. C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. U.S. Army Engineer Research and Development Center. ERDC-TN-EMRRPSR-24. Available online
Forman, R.T.T., et al. 2003. Road ecology: science and solutions. Island Press: Washington, D.C.

Friesen, L.E., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.
Gallina, S., E. Maury, and V. Serrano. 1981. Food habits of white-tailed deer. Pages 133-148 in P.F. Ffolliot and S. Gallina,eds. Deer biology, habitat requirements, and management in western North America. Inst. De Ecol. Publ. 9, Hermosillo, Sonora, Mexico. 238 pp.
Geist, V. 2002. Adaptive behavioral strategies, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 389-433.
Germaine, S.S., and B.F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229-237.
Germaine, S.S., S.S. Rosenstock, R.E. Schweinsburg, and W.S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson, Arizona. Ecological Applications 8:680-691.
Germano, D.J. 1992. Longevity and age-size relationships of populations of desert tortoises. Copeia 1992: 367-374.
Goodrich, J.M., and S.W. Buskirk. 1998. Spacing and ecology of North American badgers (Taxidea taxus) in a prairie-dog (Cynomys leucurus) complex. Journal of Mammalogy 78: 171-179.
Gross, J.E., F.J. Singer, and M.E. Moses. 2000. Effects of disease, dispersal, and area on bighorn sheep restoration. Restoration Ecology 8: 25-37.
Halloran, A.F.. and W.E. Blanchard. 1954. Carnivores of Yuma County, Arizona. American Midland Naturalist 51: 481-487.
Hart, D.D., T.E. Johnson, K.L. Bushaw-Newton, R.J. Horowitz, A.T. Bednarek, D.F. Charles, D.A. Kreeger, and D.J. Velinsky. 2002. Dam removal: challenges and opportunities for ecological research and river restoration. Bioscience 52: 669- 681.
Henry, R.S., and L.K. Sowls. 1980. White-tailed deer of the Organ Pipe Cactus National Monument, Arizona. Univ. Arizona Coop. Park Resour. Stud. Unit Tech. Rep. 6, Tucson, 85 pp.
Hervert, J.J., J.L. Bright, R.S. Henry, L.A. Piest, and M.T. Brown. 2005. Home-range and habitat-use patterns of Sonoran pronghorn in Arizona. Wildlife Society Bulletin 33: 8-15.
Hoffmeister, D.F. 1986. Mammals of Arizona. The University of Arizona Press and The Arizona Game and Fish Department. 602 pp.
Jennings, W.B. 1997. Habitat use and food preferences of the desert tortoise, Gopherus agassizii, in the Western Mojave Desert and impacts of off-road vehicles. Proccedings: Conservation, Restoration, and Management of Tortoises and turtles – An International Conference: pp. 42-45.
Johnson, T.L., and D.M. Swift. 2000. A test of a habitat evaluation procedure for Rocky Mountain Bighorn Sheep. Restoration Ecology 8: 47-56.
Kiesecker, J. M. and A. R. Blaustein. 1998. Effects of Introduced Bullfrogs and Smallmouth Bass on Microhabitat Use, Growth, and Survival of Native Red-Legged Frogs (Rana aurora). Conservation Biology 12: 776-787.
Knipe, T. 1977. The Arizona whitetail deer. Arizona Game and Fish Departmenet Special Report 6, Phoenix, 108 pp.
Kraussman, P.R. 2000. An Introduction to the restoration of bighorn sheep. Restoration Ecology 8: 3-5.
Krueper, D. J. 1993. Conservation priorities in naturally fragmented and human-altered riparian habitats of the arid West. USDA Forest Service. General Technical Report RM-43. Available online: www.birds.cornell.edu/pifcapemay/krueper.htm.
Kupferberg, S. J. 1997. Bullfrog (Rana catesbeiana) invasion of a California river: the role of larval competition. Ecology 78: 1736-1751.
Lambeck, R. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.
Larivière, S. 2001. Ursus americanus. Mammalian Species 647: 1-11.
LeCount, A.L. 1982. Characteristics of a central Arizona black bear population. Journal of Wildlife Management 46:861-868.
LeCount A.L., R.H. Smith, and J.R. Wegge. 1984. Black Bear habitat requirements in central Arizona. Federal Aid Final Report. Arizona Game and Fish Department. Phoenix. USA.
Lee, P., C. Smyth, and S. Boutin. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70:165-180.
Leopold, A.S. 1959. White-tailed deer. Odocoileus virginianus. Pages 507-513 in Wildlife of Mexico: the game birds and mammals. Univ. California Press, Berkley. 568 pp
Levey, D., B.M. Bolker, J.T. Tewksbury, S. Sargent, and N. Haddad. 2005. Effects of Landscape Corridors on Seed Dispersal by Birds. Science 309: 146-148.
Ligon, J.S. 1927. Wild life of New Mexico: its conservation and management. New Mexico Dept. Game and Fish,

Santa Fe. 212 pp.
Lite, S.J., and J.C. Stromberg. 2005. Surface water and ground-water thresholds for maintaining Populus - Salix forests, San Pedro River, Arizona. Biological Conservation 125:153–167.
Little, S.J. 2003. The influence of predator-prey relationships on wildlife passage evaluation. ICOET 2003.
Logan, K.A., and L.L. Sweanor. 2001. Desert Puma: Evolutionary Ecology and Conservation of an Enduring Carnivore. Island Press, Washington D.C. 463 pp.
Long, C.A. 1973. Taxidea taxus. Mammalian Species 26: 1-4.
Long, C.A., and C.A. Killingley. 1983. The badgers of the world. Charles C. Thomas Publishing, Springfield, IL.
Lowe, C.H. 1978. The Vertebrates of Arizona. The University of Arizona Press. Tuscon, Arizona. 270pp.
Luckenbach, R.A., and R.B. Bury. 1983. Effects of off-road vehicles on the biota of the Algodones Dunes, Imperial County, California. Journal of Applied Ecology 20: 265-286.
Lyon, L.J. 1979. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry 77: 658-660.
Lyon, L.J. and A.G. Christianson. 2002. Elk and land management, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 557-581.
Malo, J.E., F. Suarez, and A. Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models. Journal of Applied Ecology 41: 701-710.
Maret, T.J., J.D. Snyder, and J.P. Collins. Altered drying regime controls distribution of endangered salamanders and introduced predators. Biolocial Conservation 127: 129-138.
Marshall, R.M., S. Anderson, M. Batcher, P. Comer, S. Cornelius, R. Cox, A. Gondor, D. Gori, J. Humke, R. Paredes Aguilar, I.E. Parra, and S. Schwartz. 2000. An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion. Prepared by The Nature Conservancy Arizona Chapter, Sonoran Institute, and Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora with support from Department of Defense Legacy Program, Agency and Institutional partners. 146 pp.
Mata, C., I. Hervas, J. Herranz, F. Suarez, and J.E. Malo. 2005. Complementary use by vertebrates of crossing structures along a fences Spanish motorway. Biological Conservation 124: 397-405.
McCoy, J. Evan, David G. Hewitt, and Fred C. Bryant. 2005. Dispersal by yearling male white-tailed deer and implications for management. Journal of Wildlife Management: Vol. 69, No. 1, pp. 366–376.
McCulloch, C.Y. 1973. Seasonal diets of mule and white-tailed deer. Pages 1-38 in Deer nutrition in Arizona chaparral and desert habitats. AZGFD Spec. Rep. 3, Phoenix, 68 pp.
McDonald, W., and C.C. St Clair. 2004. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41: 82-93.
Messick, J.P., and M.G. Hornocker. 1981. Ecology of the badger in southwestern Idaho. Wildlife Monographs 76.
Morgantini, L.E., and R.J. Hudson. 1979. Human disturbance and habitat selection in elk in Boyce, M.S. and L.D. Hayden-Wing, eds. North American Elk: Ecology, Behavior and Mgt. University of Wyoming. pp 132-139.
Naiman, R. J., H. Decamps and M. Pollock. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.
National Academy of Sciences. 2002. Riparian areas: functions and strategies for management. National Academy Press. Washington D. C. 436 p.
NatureServe. 2005. NatureServe Explorer: An online encyclopedia of life [web application]. Version 4.6. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: November 29, 2005).
New Mexico Department of Game & Fish. 2002. Biota Information System of New Mexico. New Mexico Department of Game & Fish electronic database, BISON, Version 1/2004, Santa Fe, New Mexico. http://nmnhp.unm.edu/bisonm/bisonquery.php. Accessed 9 September 2005.
Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115: 499-507.
Ockenfels, R.A., A.A. Alexander, C.L. Dorothy Ticer, and W.K. Carrel. 1994. Home ranges, movement patterns and habitat selection of pronghorn in central Arizona. Arizona Game and Fish Technical Report 13. Phoenix, AZ.
Ockenfels, R.A., D.E. Brooks, and C.H. Lewis. 1991. General ecology of Coues' white-tailed deer in the Santa Rita Mountains. AZGFD Tech Rep. 6, Phoenix. 73 pp.
Ockenfels, Richard A. and William K. Carrel, and C. van Riper III. 1997. Home ranges and movements of pronghorn in northern Arizona. Biennial Conf. Res. Colorado Plateau 3: 45-61.
Ockenfels, R.A., and G.I. Day. 1990. Determinants of collared peccary home-range size in central Arizona. In Managing wildlife in the southwest (Krausman, P.R. and N.S. Smith, eds), Arizona chapter of the Wildlife Society, Phoenix, Arizona. Pps 76-81.
Ockenfels, R.A., C.L. Dorothy, and J.D. Kirkland. 1992. Mortality and home range of pronghorn fawns in central

Arizona. Proc. Pronghorn Antelope Workshop 15: 78-92.
Ockenfels, R.A., L.W. Luedeker, L.M. Monroe, and S.R. Roe. 2002. A Pronghorn Metapopulation in northern Arizona. Proceedings of the 20th Biennial Pronghorn Workshop 20:42-59.
Ockenfels, Richard A., Cindy L. Ticer, Amber Alexander, Jennifer A. Wennerlund. 1996. A landscape-level pronghorn habitat evaluation model for Arizona. Arizona Game and Fish Department. Tech. Rep. 19, Phoenix. 50pp.
Odell, E.A., and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.
Oftedal, O.T. 2002. Nutritional ecology of the desert tortoise in the Mohave and Sonoran deserts. Pp. 194-241 in Van Devender, T.R. (ed) The Sonoran Desert Tortoise. Natural History, Biology, and Conservation. Univ. of Arizona Press, Tucson.
O'Gara. 1978. Antilocapra americana. Mammalian Species 90: 1-7.
O'Gara, B.W., and R.G. Dundes 2002. Distribution: past and present, in Toweill, D. E. & Thomas, J. W. eds. North American elk ecology and management. Smithsonian Press, Wash D.C. pp 67-119.
Olsen, D.M., and E. Dinnerstein. 1998. The Global 200: A Representation approach to Conserving the Earth's Most Biologically Valuable Ecoregions. Conservation Biology 12:502-515.
Parkyn, S. 2004. Review of riparian buffer zone effectiveness. MAF Technical Paper No: 2004/05. Available online: www.maf.govt.nz/publications.
Peris, S., and J. Morales. 2004. Use of passages across a canal by wild mammals and related mortality. European Journal of Wildlife Research. 50: 67-72.
Pima County, Arizona. 2001. Sonoran Desert Conservation Plan: Priority Vulnerable Species. Unpublished report by Pima County, Arizona. Available from http://www.co.pima.az.us/cmo/sdcp website. (Accessed February 13, 2006).
Rosen, P.C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation 68: 143-148.
Rottenborn, S.C. 1999. Predicting impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.
Rowland, M.M., M.J. Wisdom, B.K. Johnson, and M.A. Penninger. 2004. Effects of roads on elk: implications for management in forested ecosystems. Transactions of the North American Wildlife and Natural Resource Conference 69.
Ruediger, B. 2001. High, wide, and handsome: designing more effective wildlife and fish crossings for roads and highways. ICOET 2001.
Savage, M. 2004. Community monitoring for restoration projects in Southwestern riparian communities. National Community Forestry Center Southwest Working Paper No. 16. Forest Guild. Santa Fe, NM.
Scarbrough, D.L., and P.R. Krausman. 1988. Sexual selection by desert mule deer. Southwestern Naturalist 33: 157-165.
Schwartz, C.C. and A.W. Franzmann. 1992. Dispersal and survival of subadult black bears from the Kenai Peninsula, Alaska. Journal of Wildlife Management 56: 426-431.
Shackleton, D.M. 1985. Ovis canadensis. Mammalian Species 230: 1-9.
Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12: 107-123.
Singer, F.J., C.M. Papouchis, and K.K. Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8: 6-13.
Singer, F.J., M.E. Moses, S. Bellew, and W. Sloan. 2000. Correlates to colonizations of new patches by translocated populations of bighorn sheep. Restoration Ecology 8: 66-74.
Singer, F.J., V.C. Bleich, and M.A. Gudorf. 2000. Restoration of Bighorn Sheep Metapopulations in and Near Western National Parks. Restoration Ecology 8: 14-24.
Singer,F.J., L.C. Zeigenfuss, and L. Spicer. 2001. Role of Patch Size, Disease, and Movement in Rapid Extinction of Bighorn Sheep. Conservation Biology 15: 1347-1354.
Smith, W.P. 1991. Odocoileus virginianus. Mammalian Species 388: 1-13.
Sowls, L. K. 1997. Javelinas and other peccaries: their biology, management, and use. Second edition. Texas A & M University, College Station, Texas, USA.
Springer, A. E., J. M. Wright, P. B. Shafroth, J. C. Stromberg, and D. T. Patten 1999. Coupling ground-water and riparian vegetation models to simulate riparian vegetation changes due to a reservoir release. Water Resources Research 35: 3621-3630.

Stralberg, D., and B. Williams. 2002. Effects of residential development and landscape composition on the breeding birds of Placer County's foothill oak woodlands. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

Stromberg, J. 2000. Parts 1-3: Restoration of riparian vegetation in the arid Southwest: challenges and opportunities. Arizona Riparian Council Newsletter vol. 13 no. 1-3. Arizona Riparian Council. Tempe, Arizona. Available online: http://azriparian.asu.edu/newsletters.htm.

Stromberg, J.C., J.A. Tress, S.D. Wilkins, and S. Clark. 1992. Response of velvet mesquite to groundwater decline. Journal of Arid Environments 23:45-58.

Stromberg, J.C., M.R. Sommerfield, D.T. Patten, J. Fry, C. Kramer, F. Amalfi, and C. Christian. 1993. Release of effluent into the Upper Santa Cruz River, Southern Arizona: ecological considerations. Pp. 81-92 in M. G. Wallace, ed. Proceedings of the Symposium on Effluent Use Management. American Water Resources Association, Tucson, AZ.

Stromberg, J.C. 1997. Growth and survivorship of Fremont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist 57:198-208.

Sullivan T.L., and T.A. Messmer. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. Wildlife Society Bulletin 31:163-173.

Thomas, J.W., D.A. Leckenby, H. Henjum, R.J. Pedersen, and L.D. Bryant. 1988. Habitat-effectiveness index for elk on Blue Mountain winter ranges. USDA Forest Service Pacific Northwest Research Station, General Technical Report PNW-GTR-218. 28 p.

Ticer, C.L., R.A. Ockenfels, J.C. DeVos Jr., and T.E. Morrell. 1998. Habitat use and activity patterns of urban-dwelling javelina. Urban Ecosystems 2:141-151.

Ticer, C.L., and R.A. Ockenfels. 2001. A validation of Arizona's Landscape-level pronghorn habitat model. Proc. Pronghorn Antelope Workshop 19: 63-71.

Ticer, C.L., T.E. Morrell, and J.C. DeVos Jr. 2001. Diurnal bed-site selection of urban-dwelling javelina in Prescott, Arizona. Journal of Wildlife Management 65:136-140.

Turner et al. 1995. Preserve Design for maintaining biodiversity in the Sky Island region. In: De Bano, Leonard F., Peter F. Ffolliott, Alfredo Ortega-Rubio, Gerald J. Gottfried, Robert H. Hamre, and Carleton B. Edminster (tech. cords.). 1995. Biodiversity and Management of the Madrean Archipelago: the sky islands of southwestern United States and northwestern Mexico. Gen. Tech. Report RM-GTR-264. Ft. Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountatin Forest and Range Experiment Station. pp. 524-530.

U.S. Fish and Wildlife Service. 1994. Desert Tortoise (Mojave Population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon, USA. 73pp.

U.S. Fish and Wildlife Service. 1981. Standards for the development of Suitability Index Models. Division of Ecological Services. Government Printing Office, Washington D.C., USA.

U.S. Fish and Wildlife Service. 2001. Gila Topminnow General Species Information. Unpublished abstract compiled by the Arizona Ecological Services Field Office, U.S. Fish and Wildlife Service, Phoenix, AZ. Available from http://www.fws.gov/arizonaes/Southwes.htm website. (Accessed January 27, 2006).

US Fish and Wildlife Service. 2005. Species Information: Threatened and Endangered Animals and Plants website: http://www.fws.gov/endangered/wildlife.html#Species (Accessed January 4, 2006).

Van Wieren, S.E., and P.B. Worm. 2001. The use of a motorway wildlife overpass by large mammals. Netherlands Journal of Zoology 51: 97-105.

Vander Haegen, W.M., G.R. Orth, and L.M. Aker. 2005. Ecology of the western gray squirrel in south-central Washington. Progress report. Washington Department of Fish and Wildlife, Olympia. 41pp.

Vohies, C.T., and W.P. Taylor. 1933. The life histories and ecology of jack rabbits, Lepus alleni and Lepus californicus spp., in relation to grazing in Arizona. University of Arizona College Agricultural Technical Bulletin 49: 471-587.

Vos, C.C., J. Verboom, P.F.M. Opdam, and C.J.F. Ter Braak. 2001. Toward ecologically scaled landscape indices. The American Naturalist 183: 24-41.

Ward, A.L., N.E. Fornwalt, S.E. Henry, and R.A. Hodorff. 1980. Effects of highway operation practices and facilities on elk, mule deer, and pronghorn antelope. Rocky Mountain forest and Range Experiment Station, Ft., Collins, CO Report FHWA-RD-79-143.//Lyons, L.J. 1979, Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry October 1979: 658-660.

Wallmo, O.C. 1981. Mule and Black-tailed deer of North America. University of Nebraska Press. Lincoln and London. 605 pp.

Webb, R.H. and H.G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. New York : Springer-Verlag.

Welch, J.M. 1960. A study of seasonal movements of white-tailed deer (Odocoileus virginianus Couesi) in the Cave Creek Basin of the Chiricahua Mountains. M.S. Thesis, Univ. Arizona, Tucson, 79 pp.
Wenger, S.J. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Athens, GA: University of Georgia, Public Service & Outreach, Institute of Ecology. 59 p.
Wenger, S.J., and L. Fowler. 2000. Protecting stream and river corridors. Policy Notes, Public Policy Research Series vol 1, no. 1. Carl Vinson Institute of Government, University of Georgia, Athens, GA. Available online: http://www.cviog.uga.edu/publications/pprs/96.pdf.
Wilbor, S. 2005. Audubon's important bird areas program's avian habitat conservation plan: U.S. Upper Santa Cruz River Riparian Corridor, Santa Cruz County, Arizona. Audubon Society, Tucson, AZ. Available online: http://www.tucsonaudubon.org/azibaprogram/UpperSantaCruzRiverAvianHabitatConsPlan.doc.
Wissmar, R.C. 2004. Riparian corridors of Eastern Oregon and Washington: Functions and sustainability along lowland-arid to mountain gradients. Aquatic Sciences 66: 373-387.
Yanes, M., J.M. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71: 217-222.
Yoakum, J.D., O'Gara, B.W., and Howard, V.W. 1996. Pronghorn on western rangelands. Pages 211-216 In P.R. Krausman, ed. Rangeland Wildlife. Society for Range Management, Denver, Colorado.
Zeigenfuss, L.C., F.J. Singer, and M.A. Gudorf. 2000. Test of a modified habitat suitability model for bighorn sheep. Restoration Ecology 8: 38-46.

Appendix F: Database of Field Investigations

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

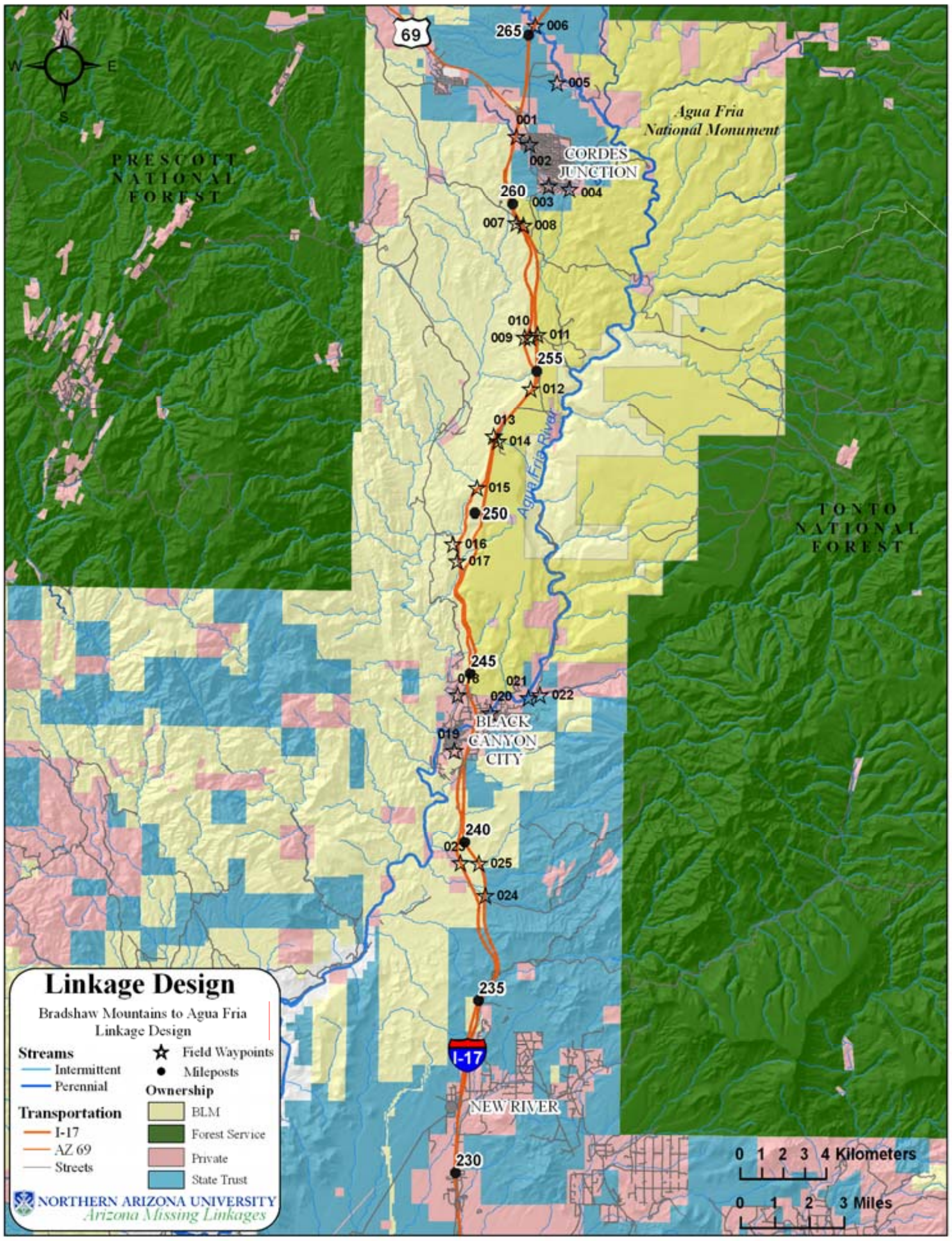
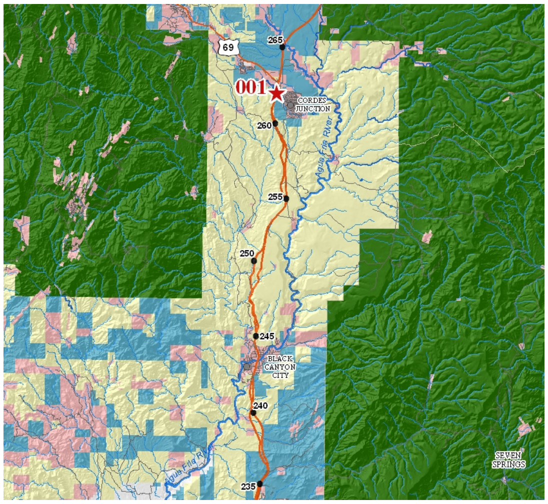


Figure 46: Field investigation waypoints in Linkage Planning Area.

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	001		
Linkage Zone:	Black Hills	**Latitude:**	34.32050678	**Longitude:**	-112.122436
Observers:	Paul Beier, Emily Garding	**UTM X:**	396733.964	**UTM Y:**	3798264.412
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Big Bug Creek at I-17

Site Photographs

Name: IMG_0091.jpg

Azimuth: 250 **Zoom:** 1X

Notes: Bridge over Big Bug Creek at I-17

Name: IMG_0092.jpg

Azimuth: 315 **Zoom:** 1X

Notes: Upstream

Name: IMG_0093.jpg

Azimuth: 145 **Zoom:** 1X

Notes: Downstream toward Cordes Lakes

Appendix F: Database of Field Investigations

Linkage #: 37

Linkage Zone: Black Hills

Observers: Paul Beier, Emily Garding

Field Study Date: 2/20/2007

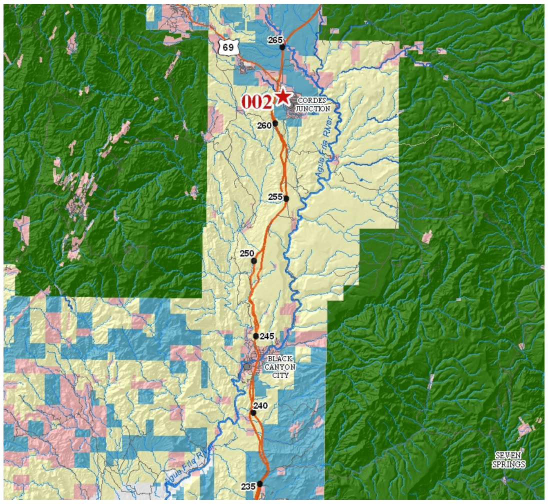
Waypoint #: 002

Latitude: 34.31722317 **Longitude:** -112.115695

UTM X: 397350.1378 **UTM Y:** 3797893.458

Last Printed: 7/12/2007

Waypoint Map



Waypoint Notes

A crossing in Big Bug Creek near Cordes Lakes

Site Photographs

Name: IMG_0094.jpg

Azimuth: 315 **Zoom:** 1X

Notes: Upstream

Name: IMG_0095.jpg

Azimuth: 315 **Zoom:** 3X

Notes: Upstream

Name: IMG_0096.jpg

Azimuth: 150 **Zoom:** 2X

Notes: Downstream

Name: IMG_0097.jpg

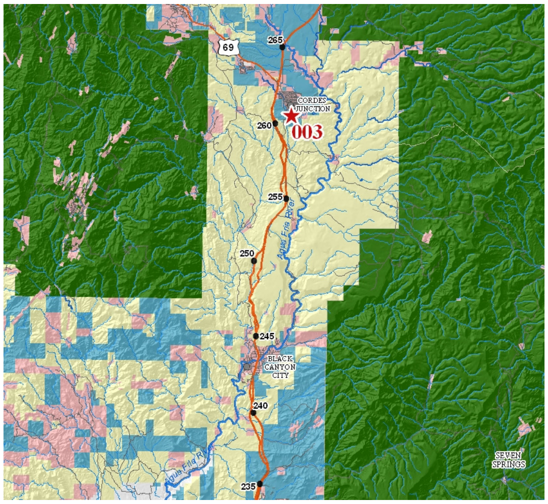
Azimuth: 60 **Zoom:** 1X

Notes: Creek crossing

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	003		
Linkage Zone:	Black Hills	**Latitude:**	34.29978386	**Longitude:**	-112.105912
Observers:	Paul Beier, Emily Garding	**UTM X:**	398229.3038	**UTM Y:**	3795949.751
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Development in the Big Bug Creek floodplain in Cordes Lakes

Site Photographs

Name: IMG_0098.jpg

Azimuth: 310 **Zoom:** 3X

Notes: Development within the Big Bug Wash includes horse stables, a municipal brush lot, and a road.

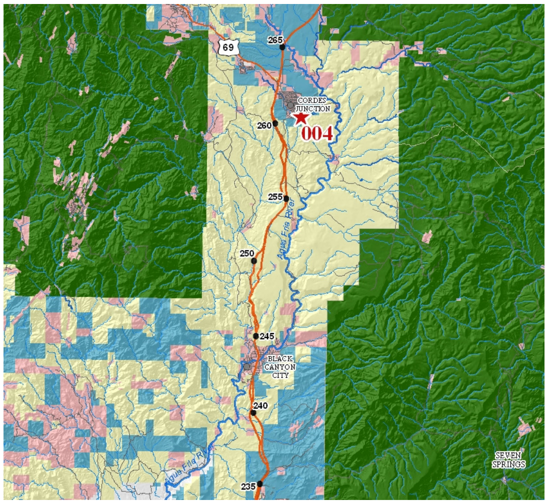
Name: IMG_0099.jpg

Azimuth: 65 **Zoom:** 1X

Notes: Downstream; Big Bug Creek runs through a 4 box culvert

Linkage #:	37	**Waypoint #:**	004		
Linkage Zone:	Black Hills	**Latitude:**	34.29847595	**Longitude:**	-112.095349
Observers:	Paul Beier, Emily Garding	**UTM X:**	399199.7792	**UTM Y:**	3795794.192
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

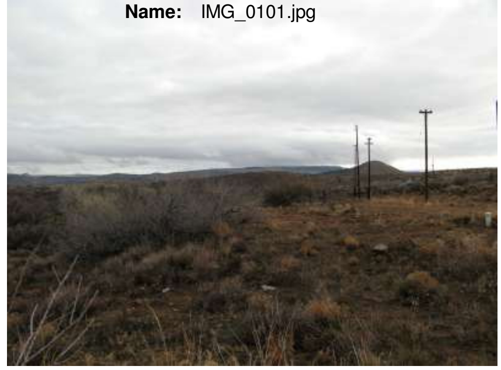
The Big Bug Creek floodplain in Cordes Lakes

Site Photographs

Name: IMG_0100.jpg

Azimuth: 270 **Zoom:** 4X
Notes: Upstream

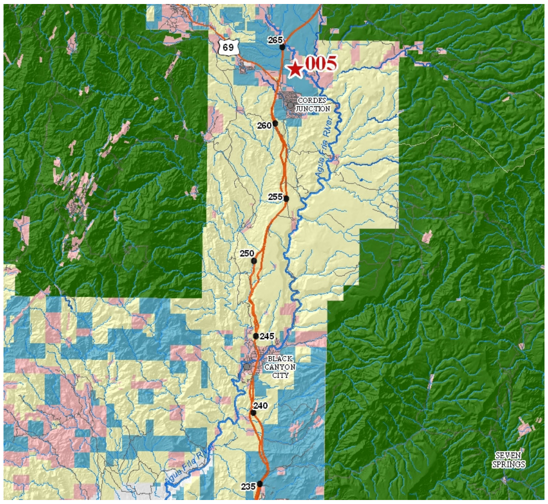
Name: IMG_0101.jpg



Azimuth: 70 **Zoom:** 1X
Notes: The edge of Cordes Lakes

Linkage #:	37	**Waypoint #:**	005		
Linkage Zone:	Black Hills	**Latitude:**	34.34290071	**Longitude:**	-112.102346
Observers:	Paul Beier, Emily Garding	**UTM X:**	398609.2734	**UTM Y:**	3800727.474
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Arcosanti

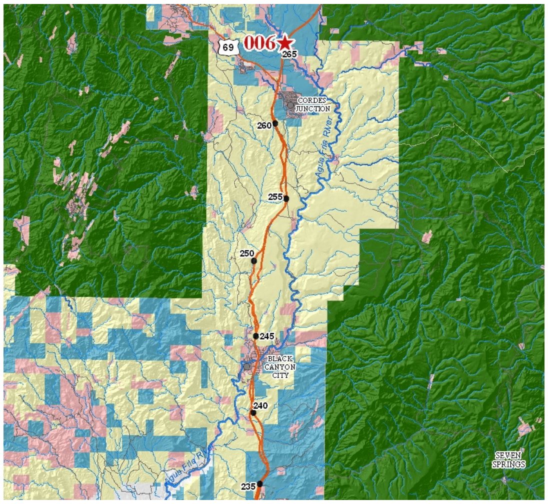
Site Photographs

Name: IMG_0102.jpg

Zoom: 1X

Linkage #:	37	**Waypoint #:**	006		
Linkage Zone:	Black Hills	**Latitude:**	34.36693112	**Longitude:**	-112.113602
Observers:	Paul Beier, Emily Garding	**UTM X:**	397603.195	**UTM Y:**	3803403.553
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Agua Fria River and I-17 at Milepost 265

Site Photographs

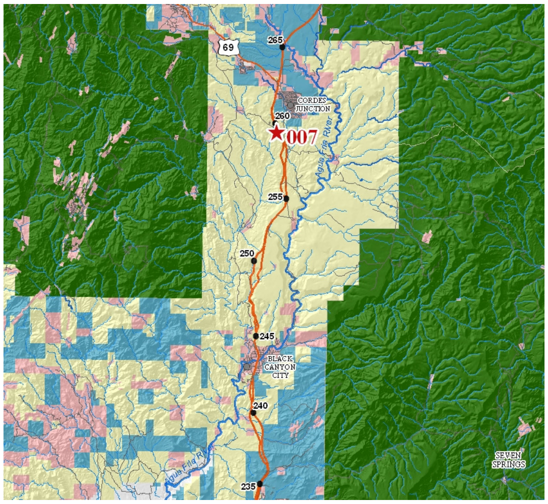
Name: IMG_0103.jpg

Zoom: 1X

Notes: Bridge over the river bed

Linkage #:	37	**Waypoint #:**	007		
Linkage Zone:	Black Hills	**Latitude:**	34.28397367	**Longitude:**	-112.122042
Observers:	Paul Beier, Emily Garding	**UTM X:**	396725.5165	**UTM Y:**	3794212.807
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Bloody Basin Traffic Interchange

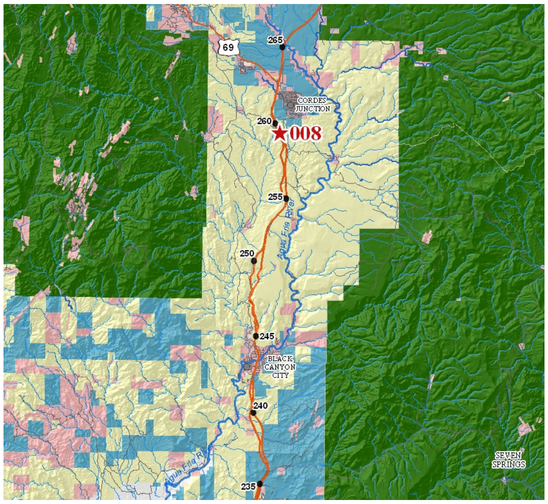
Site Photographs

Name: IMG_0104.jpg

Azimuth: 55 **Zoom:** 1X

Linkage #:	37	**Waypoint #:**	008		
Linkage Zone:	Black Hills	**Latitude:**	34.28303699	**Longitude:**	-112.118502
Observers:	Paul Beier, Emily Garding	**UTM X:**	397050.1871	**UTM Y:**	3794105.349
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Agua Fria National Monument

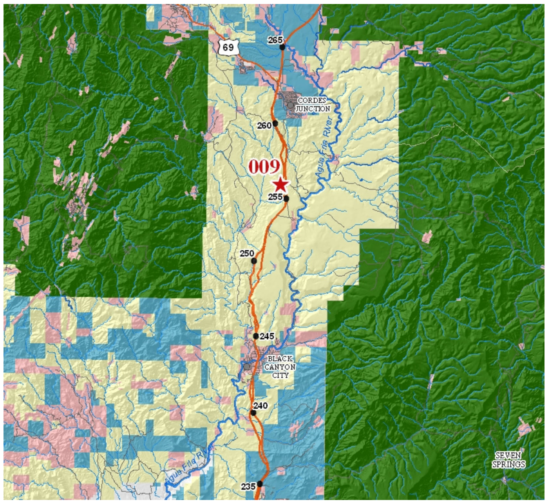
Site Photographs

Name: IMG_0105.jpg

Zoom: 1X

Linkage #:	37	**Waypoint #:**	009		
Linkage Zone:	Black Hills	**Latitude:**	34.23587093	**Longitude:**	-112.117273
Observers:	Paul Beier, Emily Garding	**UTM X:**	397105.863	**UTM Y:**	3788873.838
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



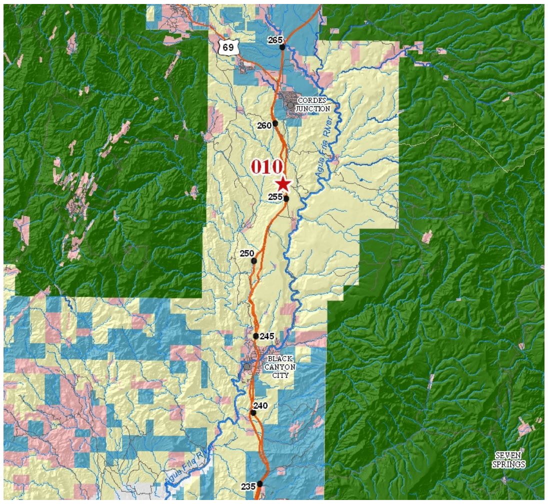
Waypoint Notes

Badger Point Traffic Interchange

Site Photographs

Linkage #:	37	**Waypoint #:**	010		
Linkage Zone:	Black Hills	**Latitude:**	34.23606321	**Longitude:**	-112.114314
Observers:	Paul Beier, Emily Garding	**UTM X:**	397378.6132	**UTM Y:**	3788892.174
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Badger Point Traffic Interchange

Site Photographs

Name: IMG_0108.jpg

Azimuth: 260 **Zoom:** 2X

Notes: The Southbound Land from between the divided lanes of I-17

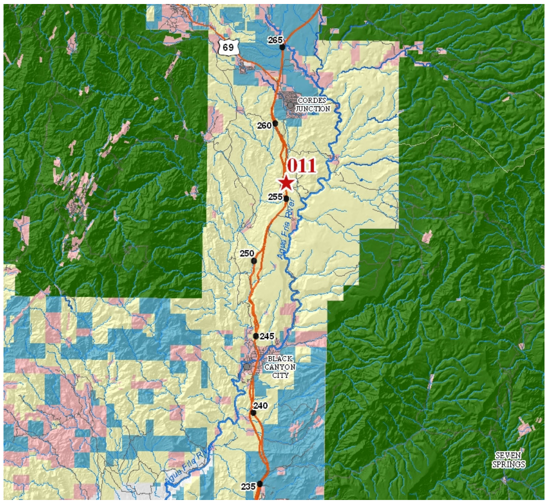
Name: IMG_0110.jpg

Azimuth: 80 **Zoom:** 3X

Notes: Northbound Lane from between divided lanes of I-17

Linkage #:	37	**Waypoint #:**	011		
Linkage Zone:	Black Hills	**Latitude:**	34.23717633	**Longitude:**	-112.110604
Observers:	Paul Beier, Emily Garding	**UTM X:**	397721.7279	**UTM Y:**	3789011.874
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Badger Point Traffic Interchange

Site Photographs

Name: IMG_0111.jpg

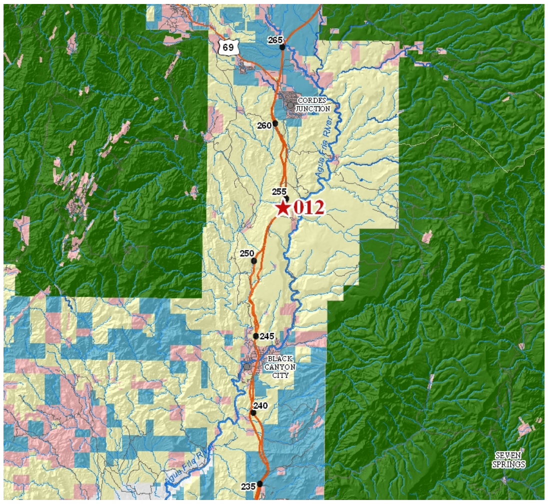
Azimuth: 275 **Zoom:** 1X

Notes: Pavement ends

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	012		
Linkage Zone:	Black Hills	**Latitude:**	34.21429985	**Longitude:**	-112.113809
Observers:	Paul Beier, Emily Garding	**UTM X:**	397398.7648	**UTM Y:**	3786478.329
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



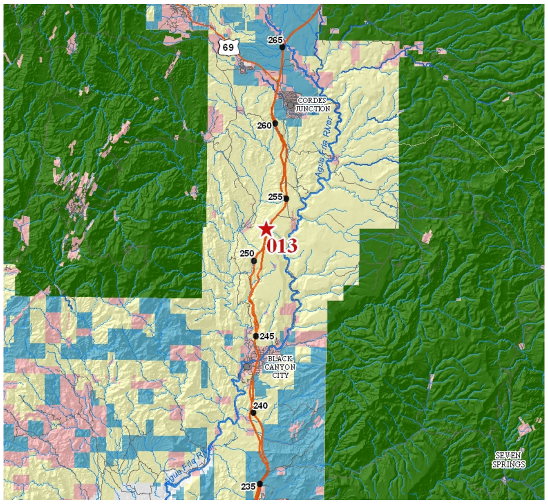
Waypoint Notes

Potential Crossing near Milepost 254

Site Photographs

Linkage #:	37	**Waypoint #:**	013		
Linkage Zone:	Black Hills	**Latitude:**	34.19403266	**Longitude:**	-112.132336
Observers:	Paul Beier, Emily Garding	**UTM X:**	395667.1036	**UTM Y:**	3784249.719
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Sunset Point Interchange

Site Photographs

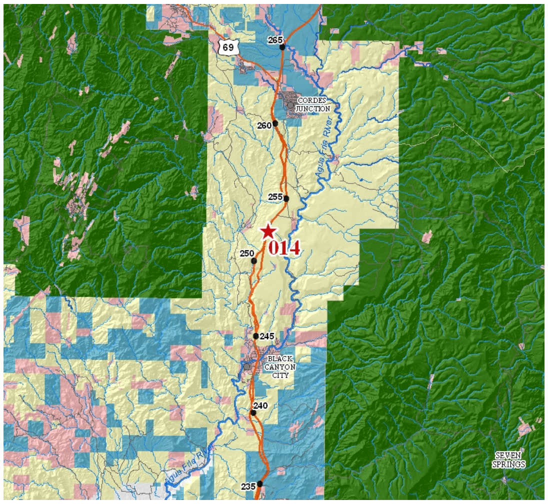
Name: IMG_0112.jpg

Zoom: 1X

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	014		
Linkage Zone:	Black Hills	**Latitude:**	34.19197356	**Longitude:**	-112.130168
Observers:	Paul Beier, Emily Garding	**UTM X:**	395864.2925	**UTM Y:**	3784019.17
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Sunset Point Interchange

Site Photographs

Name: IMG_0114.jpg

Azimuth: 340 **Zoom:** 4X

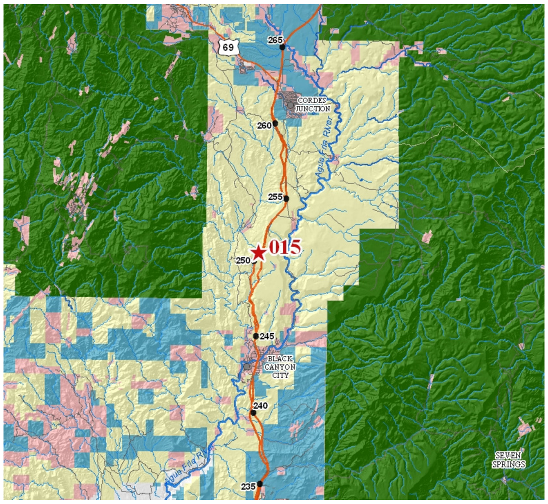
Name: IMG_0115.jpg

Azimuth: 110 **Zoom:** 110

Notes: Toward the Agua Fria River Canyon

Linkage #:	37	**Waypoint #:**	015		
Linkage Zone:	Black Hills	**Latitude:**	34.17225949	**Longitude:**	-112.140484
Observers:	Paul Beier, Emily Garding	**UTM X:**	394889.2735	**UTM Y:**	3781843.673
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Potential Crossing near Milepost 251

Site Photographs

Name: IMG_0116.jpg

Azimuth: 80 **Zoom:** 1X

Name: IMG_0117.jpg

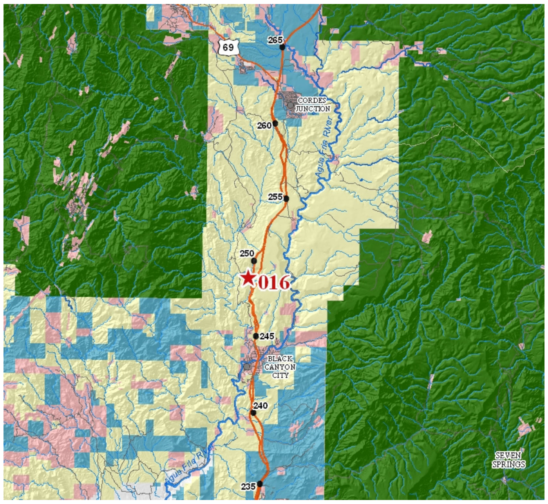
Notes: Existing Box Culvert

Name: IMG_0118.jpg

Notes: Existing Box Culvert

Linkage #:	37	**Waypoint #:**	016		
Linkage Zone:	Black Hills	**Latitude:**	34.14869486	**Longitude:**	-112.152233
Observers:	Paul Beier, Emily Garding	**UTM X:**	393776.9133	**UTM Y:**	3779242.779
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Site Photographs

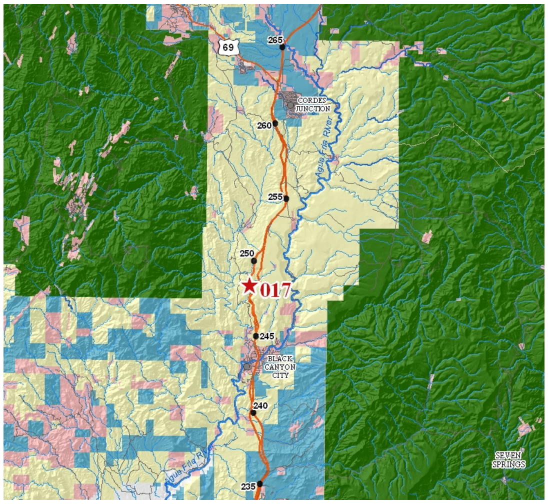
Name: IMG_0119.jpg

Azimuth: 40 **Zoom:** 3X

Notes: Potential Crossing near Milepost 249.5

Linkage #:	37	**Waypoint #:**	017		
Linkage Zone:	Black Hills	**Latitude:**	34.1415477	**Longitude:**	-112.150118
Observers:	Paul Beier, Emily Garding	**UTM X:**	393962.9258	**UTM Y:**	3778448.039
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Bumble Bee Traffic Interchange

Site Photographs

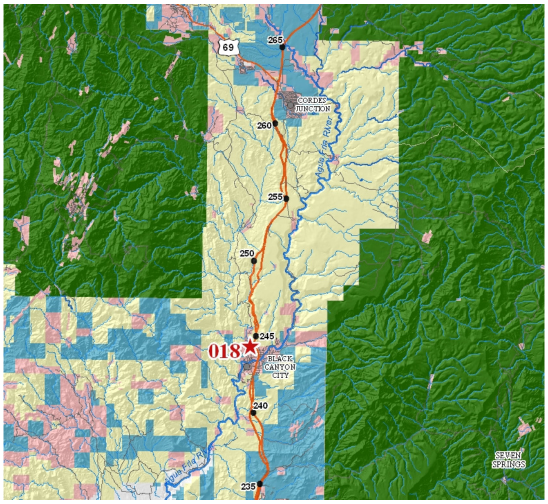
Name: IMG_0122.jpg

Zoom: 1X

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	018		
Linkage Zone:	Black Hills	**Latitude:**	34.08492627	**Longitude:**	-112.149127
Observers:	Paul Beier, Emily Garding	**UTM X:**	393983.6642	**UTM Y:**	3772168.35
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Black Canyon City

Site Photographs

Name: IMG_0123.jpg

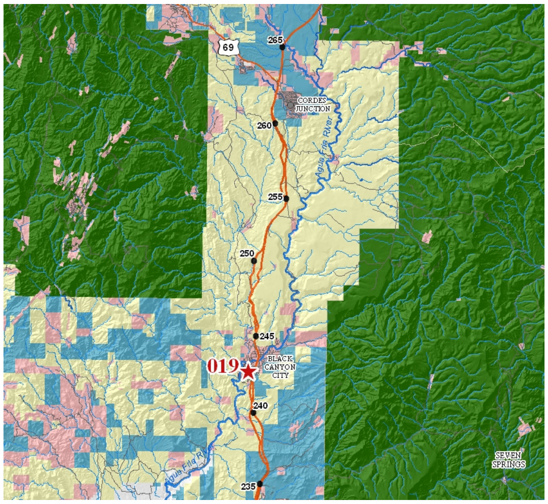
Azimuth: 330 **Zoom:** 1X

Notes: Residential development

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	019		
Linkage Zone:	Black Hills	**Latitude:**	34.06180889	**Longitude:**	-112.150439
Observers:	Paul Beier, Emily Garding	**UTM X:**	393833.7959	**UTM Y:**	3769606.277
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Black Canyon City

Site Photographs

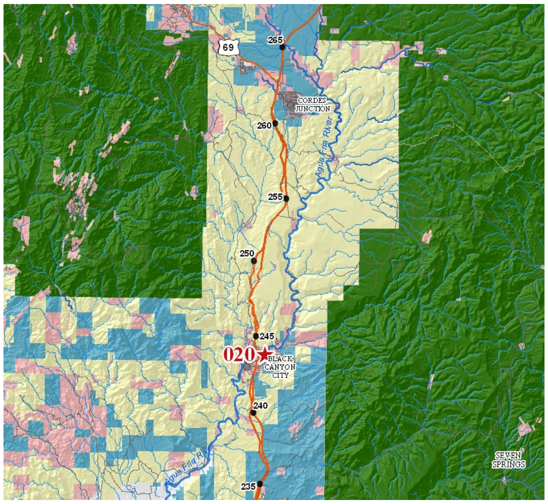
Name: IMG_0124.jpg

Azimuth: 10 **Zoom:** 4X

Notes: Overview of the community

Linkage #:	37	**Waypoint #:**	020		
Linkage Zone:	Black Hills	**Latitude:**	34.07757333	**Longitude:**	-112.132449
Observers:	Paul Beier, Emily Garding	**UTM X:**	395513.4339	**UTM Y:**	3771335.827
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

The Agua Fria River

Site Photographs

Name: IMG_0125.jpg

Azimuth: 215 **Zoom:** 1X

Notes: Downstream

Name: IMG_0126.jpg

Azimuth: 215 **Zoom:** 3X

Notes: Downstream

Name: IMG_0127.jpg

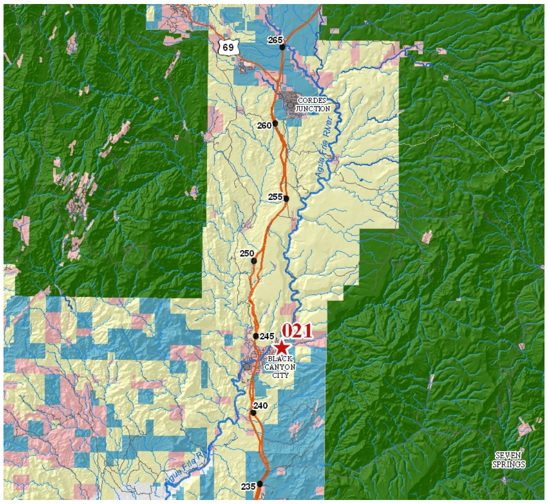
Azimuth: 35 **Zoom:** 1X

Notes: Upstream

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	021		
Linkage Zone:	Black Hills	**Latitude:**	34.08413325	**Longitude:**	-112.113445
Observers:	Paul Beier, Emily Garding	**UTM X:**	397274.8287	**UTM Y:**	3772043.981
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

The Agua Fria river

Site Photographs

Name: IMG_0129.jpg

Azimuth: 5 **Zoom:** 1X

Notes: Upstream

Name: IMG_0131.jpg

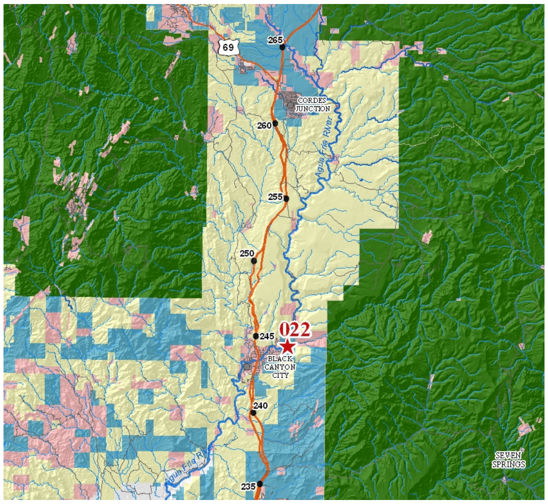
Azimuth: 195 **Zoom:** 1X

Notes: Downstream

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	022		
Linkage Zone:	Black Hills	**Latitude:**	34.08532139	**Longitude:**	-112.107441
Observers:	Paul Beier, Emily Garding	**UTM X:**	397830.2236	**UTM Y:**	3772169.713
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

The Agua Fria River

Site Photographs

Name: IMG_0132.jpg

Azimuth: 270 **Zoom:** 1X
Notes: Industrial development along the River

Name: IMG_0133.jpg

Azimuth: 100 **Zoom:** 1X
Notes: Upstream

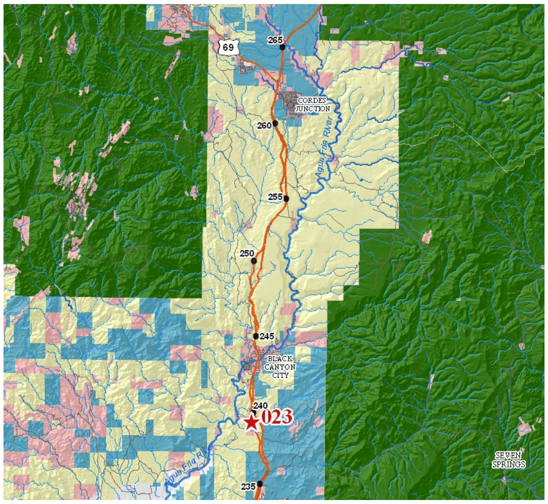
Name: IMG_0134.jpg

Azimuth: 100 **Zoom:** 3X
Notes: Upstream

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	023		
Linkage Zone:	Black Hills	**Latitude:**	34.01439146	**Longitude:**	-112.146687
Observers:	Paul Beier, Emily Garding	**UTM X:**	394121.1028	**UTM Y:**	3764344.41
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map

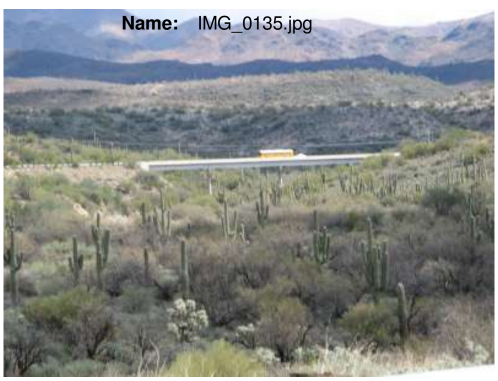


Waypoint Notes

Little Squaw Creek

Site Photographs

Name: IMG_0135.jpg



Azimuth: 100 **Zoom:** 6X

Notes: Northbound Lane

Name: IMG_0136.jpg

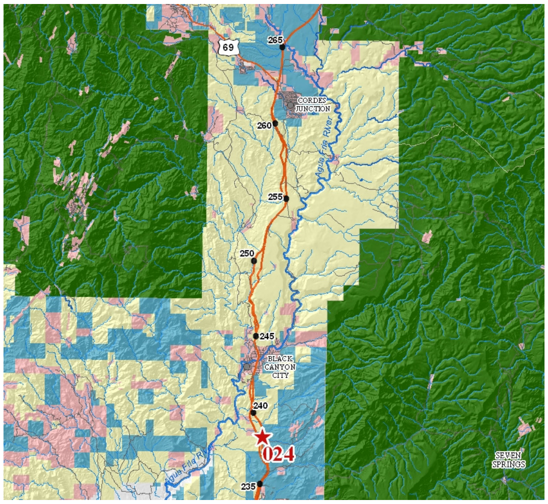
Azimuth: 100 **Zoom:** 1X

Notes: Northbound Lane

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	024		
Linkage Zone:	Black Hills	**Latitude:**	34.00085636	**Longitude:**	-112.13398
Observers:	Paul Beier, Emily Garding	**UTM X:**	395277.8996	**UTM Y:**	3762830.486
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map



Waypoint Notes

Site Photographs

Name: IMG_0137.jpg

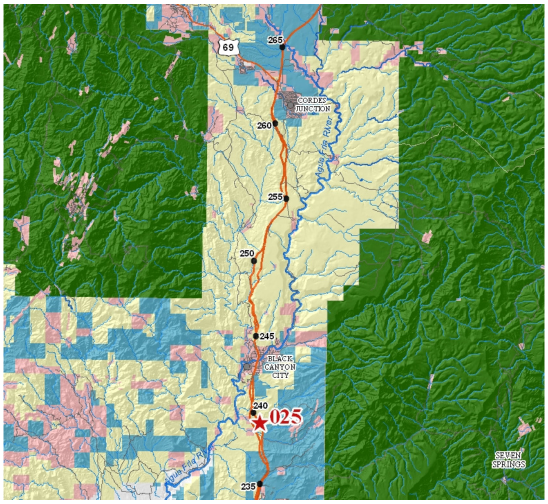
Azimuth: 290 **Zoom:** 6X

Notes: Southbound Lane

Appendix F: Database of Field Investigations

Linkage #:	37	**Waypoint #:**	025		
Linkage Zone:	Black Hills	**Latitude:**	34.01431586	**Longitude:**	-112.137457
Observers:	Paul Beier, Emily Garding	**UTM X:**	394973.2911	**UTM Y:**	3764326.522
Field Study Date:	2/20/2007	**Last Printed:**	7/12/2007		

Waypoint Map

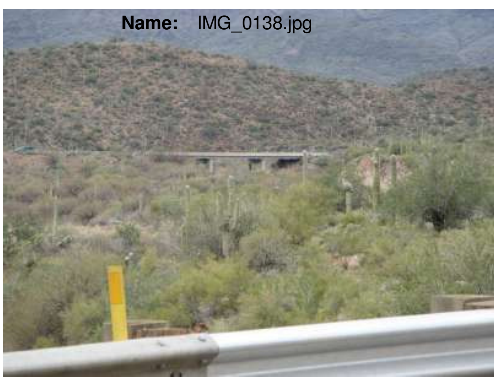


Waypoint Notes

Little Squaw Creek

Site Photographs

Name: IMG_0138.jpg



Zoom: 1X

Notes: Southbound Lane