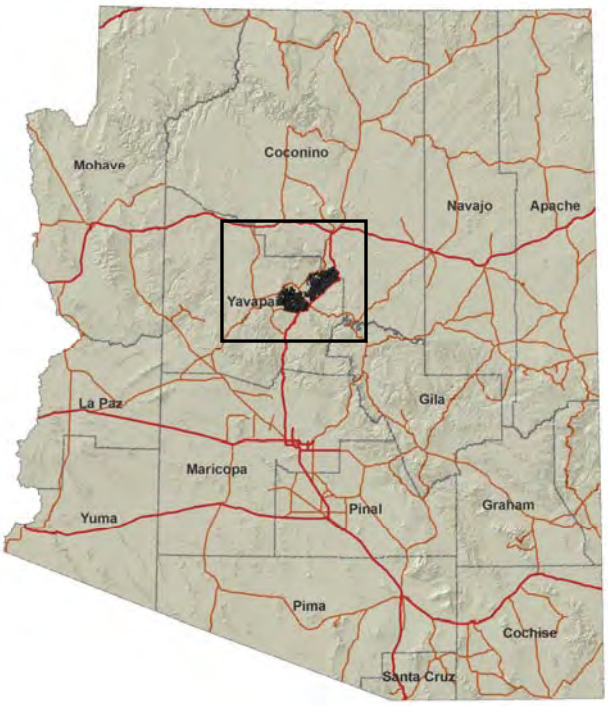
ARIZONA MISSING LINKAGES

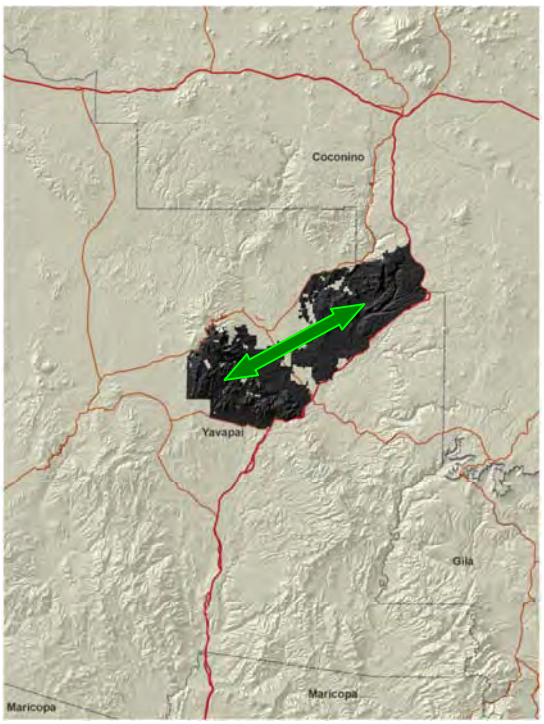
Munds Mountain – Black Hills Linkage Design

Paul Beier, Daniel Majka, Emily Garding
submitted September 2006
last revised March 13, 2007

NORTHERN ARIZONA UNIVERSITY

MUNDS MOUNTAIN-BLACK HILLS LINKAGE DESIGN





Acknowledgments
This project would not have been possible without the help of many individuals. We thank Chasa O'Brien, and Dr. Jason Marshal for parameterizing models for focal species and suggesting focal species. Catherine Wightman, Fenner Yarborough, Janet Lynn, Mylea Bayless, Andi Rogers, Mikele Painter, Valerie Horncastle, Matthew Johnson, Jeff Gagnon, Erica Nowak, Lee Luedeker, Allen Haden, Shaula Hedwall, and Martin Lawrence helped identify focal species and species experts. Robert Shantz provided photos for many of the species accounts. Shawn Newell, Jeff Jenness, Megan Friggens, and Matt Clark provided helpful advice on analyses and reviewed portions of the results.

Funding
This project was funded by a grant from Arizona Game and Fish Department to Northern Arizona University.

Recommended Citation
Beier, P., D. Majka, and E. Garding. 2006. Arizona Missing Linkages: Munds Mountain – Black Hills Linkage Design. Report to Arizona Game and Fish Department. School of Forestry, Northern Arizona University.

Table of Contents

TABLE OF CONTENTS ..... **I**

LIST OF TABLES & FIGURES ..... **III**

TERMINOLOGY ..... **V**

EXECUTIVE SUMMARY ..... **VI**

INTRODUCTION **1**

NATURE NEEDS ROOM TO MOVE 1
A STATEWIDE VISION 1
ECOLOGICAL SIGNIFICANCE OF THE MUNDS MOUNTAIN – BLACK HILLS LINKAGE 2
EXISTING CONSERVATION INVESTMENTS 3
THREATS TO CONNECTIVITY 4

LINKAGE DESIGN & RECOMMENDATIONS **9**

FOUR ROUTES AND A TWISTING RIPARIAN STRAND PROVIDE CONNECTIVITY ACROSS A DIVERSE LANDSCAPE 9
LAND OWNERSHIP, LAND COVER, AND TOPOGRAPHIC PATTERNS WITHIN THE LINKAGE DESIGN 10
IMPACTS OF ROADS ON WILDLIFE 14
Mitigation for Roads *14*
Existing Roads in the Linkage Design Area *18*
Existing Crossing Structures on Highway 89A and Highway 260 ..... *18*
Recommendations for Highway Crossing Structures *24*
IMPEDIMENTS TO STREAMS 26
Importance of Riparian Systems in the Southwest *26*
Stream Impediments in the Linkage Design Area *26*
Mitigating Stream Impediments *26*
URBAN DEVELOPMENT AS BARRIERS TO MOVEMENT 28
Urban Barriers in the Linkage Design Area *28*
Mitigation for Urban Barriers *29*

APPENDIX A: LINKAGE DESIGN METHODS **31**

FOCAL SPECIES SELECTION 31
HABITAT SUITABILITY MODELS 32
IDENTIFYING POTENTIAL BREEDING PATCHES & POTENTIAL POPULATION CORES 33
IDENTIFYING BIOLOGICALLY BEST CORRIDORS 34
PATCH CONFIGURATION ANALYSIS 35
MINIMUM LINKAGE WIDTH 36
FIELD INVESTIGATIONS 37

APPENDIX B: INDIVIDUAL SPECIES ANALYSES **38**

BLACK BEAR (*URSUS AMERICANUS*) 40
ELK (*CERVUS ELAPHUS*) 43
JAVELINA (*TAYASSU TAJACU*) 46
MOUNTAIN LION (*PUMA CONCOLOR*) 49
MULE DEER (*ODOCOILEUS HEMIONUS*) 52
PRONGHORN (*ANTILOCAPRA AMERICANA*) 55
RIPARIAN AND AQUATIC OBLIGATES 58

APPENDIX C: SUGGESTED FOCAL SPECIES NOT MODELED **61**

APPENDIX D: CREATION OF LINKAGE DESIGN **63**

APPENDIX E: DESCRIPTION OF LAND COVER CLASSES **64**

APPENDIX F: LITERATURE CITED **67**
APPENDIX G: DATABASE OF FIELD INVESTIGATIONS **72**

List of Tables & Figures

List of Tables

TABLE 1: FOCAL SPECIES SELECTED FOR MUNDS MOUNTAIN – BLACK HILLS LINKAGE..... VII
TABLE 2: APPROXIMATE LAND COVER FOUND WITHIN LINKAGE DESIGN.....10
TABLE 3: MAJOR TRANSPORTATION ROUTES IN THE LINKAGE DESIGN. 20
TABLE 4: HABITAT SUITABILITY SCORES AND FACTOR WEIGHTS FOR EACH SPECIES. SCORES RANGE FROM 1 (BEST) TO 10 (WORST), WITH 1-3 INDICATING OPTIMAL HABITAT, 4-5 SUBOPTIMAL BUT USABLE HABITAT, 6-7 OCCASIONALLY USED BUT NOT BREEDING HABITAT, AND 8-10 AVOIDED. 38

List of Figures

FIGURE 1: THE LINKAGE DESIGN BETWEEN THE MUNDS MOUNTAIN AND BLACK HILLS WILDLAND BLOCKS INCLUDES FOUR TERRESTRIAL STRANDS (LABELED A-D), AND A TWISTING RIPARIAN STRAND (LABELED E), EACH OF WHICH IS IMPORTANT TO DIFFERENT SPECIES..... VIII
FIGURE 2: LAND OWNERSHIP WITHIN THE LINKAGE PLANNING AREA.....5
FIGURE 3: LAND COVER WITHIN THE LINKAGE PLANNING AREA. 6
FIGURE 4: THE LINKAGE PLANNING AREA (CIRCLED) IS CONNECTED TO VAST STRETCHES OF NATIONAL FOREST LAND AND OTHER PUBLIC INVESTMENTS IN CONSERVATION. 7
FIGURE 5: BOTH SMALLER PUBLICLY-OWNED HOLDINGS AND LARGE WILDERNESS AREAS ADD TO THE IMPORTANCE OF MAINTAINING CONNECTIVITY WITHIN THE LINKAGE PLANNING AREA.....8
FIGURE 6: PROPERTY OWNERSHIP AND FIELD INVESTIGATION WAYPOINTS WITHIN LINKAGE DESIGN. THE ACCOMPANYING CD-ROM INCLUDES PHOTOGRAPHS TAKEN AT MOST WAYPOINTS. 11
FIGURE 7: LAND COVER WITHIN LINKAGE DESIGN.....12
FIGURE 8: TOPOGRAPHIC DIVERSITY ENCOMPASSED BY LINKAGE DESIGN: A) TOPOGRAPHIC POSITION, B) SLOPE, C) ASPECT.....13
FIGURE 9: CHARACTERISTICS WHICH MAKE SPECIES VULNERABLE TO THE THREE MAJOR DIRECT EFFECTS OF ROADS (FROM FORMAN ET AL. 2003). 15
FIGURE 10: POTENTIAL ROAD MITIGATIONS (FROM TOP TO BOTTOM) INCLUDE: HIGHWAY OVERPASSES, BRIDGES, CULVERTS, AND DRAINAGE PIPES. FENCING (LOWER RIGHT) SHOULD BE USED TO GUIDE ANIMALS INTO CROSSING STRUCTURES.....16
FIGURE 11: A LARGE BRIDGE SPANS BLACK CANYON ON HIGHWAY 260 IN STRAND B (WAYPOINT 008). 21
FIGURE 12: A SMALL BOX CULVERT CROSSES UNDER HIGHWAY 260 IN STRAND B (WAYPOINT 009).....21
FIGURE 13: A LARGE NEW BRIDGE CROSSES ALONG HWY 89 OVER SPRING CREEK IN STRAND B (WAYPOINT 010).....22
FIGURE 14: A LARGE BRIDGE SPANS WILBUR CANYON ON HIGHWAY 260 ½ MILE NORTH OF STRAND C (WAYPOINT 007).....22
FIGURE 15: A 4-SPAN CULVERT CROSSES UNDER HIGHWAY 260 ½ MILE SOUTH OF STRAND C (WAYPOINT 003).....23
FIGURE 16: A LARGE MULTISPAN BRIDGE CROSSES OVER CHERRY CREEK ON HIGHWAY 260 (WAYPOINT 011).....23
FIGURE 17: POTENTIAL LOCATIONS FOR BRIDGES IN THE EASTERNMOST STRAND OF THE LINKAGE DESIGN.....25
FIGURE 18: THE VERDE RIVER PROVIDES IMPORTANT RIPARIAN HABITAT IN THE LINKAGE PLANNING AREA (PHOTO TAKEN FROM WAYPOINT 005).....28
FIGURE 19: INDUSTRIAL PARK IN STRAND C (WAYPOINT 004).....29
FIGURE 20: FOUR HABITAT FACTORS USED TO CREATE HABITAT SUITABILITY MODELS. INPUTS INCLUDED VEGETATION, ELEVATION, TOPOGRAPHIC POSITION, AND DISTANCE FROM ROADS. 33
FIGURE 21: EXAMPLE MOVING WINDOW ANALYSIS WHICH CALCULATES THE AVERAGE HABITAT SUITABILITY SURROUNDING A PIXEL. A) ORIGINAL HABITAT SUITABILITY MODEL, B) 3X3-PIXEL MOVING WINDOW, C) 200M RADIUS MOVING WINDOW.....34
FIGURE 22: A) LANDSCAPE PERMEABILITY LAYER FOR ENTIRE LANDSCAPE, B) BIOLOGICALLY BEST CORRIDOR COMPOSED OF MOST PERMEABLE 10% OF LANDSCAPE. 36
FIGURE 23: MODELED HABITAT SUITABILITY OF BLACK BEAR. 41
FIGURE 24: POTENTIAL HABITAT PATCHES AND CORES FOR BLACK BEAR. 42
FIGURE 25: MODELED HABITAT SUITABILITY OF ELK. 44

FIGURE 26: POTENTIAL HABITAT PATCHES AND CORES FOR ELK. 45
FIGURE 27: MODELED HABITAT SUITABILITY OF JAVELINA. 47
FIGURE 28: POTENTIAL HABITAT PATCHES AND CORES FOR JAVELINA. 48
FIGURE 29: MODELED HABITAT SUITABILITY OF MOUNTAIN LION. 50
FIGURE 30: POTENTIAL HABITAT PATCHES AND CORES FOR MOUNTAIN LION. 51
FIGURE 31: MODELED HABITAT SUITABILITY OF MULE DEER. 53
FIGURE 32: POTENTIAL HABITAT PATCHES AND CORES FOR MULE DEER. 54
FIGURE 33: MODELED HABITAT SUITABILITY OF PRONGHORN, WITH UBBC. 56
FIGURE 34: POTENTIAL HABITAT PATCHES AND CORES FOR PRONGHORN, WITH UBBC. 57
FIGURE 35: IMPORTANT RIPARIAN HABITAT FOR FISH, HERPETOFAUNA, AND BIRDS ALONG THE VERDE RIVER AND TRIBUTARIES WAS INCORPORATED INTO THE LINKAGE DESIGN. 60
FIGURE 36: EDITS MADE TO UNION OF BIOLOGICALLY BEST CORRIDORS TO CREATE FINAL LINKAGE DESIGN. 63

Terminology

Key terminology used throughout the report includes:

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

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

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

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

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

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

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

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

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design corridors (Linkage Design) that will conserve and enhance wildlife movement between two large areas of USFS-administered wildlands between and near the towns of Clarkdale and Camp Verde, Arizona. Running north-south through this region, State Route 260 and future urban development present impediments to animal movement between the Black Hills, Mingus Mountain and the Woodchute Wilderness area to the west, and Munds Mountain and adjacent Forest Service lands to the east. These areas represent a large public investment in biological diversity, and this Linkage Design is a reasonable science-based approach to maintain the value of that investment.

To begin the process of designing this linkage, academic scientists, agency biologists, and conservation organizations identified 33 focal species that are sensitive to habitat loss and fragmentation, including 1 amphibian, 3 reptiles, 2 invertebrates, 5 birds, 7 fish, 5 plants, 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. black bear, mountain lion). Some species are habitat specialists (e.g. southwestern willow flycatcher), and others are reluctant to cross barriers such as freeways (e.g. elk, mule deer). Some species are rare and/or endangered (Arizona cliffrose, longfin dace), while others, like javelina, are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of highlands. Together, these 33 species cover a wide array of habitats and movement needs in the region, so that the linkage design should cover connectivity needs for other species as well.

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

The ecological, educational, recreational, and spiritual values of protected wildlands surrounding Clarkdale and Camp Verde are immense. Our Linkage Design represents an opportunity to protect a functional landscape-level connection. The cost of implementing this vision will be substantial—but reasonable in relation to the benefits and the existing public investments in protected wild habitat. If implemented, our plan would not only permit movement of individuals and genes between the Black Hills and Munds Mountain protected blocks, but should also conserve large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the US Forest Service,

Arizona State Parks, Bureau of Land Management, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and other conservancy lands.

Next Steps: This Linkage Design Plan is a science-based starting point for conservation actions. The plan can be used as a resource for regional land managers to understand their critical role in sustaining biodiversity and ecosystem processes. Relevant aspects of this plan can be folded into management plans of agencies managing public lands. The riparian strand of our linkage design largely overlaps the Verde River Greenway plan, and our linkage design reinforces the importance of that effort. 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 Munds Mountain – Black Hills Linkage.

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

* Species modeled in this report. 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 depend on limestone outcrops), or because the species probably can travel (e.g., by flying) across unsuitable habitat.
§ Species modeled as a group of "riparian obligate species."

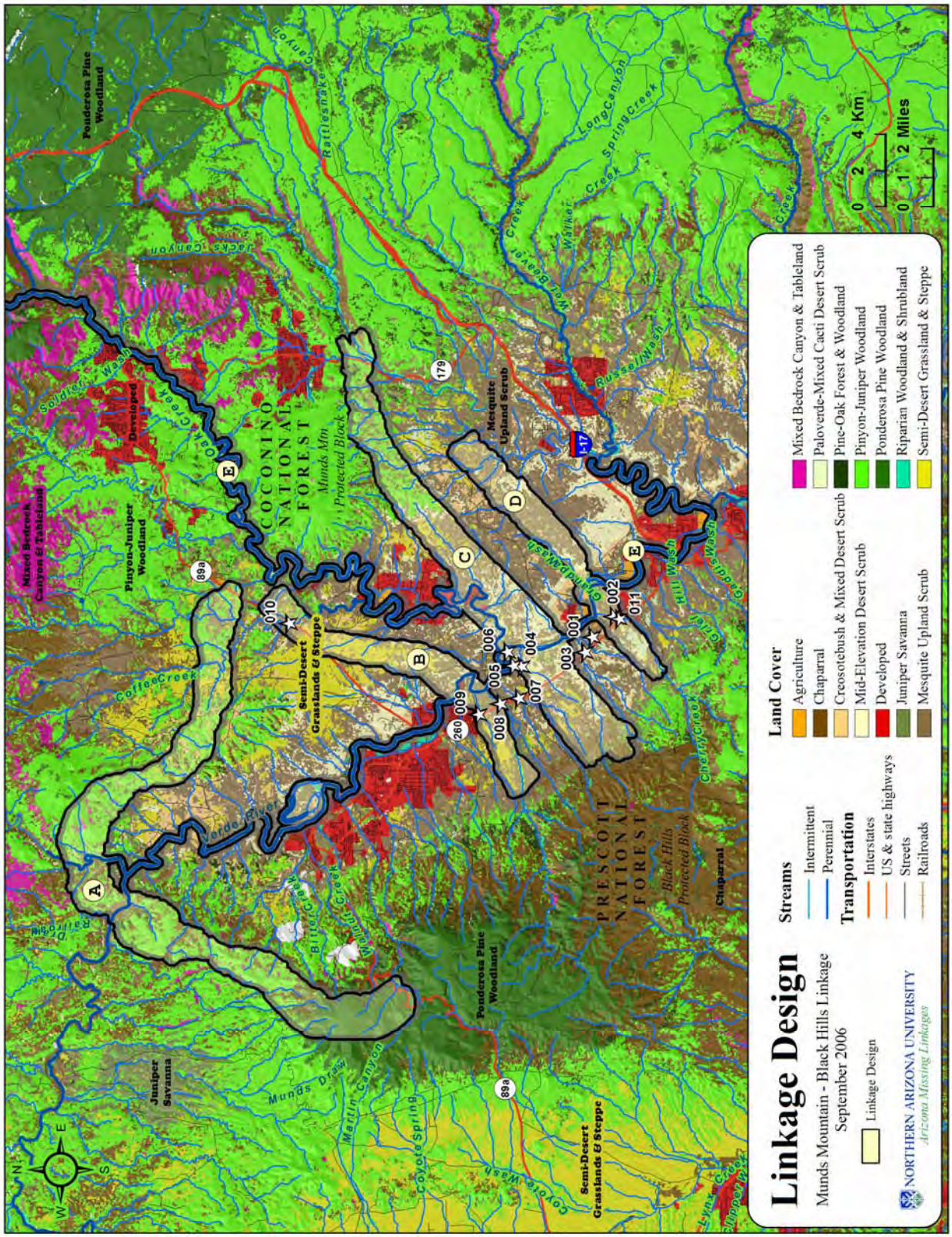


Figure 1: The Linkage Design between the Munds Mountain and Black Hills wildland blocks includes four terrestrial strands (labeled A-D), and a twisting riparian strand (labeled E), each of which is important to different species.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

The workshop was convened by the Arizona Wildlife Linkage Workgroup, a collaborative effort led by Arizona Game and Fish Department, Arizona Department of Transportation, Federal Highways Administration, US Forest Service, Bureau of Land Management, US Fish and Wildlife Service, Sky Island Alliance, Wildlands Project, and Northern Arizona University. The Workgroup prioritized the potential linkages based on biological importance and the conservation threats and opportunities in each area (AWLW 2006). Eight potential linkages emerged as priorities for more detailed planning. The Munds Mountain – Black Hills Linkage is one of these first 8 linkages.

Ecological Significance of the Munds Mountain – Black Hills Linkage

The Munds Mountain-Black Hills Linkage Planning Area lies within two ecoregions of central and southern Arizona and New Mexico. Most of the planning area, including the western Black Hills protected block, and portions of the eastern Munds Mountain protected block east of State Route 179, falls within the Apache Highlands Ecoregion. The Apache Highlands Ecoregion encompasses 30 million acres of central and southeastern Arizona, northern Sonora, northwestern Chihuahua, and southwestern New Mexico (Marshall et al 2004). This ecoregion spans 7,000 feet in elevation, providing varied ecosystems including sky island forests, grasslands, and riparian corridors (The Nature Conservancy 2006). This variation supports a high level of biological diversity, including 110 mammals, 265 birds, 75 reptiles, and 2000 plant species (TNC 2006).

East of State Route 179, the Linkage Planning Area transitions into the Arizona/New Mexico Mountains Ecoregion. This ecoregion encompasses 29 million acres of the mountains of Arizona and New Mexico above the Mogollon Rim. This ecoregion ranges from 4,500 to 12,600 ft in elevation, from pinyon-juniper dominated woodlands at lower elevations, to ponderosa pine at mid-elevations, and mixed conifer and aspen at high elevations. This range of forest of vegetation associations supports a wide array of species, with up to 200 species within the ecoregion considered rare (TNC 2006).

The Linkage Planning Area includes two protected blocks which are separated by State Highway 260 and a matrix of private and state land surrounding the towns of Clarkdale, Cottonwood, and Camp Verde (Figure 2). We have named these wildland blocks the Black Hills and the Munds Mountain blocks[1]. The Black Hills block is administered by the Prescott National Forest, while the Munds Mountain block is administered by the Coconino National Forest. Each protected blocks is contiguous with hundreds of thousands of acres of National Forest land. However, for this report, we wanted to focus on animal movement at a scale smaller than these two National Forests; therefore we used major highways, such as I-17 and State Route 89A, to delimit these two blocks in our analyses.

The western Black Hills protected block encompasses the Black Hills, which support drainages such as Ash Creek, Cherry Creek, Johnson Wash, and Little Hackberry Wash. Elevation within this block ranges from 3500 ft to 7825 ft , supporting ponderosa pine woodland, pinyon-juniper woodland, and chaparral vegetation associations (Figure 3).

The eastern Munds Mountain protected block encompasses the White Hills, House Mountain, Horse Mesa, Beaverhead Flat, Munds Mountain, and Schnebly Hill, which support drainages such as Dry Beaver Creek, Jacks Canyon, Oak Creek, Rattlesnake Canyon, Verde River, and Wet Beaver Creek. Within this protected block, elevation ranges from 3100 ft to 6850 ft, supporting a matrix of mesquite upland scrub, pinyon-juniper woodlands, chaparral, and ponderosa pine woodlands. Additionally, a unique geologic history has created the spectacular rock formations of the "Sedona Redrock Region."

Within the Linkage Planning Area, thousands of years of winter snowmelt and summer rains carved deep canyons into the Mogollon rim. This seasonal precipitation now sustains rich oases of riparian vegetation within the Verde River, Oak Creek, and Wet Beaver Creek. These perennial streams support a large number of species dependent on these aquatic and riparian systems, including black-necked garter snake, Mexican garter snake, narrow-headed garter snake, and lowland leopard frog, birds such as southwestern willow flycatcher and yellow-billed cuckoo, fish such as the longfin dace, desert sucker, roundtailed chub, speckled dace, spikedace, and Colorado pikeminnow, mammals such as beaver and river otter, and plants such as willow and cottonwood. Additionally, the Verde River is the only designated Wild and Scenic

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

River in Arizona. The Wild and Scenic Rivers Act of 1968 acknowledges that rivers "which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition."

The varied habitat types in the Linkage Planning Area support many animal species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service include Arizona cliffrose, southwestern willow flycatcher, yellow-billed cuckoo, bald eagle, razorback sucker, roundtail chub, spikedace, and the Mexican garter snake (USFWS 2005). The Linkage Design incorporates and connects habitat needed for these species. The Linkage Planning Area is also home to far-ranging mammals such as mule deer, elk, black bear, and mountain lion. These animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species such as javelina also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics.

Existing Conservation Investments

The proposed Munds Mountain-Black Hills Linkage is designed to protect and enhance the public investments in conservation in the two wildland blocks it would link. It is therefore important to understand the public investments at stake in each wildland block and within the Potential Linkage Area.

Public investments in the Linkage Planning Area consist of two USFS-administered wildland blocks which are part of Arizona's five contiguous National Forests along the Mogollon Rim, as well as a number of smaller state parks and national monuments (Figure 4, Figure 5). The 1.25 million acre Prescott National Forest and the 1.8 million acre Coconino National Forest are most directly affected by our linkage design, and are contiguous with 559,000 acres of the southern Kaibab National Forest, the 2.9 million acre Tonto National Forest, and the 2 million acre Apache-Sitgreaves National Forest. National monuments contiguous with these national forests include the 36,500 acre Wupatki National Monument, the 3,000 acre Sunset Crater National Monument, and the 1,900 acre Walnut Canyon National Monument (Figure 4). Together, these investments in public land total over 8.5 million acres in conservation.

The **Black Hills protected block** is administered by the Prescott National Forest, and consists of 92,100 acres of ponderosa pine woodlands, pinyon-juniper woodlands, and chaparral, between State Highway 89A to the north, and Interstate-17 to the south. Beyond these highways, this protected block is contiguous with 586,500 total acres of the Prescott National Forest to the north, and via 164,000 acres of BLM land to the south, is connected with another 616,000 acres of the Prescott National Forest. North of State Highway 89A the Woodchute Wilderness area is a 5,923-acre highland wilderness dominated by ponderosa pine.

The **Munds Mountain protected block** is administered by the Coconino National Forest, and consists of 92,400 acres of mesquite upland scrub, mid-elevation desert scrub, pinyon-juniper woodlands, and ponderosa pine woodlands. Multiple wilderness areas are adjacent and within this protected block. Munds Mountain Wilderness area spans 18,150 acres from Munds and Lee mountains to Jacks, Woods, and Rattlesnake Canyons. In addition to the pinyon-juniper woodlands and chaparral vegetation found in this wilderness, there are also substantial amounts of rugged red rock geological formations. These geologic formations dominate the 286-acre Red Rock State Park on Oak Creek. Between 76 acres of land cooperatively managed by AZGFD and the Northern Arizona Audubon Society is the Lower Oak Creek Important Bird Area (IBA), a stretch of Oak Creek important for riparian and migratory birds. Just northwest of the Munds Mountain protected block is Red Rock-Secret Wilderness area, containing 43,950 acres of cliffs, canyons and pinyon-juniper and ponderosa pine woodlands, and further west is the 56,000 acre Sycamore Canyon Wilderness.

In the Potential Linkage Area adjacent to the protected blocks are a number of small, but significant conservation investments (Figure 5) along the Verde River. Dead Horse Ranch State Park protects 423 acres, and is the anchor for a planned six-mile stretch of protected willow-cottonwood gallery forest along the Verde River known as the Verde River Greenway. At 70 acres, Tavasci Marsh is the largest freshwater marsh in Arizona outside of the Colorado River, and has been declared an Important Bird Area (IBA) by the Audubon Society. It supports many aquatic species, such as river otters, beaver, and numerous waterfowl. Adjacent to Tavasci Marsh is Peck's Lake, a now man-made impoundment which used to function as part of the Marsh. Between Dead Horse Ranch State Park and Tavasci Marsh is Tuzigoot National Monument, an 834 acre National Park Service holding along the Verde River which contains an ancient Sinaguan pueblo. The Verde River Greenway plan is in the process of expanding to include all of the Verde River between Clarkdale and Camp Verde.

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

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include State Highway 260, State Highway 89A, the Arizona Central Railroad, and expanding urban development in and near Cottonwood, Clarkdale, and Camp Verde. Additionally, introduced species such as green sunfish, smallmouth and largemouth bass, flathead catfish, and tamarisk threaten native wildlife within the linkage zone's important riparian corridor. These barriers inhibit wildlife movement between the Black Hills and Munds Mountain protected blocks.

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

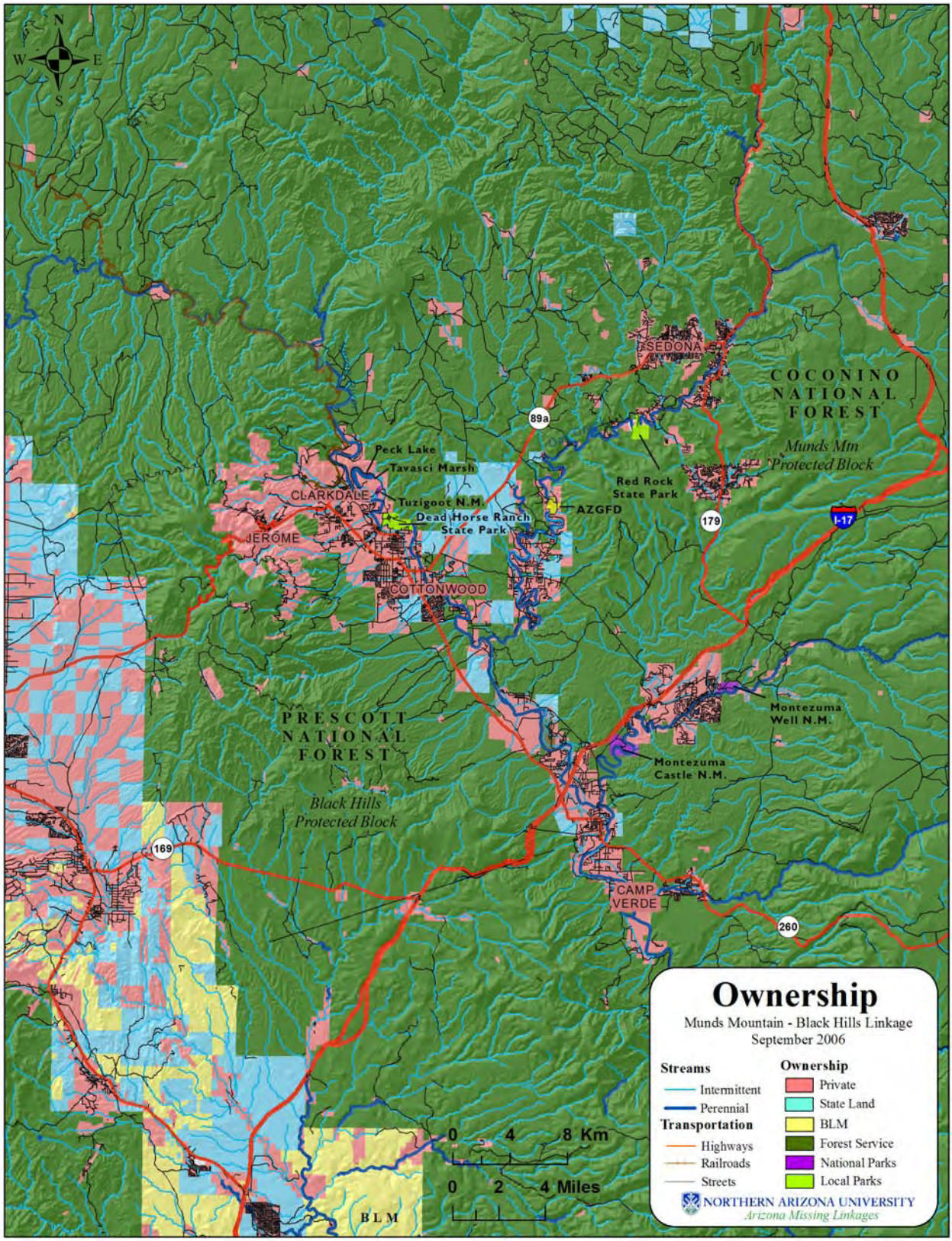


Figure 2: Land ownership within the Linkage Planning Area.

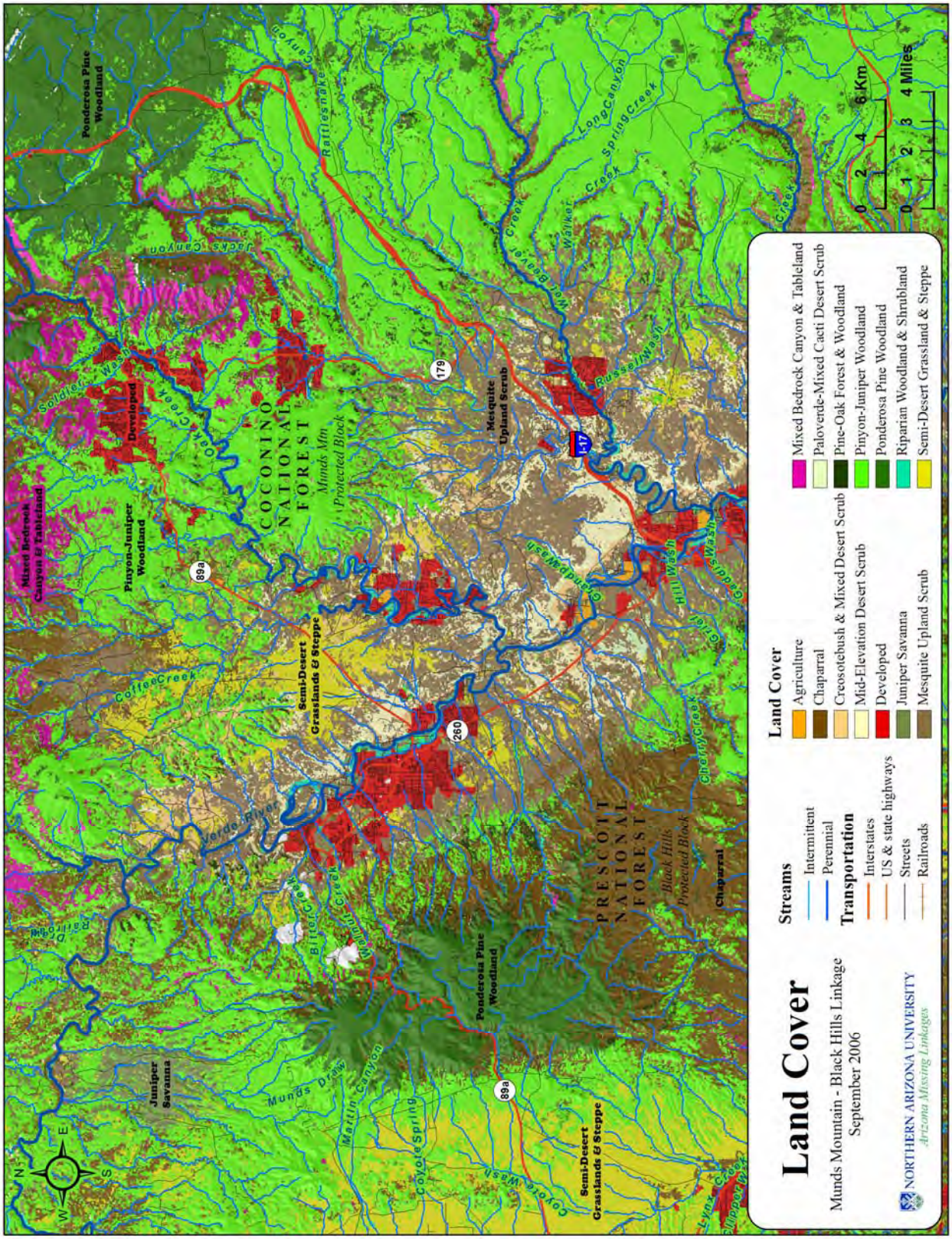


Figure 3: Land cover within the Linkage Planning Area.

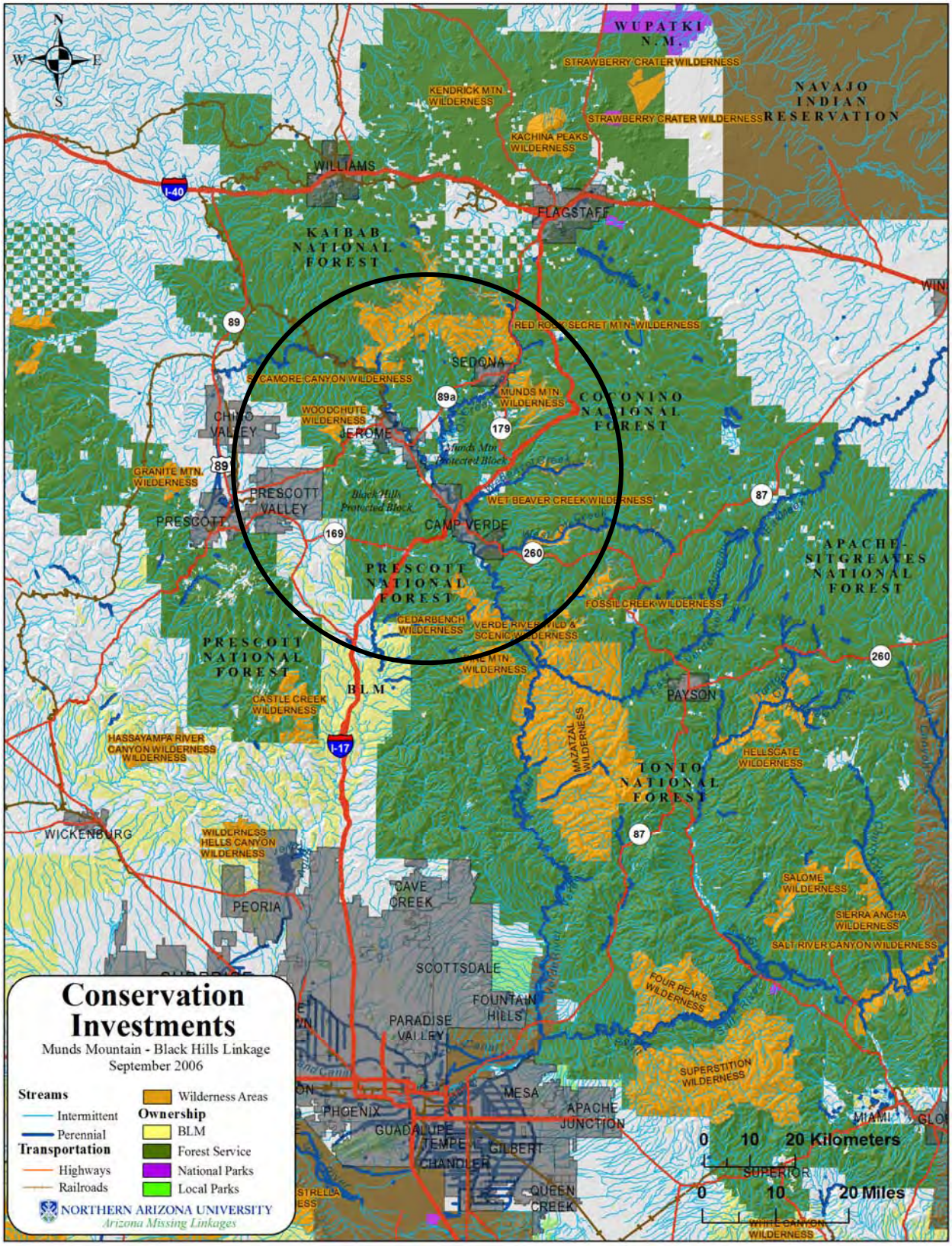


Figure 4: The Linkage Planning Area (circled) is connected to vast stretches of National Forest Land and other public investments in conservation.

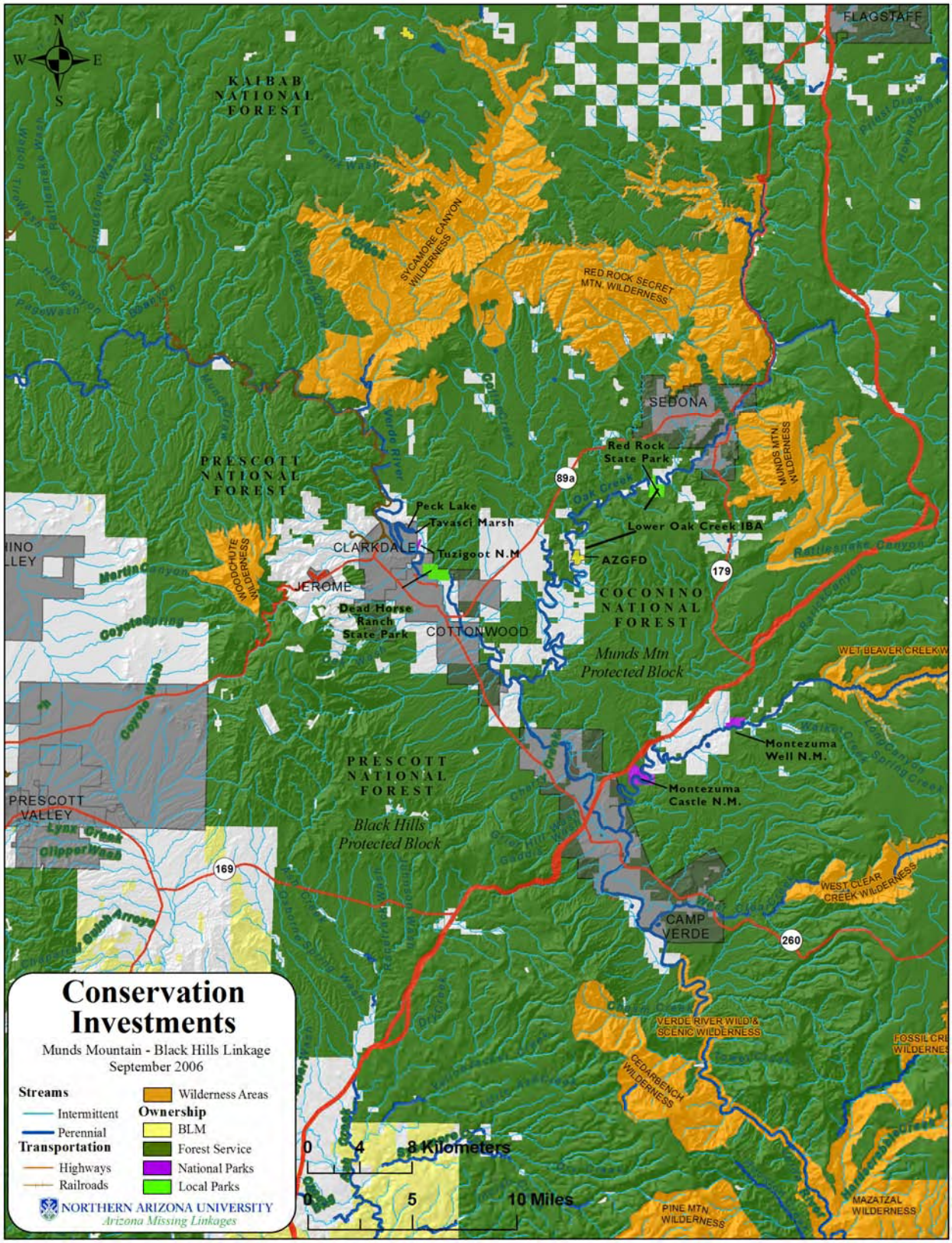


Figure 5: Both smaller publicly-owned holdings and large wilderness areas add to the importance of maintaining connectivity within the Linkage Planning Area.

Linkage Design & Recommendations

The final Linkage Design is composed of four strands which together provide habitat for movement and reproduction of wildlife between USFS-administered lands on either side of the Verde River. In this section, we describe the land cover and ownership patterns in the linkage design, and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Four Routes and a Twisting Riparian Strand Provide Connectivity Across a Diverse Landscape

The linkage design consists of four distinct terrestrial strands and one riparian strand, which together connect the Munds Mountain and Black Hills protected wildland blocks. We label these strands A through E from north to south and describe them in that order.

LINKAGE DESIGN GOALS

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

The northernmost strand of the linkage design (Strand A) is dominated by woodlands and forest, and provides live-in and pass-through habitat for species dependent on woodlands and/or rugged topography such as elk and mountain lions. Although this is the longest strand (41 km) and loops north into the Antelope Hills and the Sycamore Canyon Wilderness, it is almost entirely protected within Prescott and Coconino National Forests. It is and primarily composed of Pinyon-Juniper Woodlands (49%), Ponderosa Pine Woodlands (15%), Chaparral (14%), and Mesquite Upland Scrub (10%). It is the most topographically complex strand, with an average slope of 28% (Range: 0-160%, SD: 19.7), and roughly half (53%) of strand consists of steep slopes.

Strand B of the linkage design follows Black Canyon from the Black Hills to the Verde River, runs between Cottonwood and Clarkdale, and includes Sheepshead Canyon and a portion of Spring Creek. The strand is approximately 19 km long, and is primarily composed of Mesquite Upland Scrub (50%), Semi-Desert Grassland and Steppe (31%), and Mid-elevation Desert Scrub (4%). This strand has relatively little topographic complexity, with 80% of the area in flat to gentle (i.e., < 12%) slopes and an average slope of 7.3% (Range: 0-56.8%, SD: 6.6). Strand B provides live-in and pass-through habitat for species that use scrub and steppe habitats, including mule deer and mountain lion.

Strand C encompasses about 28 km of varied terrain and habitat, and serves species that reside in or travel through canyons, or upland shrub and woodland communities, such as black bear. In the Black Hills it includes much of Hayfield Draw and Wilbur Canyon, its central portion includes the confluence of the Verde River and Oak Creek, and in the east it extends to Jack's Canyon and Dry Beaver Creek. This strand is composed of Mesquite Upland Scrub (45%), Pinyon-Juniper Woodlands (18%), Mid-elevation Desert Scrub (15%), and Chaparral. This strand is made up of nearly equal parts flat to gentle slopes and steep slopes (45.3 and 44.6%, respectively), with an average slope of 14.8% (Range: 0-95%, SD: 1.9).

The 17-km Strand D follows Cherry Creek from the Black Hills to the Verde River, and Grandpa Wash east of the Verde River through the White Hills to Munds Mountain near Beaverhead Flat. This strand is made up primarily of Mesquite Upland Scrub (66%), blended with Mid-elevation Desert Scrub (12%),

Creosotebush-White Bursage Desert Scrub (7%), and Paloverde-Mixed Cacti Desert Scrub (6%). It provides densely vegetated desert habitats that species such as javelina prefer.

The Aquatic-Riparian Strand (Strand E) consists of nearly 15,000 acres of riverine environments and adjacent habitat on either side of the Verde River and its major tributaries including Sycamore Creek, Oak Creek, and Beaver Creek. Land covers include Mesquite Upland Scrub (30%), Riparian Woodlands and Shrublands (24%), and Pinyon-Juniper Woodlands (11%). This strand provides for species dependent on riparian or aquatic habitat, such as the southwestern willow flycatcher, yellow-billed cuckoo, river otters, beavers, three species of gartersnake, lowland leopard frogs, longfin dace, and bonytail chub.

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

The Linkage Design encompasses 69,630 acres (28,070 ha), of which 75% is National Forest land, 19% private land, 5% state trust land, 0.5% National Park Service land, 0.3% county land, and 0.2% Arizona Game and Fish land (Figure 6). Fifteen natural vegetation communities account for 96% of the land cover (Figure 7), barren lands account for 1.2%, and developed land accounts for approximately 2.8% of the linkage design (Table 2). Natural vegetation varies among linkage strands (above) and includes the major communities found in the adjoining protected blocks. Riparian vegetation accounts for 6.5% of the linkage design.

The Linkage Design captured a range of topographic diversity, providing for the present ecological needs of species, as well as creating a buffer against a potential shift in ecological communities due to future climate change. Within the Linkage Design, roughly 46% of the land is classified as gentle slopes, 39% is classified as steep slopes, and 15% is classified as either canyon bottom or ridgetop (Figure 8). All aspects are well represented in the linkage (Figure 8).

Table 2: Approximate land cover found within Linkage Design.

LAND COVER CATEGORY	ACRES	HECTARES	% OF TOTAL AREA
Evergreen Forest (30.5%)			
Mixed Conifer Forest and Woodland	16	7	< 0%
Pine Oak Forest and Woodland	1711	693	2.5%
Pinyon-Juniper Woodland	15709	6357	22.6%
Ponderosa Pine Woodland	3723	1507	5.4%
Grasslands-Herbaceous (7.2%)			
Juniper Savanna	309	125	0.4%
Semi-Desert Grassland and Steppe	4743	1920	6.8%
Scrub-Shrub (51.8%)			
Chaparral	5302	2146	7.6%
Creosotebush, Mixed Desert and Thorn Scrub	237	96	0.3%
Creosotebush-White Bursage Desert Scrub	1388	562	2.0%
Mesquite Upland Scrub	23469	9498	33.8%
Mid-elevation Desert Scrub	4285	1734	6.2%
Paloverde-Mixed Cacti Desert Scrub	1233	499	1.8%
Woody Wetland (6.5%)			
Open Water	126	51	0.2%
Riparian Mesquite Bosque	51	22	0.1%
Riparian Woodland and Shrubland	4276	1730	6.2%
Barren Lands (1.2%)			
Mixed Bedrock Canyon and Tableland	771	312	1.1%
Volcanic Rock Land and Cinder Land	46	19	0.1%
Developed and Agriculture (2.8%)			
Agriculture	224	91	0.3%
Medium-High Intensity Developed	1749	708	2.5%

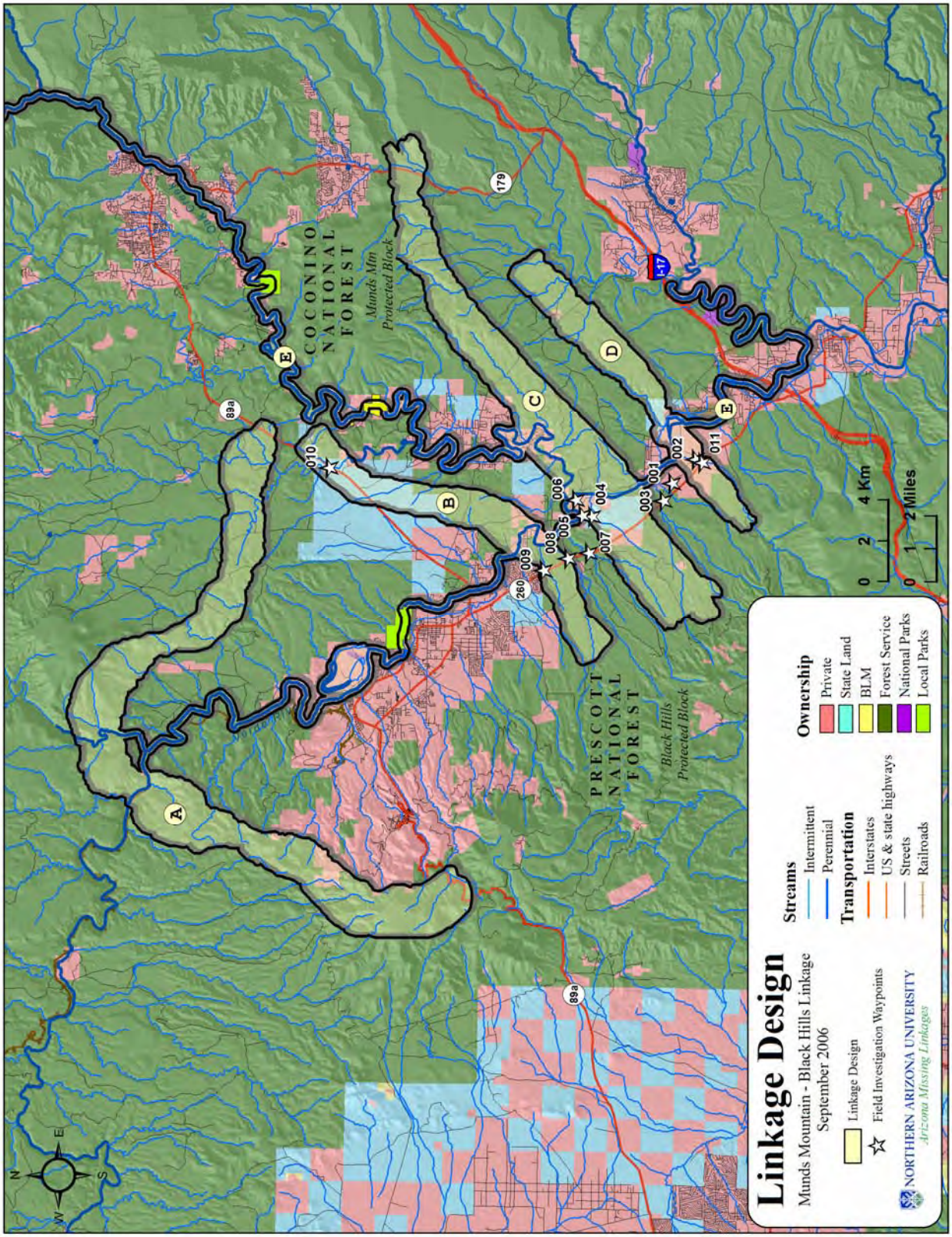


Figure 6: Property ownership and field investigation waypoints within Linkage Design. The accompanying CD-ROM includes photographs taken at most waypoints.

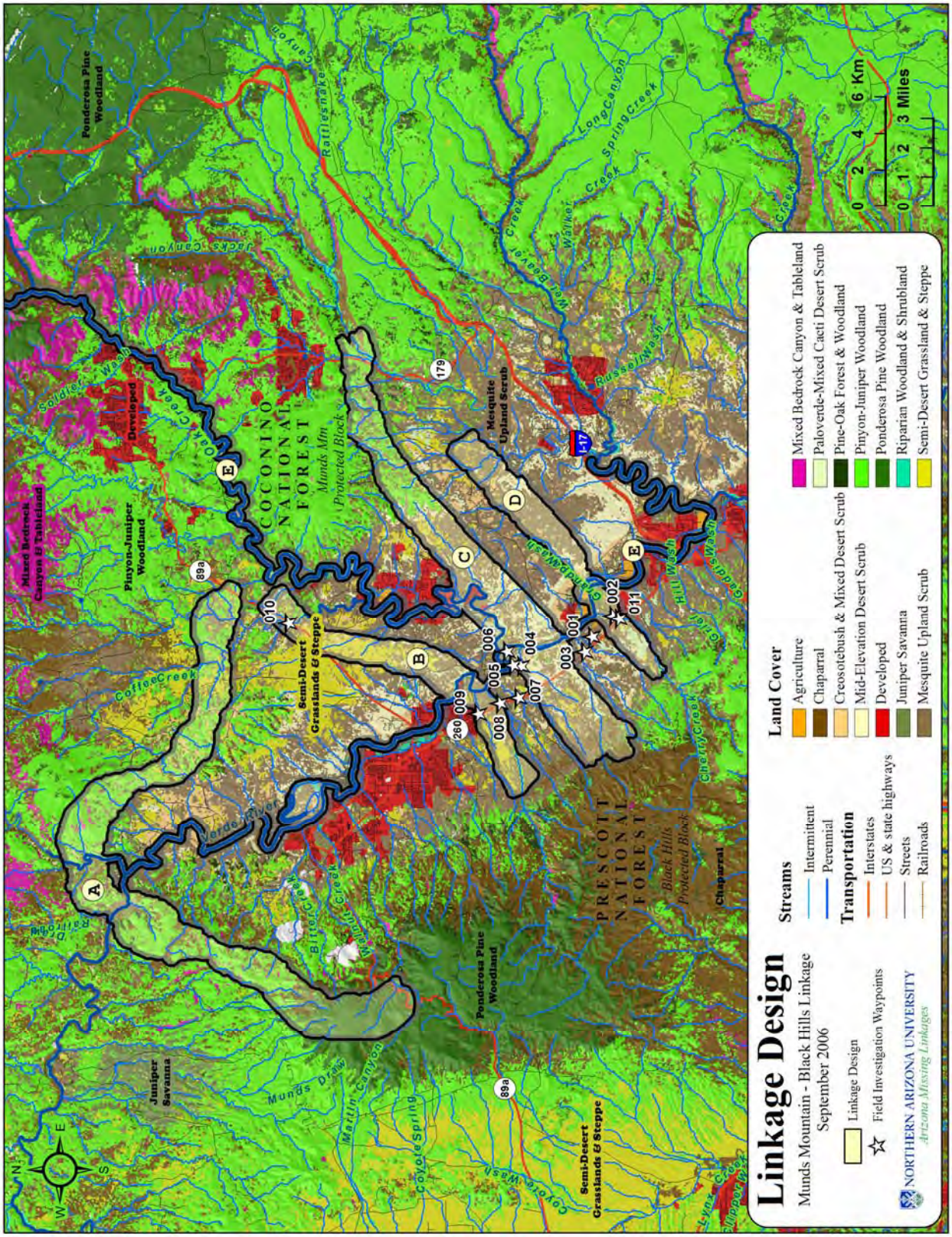


Figure 7: Land cover within Linkage Design.

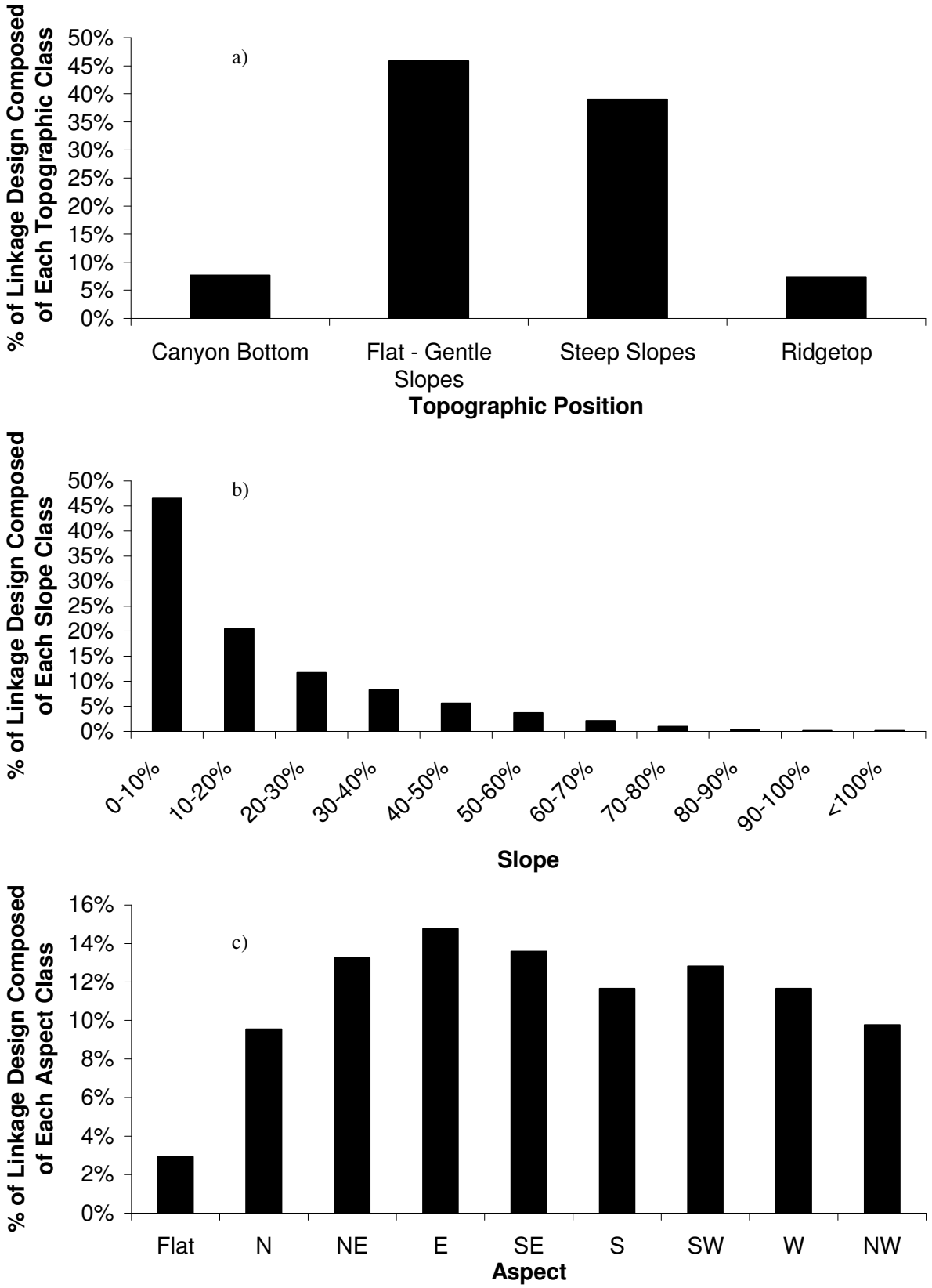


Figure 8: Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect.

Removing and Mitigating Barriers to Movement

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

While roads and fences impede animal movement, and the crossing structures we recommend are important, we remind the reader that crossing structures are only part of the overall linkage design. To restore and maintain connectivity between the Munds Mountain – Black Hills protected wildland blocks, it is essential to consider the *entire* linkage design, including conserving the land in the linkage. Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either protected block is lost.

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Figure 9). Direct **roadkill** affects most species, with severe documented impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the Iberian lynx (Forman et al. 2003). In a 4-year study of 15,000 km of road observations in Organ Pipe Cactus National Monument, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km per year killed due to vehicle collisions. Although we may not often think of roads as causing **habitat loss**, a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. Roads cause **habitat fragmentation** because they break large habitat areas into small, isolated habit patches which support few individuals; these small populations lose genetic diversity and are at risk of local extinction.

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

Mitigation for Roads

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

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. Approximately 50 overpasses have been built in the world, with only 6 of these occurring in North America (Forman et al. 2003). Overpasses are typically 30 to 50 m wide, but can be as large as 200

m wide. In Banff National Park, Alberta, grizzly bears, wolves, and all ungulates (including bighorn sheep, deer, elk, and moose) prefer overpasses to underpasses, while species such as mountain lions prefer underpasses (Clevenger & Waltho 2005).

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

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

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

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

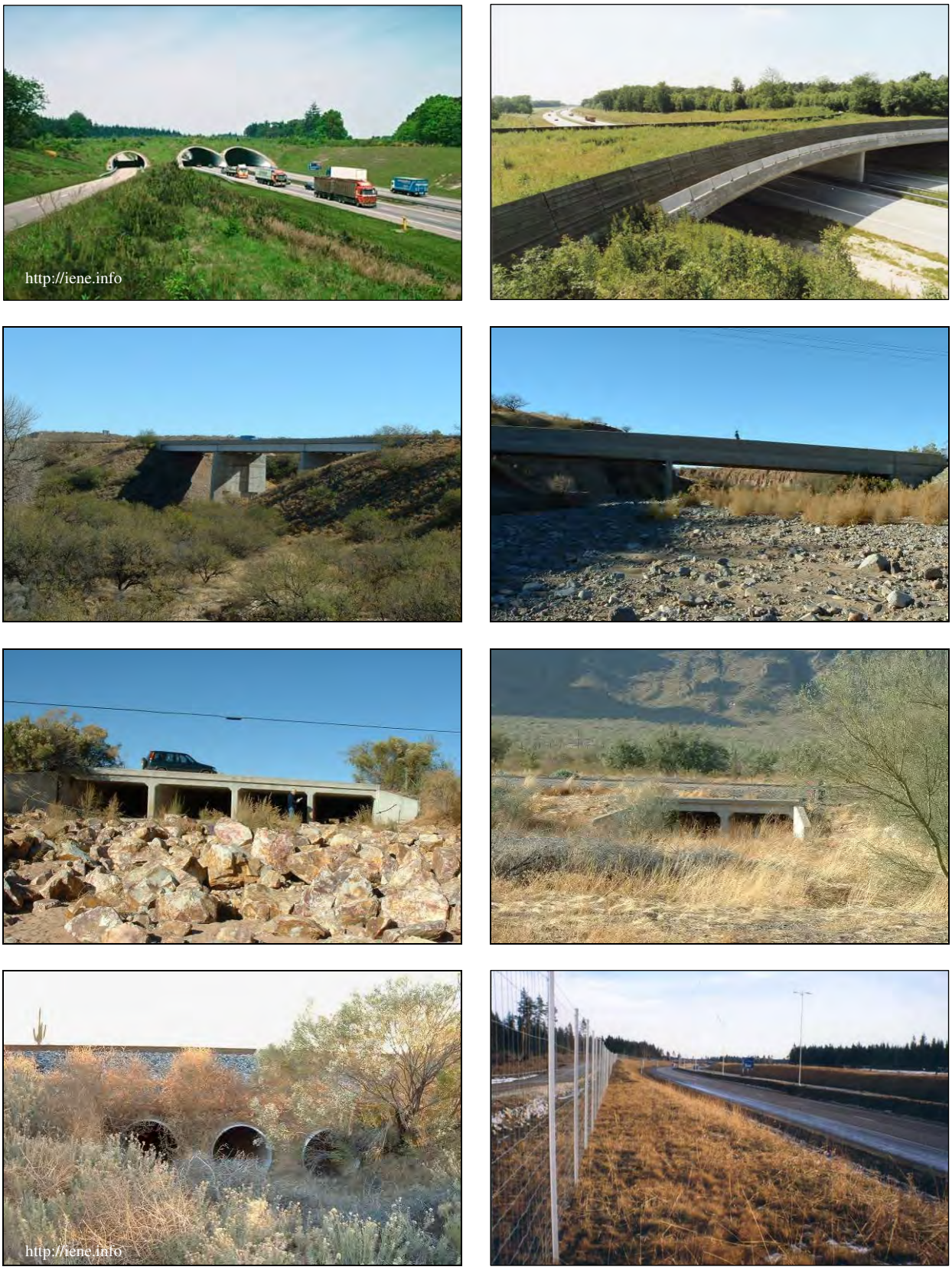


Figure 10: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (lower right) should be used to guide animals into crossing structures.

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

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

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

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

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

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

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

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

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

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

Existing Roads in the Linkage Design Area

There are approximately 274 km (170 mi) of transportation routes in the Linkage Design, including 44.3 km (27.5 mi) of highways. State Highway 260 runs northwest-southeast through three of four terrestrial linkage strands. State Highway 89A runs through two of the strands and effectively bisects the linkage area. These highways present the most important transportation threat to connecting the Black Hills and Munds Mountain protected areas. We conducted field investigations of many of these roads to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Existing Crossing Structures on Highway 89A and Highway 260

State Highway 260 runs northwest-southeast through three of the five linkage strands, while State Highway 89A runs through two of the strands, bisecting the linkage area. Because every animal moving between the Black Hills and Munds Mountain wildland blocks must traverse Highway 260, crossing structures along this highway are crucial to the success of the linkage design. We list existing crossing structures in the linkage design from north to south:

- We did not check for crossing structures where Highway 89A crosses the western portions of Strand A near Mingus Mountain. There were no large crossing structures where Highway 89A crosses the eastern end of Strand A.

- Highway 260 has two crossing structures in Strand B. A large multi-span bridge crosses Black Canyon (Figure 11) near the southern border of Strand B. About 1.3 km north of Black Canyon, a small box-culvert for a large unnamed draw below Black Mesa Tank crosses under Highway 260 (Figure 12). This single culvert is installed under a very large fill slope. At the northeast end of

Strand B, a new, large, open bridge at Spring Creek crosses under Highway 89A (Figure 13). This bridge is highly permeable for wildlife

- There are no large crossing structures where Highway 260 crosses Strand C. A large concrete bridge crosses over Wilbur Canyon ½ mile north of Strand C (Figure 14) and a 4-span culvert crosses over Hayfield Draw approximately ½ mile south of the strand (Figure 15).

- In Strand D of the linkage design, we identified one substantial crossing structure on AZ 260, namely a multi-span bridge at Cherry Creek (Figure 16).

- Although we did not systematically check for barriers along the 3 perennial streams (Verde River, Oak Creek, Spring Creek) in the Aquatic Strand, our observations suggest that aquatic connectivity in this strand is largely intact. Very few roads cross the Verde River, Oak Creek, or Spring Creek. There are large bridges where Highway 89 crosses the Verde River and where Cornville Road crosses Oak Creek. Small roads crossed Spring Creek and Oak Creek via fords that did not seem to present barriers to fish or amphibians. Although we did not search for all locations where dirt roads may have forded these perennial waters, we believe that there are few such crossings and that all are probably low-cost low-impact fords.

Table 3: Major transportation routes in the Linkage Design.

ROAD NAME	KILOMETERS	MILES
State Highway 89A	31.1	19.3
Arizona Central Railroad	11.7	7.3
Cornville Rd	6.7	4.1
State Highway 260	6.1	3.8
Forest Service 318 Rd	5.5	3.4
Forest 361 Rte	5.4	3.3
Page Springs Rd	5.1	3.2
Sycamore Canyon Rd	5.1	3.1
Ogden Ranch Rd	5.0	3.1
Old Hwy 279	3.6	2.2
Pecks Lake Rd North	3.2	2.0
Forest 761B Rd	3.1	1.9
Fr 258	2.7	1.7
Tissaw Rd	2.6	1.6
Thousand Trails Rd	2.6	1.6
Tuzigoot Rd	2.4	1.5
Cloverleaf Ranch Rd	2.4	1.5
Bill Gray Rd	2.3	1.4
Forest Road 9500A	2.3	1.4
Montezuma Castle Hwy	2.3	1.4
361A	2.3	1.4
Forest 120 Rd	2.3	1.4
Forest Rd 525A	2.2	1.3
I-17	2.0	1.3
Echo Canyon Rd	2.0	1.3
Middle Verde Rd	1.9	1.2
Tapco Rd	1.8	1.1
Willow Point Rd	1.8	1.1
State Highway 179	1.8	1.1
Highway 179	1.7	1.1
Chavez Ranch Rd	1.6	1.0
Sugarloaf Rd	1.6	1.0
East Comanche Dr	1.6	1.0
Named Roads < 1 mile long each	84.3	52.4
Unnamed Roads (mostly dirt roads)	54.1	33.6
Total length of transportation routes	274	170

Figure 11: A large bridge spans Black Canyon on Highway 260 in Strand B (waypoint 008).

Figure 12: A small box culvert crosses under Highway 260 in Strand B (waypoint 009).

Figure 13: A large new bridge crosses along Hwy 89 over Spring Creek in Strand B (waypoint 010).

Figure 14: A large bridge spans Wilbur Canyon on Highway 260 ½ mile north of Strand C (waypoint 007).

Figure 15: A 4-span culvert crosses under Highway 260 ½ mile south of Strand C (waypoint 003).

Figure 16: A large multispan bridge crosses over Cherry Creek on Highway 260 (waypoint 011).

Recommendations for Highway Crossing Structures

Fortunately, there appear to be adequate road crossing structures in the Aquatic Strand (although there may have been impediments we did not find). In the Aquatic Strand, mitigating road impacts may simply be a matter of conserving the connectivity these streams currently enjoy.

In the terrestrial linkage design strands, the existing crossing structures are not adequate to serve the movement needs of wildlife in strands A through D. Because every non-aquatic animal moving between the Black Hills and Munds Mountain protected wildland blocks must traverse at least one of the existing highways, crossing structures along these highways are crucial to success of the linkage design. We recommend upgrading the crossing structures described above as follows:

- In Strand A, the standard road recommendations (above) should be followed during any upgrading of Highway 89A on Mingus Mountain or in the Page Springs area. Because these portions of Highway 89A are entirely on Forest Service land, the road should be highly permeable throughout this area, not just within linkage strands. Because traffic volumes on this highway are currently low, upgraded crossing structures can await the next major road project.

- In strand B, there should be at least one additional large crossing structure on Highway 260 to complement the existing bridge at Black Canyon, and one pipe culvert every 300m for passage by small animals. Because we did not attempt to locate small pipe culverts, we do not know how many new ones will be needed. Only one intermittent wash crosses Highway 260 in this linkage strand, at MP 209.1 (Figure 12); the existing crossing structure at this location is a single cement box culvert installed in a very large fill slope, making this wash a good location for a larger, more open bridge usable by large animals.

- Build 2 new bridges on Highway 260 in strand C. This strand provides connectivity for large mammals such as black bear, mountain lion, and mule deer; however, existing crossing structures are not large or open enough to meet the needs of these species. One intermittent wash crosses Highway 260 in the middle of this linkage strand, at MP 211.8, providing 1 location where a bridge could be built. In addition to at least 1 bridge, one pipe culvert should be installed every 300m for passage by smaller animals.

- One large bridge already occurs over Cherry Creek in strand D. To complement this bridge, at least two mid-size culverts should be built to accommodate small to mid-sized animals.

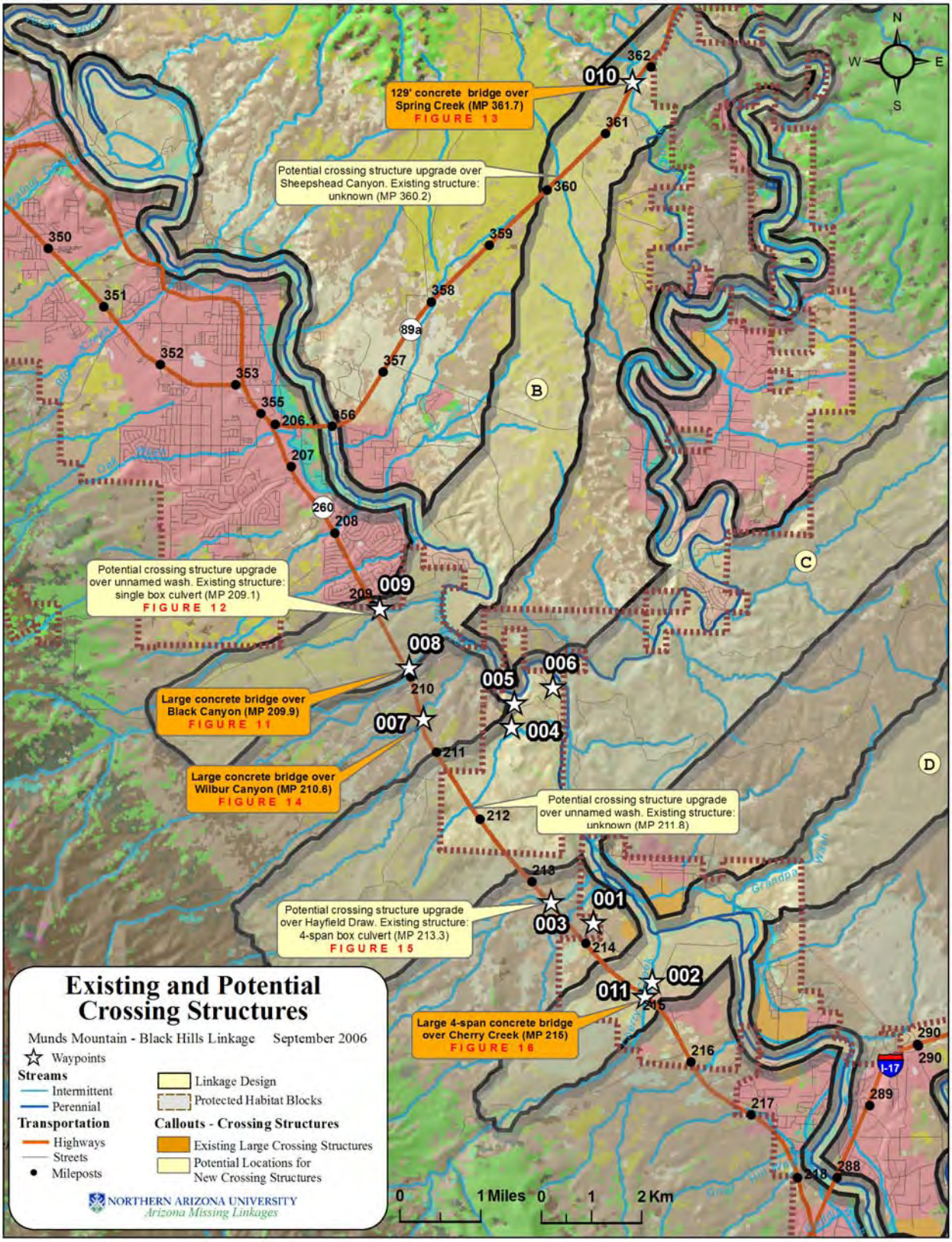


Figure 17: Potential locations for bridges in the easternmost strand of the Linkage Design.

Impediments to Streams

Importance of Riparian Systems in the Southwest

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

Stream Impediments in the Linkage Design Area

Most streams in Arizona have areas without surface water or riparian vegetation, and thus are naturally fragmented from the perspective of many wildlife species. But nearly all riparian systems in the Southwest also have been altered by human activity (Stromberg 2000) in ways that increase fragmentation. For animals associated with streams or riparian areas, impediments are presented by road crossings, vegetation clearing, livestock grazing, invasion of non-native species, accumulation of trash and pollutants in streambeds, farming in channels, and gravel mining. Groundwater pumping, upland development, water recharge basins, dams, and concrete structures to stabilize banks and channels change natural flow regimes, with negative impacts on 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 reeds, displace native species in some permanent waters.

The Verde River, Oak Creek, and Beaver Creek make up the perennial flowing waters in the linkage area (Figure 18). The rivers are fortunate to have no dams or diversions in or upstream from the linkage area, and few farms or road crossings in the floodplain. Furthermore, while there is growing urban development in the watershed within linkage area, most of the land immediately surrounding the Verde River is undeveloped. Therefore a functioning riparian ecosystem can be restored and maintained along the Verde, especially if action is taken promptly before conditions get worse.

Mitigating Stream Impediments

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

1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency, and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).
   - Urban development contributes to a "flashier" (more flood-prone) system. Check dams and settling basins should be required in urban areas within the Verde 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). Cottonwoods and willows require 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 restore riparian communities, however some exotics are persistent and significant benefits can accrue from control efforts that fall short of full eradication (Stromberg 2000, Savage 2004, D'Antonio and Meyerson 2002). Elimination of unnatural perennial surface pools can eradicate water-dependent invasives like bullfrogs, crayfish, and mosquitofish.

6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.

7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. OHV use should be restricted in the buffer zone because it disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

Figure 18: The Verde River provides important riparian habitat in the Linkage Planning Area (photo taken from waypoint 005).

Urban Development as Barriers to Movement

Urban and industrial development, unlike roads, creates barriers to movement which cannot easily be removed, restored, or otherwise mitigated. Most large carnivores, small mammals, and reptiles cannot occupy these areas for a significant period of time, although several species of lizards or small mammals may occasionally occupy residential areas. While mapped urban and agricultural areas only accounted for 2.8% of the land cover, development may increase rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

At both protected blocks, Strand A adjoins Highway 89a near existing communities. However, the vast majority of this strand is free of urban barriers. Each of the remaining four strands border residential and/or industrial areas. While some developed areas may not be densely populated, unregulated expansion could easily result in impeding wildlife movement between protected blocks (Figure 19).

The riparian corridor that buffers the Verde River is flanked by Clarkdale, Cottonwood, and smaller communities to the south. Strand B borders Cottonwood as well. Strand C and the adjacent riparian corridor along Oak Creek traverse an array of developed lands. Strand D is situated between small developments north of I-17.

The biologically best corridors strands for mule deer, black bear, javelina, and riparian obligates, encompassed by these strands, could easily be severed by future developments. Due to the importance

and relative uncommonness of riverine environments in the state, it is especially important to prevent future urban growth in the Verde River Valley and its major tributaries in the riparian strand, including Sycamore, Oak, and Beaver Creeks.

The ASLD land in Strands B, C, and D, and in the Aquatic Strand, should be targeted for conservation, and should not be sold for conversion to urban uses. Public and private groups will need to develop cooperative efforts with private landowners, or purchase development rights, to prevent urbanization of the private land in these strands. Existing collaborative efforts such as the Verde River Greenway and the Lower Oak Creek Important Bird Area should be strongly supported. They provide a model for conservation in other areas as well.

Figure 19: Industrial Park in Strand C (waypoint 004).

Mitigation for Urban Barriers

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

1) Encourage conservation easements and land acquisition with willing land owners in the Linkage Design to protect important habitat.
2) Develop a public education campaign to inform those living and working within the linkage area about the local wildlife and the importance of maintaining ecological connectivity.
3) Encourage homeowners to focus outside lighting on their houses only, and never out into the linkage area.
4) Ensure that all domestic pets are kept indoors or in fenced areas.
5) Reduce vehicle traffic speeds in sensitive locations.

6) Discourage the conversion of natural areas within the Linkage Design into residential areas. Where development is permitted, encourage small building footprints on large (> 10-acre) parcels. It is especially important to prevent future urban growth in the Verde River valley and its major tributaries such as Oak Creek.
7) Encourage the use of wildlife-friendly fencing.
8) Discourage the killing of 'threat' species such as rattlesnakes.

Appendix A: Linkage Design Methods

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

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

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

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 35 species (Table 1) that had one or more of the following characteristics:

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

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

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

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

Habitat Suitability Models

We created habitat suitability models (Appendix B) for each species by estimating how the species responded to four habitat factors that were mapped at a 30x30 m level of resolution (Figure 20):

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

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

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

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

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

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

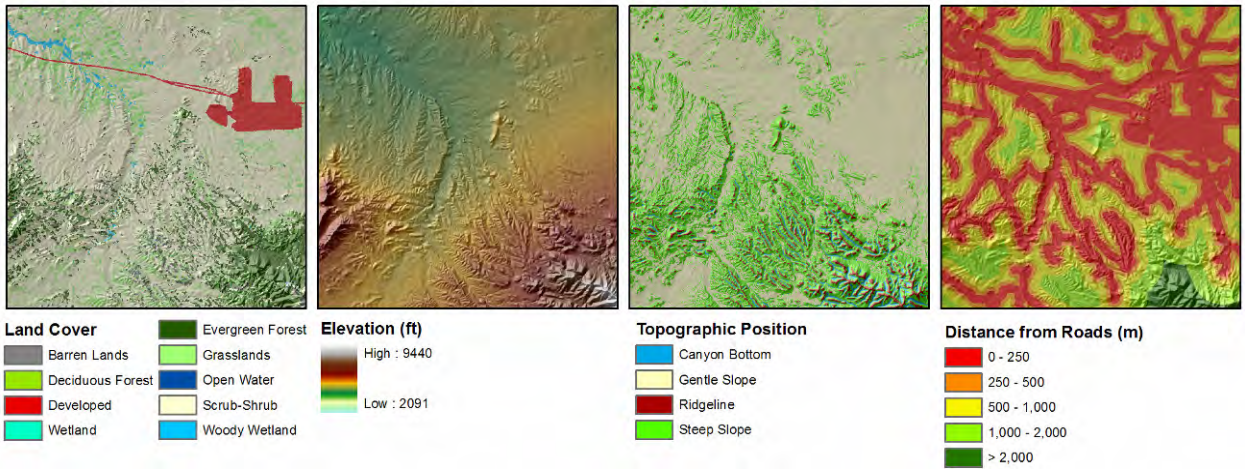


Figure 20: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

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 21). We averaged habitat suitability within a 3x3-pixel neighborhood (0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[5]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) into polygons that represented potential breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

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

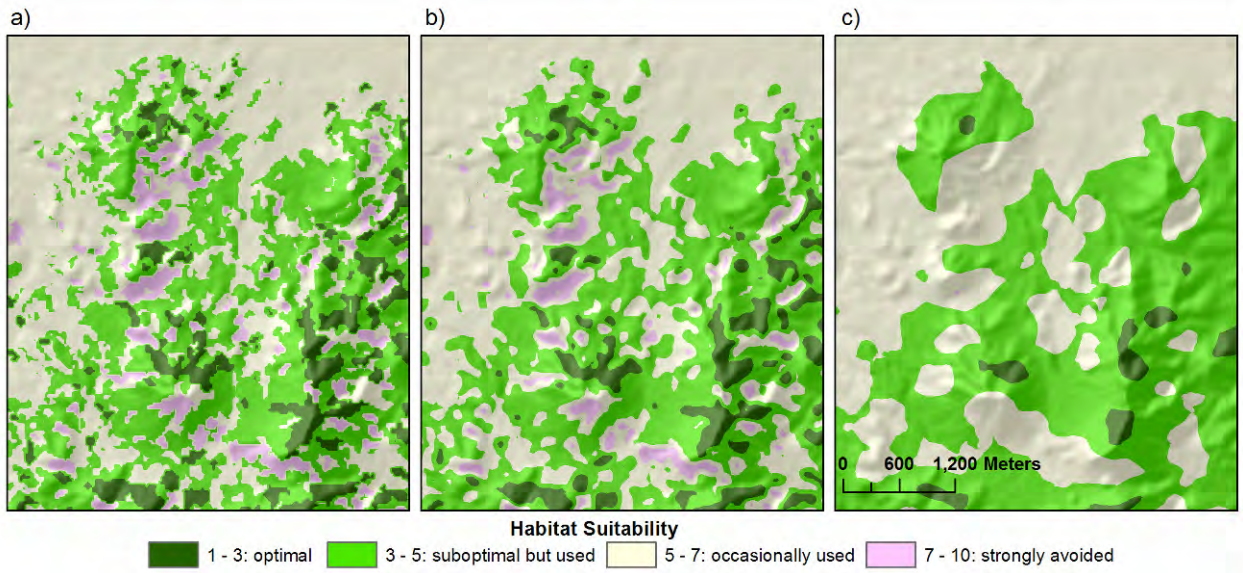


Figure 21: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window.

Identifying Biologically Best Corridors

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

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

The two protected wildland blocks are separated mainly by Highway 260 (Figure 2).The close proximity of the blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[7]. A BBC drawn in this way has 2 problems: (1) It could be unrealistic (previous footnote). (2) It could serve small wildlife populations near the road while failing to serve much larger populations in the rest of the protected wildland block. To address these issues, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel to each other, and were set back at least 1 mile from any existing highway or any new or potential urban area. Thus for purposes of BBC analyses, we redefined the wildland blocks in such that the Black Hills protected block was roughly 17

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

km (10.6 mi) from the Munds Mountain protected block.

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[8]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one protected wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd protected wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 500 m (Figure 22). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

Patch Configuration Analysis

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

[8] Levey et al. (2005) provide evidence that animals make movement decisions based on habitat suitability.
[9] Dispersal distance is how far an animal moves from its birthplace to its adult home range. We used dispersal distances reported by the species expert, or in published literature. In some cases, we used dispersal distance for a closely-related species.

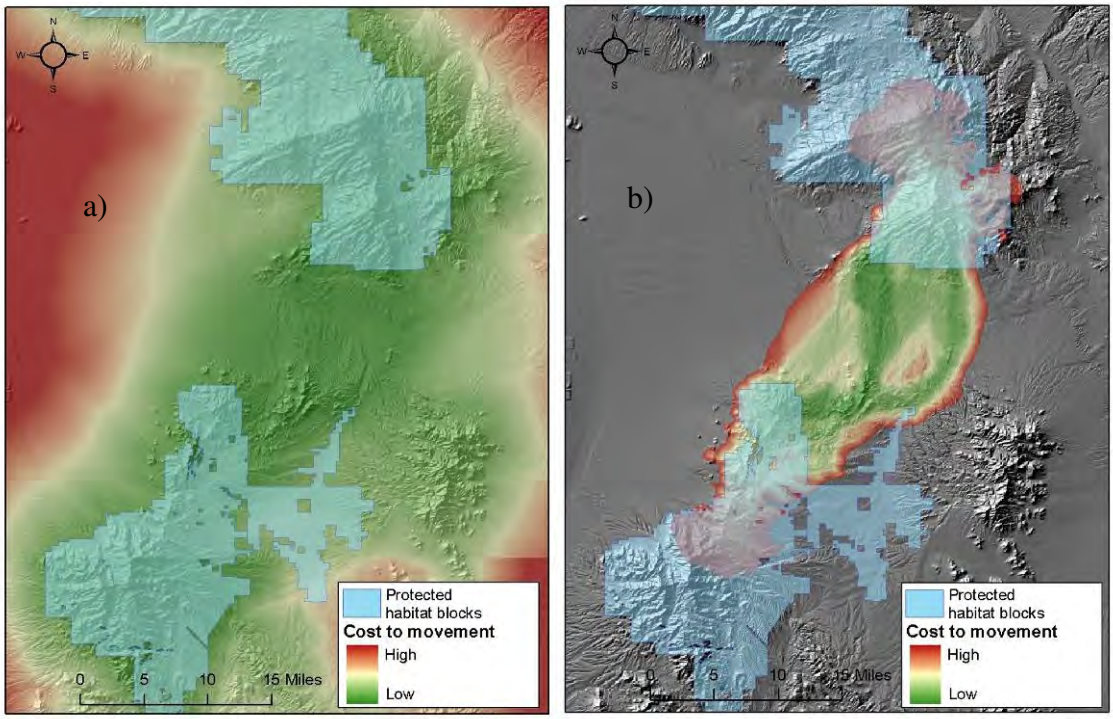


Figure 22: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

Minimum Linkage Width

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

To address these concerns, we established a minimum width of 1.5 km (0.94 mi) along the length of each terrestrial branch of the preliminary linkage design, except where existing urbanization precluded such widening. We widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available.

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

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

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

Field Investigations

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

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

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

	Pronghorn
Factor Weights	
Land Cover	45
Elevation	0
Topography	37
Distance from Roads	18
Land Cover	
Pine-Oak Forest and Woodland	8
Pinyon-Juniper Woodland	6
Ponderosa Pine Woodland	7
Juniper Savanna	4
Chaparral	8
Creosotebush, Mixed Desert and Thorn Scrub	2
Creosotebush-White Bursage Desert Scrub	2
Desert Scrub (misc)	3
Mesquite Upland Scrub	7
Paloverde-Mixed Cacti Desert Scrub	3
Riparian Woodland and Shrubland	8
Mixed Bedrock Canyon and Tableland	8
Agriculture	8
Developed, Medium - High Intensity	10
Developed, Open Space - Low Intensity	8
Topographic Position	
Canyon Bottom	7
Flat - Gentle Slopes	1
Steep Slope	8
Ridgetop	6
Distance from Roads (m)	
Distance from Roads range: cost	0-100: 10
	100-250: 6
	250-1000: 3
	1000-15000: 1

Black Bear (*Ursus americanus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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, personal comm.). Minimum potential habitat core size was defined as 50km^2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat

suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the standard habitat suitability model in the corridor analyses for this species.

Results & Discussion

Initial biologically best corridor – The biologically best corridor for this species was comprised of one strand connecting the protected blocks. Suitable habitat was patchily distributed along the strand (Figure 23). Between the Munds Mountain and Black Hills blocks, the average habitat suitability ranged from 1.3 to 10.0, with an average suitability of 5.4 (S.D: 1.0).

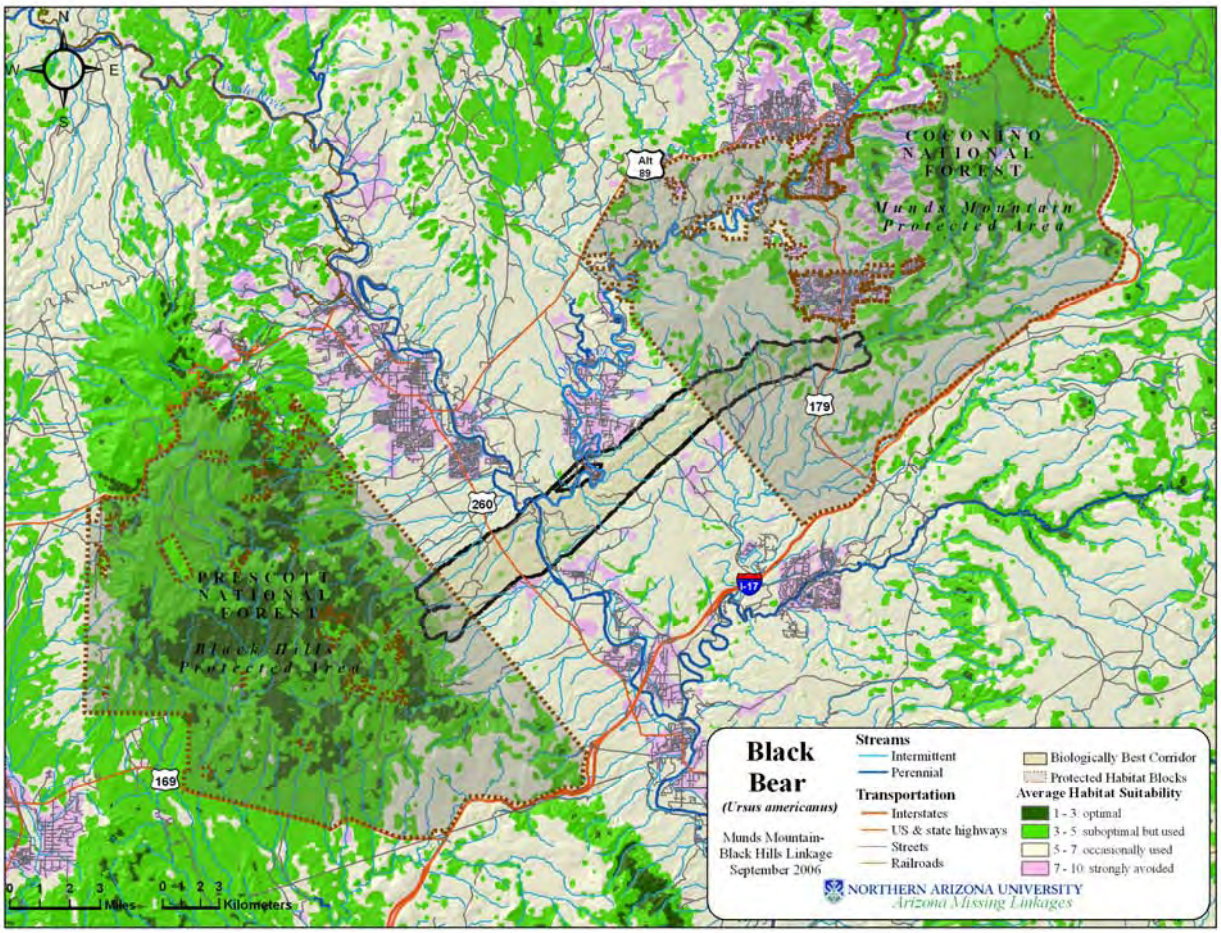


Figure 23: Modeled habitat suitability of black bear.

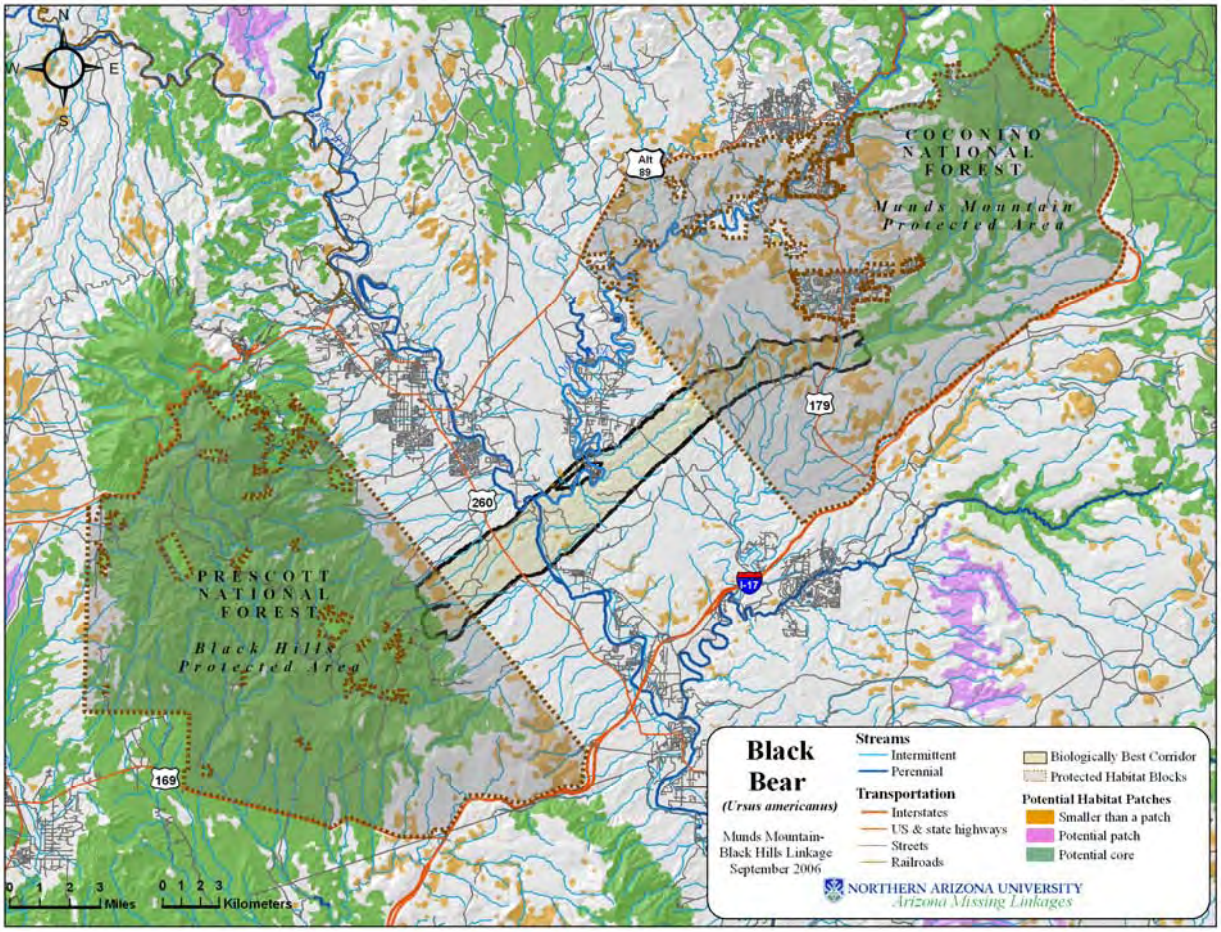


Figure 24: Potential habitat patches and cores for black bear.

Union of biologically best corridors – Because the black bear is primarily associated with mountainous areas, the union of biologically best corridors provides only marginal bear habitat. In the black bear BBC, the farthest distance between a core or patch and another core or patch is approximately 27 km.

Elk (*Cervus elaphus*)

Justification for Selection

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

Distribution

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). 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). Within the linkage planning area, elk occur within the juniper and shrub oak habitat types in areas including Onion Mountain, Boulder Canyon, upper Cherry Creek, Powell Springs, Goat Peak, Ash Creek, and Burnt Canyon. Areas west of the Woodchute Wilderness, CCC Canyon, and near the Verde River support lower elk densities.

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 (7,000 to 10,000 ft) and lower elevation winter range (5,500 to 6,500) (Arizona Game and Fish Department 2006). 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 weight of 25%. For specific scores of classes within each of these factors, see Table 4.

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). In our analyses, minimum patch size for elk was defined as 60 km^2 and minimum core size as 300 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species along the northern edge the potential linkage area (Figure 25). Within the biologically best corridor linking the protected blocks, habitat suitability ranged from 1.0 to 10.0, with an average suitability cost of 2.8 (S.D: 2.1). Within the corridor, potential suitable habitat appears to be available, and much of the corridor is a potential habitat core (Figure 25).

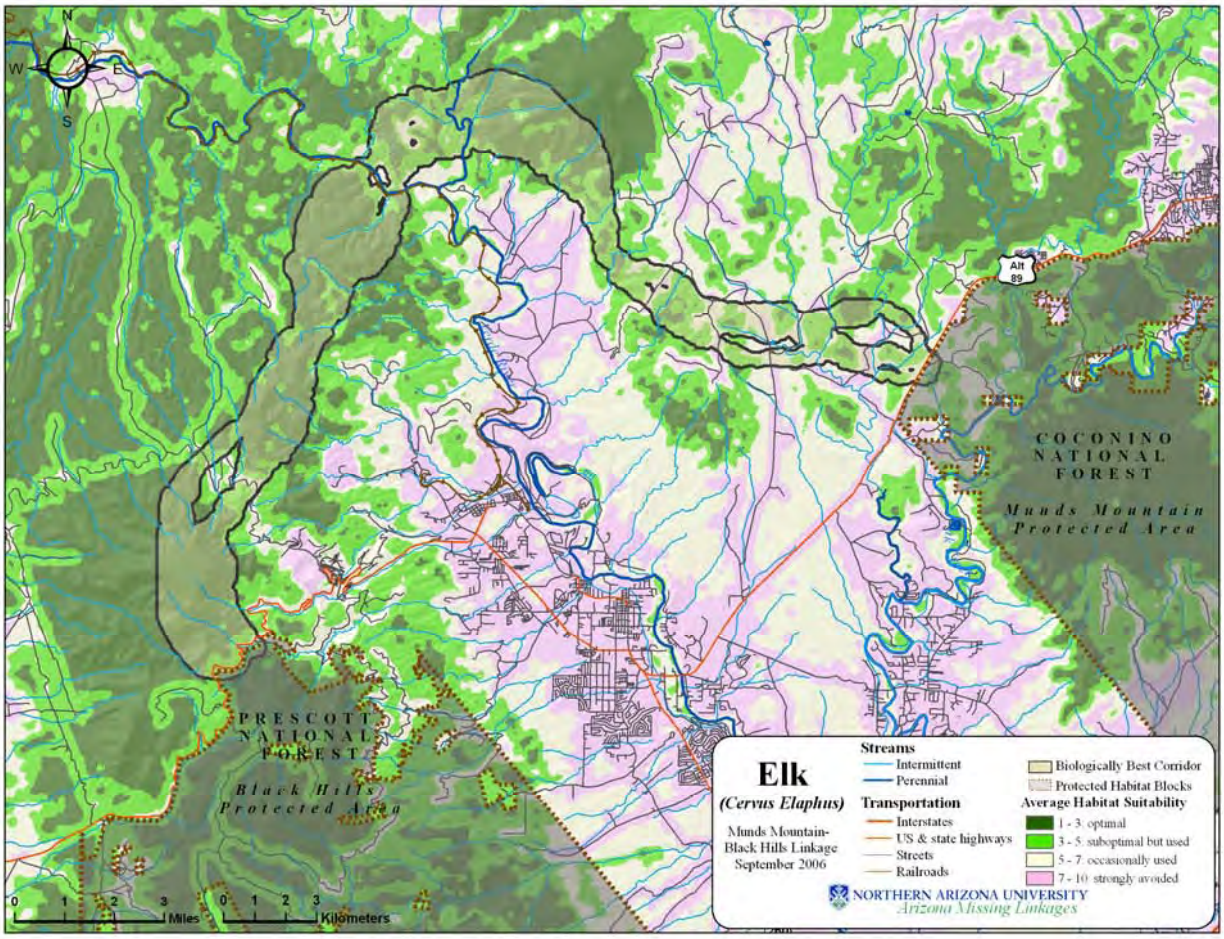


Figure 25: Modeled habitat suitability of elk.

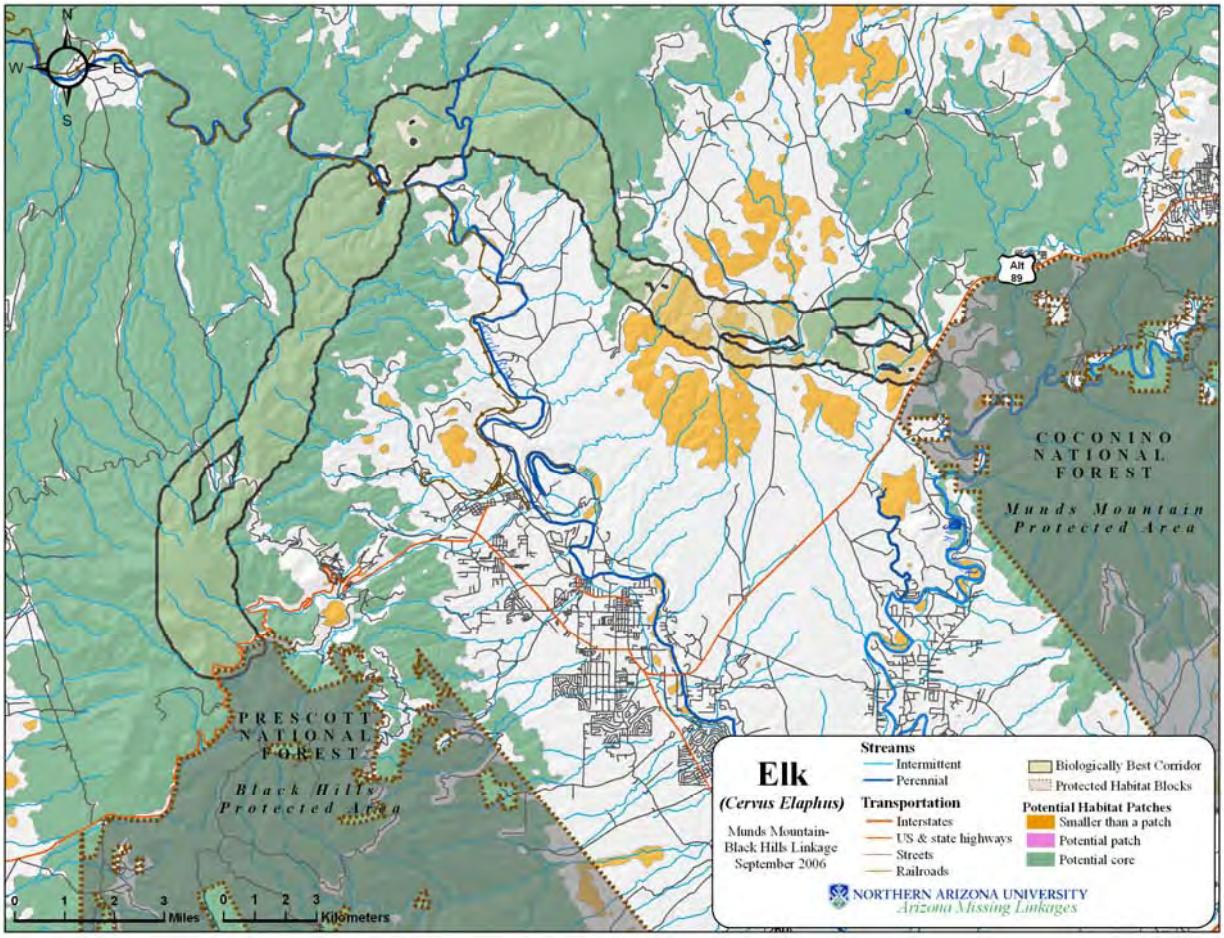


Figure 26: Potential habitat patches and cores for elk.

Union of biologically best corridors – The UBBC provides little additional habitat for elk since the optimal habitat is concentrated within the northern linkage strand. Connectivity throughout the area north of the protected blocks, including between the Woodchute and Sycamore Wilderness areas, and the Sycamore and Munds Mountain Wilderness areas, is essential for elk movements between the protected blocks.

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 paloverde, 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 4.

Patch size & configuration analysis – Minimum habitat patch size for javelina was defined as 44 ha, based on an estimate for a single breeding season for one "herd" of one breeding pair. The estimate for

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant suitable habitat for this species within the potential linkage area (Figure 27). Within the biologically best corridor for this species, habitat suitability ranged from 1.0 to 9.0, with an average suitability cost of 1.9 (S.D: 0.9). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 28).

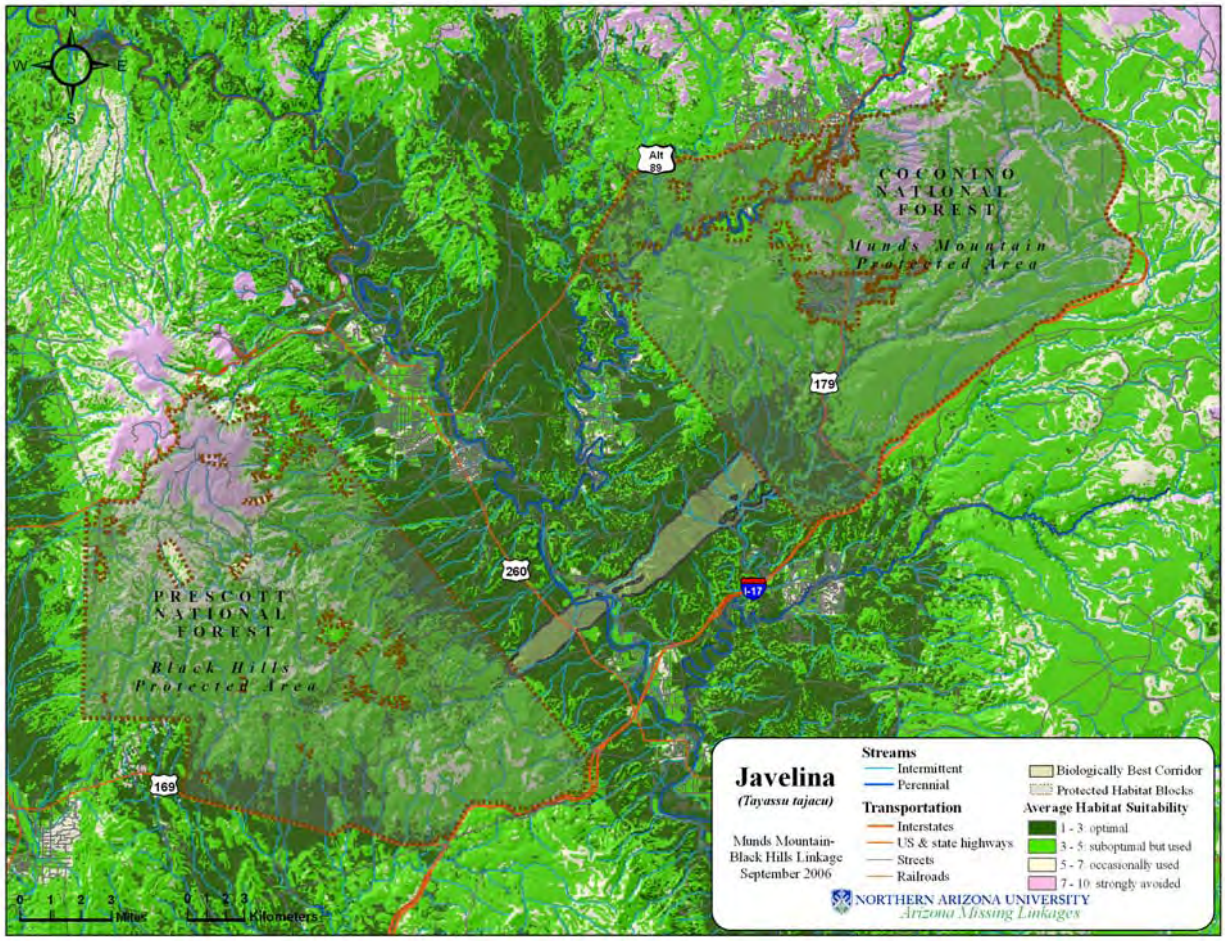


Figure 27: Modeled habitat suitability of javelina.

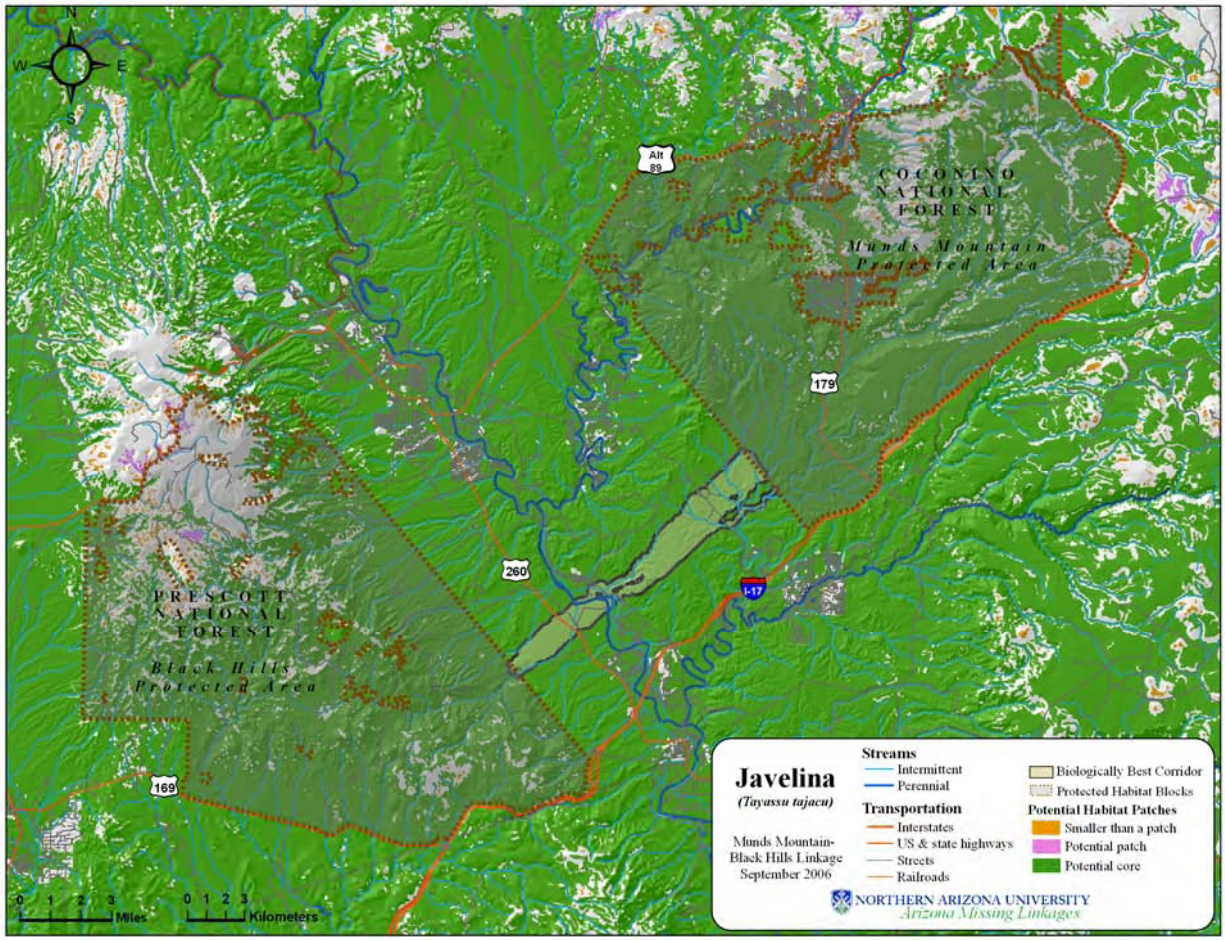


Figure 28: Potential habitat patches and cores for javelina.

Union of biologically best corridors – The additional strands of the UBBC significantly increase potential habitat for javelina. Because there is ample habitat for this species, and nearly all portions of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-17, US 89, AZ 179, and AZ 260, and habitat fragmentation.

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 km² for males and 69.9 km² for females (Logan and Sweanor 2001). This study also reported daily movements averaging 4.1 km for males and 1.5 km for females (Logan and Sweanor 2001). Dispersal rates for juvenile mountain lions also vary between males and females. Logan and Sweanor's study found males dispersed an average of 102.6 km from their natal sites, and females dispersed an average of 34.6 km. A mountain lion population requires 1000 - 2200 km² of available habitat in order to persist for 100 years (Beier 1993). These minimum areas would support about 15-20 adult cougars (Beier 1993).

Conceptual Basis for Model Development

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

Patch size & configuration analysis – Minimum patch size for mountain lions was defined as 79 km^2, 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 km^2, or five times minimum patch size.

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

Biologically best corridor analysis: Most of the habitat was calculated as suitable (cost <5),and the standard habitat suitability model was used in the corridor analysis.

Results & Discussion

Initial biologically best corridor – Modeling results indicate a fair amount of suitable habitat for this species within the potential linkage area, although optimal habitat is concentrated within the protected blocks of mountainous habitat (Figure 29). Between the Munds Mountain and Black Hills blocks, the average habitat suitability ranged from 1.4 to 9.6, with an average suitability of 4.2 (S.D: 1.4). The area with the least distance between potential cores was identified as a corridor in the analysis. Because this strand depends on narrow passageways abutting developed land, we decided not to include it in the Union. However, further analysis indicates that strands developed for other species, including mule deer and elk, contain large amounts of optimal or suitable lion habitat as well.

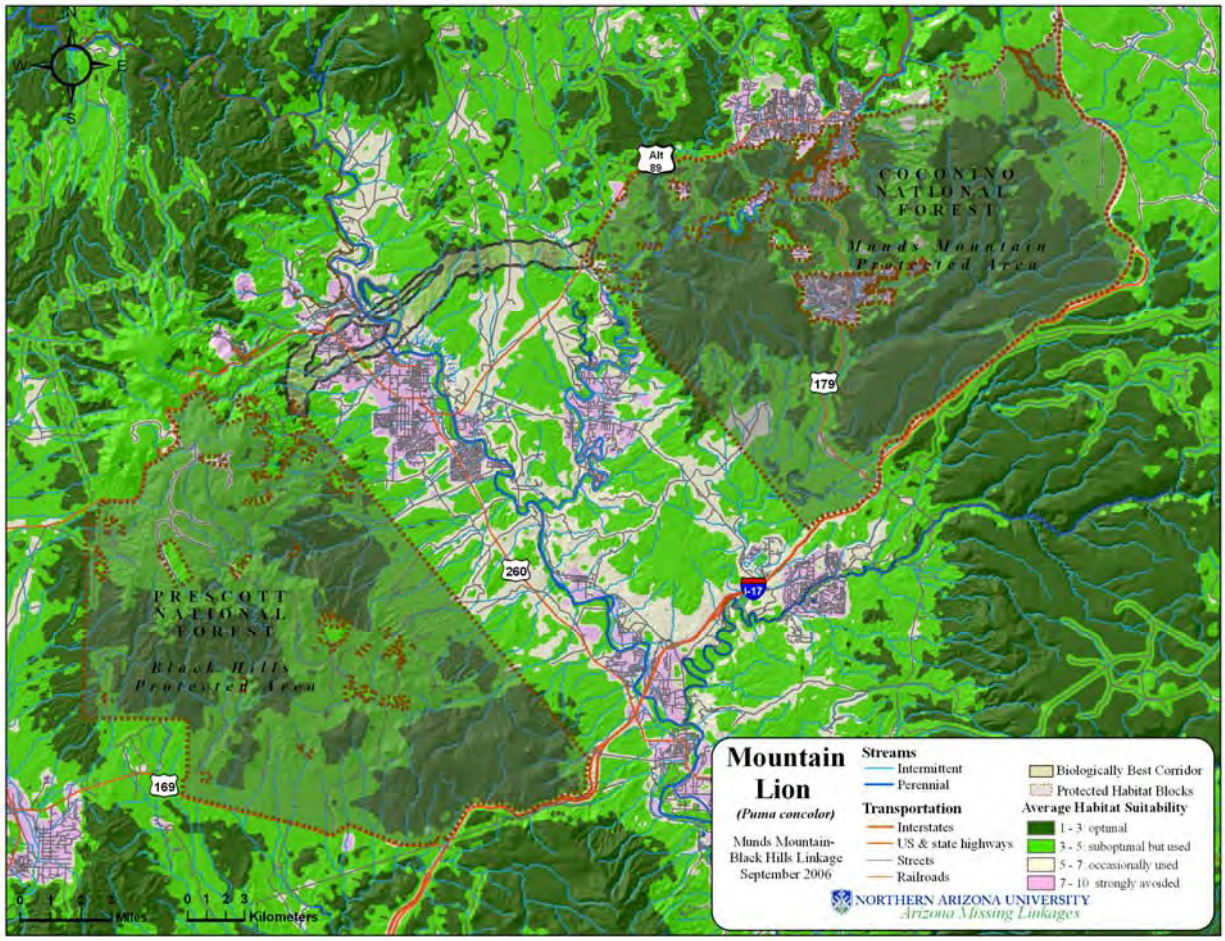


Figure 29: Modeled habitat suitability of mountain lion.

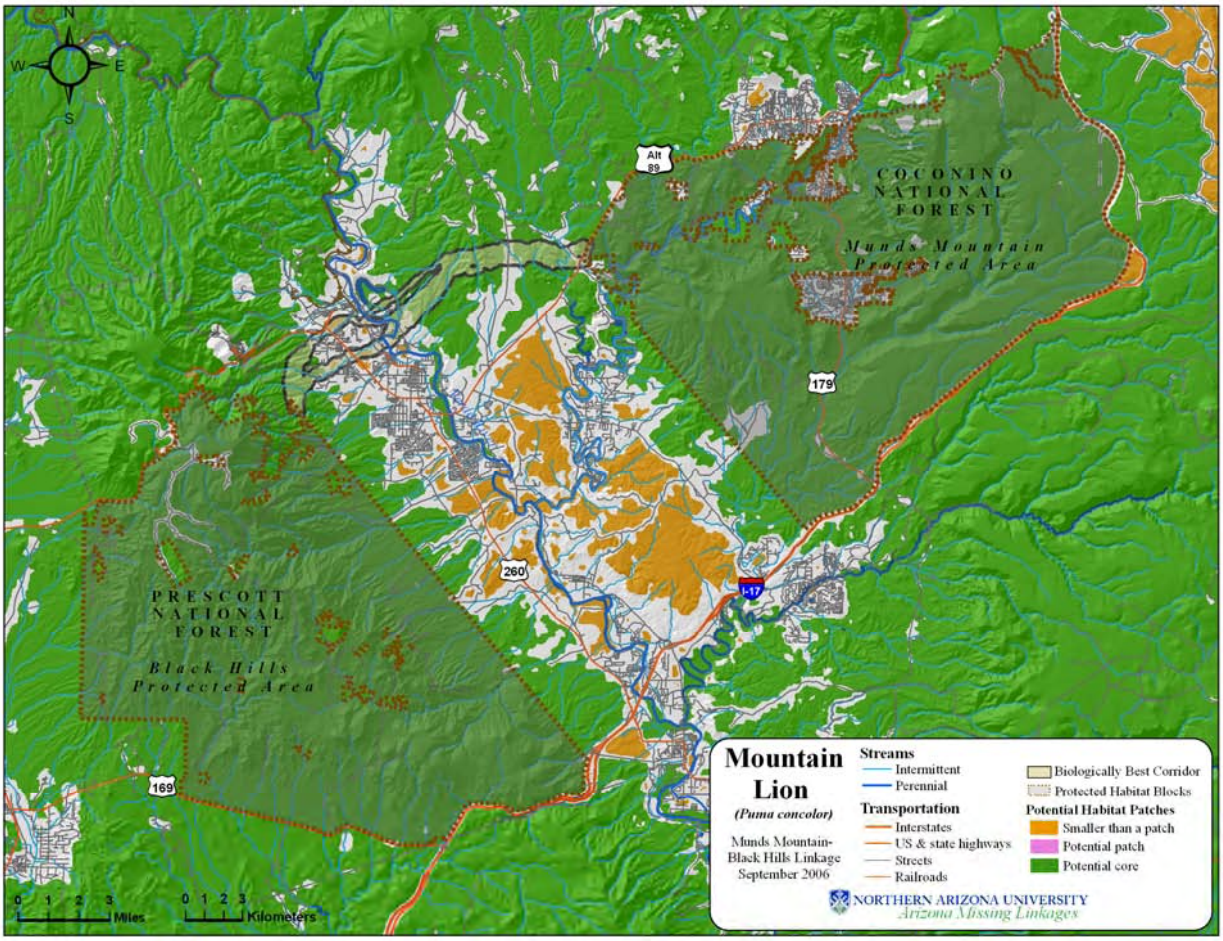


Figure 30: Potential habitat patches and cores for mountain lion.

Union of biologically best corridors – – The union of biologically best corridors provides a significant amount of suitable habitat for mountain lion. Analysis indicates that strands developed to serve other large mammal species, including mule deer and elk, contain large amounts of optimal or suitable lion habitat. This species appears to be well-served by the linkage design.

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of suitable habitat for this species within the potential linkage area (Figure 31). Within the biologically best corridor linking the protected blocks, habitat suitability ranged from 2.0 to 8.6, with an average suitability cost of 3.0 (S.D: 1.1). Within the BBC for this species, potential suitable habitat appears to be abundant, and the entirety of the corridor is a potential habitat core (Figure 32).

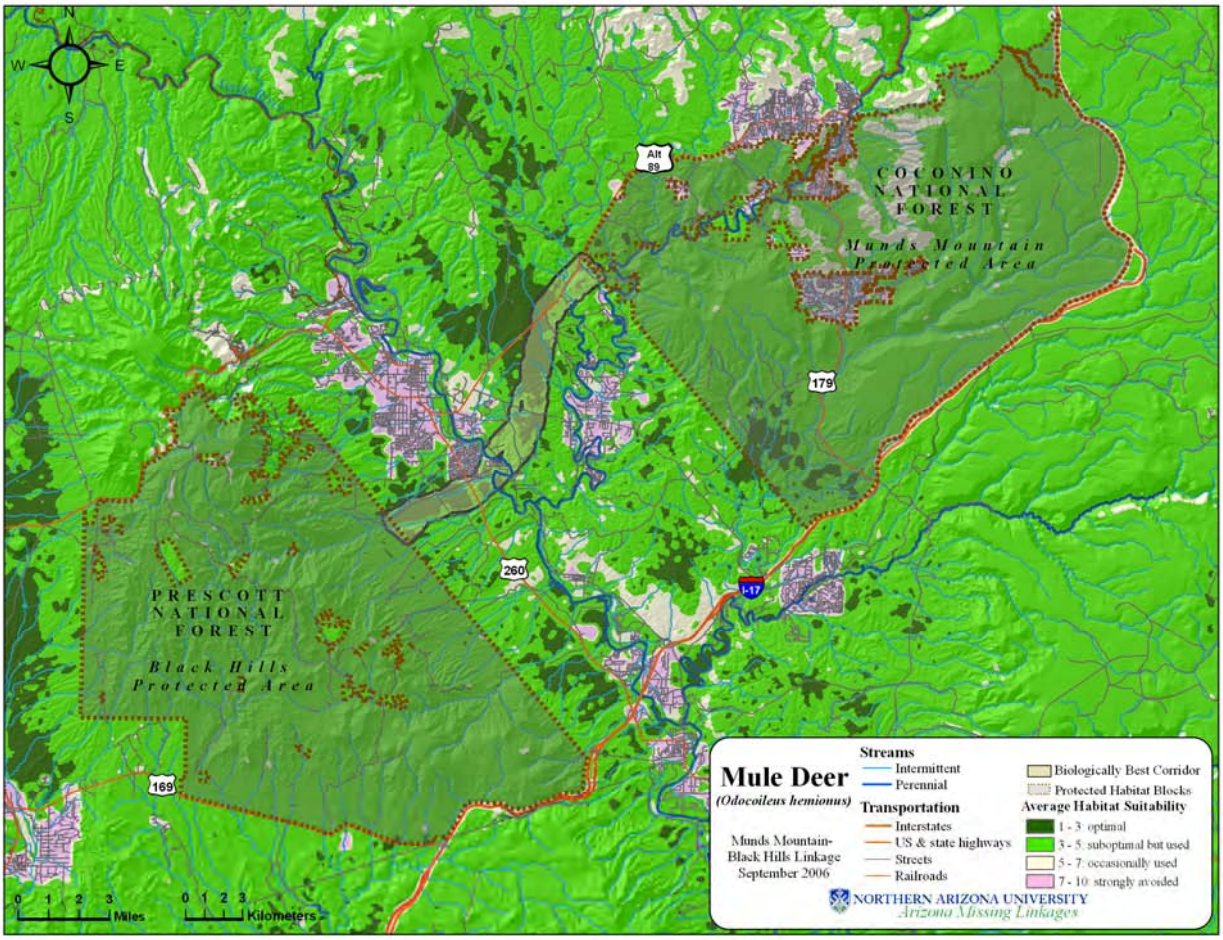


Figure 31: Modeled habitat suitability of mule deer.

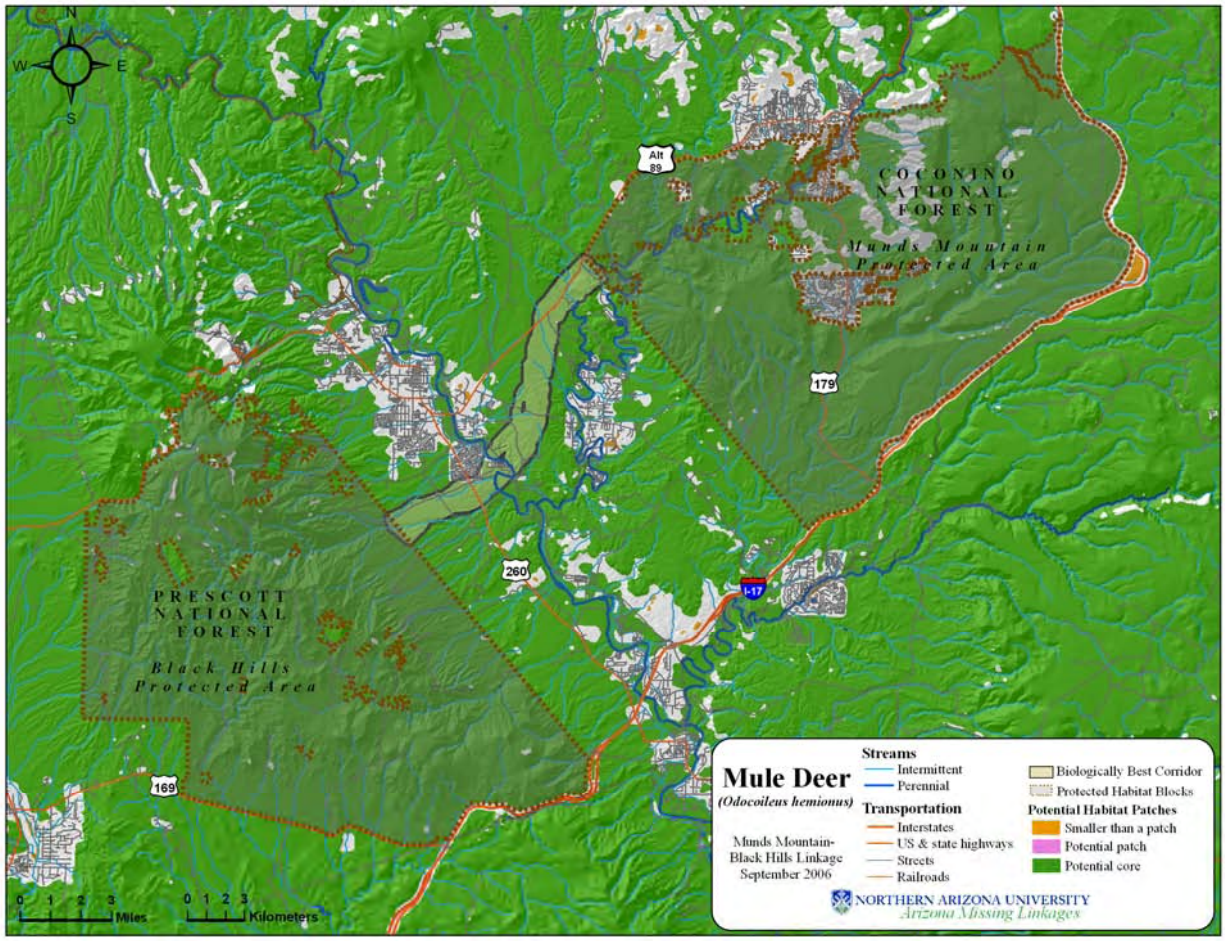


Figure 32: Potential habitat patches and cores for mule deer.

Union of biologically best corridors – The UBBC contains significant amounts of potential habitat for mule deer. Because there is ample habitat for this species, and much of the UBBC could be a potential habitat core, the greatest threat to its connectivity and persistence is most likely high-traffic roads such as I-17, US 89, AZ 179, and AZ 260, and habitat fragmentation.

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). The Sonoran pronghorn subspecies is known to require even larger tracts of land to obtain adequate forage (AZGFD 2002b). One study of collared Sonoran pronghorn found the home range of 4 males to range from 64 km^2 – 1214 km^2 (avg. 800 km^2), while females ranged from 41km^2 -1144 km^2 (avg. 465.7 km^2) (AZGFD 2002b). Another study of Sonoran pronghorn found home range to range from 43 to 2,873 km^2, with mean home range size of 511 + 665 SD km^2 (n=22), which is much larger than other pronghorn subspecies (Hervert et al. 2005). 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 4.

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

Biologically best corridor analysis – While pronghorn habitat is limited in the linkage planning area, they do occur to the north and west of the linkage planning zone, and have been seen crossing both the Verde river and US Highway 89A (Mylea Bayless, Arizona Game and Fish Department, personal communication). We did not create a biologically best corridor for the species. Instead, we used the standard habitat suitability model to assess potential habitat for this species within the union of biologically best corridors.

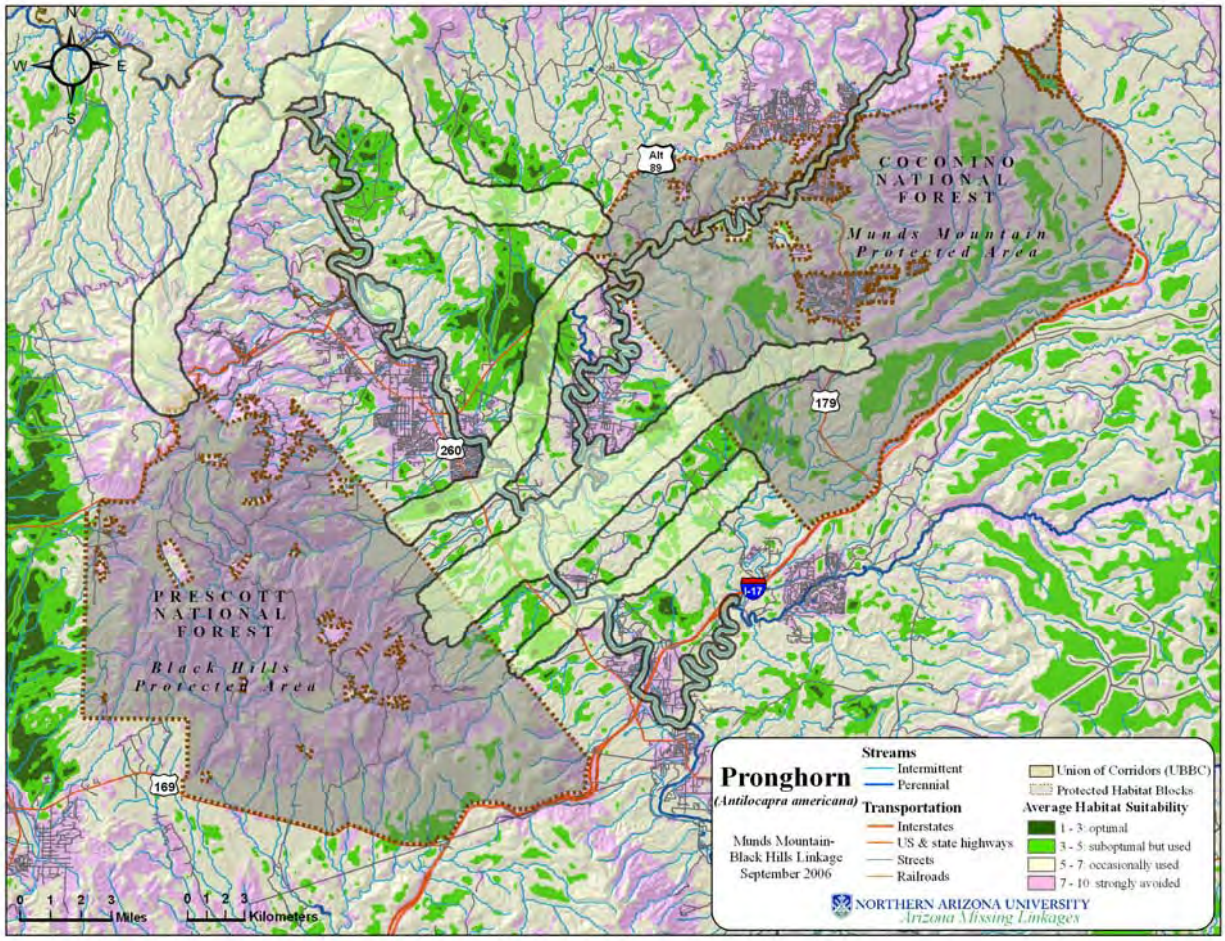


Figure 33: Modeled habitat suitability of pronghorn, with UBBC.

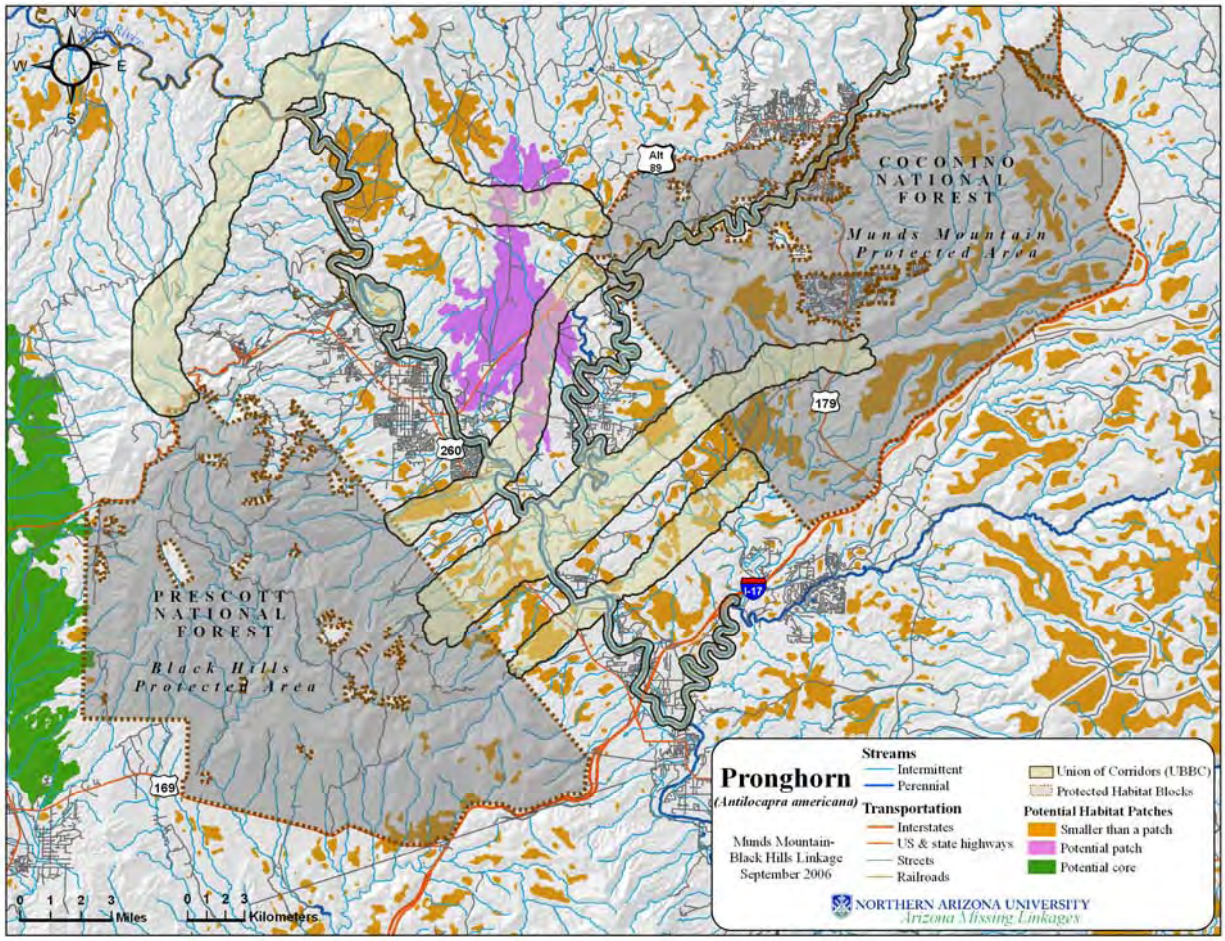


Figure 34: Potential habitat patches and cores for pronghorn, with UBBC.

Results & Discussion

Union of biologically best corridors – Most suitable habitat for this pronghorn is concentrated to the west of the protected blocks (Figure 33). The union of least-cost corridors encompasses some potential habitat for this species however no potential cores exist on the eastern side of the linkage area (Figure 34).

Riparian and Aquatic Obligates

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

Mammals

- Southwestern River Otter (Lontra canadensis sonora) – this very rare species is and considered a Species of Concern by the U.S. Fish and Wildlife Service and a Species of Special Concern in Arizona. The species appears to have been extirpated in Arizona (New Mexico Game and Fish 2006). Another species (Lontra canadensis laxatina), from Louisiana was introduced into the Verde River in the early 1980's, though it is also appears to be very rare (New Mexico Game and Fish 2006).
- Beaver (Castor Canadensis)- occur in association with aquatic habitats including large rivers, streams, ponds, and lakes, along parts of the most continuously flowing waterways in western, central, and northern Arizona. Riparian habitat is a requirement for beavers (New Mexico Game and Fish 2006).

Fish

- Longfin dace (*Agosia chrysogaster*) – longfin dace is listed as sensitive by the BLM, threatened in Mexico, and considered a Species of Concern by the U.S. Fish and Wildlife Service. (Arizona Game and Fish Department 2002).
- Razorback sucker (*Xyrauchen texanus*) – The razorback sucker is listed as federally endangered with critical habitat by the U.S. Fish and Wildlife Service.
- Roundtailed chub (*Gila robusta*)- This chub is considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It occurs in the mainstem and tributaries of the Verde River (Heritage Data Management System 2004), although populations appear to be declining (New Mexico Game and Fish 2006).
- Speckled dace (*Rhinichthys osculus*) – speckled dace is listed as endangered in Mexico, its population trend is listed as "Declining" in the federal register, and its disappearance was documented along the main channels of the Gila drainage (New Mexico Game and Fish 2006).
- Spikedace (*Meda fulgida*) – listed as threatened in Arizona and by the U.S. Fish and Wildlife Service with critical habitat designated. Once abundant in Arizona, it is now found in the reaches of 3 waterways in the state, including the upper Verde River (Heritage Data Management System 2004).
- Colorado Pikeminnow (*Ptychocheilus lucius*) – listed as endangered by the U.S. Fish and Wildlife Service, this species was once widespread from Wyoming to Arizona. They are restricted to two "experimental, non-essential" reintroduced populations in Arizona including the Verde and Salt River drainages (Heritage Data Management System 2004).
- Desert Sucker (*Catostomus clarki*) – desert sucker is listed as sensitive by the BLM River (Heritage Data Management System 2004) and considered a Species of Concern by the U.S. Fish and Wildlife Service though it is thought to be fairly common in Arizona (New Mexico Game and Fish 2006).

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 Coconino and Prescott National Forests, and may be associated with pinyon-juniper woodlands (New Mexico Game and Fish 2006).
- Mexican gartersnake (*Thamnophis eques megalops*) - This subspecies is 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 (New Mexico Game and Fish 2006) and is known to occur in Oak Creek (Heritage Data Management System 2004).
- Narrow-headed gartersnake (*Thamnophis rufipunctatus rufipunctatus*) - This subspecies is considered a Species of Concern by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. It is an almost strictly aquatic species with good populations known to exist in Oak Creek (Heritage Data Management System 2004).
- Lowland leopard frog (*Rana yavapaiensis*) – Lowland leopard frog is considered a Species of Concern by the U.S. Fish and Wildlife Service, is USFS Sensitive, and a Wildlife Species of Special Concern in Arizona.

Birds

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

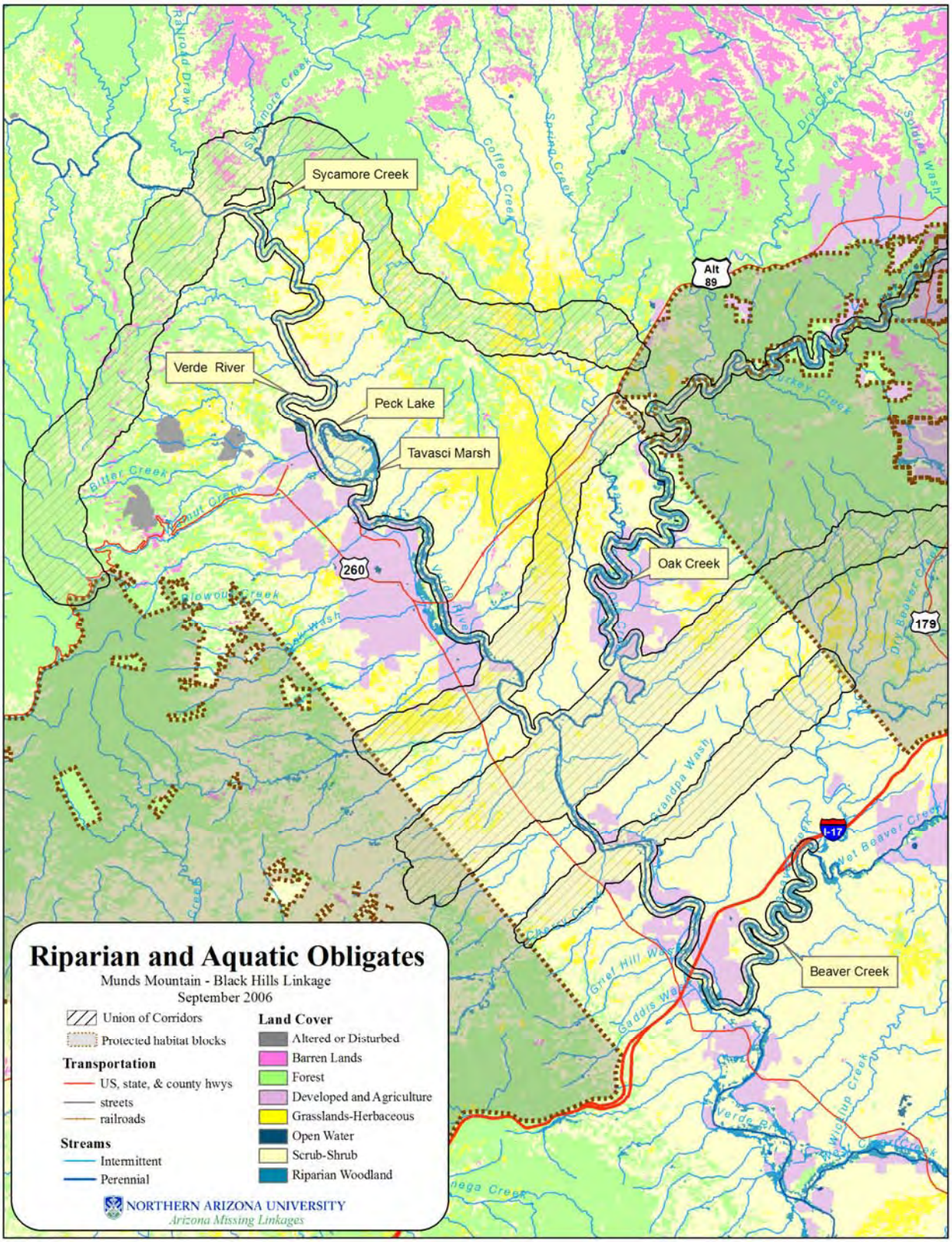


Figure 35: Important riparian habitat for fish, herpetofauna, and birds along the Verde River and tributaries was incorporated into the Linkage Design.

Appendix C: Suggested Focal Species not Modeled

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

Mammals

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

Birds

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

- Bald Eagle (*Haliaeetus leucocephalus*) – listed as threatened by the U.S. Fish and Wildlife Service, and a Species of Special Concern in Arizona. Historically, Bald eagles have nested along the Verde River on cliff ledges and in live trees or snags, though long-term data are lacking (New Mexico Game and Fish 2006). In order for the bald eagle population to recover these birds must have continued protection and management of their habitat, continued population monitoring, and re-establishment of breeding populations throughout their historic range.
- Common black-hawk (*Buteogallus anthracinus anthracinus*) – Common black-hawks occur in riparian woodlands, especially cottonwood forests (New Mexico Game and Fish 2006). They tend to nest within 500 meters of permanent, flowing water (Heritage Data Management System 2004). They are also highly mobile.
- 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).
- 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 2006).
- Gambel's Quail (*Callipepla gambelii*) – Gambel's quail prefer xeric habitats dominated by shrubs and populations appear to be secure in Arizona (New Mexico Game and Fish 2006).

Plants

- Arizona Cliffrose (*Purshia subintegra*) – is listed as endangered without critical habitat by U.S. Fish and Wildlife Service. It is a xeric evergreen shrub restricted to habitat consisting of lake deposit limestone. The largest population occurs in the Verde Valley (Phillips et al. 1996).
- Cottonwood (*Populus fremontii*) – occurs in aquatic environments such as those found along the Verde River and Oak Creek.
- Hualapai Milkwort (*Polygala rusbyi*) – Also Rusby's milkwort, a perennial subshrub known to occur in the Verde Valley.

- Ripley's wild buckwheat (*Eriogonum ripleyi*) – occurs on sandy clay flats and slopes and oak-juniper woodlands. Listed as a sensitive species in Arizona, this plant is restricted to a few areas in the state, including the Verde Valley ((New Mexico Game and Fish 2006).
- Verde Valley Sage (*Salvia Dorii Mearnsii*) – Restricted to open Creosotebush-Shrub communities on gypseious limestone
- Desert Willow (*Chilopsis linearis*) –Occurs in low floodplain terraces of the Verde Valley.

Insects

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

Appendix D: Creation of Linkage Design

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

- We removed a sixth strand, the mountain lion corridor, which we deemed impractical as it straddled densely inhabited urban areas. We found that two other strands (mule deer and elk) encompassed high quality lion habitat in areas where lions would be more likely to occur.
- We removed an unnecessary portion of the UBBC near Dry Beaver Creek.
- We widened the UBBC in several locations to ensure all strands were at least 1.5 km wide, eliminated gaps in the corridors where habitat was suitable, and buffered the Verde River and its major tributaries by approximately 200 meters.

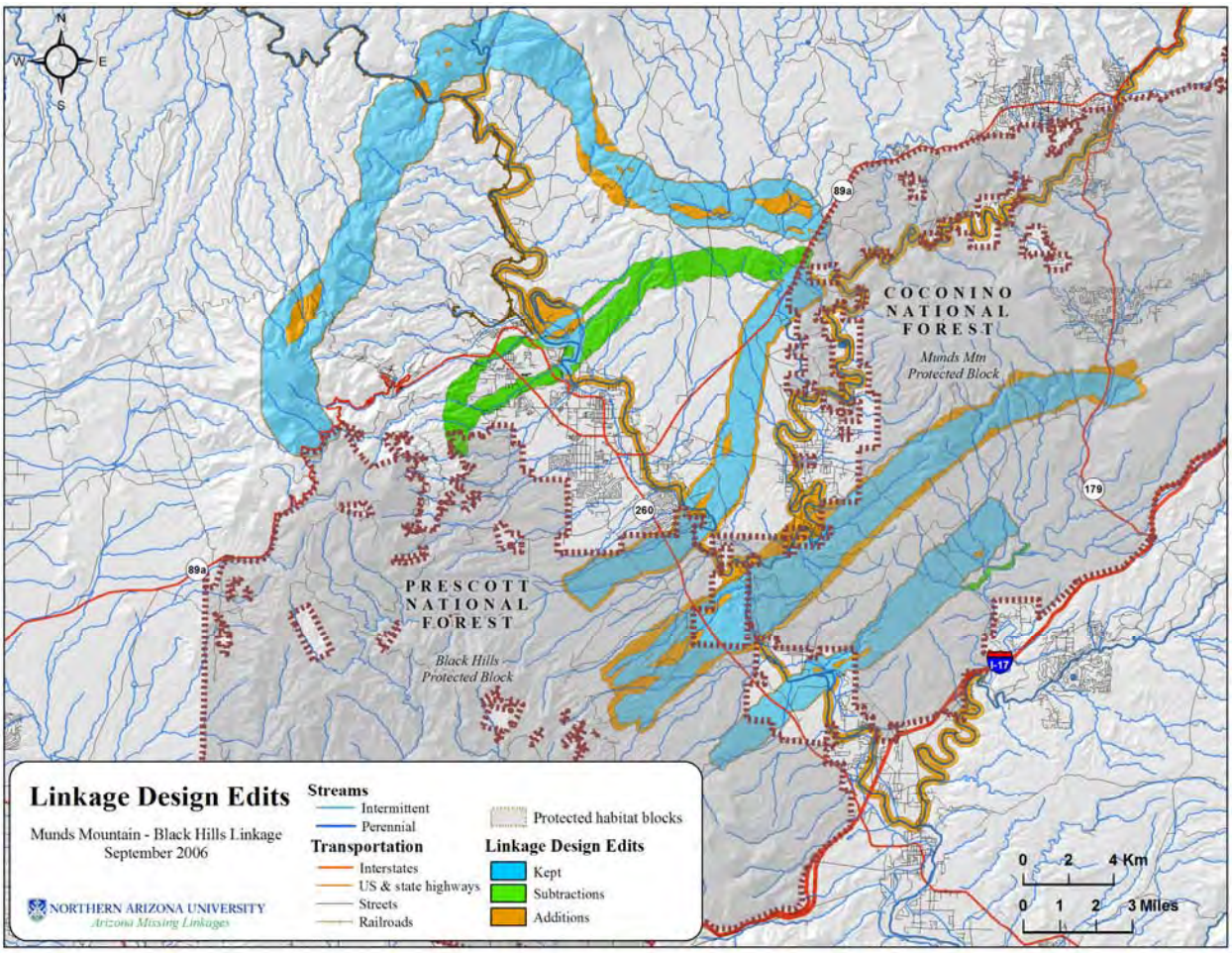


Figure 36: Edits made to Union of Biologically Best Corridors to create final Linkage Design.

Appendix E: Description of Land Cover Classes

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

EVERGREEN FOREST (3 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 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 mountains of New Mexico. 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 typically diverse perennial grasses. Common grass species include *Bouteloua eriopoda, B. hirsuta,B. rothrockii, B. curtipendula, B. gracilis, Eragrostis intermedia, Muhlenbergia porteri, Muhlenbergia setifolia, Pleuraphis jamesii, Pleuraphis mutica*, and *Sporobolus airoides*, succulent species of *Agave, Dasylirion*, and *Yucca*, and tall shrub/short tree species of *Prosopis* and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica*).

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

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

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

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

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

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

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

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

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

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

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

Developed, Medium - High Intensity – *Developed, Medium Intensity*: Includes areas with a mixture of constructed materials and vegetation. Impervious surface accounts 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 settings 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 F: Literature Cited

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

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. 2001. *Puma concolor browni.* 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 Department of Game and Fish. http://www.gf.state.az.us/h_f/game_elk.shtml, 2006.

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.

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.

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

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

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

Boyce, M.S. 1991. Migratory behavior and management of elk (Cervus elaphus). Applied Animal Behaviour 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.

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.

Crooks, K. and M. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563-566.

Cunningham, S.C., and W. Ballard. 2004. Effects of wildfire on black bear demographics in central 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, J.C. and W.H. Miller. 2005. Habitat use and survival of Sonoran pronghorn in years with above-average rainfall. Wildlife Society Bulletin 33: 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.
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.
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 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press: Cambridge.
Forman, R.T.T., et al. 2003. Road ecology: science and solutions. Island Press: Washington, D.C.
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.
Hanski, I. and M. Gilpin. 1991. Metapopulation Dynamics. Academic Press, London.
Harris, L.D. and P.B. Gallagher. 1989 New initiatives for wildlife conservation: the need for movement corridors. Pages 11-34 in G. Mackintosh, editor. Preserving communities and corridors. Defenders of Wildlife, Washington, D.C.
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.
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.
Hoback, W.W., and J.J. Riggins. 2001. Tiger beetles of the United States. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/distr/insects/tigb/index.htm (Version 12DEC2003).
Hoffmeister, D.F. 1986. Mammals of Arizona. The University of Arizona Press and The Arizona Game and Fish Department. 602 pp.
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.
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.
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.
Levins, R. 1970. Extinction. Pages 77-107 in M. Gerstenhaber, ed. Some Mathematical Questions in Biology. Lectures on Mathematics in the Life Sciences, Vol. 2. American Mathematical Society, Providence, RI.

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.
Lowe, C.H. 1978. The Vertebrates of Arizona. The University of Arizona Press. Tuscon, Arizona. 270pp.
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.
MacArthur, R.G., and E.O.Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, NJ.
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.
Mills, L.S., and P.E. Smouse. 1994. Demographic consequences of inbreeding in remnant populations. American Naturalist 144:412-431.
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.
Noss, R.F. 1987. Protecting natural areas in fragmented landscapes. Natural Areas Journal 7:2-13.
Noss, R.F. 1991. Landscape Linkages and biodiversity. Pages 27 – 39 In: W.E. Hudson, ed. Washington, D.C.
Noss R.F., 1992. The Wildlands Project: Land conservation strategy. Wild Earth (Special Issue), Vol. 1, pp.10-25.
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., 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., C.L. Ticer, A. Alexander, J.A. Wennerlund. 1996. A landscape-level pronghorn habitat evaluation model for Arizona. Arizona Game and Fish Department. Tech. Rep. 19, Phoenix. 50pp.
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.
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.

Phillips, B. D. Lutz, R. Popowski, and H. Shaw. The Verde Valley Sonoran Desertscrub: An Ecosystem at Risk. Gen. Tech. Rep. RM-GTR-283. Proceedings of the Southwestern Rare and Endangered Plant Conference; September 11-14; Flagstaff, AZ. In: Maschinski, J.; Hammond, H.D.; Holter, L., editors. 1996. USDA and US Forest Service. p 231-236.

Rich, C. and T. Longcore (eds). 2006. Ecological Consequences of Artificial Night Lighting. Island Press, Washington D.C.

Rosen, P.C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation 68: 143-148.

Rollins, D. Managing Desert Mule Deer. Wildlife Management Handbook: 41-46.

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.

Severson, K.E., and A.L. Medina. 1983. Deer and elk habitat management in the Southwest. Journal of Range Management Monograph No. 2. Society for Range Management, Denver, CO. 64 p.

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.

Schonewald-Cox, C.M. 1983. Conclusions. Guidelines to management: A Beginning attempt. Pages 141-145 in C.M. Schonewald-Cox, S.M. Chambers, B. MacBryde, and W.L. Thomas, eds. Genetics and Conservation: A Reference for Managing Wild Animal and Plant Populations. Benjamin/Cummings, Menlo Park, CA.

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.

Shaffer, M.L. 1981. Minimum population sizes for species conservation. BioScience 31:131-134.

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.

Smith, W.P. 1991. Odocoileus virginianus. Mammalian Species 388: 1-13.

Soulé, M.E., ed. 1987. Viable Populations for Conservation. Cambridge University Press,

Soulé , M.E., and J. Terborgh, editors. 1999. Continental conservation: scientific foundations of regional reserve networks. Island Press.

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.

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.

Swank, W.G. 1958. The mule deer in Arizona chaparral and an analysis of other important deer herds: a research and management study. Arizona Game and Fish Department,Fed. Aid Project Arizona W-71-R, Wildlife Bulletin 3, Phoenix, Ariz. 109pp.

Taylor, A.D. 1990. Metapopulation structure in predator-prey systems: an overview. Ecology 71:429-433.

Tewksbury, J.L., D.J. Levey, N.M. Haddad, S. Sargent, J.L. Orrock, A. Welson, B.J. Danielson, J. Brinderhoff, E.L. Damschen, and P. Townsend. 2002. Corridors affect plants, animals, and their interaction in fragmented landscapes. PNAS, Vol. 99, No. 20, pp. 12923-12926.

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., 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. 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.

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.

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

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: 658-660Webb, R.H. and H.G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. New York : Springer-Verlag.

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., B.W. O'Gara, and V.W. Howard. 1996. Pronghorn on western rangelands. Pages 211-216 In P.R. Krausman, ed. Rangeland Wildlife. Society for Range Management, Denver, Colorado.

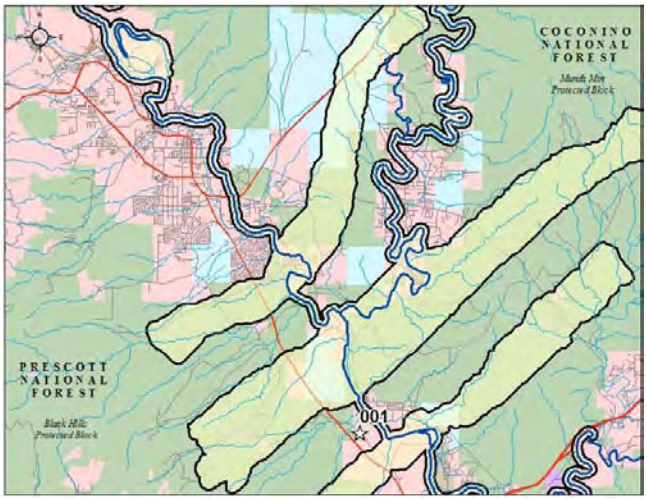
Appendix G: Database of Field Investigations

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

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	001		
Linkage Zone:	Verde Linkage	**Latitude:**	34.63277693	**Longitude:**	-111.93219
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	414556.5179	**UTM Y:**	3832715.695
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Name: DSCF0001.jpg

Azimuth: 98 **Zoom:** 1x

Notes: Flood plain and pasture with gravel mine to the far left.

Name: DSCF0002.jpg

Azimuth: 160 **Zoom:** 1x

Notes: A small industrial park and riparian area.

Name: DSCF0003.jpg

Azimuth: 184 **Zoom:** 1x

Name: DSCF0004.jpg

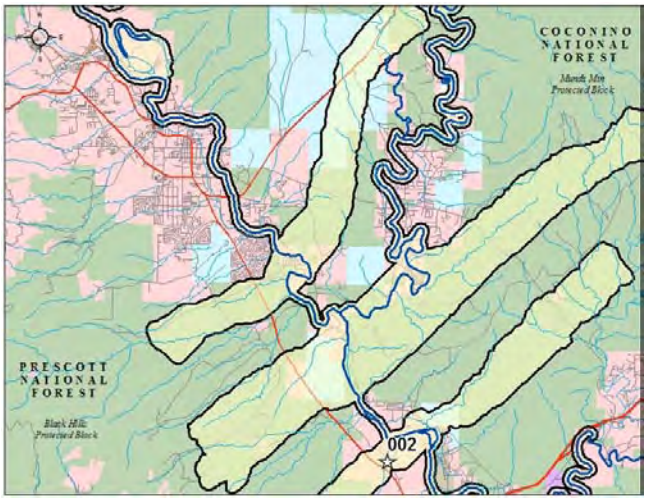
Azimuth: 310 **Zoom:** 1x

Notes: Mingus Mountain is depicted behind an industrial area with a gravel pit.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	002		
Linkage Zone:	Verde Linkage	**Latitude:**	34.62238882	**Longitude:**	-111.919388
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	415719.4902	**UTM Y:**	3831552.934
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Cherry Creek Wash at the main road crossing

Site Photographs

Name: DSCF0005.jpg

Azimuth: 210 **Zoom:** 1x

Notes: Looking upstream in Cherry Creek Wash.

Name: DSCF0006.jpg

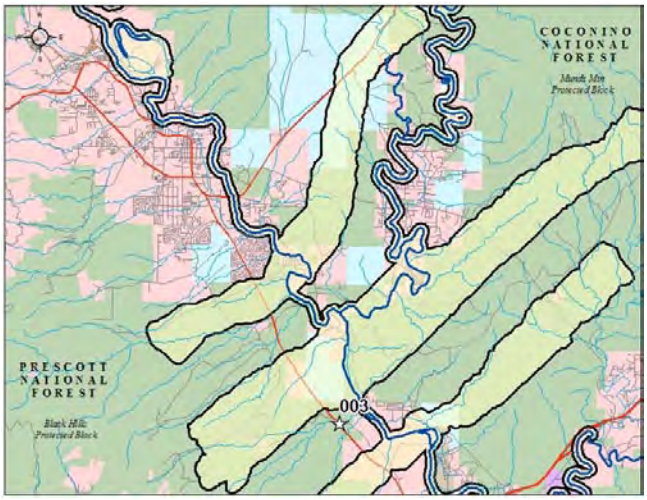
Azimuth: 30 **Zoom:** 1x

Notes: Looking Downstream in Cherry Creek Wash.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	003		
Linkage Zone:	Verde Linkage	**Latitude:**	34.63645424	**Longitude:**	-111.941435
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	413712.9064	**UTM Y:**	3833131.365
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Box culverts located in the wash between Linkage strands.

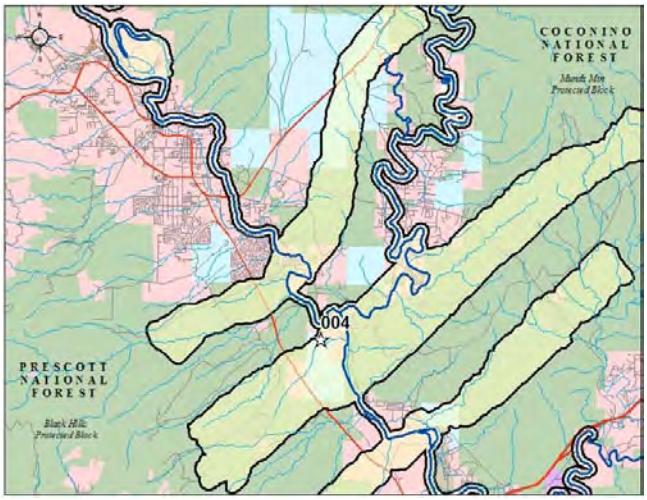
Site Photographs

Azimuth: 266 **Zoom:** 1x

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	004		
Linkage Zone:	Verde Linkage	**Latitude:**	34.66788009	**Longitude:**	-111.950368
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	412926.9884	**UTM Y:**	3836624.027
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Name: DSCF0012.jpg

Azimuth: 210 **Zoom:** 1x

Notes: Looking up the draw.

Name: DSCF0013.jpg

Azimuth: 200 **Zoom:** 4x

Notes: A close up of the Industrial Park above the draw.

Name: DSCF0014.jpg

Azimuth: 220 **Zoom:** 6x

Notes: A small culvert passing under Highway 260, behind a Motocross recreation area on the left side of the photo.

Name: DSCF0015.jpg

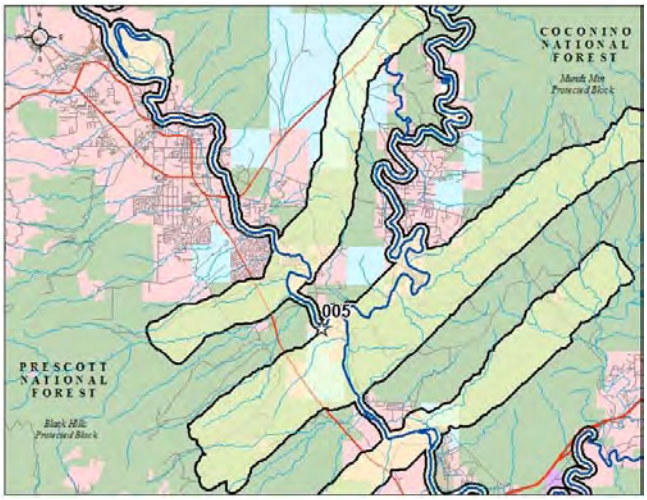
Azimuth: 90 **Zoom:** 1x

Notes: Looking down the draw toward the Verde River (An RV park is located on private land over the ridge to the East).

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	005		
Linkage Zone:	Verde Linkage	**Latitude:**	34.67207456	**Longitude:**	-111.949874
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	412976.6557	**UTM Y:**	3837088.748
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Azimuth: 40 **Zoom:** 1x

Notes: The Verde River.

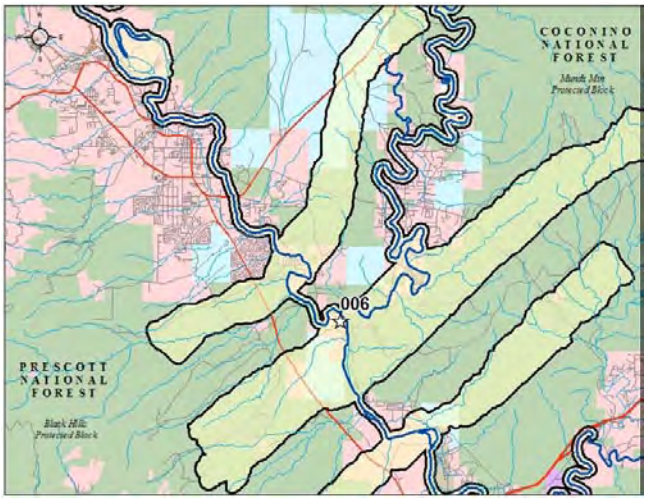
Azimuth: 328 **Zoom:** 1x

Notes: Looking up the Verde River valley toward Cottonwood, AZ.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	006		
Linkage Zone:	Verde Linkage	**Latitude:**	34.67504879	**Longitude:**	-111.941485
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	413748.2768	**UTM Y:**	3837411.361
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

The Confluence of Oak Creek and the Verde River

Site Photographs

Name: DSCF0019.jpg

Azimuth: 38 **Zoom:** 1x

Notes: Looking up Oak Creek Canyon.

Name: DSCF0020.jpg

Azimuth: 330 **Zoom:** 1x

Notes: Looking up the Verde River valley.

Name: DSCF0021.jpg

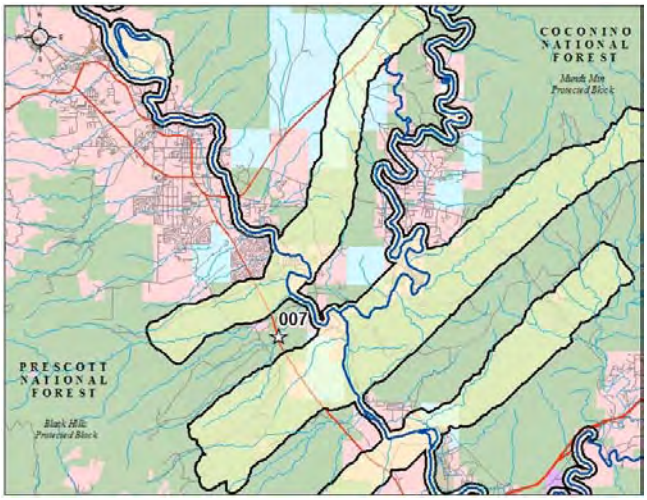
Azimuth: 134 **Zoom:** 1x

Notes: Looking downstream below the confluence.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	007		
Linkage Zone:	Verde Linkage	**Latitude:**	34.66909303	**Longitude:**	-111.969572
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	411168.7521	**UTM Y:**	3836775.308
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Azimuth: 210 **Zoom:** 1x

Notes: Bridge spanning Wilbur Canyon on Highway 260.

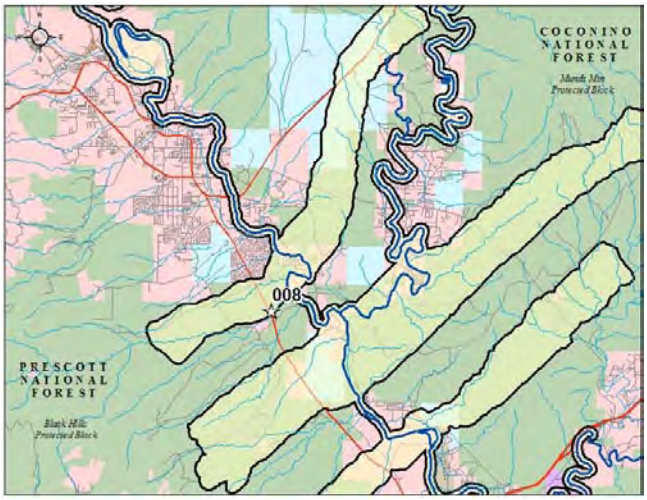
Azimuth: 2 **Zoom:** 1x

Notes: Looking downstream in Wilbur Canyon.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	008		
Linkage Zone:	Verde Linkage	**Latitude:**	34.67827583	**Longitude:**	-111.97277
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	410885.5786	**UTM Y:**	3837796.468
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Azimuth: 220 **Zoom:** 1x

Notes: Bridge spanning Black Canyon on Highway 260.

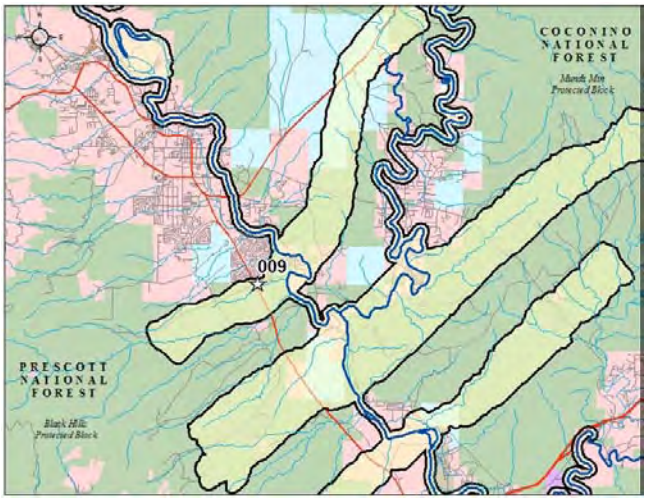
Azimuth: 40 **Zoom:** 1x

Notes: Looking downstream in Black Canyon.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	009		
Linkage Zone:	Verde Linkage	**Latitude:**	34.68885915	**Longitude:**	-111.979308
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	410298.0688	**UTM Y:**	3838975.924
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

Azimuth: 200 **Zoom:** 1x

Notes: A small box culvert under Highway 260.

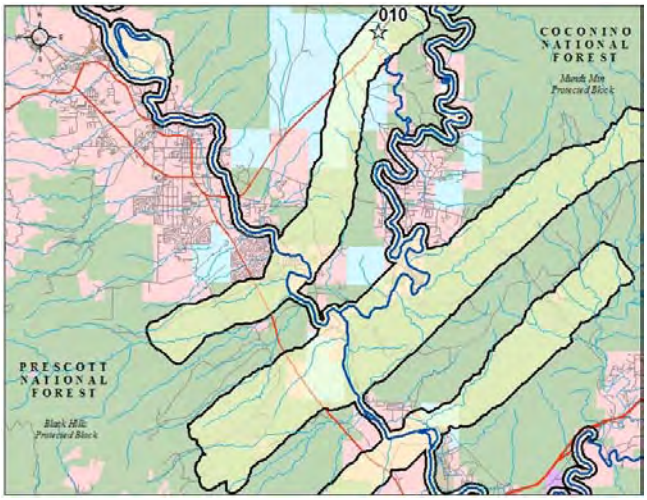
Azimuth: 200 **Zoom:** 2x

Notes: Close up of box culvert.

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	010		
Linkage Zone:	Verde Linkage	**Latitude:**	34.78378396	**Longitude:**	-111.925435
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	415329.6921	**UTM Y:**	3849456.066
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Site Photographs

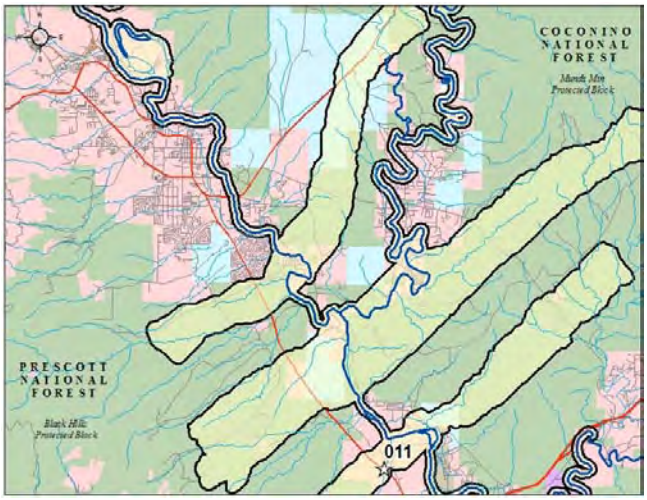
Azimuth: 80 **Zoom:** 1x

Notes: A new bridge spanning the Southbound lanes of 89A over Spring Creek (a similar one one spans the Northbound lanes.)

Appendix G: Database of Field Investigations

Linkage #:	36	**Waypoint #:**	011		
Linkage Zone:	Verde Linkage	**Latitude:**	34.619639	**Longitude:**	-111.920878
Observers:	Paul Beier, Emily Garding, Dan Majka	**UTM X:**	415579.5	**UTM Y:**	3831249
Field Study Date:	8/29/2006	**Last Printed:**	9/22/2006		

Waypoint Map



Waypoint Notes

Bridge over Cherry Creek on Arizona Highway 260.

Site Photographs

Azimuth: 210 **Zoom:** 1x

Notes: Looking upstream at the eastern portion of the 4 span bridge.

Azimuth: 204 **Zoom:** 1x

Notes: Looking upstream at the western portion of a 4 span bridge.

Azimuth: 50 **Zoom:** 1x

Notes: Looking downstream.

Zoom: 1x

Notes: Cliff swallow nests located under the bridge.