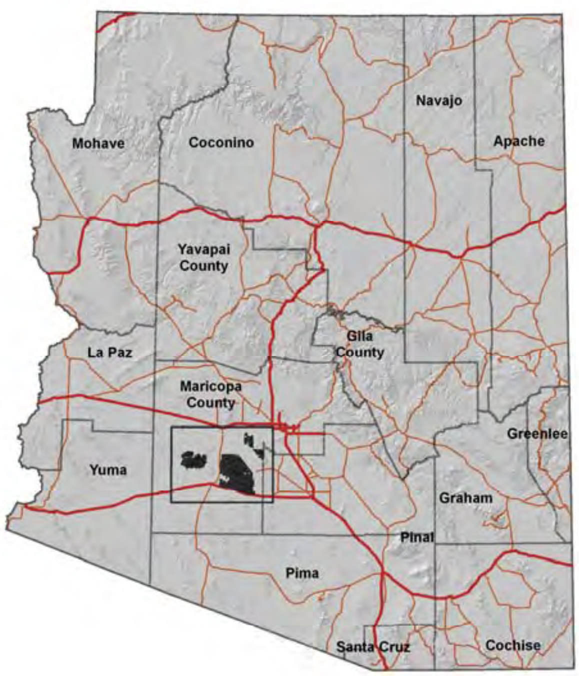
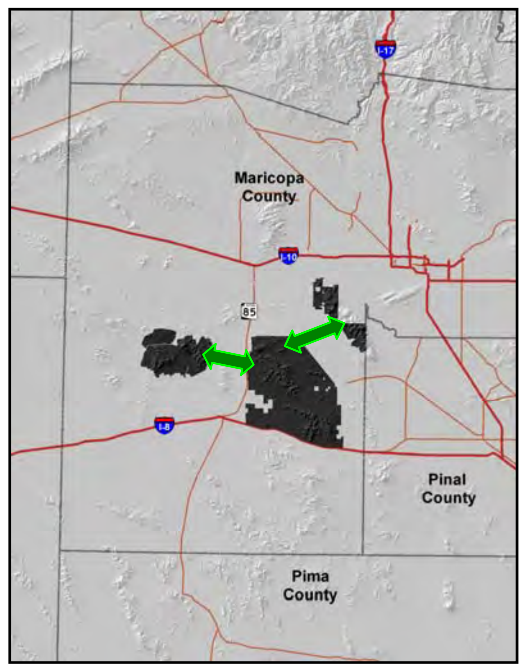
ARIZONA MISSING LINKAGES

Gila Bend - Sierra Estrella Linkage Design

Paul Beier, Emily Garding, Daniel Majka
2008

GILA BEND - SIERRA ESTRELLA LINKAGE DESIGN





Acknowledgments
This project would not have been possible without the help of many individuals. We thank Dr. Phil Rosen, Matt Good, Chasa O'Brien, Dr. Jason Marshal, Ted McKinney, and Taylor Edwards 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, Bill Broyles, Dale Turner, David Brown, Jeff Servoss 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., E. Garding, and D. Majka. 2008. Arizona Missing Linkages: Gila Bend – Sierra Estrella 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 AND EXISTING CONSERVATION INVESTMENTS IN THE REGION 2
THREATS TO CONNECTIVITY 3

LINKAGE DESIGN & RECOMMENDATIONS 5

TWO LINKAGES PROVIDE CONNECTIVITY ACROSS A DIVERSE LANDSCAPE 5
LAND OWNERSHIP, LAND COVER, AND TOPOGRAPHIC PATTERNS WITHIN THE LINKAGE DESIGN 5
REMOVING AND MITIGATING BARRIERS TO MOVEMENT 10
IMPACTS OF ROADS ON WILDLIFE 10
Mitigation for Roads *11*
Existing Roads, Rail Lines, and canals in the Linkage Design Area *14*
Recommended Crossing Structures in the Gila Bend-SDNM Linkage *15*
Recommended Crossing Structures for highways and railroads in the SDNM-Estrella Linkage *15*
IMPACTS OF CANALS ON WILDLIFE 18
Canals in the Gila Bend Mountains-Sonoran Desert National Monument Linkage *18*
Mitigation for Canals *18*
URBAN DEVELOPMENT AS BARRIERS TO MOVEMENT 21
Urban Barriers in the Linkage Design Area *22*
Mitigation for Urban Barriers *25*
IMPEDIMENTS TO THE GILA RIVER 26
Importance of Riparian Systems in the Southwest *26*
Stream Impediments in the Linkage Design Area *26*
Mitigating Stream Impediments *26*

APPENDIX A: LINKAGE DESIGN METHODS 28

FOCAL SPECIES SELECTION 28
HABITAT SUITABILITY MODELS 29
IDENTIFYING POTENTIAL BREEDING PATCHES & POTENTIAL POPULATION CORES 30
IDENTIFYING BIOLOGICALLY BEST CORRIDORS 31
PATCH CONFIGURATION ANALYSIS 32
MINIMUM LINKAGE WIDTH 33
FIELD INVESTIGATIONS 34

APPENDIX B: INDIVIDUAL SPECIES ANALYSES 35

BOBCAT (*LYNX RUFUS*) 37
DESERT BIGHORN SHEEP (*OVIS CANADENSIS NELSONI)* 41
DESERT TORTOISE (*GOPHERUS AGASSIZII*) 45
GILA MONSTER (*HELODERMA SUSPECTUM*) 49
JAVELINA (*TAYASSU TAJACU*) 53
MOUNTAIN LION (*PUMA CONCOLOR*) 57
MULE DEER (*ODOCOILEUS HEMIONUS*) 61

APPENDIX C: SUGGESTED FOCAL SPECIES NOT MODELED 65

APPENDIX D: CREATION OF LINKAGE DESIGN 66
APPENDIX E: DESCRIPTION OF LAND COVER CLASSES 68
APPENDIX F: LITERATURE CITED 71
APPENDIX G: DATABASE OF FIELD INVESTIGATIONS 77

List of Tables & Figures

List of Tables

Table 1: Focal species for the Gila Bend – Sierra Estrella Linkage vii
Table 2: Approximate land cover in the Linkage Design 6
Table 3. Characteristics which make species vulnerable to the three major direct effects of roads (from Forman et al. 2003). 10
Table 4: Major roads and canals in the Linkage Design 15
Table 5: Habitat suitability scores and factor weights for each species. Scores range from 1 (best) to 10 (worst), with 1-3 indicating optimal habitat, 4-5 suboptimal but usable habitat, 6-7 occasionally used but not breeding habitat, and 8-10 avoided. 35

List of Figures

Figure 1: The Linkage Design connects the Sonoran Desert National Monument to two other public wildlands, namely the Gila Bend Mountains to the west and the Sierra Estrella to the east. ... viii
Figure 2: Conservation investments in the linkage planning area 4
Figure 3: Land cover in Linkage Design and the linkage planning area. 7
Figure 4: Topographic diversity in the East Strand of the Linkage Design: a) Topographic position, b) Slope, ... 8
Figure 5: Topographic diversity in the West Strand of the Linkage Design: a) Topographic position, b) Slope, c) Aspect 9
Figure 6: 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. 12
Figure 7: One of the 5x10-foot box culverts that occur about every half mile along SR-85 in the Gila Bend-SDNM Linkage, providing movement for most species except bighorn sheep and mule deer... 16
Figure 8: Field investigation waypoints (stars), and existing and potential locations for crossings in the Linkage Planning Area. The accompanying CD-ROM includes photographs taken at most waypoints. 17
Figure 9: Canals in the Linkage Design area. 19
Figure 10: The Enterprise Canal has steep banks that could prevent wildlife movement or trap animals inside the canal (waypoint 77). 20
Figure 11: Narrow, poorly vegetated gaps like this one present the only opportunities for wildlife to cross the canals (waypoint 78). 20
Figure 12: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres. Data based on measurements in 60 landscapes in rural San Diego County, California (CBI 2005). 21
Figure 13: The proposed Amaranth development would bring over half a million people into this landscape; Estrella Mountains on the horizon (Waypoint 95, azimuth 25). 23
Figure 14: The proposed development in the Sonoran Valley Planning Area poses a significant threat to wildlife connectivity. 24
Figure 15: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads. 30
Figure 16: 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 31
Figure 17: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape. 33
Figure 18: Modeled habitat suitability of bobcat in the SDNM-Sierra Estrella Linkage. 38
Figure 19: Potential habitat patches and cores for bobcat in the SDNM-Sierra Estrella Linkage. 39
Figure 20: Modeled habitat suitability of bobcat in the Gila Bend-SDNM Linkage. 39

Figure 21: Potential habitat patches and cores for bobcat in the Gila Bend-SDNM Linkage. 40
Figure 22: Modeled habitat suitability of bighorn sheep in the SDNM-Sierra Estrella Linkage. 43
Figure 23: Potential habitat patches and cores for bighorn sheep in the SDNM-Sierra Estrella Linkage. 43
Figure 24: Modeled habitat suitability of bighorn sheep in the Gila Bend-SDNM Linkage. 44
Figure 25: Potential habitat patches and cores for bighorn sheep in the Gila Bend-SDNM Linkage. 44
Figure 26: Modeled habitat suitability of desert tortoise in the SDNM-Sierra Estrella Linkage. 46
Figure 27: Potential habitat patches and cores for desert tortoise in the SDNM-Sierra Estrella Linkage. 47
Figure 28: Modeled habitat suitability for desert tortoise in the Gila Bend-SDNM Linkage. 47
Figure 29: Potential habitat patches and cores of desert tortoise in the Gila Bend-SDNM Linkage. ...48
Figure 30: Modeled habitat suitability of gila monster in the SDNM-Sierra Estrella Linkage. 50
Figure 31: Potential habitat patches and cores for gila monster in the SDNM-Sierra Estrella Linkage. 51
Figure 32: Modeled habitat suitability of gila monster in the Gila Bend-SDNM Linkage........................51
Figure 33: Potential habitat patches and cores for gila monster in the Gila Bend-SDNM Linkage.......52
Figure 34: Modeled habitat suitability of javelina in the SDNM-Sierra Estrella Linkage. 54
Figure 35: Potential habitat patches and cores for javelina in the SDNM-Sierra Estrella Linkage. ...55
Figure 36: Modeled habitat suitability for javelina in the Gila Bend-SDNM Linkage..............................55
Figure 37: Potential habitat patches and cores for javelina in the Gila Bend-SDNM Linkage. 56
Figure 38: Potential habitat patches and cores for mountain lion in the SDNM-Sierra Estrella Linkage. 58
Figure 39: Modeled habitat suitability for mountain lion in the SDNM-Sierra Estrella Linkage.........59
Figure 40: Modeled habitat suitability of mountain lion in the Gila Bend-SDNM Linkage. 59
Figure 41: Potential habitat patches and cores for mountain lion in the Gila Bend-SDNM Linkage.....60
Figure 42: Modeled habitat suitability of mule deer in the SDNM-Sierra Estrella Linkage. 62
Figure 43: Potential habitat patches and cores for mule deer in the SDNM-Sierra Estrella Linkage. 63
Figure 44: Modeled habitat suitability of mule deer in the SDNM-Sierra Estrella Linkage. 63
Figure 45: Potential habitat patches and cores for mule deer in the Gila Bend-SDNM Linkage. 64
Figure 46: Adjustments to the Union of Biologically Best Corridors to create the Linkage Design....67
Figure 47: Waypoints marking field investigation sites within the linkage planning area 77

Terminology

Key terminology used throughout the report includes:

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

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

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

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

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

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

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

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

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

Executive Summary

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

Arizona is fortunate to have vast conserved wildlands that are fundamentally one interconnected ecological system. In this report, we use a scientific approach to design a corridor (Linkage Design) that will conserve and enhance wildlife movement between three large areas of BLM-administered wildlands in south-central Arizona. Running roughly north-west through this region, Arizona State Route 85 (SR 85) and associated traffic and urban development may impede animal movement between the Gila Bend Mountain range on the west and the Sonoran Desert National Monument and Sierra Estrella Mountain range 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, we asked academic scientists, agency biologists, and conservation organizations to identify species sensitive to habitat loss and fragmentation. They identified 24 species, including 1 amphibian, 14 reptiles, 3 birds, 1 plant, and 5 mammals (Table 1). These focal species cover a broad range of habitat and movement requirements. Some require huge tracts of land to support viable populations (e.g. mountain lion). Some species are habitat specialists (e.g. bighorn sheep, Gila Monster), and others are reluctant or unable to cross barriers such as freeways (e.g. mule deer, desert tortoise). Some species are rare and/or endangered while others like javelina are common but still need gene flow among populations. All the focal species are part of the natural heritage of this mosaic of Sonoran Desert. Together, these species use a wide array of habitats, so that the linkage design should cover connectivity needs for other species as well.

To identify potential routes between existing protected areas we used GIS methods to identify a biologically best corridor for each focal species to move between these wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final Linkage Design provides live-in or move-through habitat for each focal species. The Linkage Design (Figure 1) includes two linkages. The first provides habitat for movement and reproduction of wildlife between the Gila Bend Mountain range and the Sonoran Desert National Monument, where two agricultural canals, SR-85, and agricultural land use threatens wildlife movement. The second provides connectivity between Sonoran Desert National Monument and the Sierra Estrella, where proposed urban developments threaten connectivity. We visited priority areas in the field to provide detailed mitigations for barriers to animal movement in the section titled *Linkage Design and Recommendations*.

The Gila Bend region provides significant ecological, educational, recreational, and spiritual values of wildlands. 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 Gila Bend, Sonoran Desert, and Sierra Estrella wildland blocks, but should also conserve large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the US Forest Service, Arizona State Parks, Bureau of Land Management, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and other conservancy lands.

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

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

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

Table 1: Focal species for the Gila Bend – Sierra Estrella Linkage

MAMMALS	AMPHIBIANS & REPTILES	BIRDS
*Bighorn Sheep	*Desert Tortoise	Gambel's Quail
*Bobcat	*Gila Monster	Road Runner
*Javelina	Desert Iguana	Burrowing Owl
*Mountain Lion	Giant Spotted Whiptail Lizard	**FLORA**
*Mule Deer	Leopard Chuckwalla	Night Blooming Cereus
	Long-tailed Lizard	
	Red-backed Whiptail	
	Regal Ringneck Snake	
	Rosy Boa	
	Side-blotched Lizard	
	Tiger Whiptail	
	Tree Lizard	
	Tucson Shovel-nosed Snake	
	Zebra tailed Lizard	
	Sonoran Desert Toad	

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

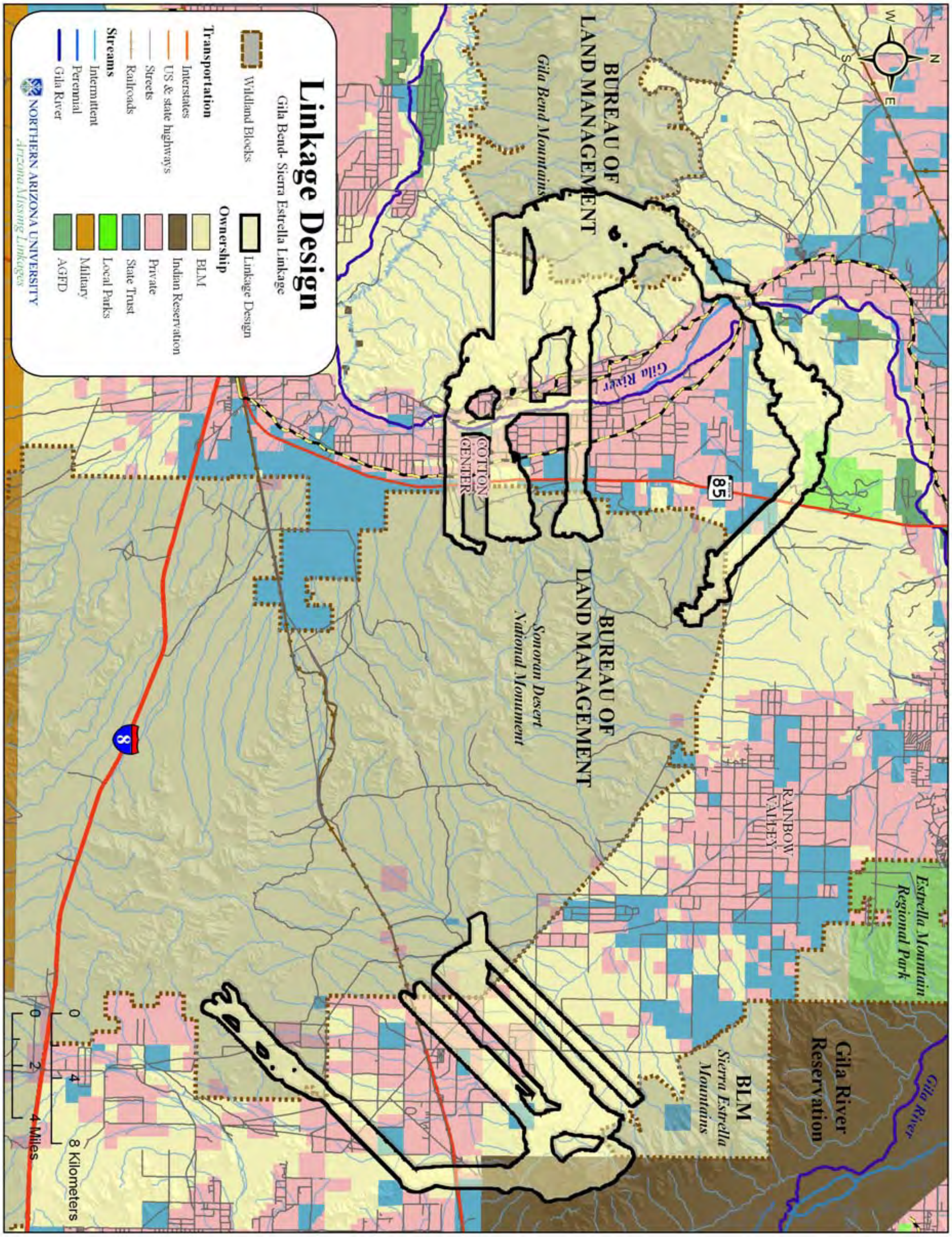


Figure 1: The Linkage Design connects the Sonoran Desert National Monument to two other public wildlands, namely the Gila Bend Mountains to the west and the Sierra Estrella to the east.

Introduction

Nature Needs Room to Move

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

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

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

A Statewide Vision

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

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

Ecological Significance and Existing Conservation Investments in the Region

The Linkage Planning Area includes three wildland blocks in the Sonoran Desert Ecoregion, namely the Gila Bend Mountains, Sonoran Desert National Monument, and Sierra Estrella Mountains. The Sonoran Desert Ecoregion consists of 55 million acres in southern Arizona, southeastern California, northern Baja California, and northwestern Sonora (Marshall et al. 2000). This ecoregion is the most tropical of North America's warm deserts (Marshall et al. 2000). Bajadas sloping down from the mountains support forests of ancient saguaro cacti, paloverde, and ironwood; creosotebush and bursage desert shrub dominate the lower desert (The Nature Conservancy 2006). The Sonoran Desert Ecoregion is home to more than 200 threatened species, and its uniqueness lends to a high proportion of endemic plants, fish, and reptiles (Marshall et al. 2000, The Nature Conservancy 2006). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of the earth's most biologically valuable ecoregions, whose conservation is critical for maintaining the earth's biodiversity.

The **Gila Bend Mountains**, administered by the Bureau of Land Management, include lava flows, rugged peaks up to 3,270 ft at Woolsey Peak, and desert flats. For purposes of modeling an optimal wildlife linkage, we delineated the Gila Bend wildland block as consisting of the 64,000-acre Woolsey Peak Wilderness Area and the adjacent 13,350-acre Signal Mountain Wilderness Area (Figure 2). The vegetation is dominated by paloverde, creosote, saguaro, cholla cacti, mesquite, and ironwood.

The **Sonoran Desert National Monument**, administered by the Bureau of Land Management, includes about 500,000 acres north of Interstate 8, and a similar amount of land south of Interstate 8. For purposes of this plan, the Sonoran Desert National Monument consists only of SDNM land north of the freeway. The wildland block include the South and North Maricopa Mountains Wilderness Areas (each over 60,000 acres), known for their saguaro cactus forests and desert plains. The monument includes a spectacular diversity of plant and wildlife species. Some of the higher peaks include unique woodland assemblages, while much of the lower elevation lands offer a palo verde-mixed cacti association unique to the Sonoran Desert. The forests are dominated by saguaros, palo-verde trees, ironwood, prickly pear, and cholla. Important natural watering holes occur in the monument. Interstate 8 forms the southern boundary of the block. South of I-8, SDNM includes Sand Tank and Table Top Wilderness areas (Figure 2).

The **Sierra Estrella** wildland block includes the 19,840-acre Estrella Mountain Regional Park, which includes a riparian area near the confluence of the Gila and Agua Fria Rivers, and the 14,400-acre Sierra Estrella Wilderness Area administered by the Bureau of Land Management. This block is bordered to the east by the Gila Indian Reservation. It is known for its steep slopes, rocky canyons, and extreme elevation changes. Landcover here includes saguaro, cholla, paloverde, and small patches of juniper at higher elevations.

The Gila River is an important riparian resource within the Linkage Planning Area (Figure 1). The Linkage Planning Area supports many animal species. Species listed as threatened or endangered by the U.S. Fish and Wildlife Service (2005) include desert tortoise and bighorn sheep; the Linkage Design connects important habitat for these species. Bighorn sheep occur in all 3 mountain ranges, but with fewer than 100 animals in any one wildland block, connectivity for gene flow is critical to their well-being. Far-ranging mammals such as mule deer, bobcat, and mountain lion need to move long distances to access suitable foraging or breeding sites, and need corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as javelina and Gila monsters also need corridors to maintain genetic diversity, allow populations to shift their range in response to climate change, and promote recolonization after fire or epidemics. This linkage design will provide the connected habitats needed to sustain populations of these and other species.

Threats to Connectivity

Major potential barriers in the Potential Linkage Area include SR-85, irrigation canals, and agricultural and urban development. Home to 60 percent of Arizona's population, Maricopa County is the nation's fourth largest county in population size. Between 1990 and 1997, Maricopa County experienced the largest net increase in population of any county in the US, adding 575,000 residents. Although there are probably fewer than 500 people living in the linkage area today, the proposed Amaranth development would increase this to over 10,000 people. Other developments will replace farmland in Rainbow Valley (soon to marketed as Sonoran Valley) and the Gila River valley along SR-85.

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

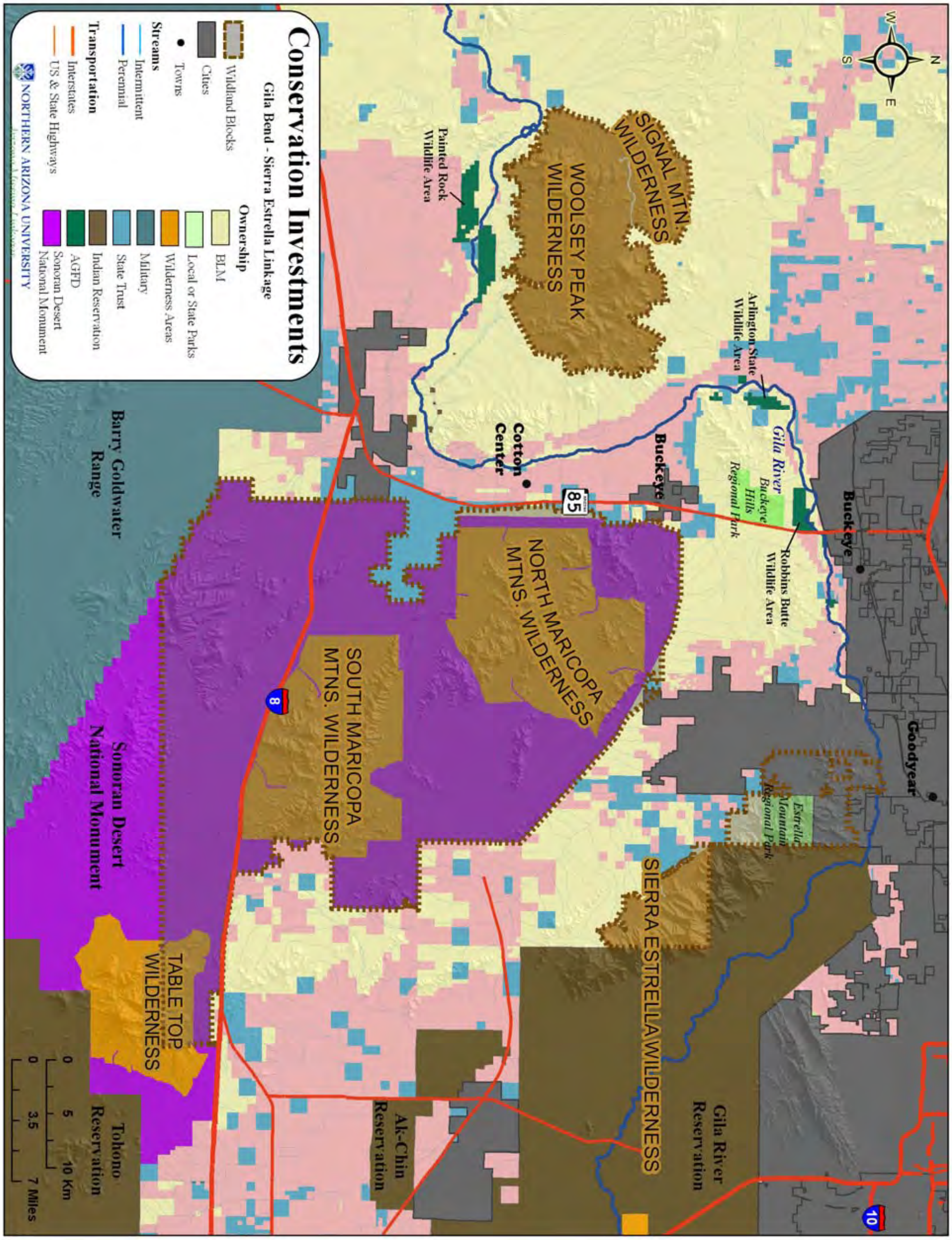


Figure 2: Conservation investments in the linkage planning area

Linkage Design & Recommendations

The Linkage Design (Figure 1) is composed of two linkages which together provide habitat for movement and reproduction of wildlife between three large areas of public wildlands in the Gila Bend area. In this section, we describe the linkage design and recommend mitigations for barriers to animal movement. Methods for developing the Linkage Design are described in Appendix A.

Two Linkages Provide Connectivity Across a Diverse Landscape

The linkage design consists of two linkages, one connecting Sonoran Desert National Monument to the Gila Bend Mountains, and another connecting Sonoran Desert National Monument to the Sierra Estrella.

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 **Sonoran Desert National Monument-Gila Bend Mountains linkage** has three main strands that serve bobcat, desert bighorn sheep, desert tortoise, gila monster, javelina, and mule deer. The linkage passes over the Gila River, urban and agricultural development near the town of Gila Bend, and SR-85. The linkage is about 20 km long, and primarily composed of Creosotebush-White Bursage Desert Scrub (62%), Paloverde-Mixed Cacti Desert Scrub (30%), and Agriculture (7%). About 65% of the linkage is flat to gently sloped (65%) and steep slopes are common (22% of area). The average slope is 15% (Range: 0-142%, SD: 20.8).

The **Sonoran Desert National Monument-Sierra Estrella linkage** has three main strands that serve bobcat, desert bighorn sheep, desert tortoise, gila monster, javelina, and mule deer. It runs from the Sonoran Desert National Monument to the Sierra Estrella Mountains. This strand is primarily composed of Paloverde-Mixed Cacti Desert Scrub (93%), with small amounts Creosotebush-White Bursage Desert Scrub (61%), and Paloverde-Mixed Cacti Desert Scrub (31 %). It is topographically complex, with an average slope of 11.8% (Range: 0-118%, SD: 19.7). Nearly three-quarters (74%) of the land is classified as flat to gentle slopes, 6% as ridgetops, and 4% as canyon bottoms, and the remainder (16%) as steep slopes.

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

The 50,175 acres (20,305 ha) Linkage Design is composed of 76% Bureau of Land Management land, 18% Private land, 4% Gila River Indian Reservation, and 3% State Trust land (Figure 1). Two natural vegetation communities account for over 90% of the land cover (Table 2) and developed or agricultural lands account for approximately 4% of the linkage design, mostly in the western linkage (Figure 3). Natural vegetation is dominated by Creosotebush-White Bursage Desert Scrub and Paloverde-Mixed Cacti Desert Scrub.

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 in response to future climate change. Southwestern aspects dominate the land in the linkage design.

Table 2: Approximate land cover in the Linkage Design

SDNM-Estrella Linkage			
Land Cover Class	Acres	Hectares	% of Area
Agriculture	0	0	0%
Creosotebush-White Bursage Desert Scrub	17703	7164	59%
Desert Scrub misc	122	49	0.4%
Developed	15	6	0.1%
Invasive Southwest Riparian Woodland and Shrubland	0	0	0%
Paloverde-Mixed Cacti Desert Scrub	12107	4900	40%
Juniper Savanna	1	0	0%
Riparian Mesquite Bosque	6	2	0%
Gila Bend Mountains-SDNM Linkage			
Land Cover Class	Acres	Hectares	% of Area
Agriculture	1993	807	4%
Creosotebush-White Bursage Desert Scrub	25560	10344	54%
Desert Scrub misc	55	22	0.1%
Developed	0	0	0%
Invasive Southwest Riparian Woodland and Shrubland	100	40	0.2%
Paloverde-Mixed Cacti Desert Scrub	19193	7767	41%
Juniper Savanna	25	10	0.1%
Riparian Mesquite Bosque	35	14	0.1%
Entire Linkage			
Land Cover Class	Acres	Hectares	% of Area
Agriculture	1996	808	3%
Creosotebush-White Bursage Desert Scrub	43400	17563	56%
Desert Scrub misc	179	72	0.23%
Developed	14	6	0.02%
Invasive Southwest Riparian Woodland and Shrubland	101	41	0.13%
Paloverde-Mixed Cacti Desert Scrub	31340	12683	41%
Juniper Savanna	27	11	0.04%
Riparian Mesquite Bosque	42	17	0.05%

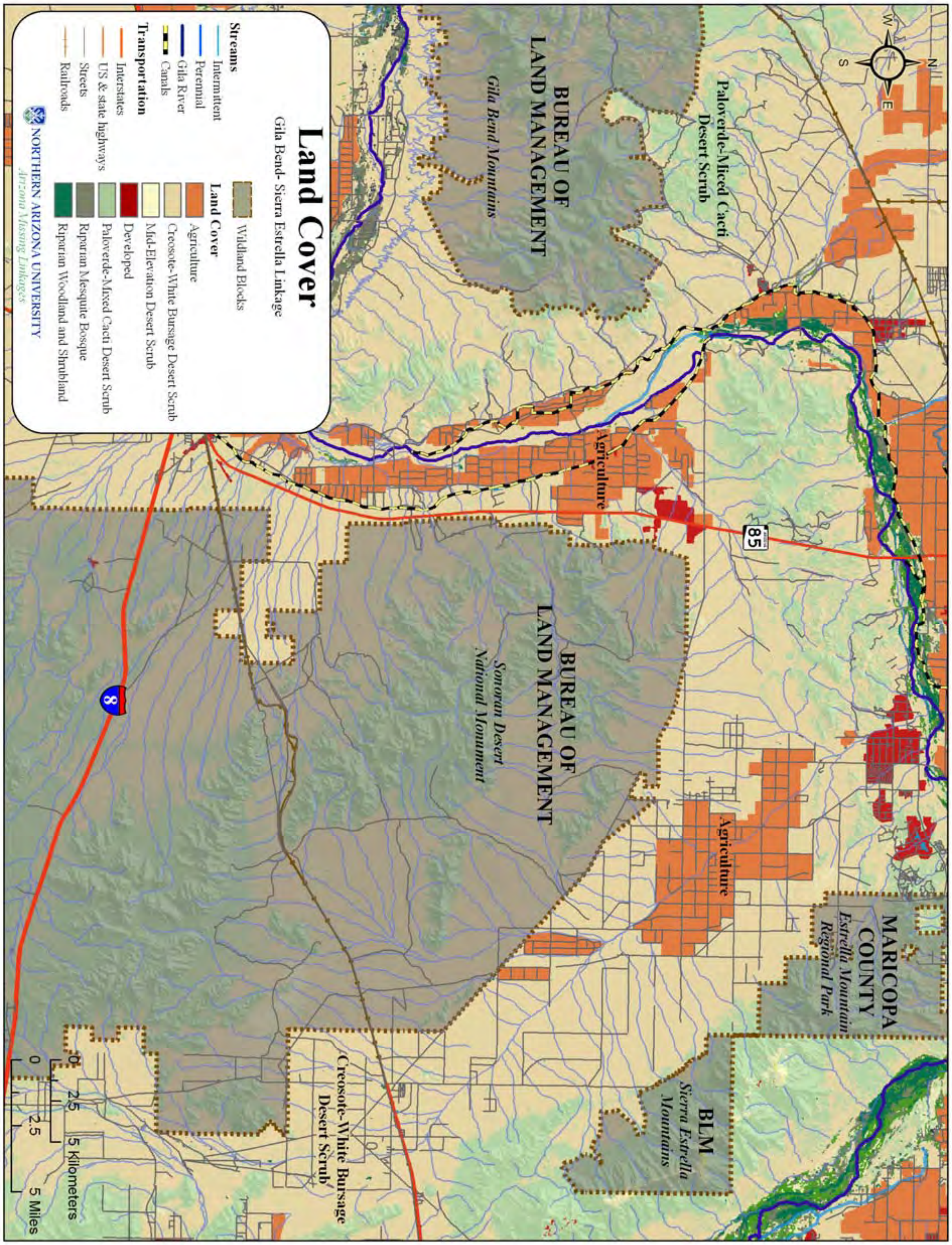


Figure 3: Land cover in Linkage Design and the linkage planning area.

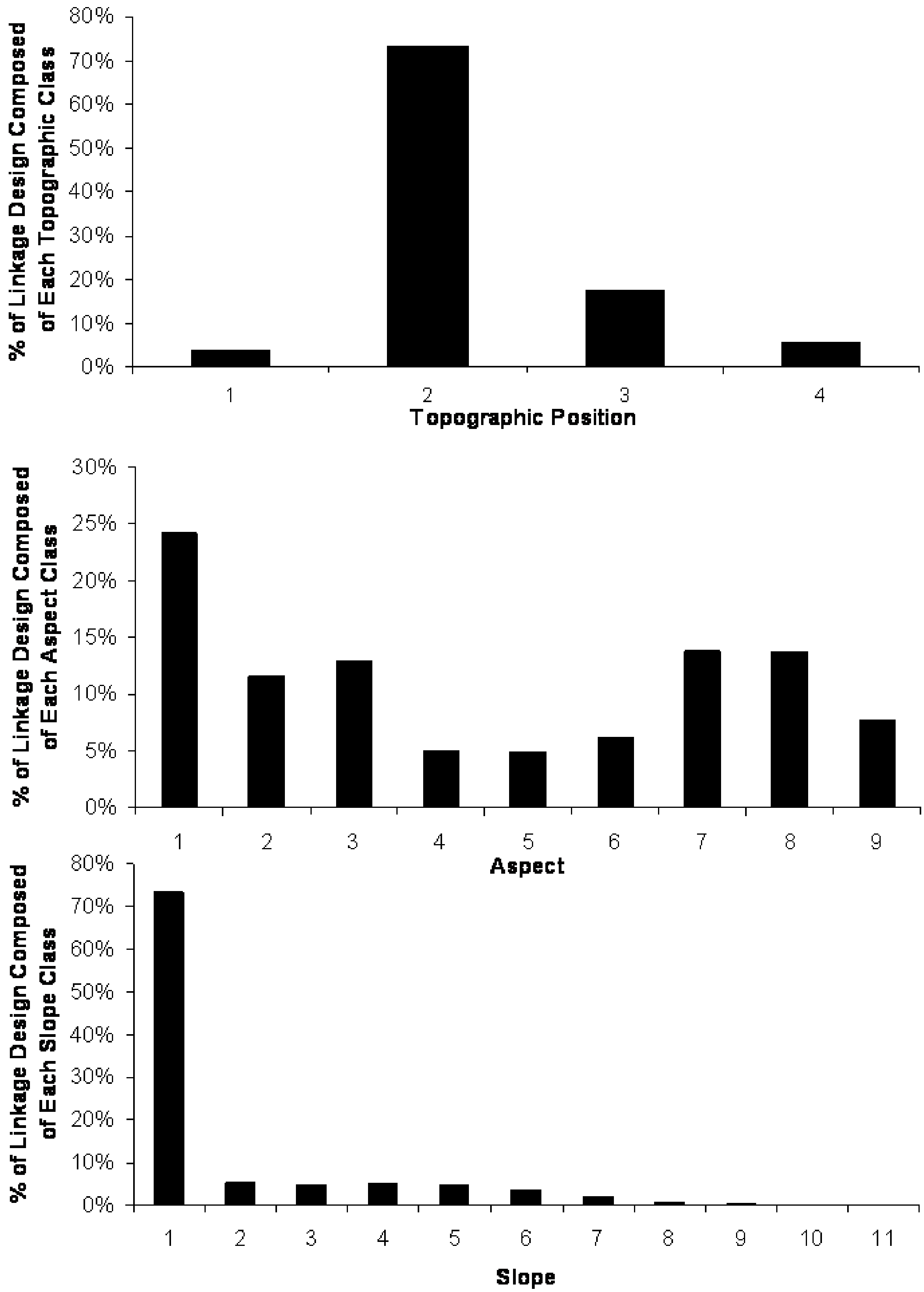


Figure 4: Topographic diversity in the East Strand of the Linkage Design: a) Topographic position, b) Slope, c) Aspect

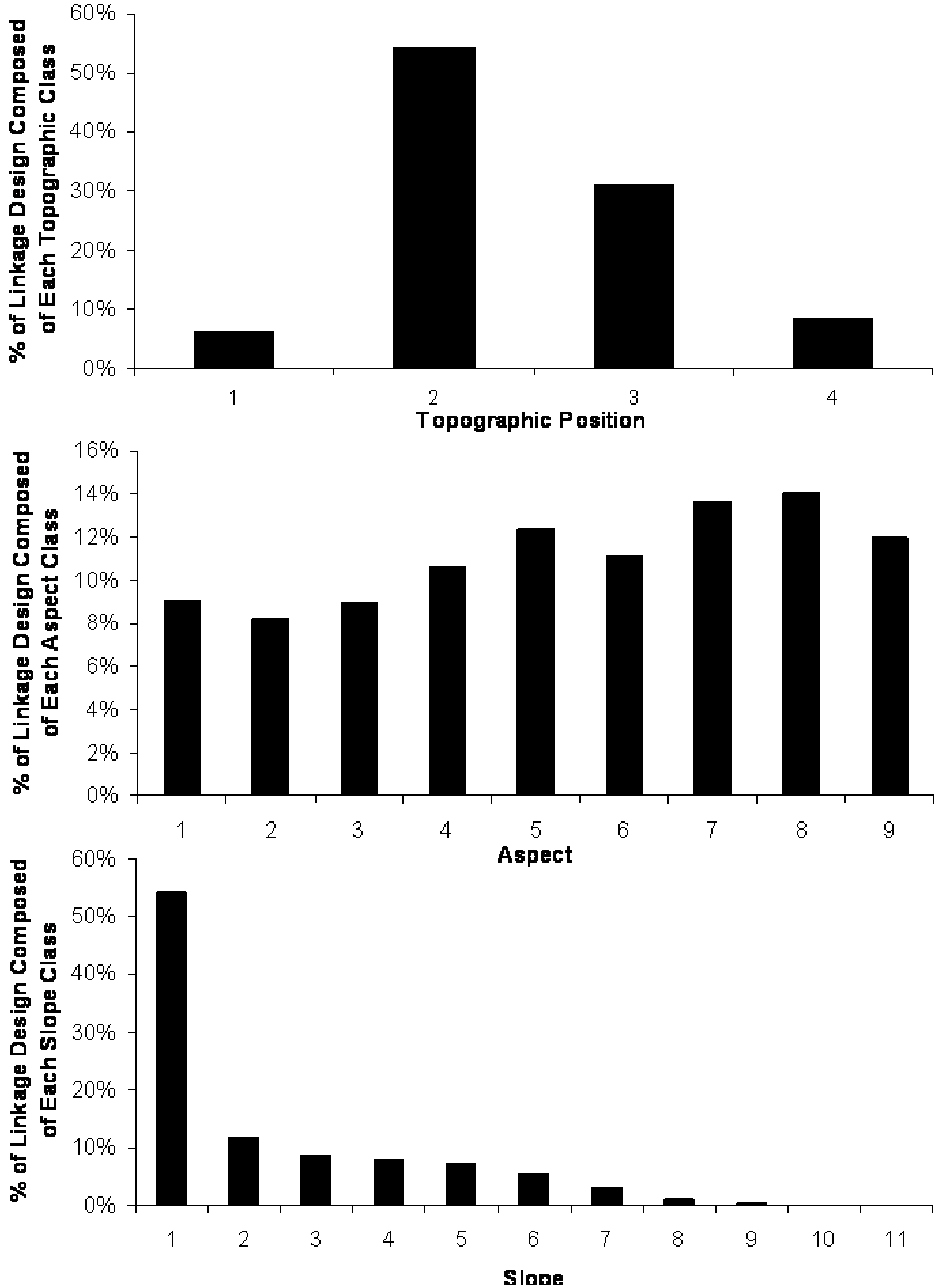


Figure 5: Topographic diversity in the West Strand of the Linkage Design: a) Topographic position, b) Slope, c) Aspect

Removing and Mitigating Barriers to Movement

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

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

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Table 3). 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).

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

Characteristics making a species vulnerable to road effects	Effect of roads		
	Road mortality	Habitat loss	Reduced connectivity
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		
Multiple-resource needs	★		★
Large area requirement/low density	★	★	★
Low reproductive rate	★	★	★
Behavioral avoidance of roads			★

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses & green bridges, bridges, culverts, and pipes (Figure 6). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004).

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

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

Figure 6: 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.

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

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

Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

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

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

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

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

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

Existing Roads, Rail Lines, and canals in the Linkage Design Area

There are approximately 184 km (114 mi) of transportation routes in the Linkage Design, including 10.6 km (6.6 mi) of the Union Pacific Railroad, 4.7 km (3.0 mi) of highways, 24.7 km (15.4 mi of canals, and 128 km (80 mi) of local roads (Table 4). We conducted field investigations of many of these potential barriers to document existing crossing structures that could be modified to enhance wildlife movement through the area.

Table 4: Major roads and canals in the Linkage Design

SDNM-Estrella Linkage			Gila Bend Mountains-SDNM Linkage		
Road Name	**Km**	**Miles**	**Road Name**	**Km**	**Miles**
State Route 85	6.4	4.0	State Route 238	1.4	0.8
Old US 80	5.8	3.5	99th Ave	6.7	4.2
Pierpoint Rd	8.7	5.4	107th Ave	3.7	2.3
Enterprise Rd	5.9	3.7	Gas Pipeline Rd	2.7	1.7
Wood Rd	2.1	1.3	Voah Shun Rd	1.6	1.0
Komatke Rd	1.8	1.1	Maricopa Rd	1.5	0.9
295th Ave	1.2	0.7	Prancer Rd	1.4	0.8
Roads less than 1 kilometer	1.3	0.8	Komatke Rd	1.2	0.7
Gas Pipeline Rd	0.3	0.2	Roads less than 1 kilometer	0.9	0.6
Gilks Ranch Rd	0.2	0.1	Unnamed Roads	37.2	23.1
Rainbow Wash	0.8	0.5	Railroads	10.6	6.6
Unnamed Roads	79.8	49.6	Canals	0	0
Railroads	0	0			
Canals	24.7	15.4			
Total (excluding canals)	114.3	71.0	Total	69.7	43.3

Recommended Crossing Structures in the Gila Bend-SDNM Linkage

The Gila Bend Canal and Enterprise Canal are **the most serious impediments to animal movement**, far worse than SR-85. The canals are impermeable to wildlife along most of their length (Figure 10). Crossing structures across the canals are typically lacking in vegetation (Figure 11) and are typically over a mile apart. There should be at least one large crossing structure with natural vegetation in every strand of this Linkage.

SR-85 runs north-south through the linkage, and has one or more 5x10-foot box culverts about every 0.5 miles (Figure 7). This is an excellent number and spacing of crossing structures for most focal species. However, mule deer and bighorn sheep need much larger structures. We recommend upgrading the crossing structures described above as follows:

- At milepost 129, waypoint 79, there is a ridge that presents an opportunity for a wildlife overcrossing.
- At milepost 131, waypoint 80, there is a ridge that presents an opportunity for a wildlife overcrossing.
- A large bridge that serves as a wildlife undercrossing should be built at Rainbow Wash, waypoint 87.
- For the existing structures, remove any wire fences across structure entrances. Instead use fencing to guide animals toward the crossing structures. Manage these crossings to ensure that they do not become filled with sediments or otherwise impede movement.

Recommended Crossing Structures for highways and railroads in the SDNM-Estrella Linkage

There were no crossing structures on SR-238 or along the adjacent rail line.

- Underpasses should be constructed under or over the rail line to accommodate desert tortoise, bighorn sheep, and mule deer.
- The expansion or construction of any roads associated with the Amaranth development, (particularly of passing through the Linkage Design) should incorporate wildlife crossing structures (Standards & Guidelines above) to facilitate the passage of small, medium, and large animals.
- The proposed 17-mile road linking the proposed city of Amaranth to Goodyear and I-10 should be a model of wildlife permeability, demonstrating that leapfrog development can occur in a way that does not impede landscape connectivity.

Figure 7: One of the 5x10-foot box culverts that occur about every half mile along SR-85 in the Gila Bend-SDNM Linkage, providing movement for most species except bighorn sheep and mule deer.

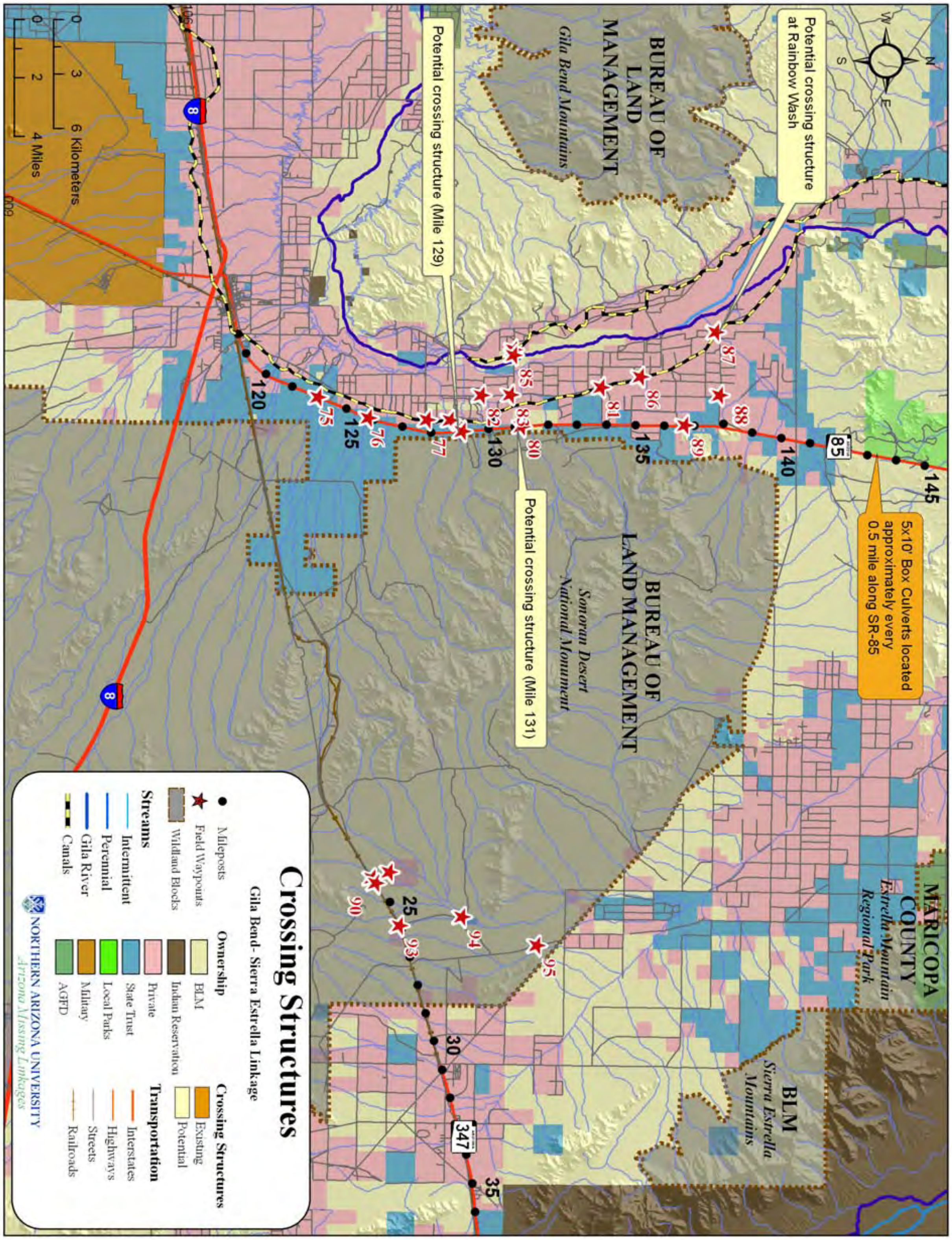


Figure 8: Field investigation waypoints (stars), and existing and potential locations for crossings in the Linkage Planning Area. The accompanying CD-ROM includes photographs taken at most waypoints.

Impacts of Canals on Wildlife

Canals can have both positive and negative impacts on desert wildlife. While some species may use canals as a water source, desert mule deer, bighorn sheep, and Sonoran pronghorn have all drowned in canals (Rautenstrauch & Krausman 1989). Canals serve as significant barriers to movement by preventing species from moving to viable habitat on the other side of the canal, drowning species, and rerouting natural movement patterns.

Canals in the Gila Bend Mountains-Sonoran Desert National Monument Linkage

The Arlington Canal, Gila Bend Canal, and Enterprise Canal are barriers to wildlife movement in the Gila Bend-Sonoran Desert National Monument Linkage (Figure 9). These canals parallel SR 85 and typically have steep (roughly 45 degree) banks that impede wildlife movement (Figure 10). There are few locations where wildlife can safely cross the canals in the linkage design area (Figure 11). A network of smaller canals lead from these main canals.

Mitigation for Canals

To conserve connectivity, we have the following recommendations for all existing and future canals in this linkage zone:

1) **Ensure opportunities for wildlife to cross every canal in the linkage area**. The most permeable method is to bury these segments of the canal below ground. For narrow canals, such as those irrigating fields, it may be cheaper to cover the canal with metal or concrete slabs, and cover these plates with soil and vegetation. Larger canals are typically elevated on levees that are hard for animals to climb. On such canals, underground siphons should be used to create gaps that follow the natural contour of the land. However, siphon gaps intended for wildlife use should at least 40-50 m wide, have natural vegetation, and follow natural grade of the surrounding un-altered landscape.

2) **Install fencing on all areas of the canal which do not have crossing structures.** This fencing must keep animals away from canals where they are likely to drown (Figure 10, Rautenstrauch & Krausman 1989). They should be high enough that deer can't jump over the fence (Peris & Morales 2004).

3) **Provide alternative water sources adjacent to crossing structures** (Rautenstrauch & Krausman 1989). To discourage use of the canals as a water supply by deer and other species, some canal water should be diverted to catchments where wildlife can drink without risk of drowning.

4) **Provide escape structures for deer and other species along any area of the canal which does not have a crossing structure or fencing.** Cable-and-float directors in conjunction with stairs or ramps should be installed in the canal to direct deer to provide deer and other species means of escaping the canal. In a study of desert mule deer use of the Mohawk Canal, Rautenstrauch and Krausman (1989) found that deer swim an average distance of 947 meters before escaping via escape structures. They recommend escape structures should be spaced 2 km apart or less and every section with a dam, siphon, or other hazard should have more than 1 escape structure, with at least 1 structure upstream from the hazard.

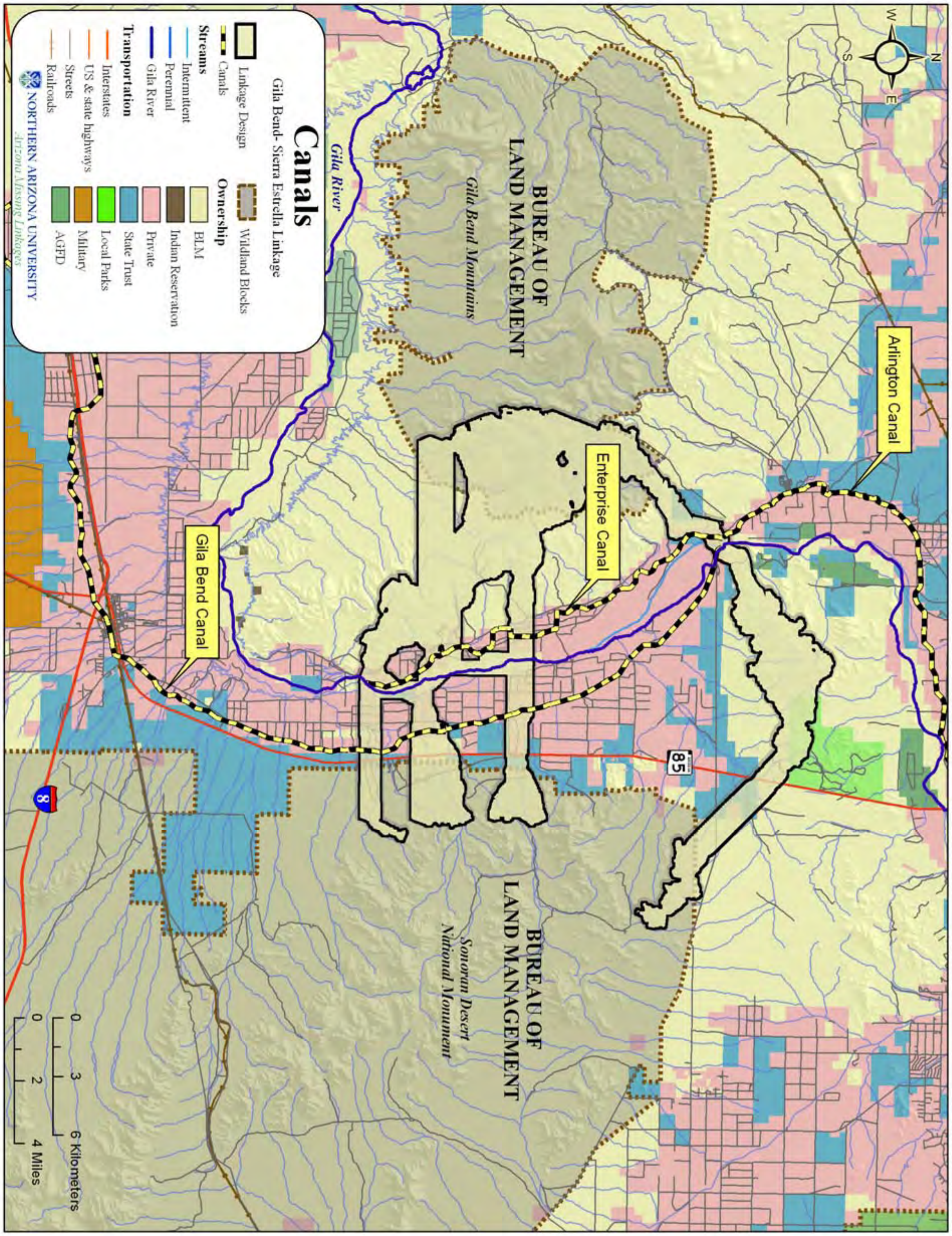


Figure 9: Canals in the Linkage Design area.

Figure 10: The Enterprise Canal has steep banks that could prevent wildlife movement or trap animals inside the canal (waypoint 77).

Figure 11: Narrow, poorly vegetated gaps like this one present the only opportunities for wildlife to cross the canals (waypoint 78).

Urban Development as Barriers to Movement

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

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997).
- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure 12). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation (CBI 2005).

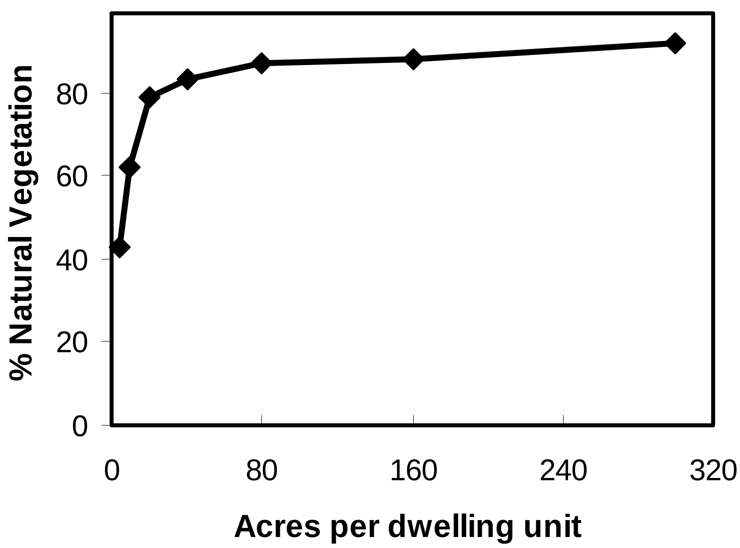


Figure 12: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres. Data based on measurements in 60 landscapes in rural San Diego County, California (CBI 2005).

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

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

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation, force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas currently accounts for less than 4% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Urban Barriers in the Linkage Design Area

The city of Goodyear has plans to annex a proposed development named Amaranth, within the Sonoran Valley Planning Area, that poses a significant threat to wildlife connectivity between the Sonoran Desert National Monument and the Sierra Estrella Mountains (Figure 14). Goodyear has recently developed plans for the Sonoran Valley Planning Area's 60,904 acres of which 51% is managed by the BLM, 9% is state land, and 40% is under private ownership (City of Goodyear 2007). The new city would border Sonoran Desert National Monument; there were fewer than 50 homes in the area in early 2007 (Figure 13). Plans call for over 200,000 homes, plus a network of roads and public services, that would include a

17-mile highway bisecting the Sierra Estrella-SDNM linkage design. Corridors for every focal species, including bighorn, desert tortoise, gila monster, javelina, bobcats, and mule deer are threatened by this proposed development associated roads in the Sonoran Valley Planning Area.

Urbanization is less of a threat in the Gila Bend-SDNM Linkage, but could become a problem if agricultural land is converted to urban uses.

Figure 13: The proposed Amaranth development would bring over half a million people into this landscape; Estrella Mountains on the horizon (Waypoint 95, azimuth 25).

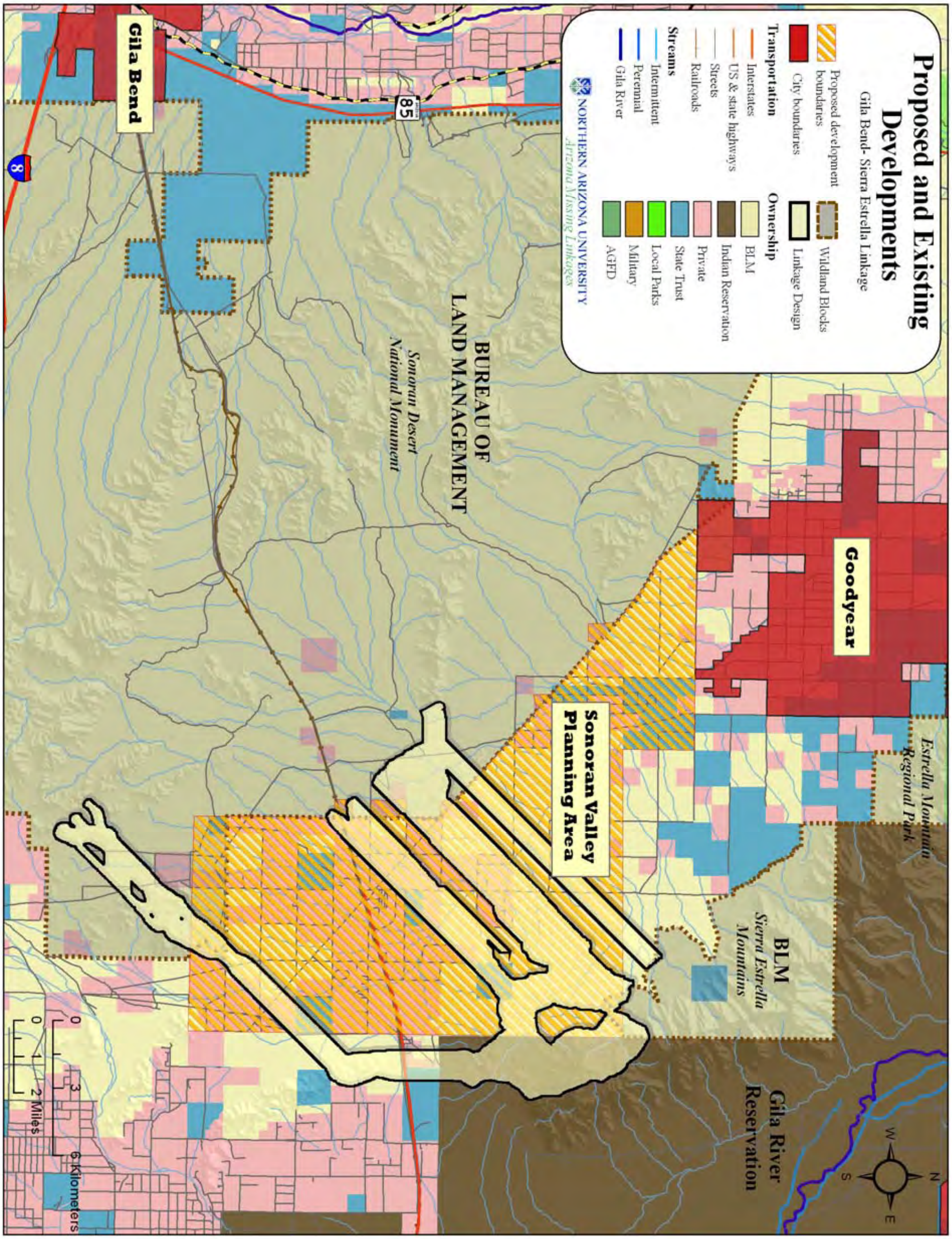


Figure 14: The proposed developments in the Sonoran Valley Planning Area pose a significant threat to wildlife connectivity.

Mitigation for Urban Barriers

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

1) Integrate this Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design.
2) Where development is permitted within the linkage design, encourage small building footprints on large (> 40 acre) parcels with a minimal road network.
3) Integrate this Linkage Design into county general plans, and conservation plans of governments and nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as recreation and protection of water quality.
6) One reason we imposed a minimum width on each strand of the linkage design was to allow enough room for a designated trail system without having to compromise the permeability of the linkage for wildlife. Nonetheless, because of the high potential for human access, the trail system should be carefully planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.
7) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area.
8) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.
9) Develop a public education campaign to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.
10) Discourage residents and visitors from feeding or providing water for wild mammals, or otherwise allowing wildlife to lose their fear of people.
11) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.
12) Do not install artificial night lighting on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
13) Encourage the use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.
14) Discourage the killing of ‘threat’ species such as rattlesnakes.

15) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.
16) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.

Impediments to the Gila River

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Gila River and its associated riparian vegetation provide habitat for many species in the linkage area, including the regal ringneck snake and mountain lion.

Stream Impediments in the Linkage Design Area

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

Mitigating Stream Impediments

We endorse the following management recommendations for riparian connectivity and habitat conservation on the Gila 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 Gila River watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000)].
- Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
- Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993). However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kupferberg 1997, Kiesecker and Blaustein 1998, Maret et al. 2006).

2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops,

and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).

3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of the river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite *bosques* should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).
4) **Maintain biotic interactions within evolved tolerance ranges**. Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas (Belsky et al. 1999, National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).
5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, with a few becoming significant problems like tamarisk and Russian olive. Removing stressors and reestablishing natural flow regimes can help bring riparian communities back into balance, however some exotics are persistent and physical eradication is necessary to restore degraded systems (Stromberg 2000, Savage 2004, but see 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. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

Appendix A: Linkage Design Methods

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

To create the Linkage Design, we used GIS approaches to identify optimal travel routes for focal species representing the ecological community in the area[1]. By carefully selecting a diverse group of focal species and capturing a range of topography to accommodate climate change, the Linkage Design should ensure the long-term viability of all species in the protected areas. Our approach included six steps:

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

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Regional biologists familiar with the region identified 22 species (Table 1) that had one or more of the following characteristics:

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

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

[1] Like every scientific model, our models involve uncertainty and simplifying assumptions, and therefore do not produce absolute “truth” but rather an estimate or prediction of 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 15):

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

To create a habitat suitability map, we assigned each of the 46 vegetation classes (and each of 4 topographic positions, and each of several elevation classes and distance-to-road classes) a score from 1 (best) to 10 (worst), where 1-3 is optimal habitat, 4-5 is suboptimal but usable habitat, 6-7 may be occasionally used but cannot sustain a breeding population, and 8-10 is strongly avoided. Whenever possible we recruited biologists with the greatest expertise in each species to assign these scores (see *Acknowledgements*). When no expert was available for a species, three biologists independently assigned scores and, after discussing differences among their individual scores, were allowed to adjust their scores before the three scores were averaged. Regardless of whether the scores were generated by a species expert or our biologists, the scorer first reviewed the literature on habitat selection by the focal species[2].

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 1 and 10. We then weighted each of the by 4 factors by a weight between 0% and 100%, subject to the constraint that the 4 weights must sum to 100%. We calculated a weighted geometric mean[3] using the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10 (USFWS 1981). For each pixel of the landscape, the weighted geometric mean was calculated by raising each factor by its weight, and multiplying the factors:

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

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

[2] Clevenger et al. (2002) found that literature review significantly improved the fit between expert scores and later empirical observations of animal movement.

[3] In previous linkage designs, we used arithmetic instead of geometric mean.

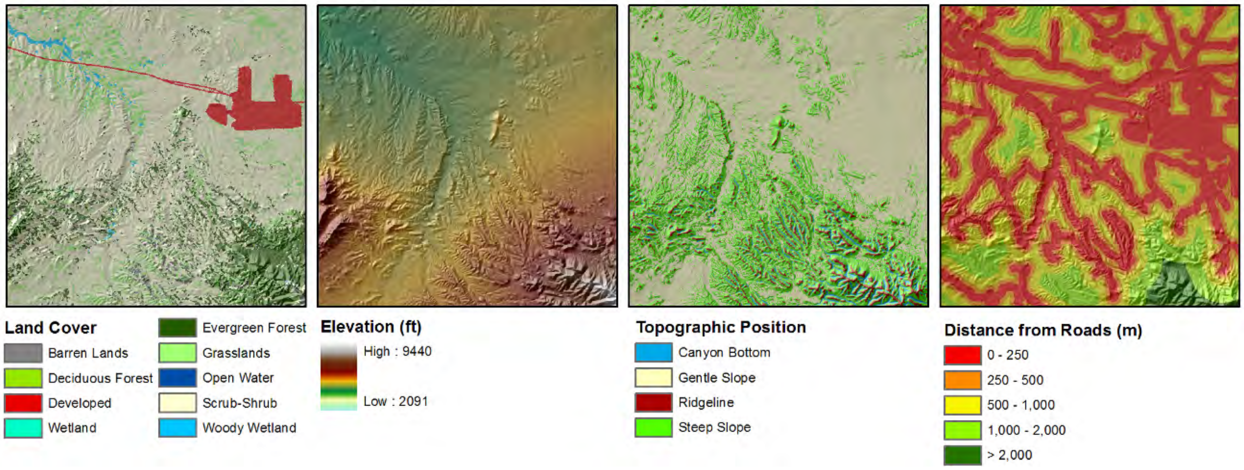


Figure 15: Four habitat factors used to create habitat suitability models. Inputs included vegetation, elevation, topographic position, and distance from roads.

Identifying Potential Breeding Patches & Potential Population Cores

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

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

To do so, we first calculated the suitability of any pixel as the average habitat suitability in a neighborhood of pixels surrounding it (Figure 16). We averaged habitat suitability within a 3x3-pixel neighborhood (90 x 90 m^2, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species[4]. Thus each pixel had both a *pixel score* and a *neighborhood score*. Then we joined adjacent pixels of suitable habitat (pixels with neighborhood score < 5) into polygons that represented potential breeding patches or potential population cores. The minimum sizes for each patch type were specified by the biologists who provided scores for the habitat suitability model.

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

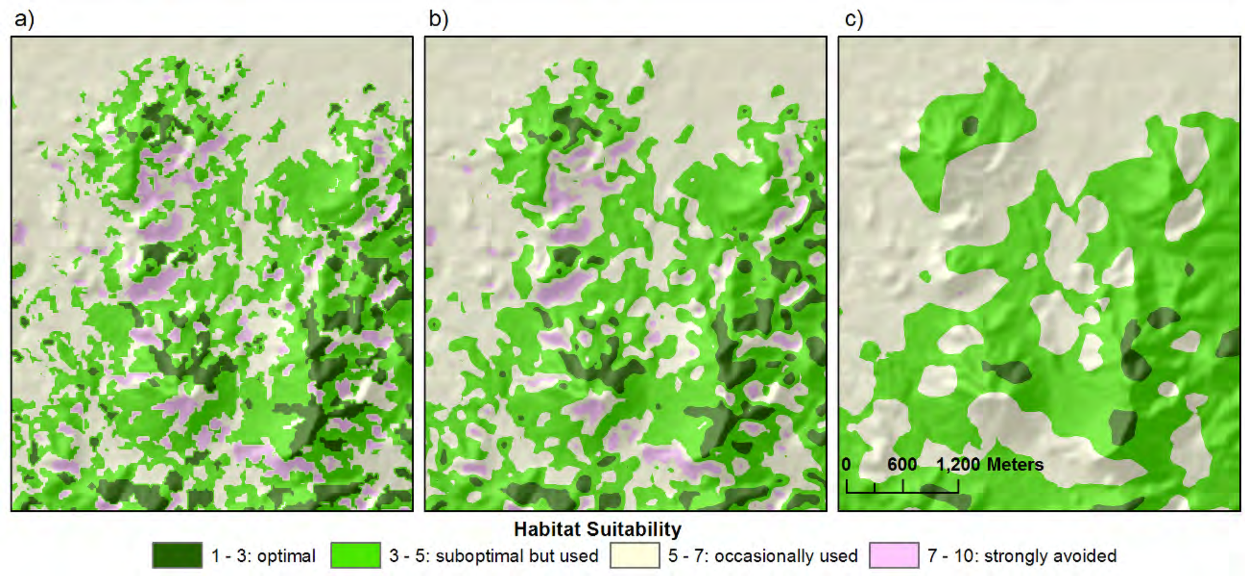


Figure 16: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window

Identifying Biologically Best Corridors

The *biologically best corridor*[5] (BBC) is a continuous swath of land that is predicted to be the best (highest permeability, lowest cost of travel) route for a species to travel from a potential population core in one wildland block to a potential population core in the other wildland block. *Travel cost* increases in areas where the focal species experiences poor nutrition or lack of suitable cover. *Permeability* is simply the opposite of travel cost, such that a perfectly permeable landscape would have a travel cost at or near zero.

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

The close proximity of the wildland blocks would cause our GIS procedure to identify the BBC in this area where the wildland blocks nearly touch[6]. A BBC drawn in this way has 2 problems: (1) It could be unrealistic (previous footnote). (2) It could serve small wildlife populations near the road while failing to serve much larger populations in the rest of the protected habitat block. To address these problems, we needed to redefine the wildland blocks so that the facing edges of the wildland blocks were parallel to each other, Thus for purposes of BBC analyses, we redefined the wildland blocks such that distances between the edges of each one are nearly uniform.

We then identified potential population cores and habitat patches that fell completely within each

---

[5] 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.

[6] 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.

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[7]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1000 m (Figure 17). 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). In this linkage planning area, the UBBC was based on models created for badger, bighorn, desert tortoise, gila monster, javelina, and mule deer.

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses were not conducted for some focal species (see 2nd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[8] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

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

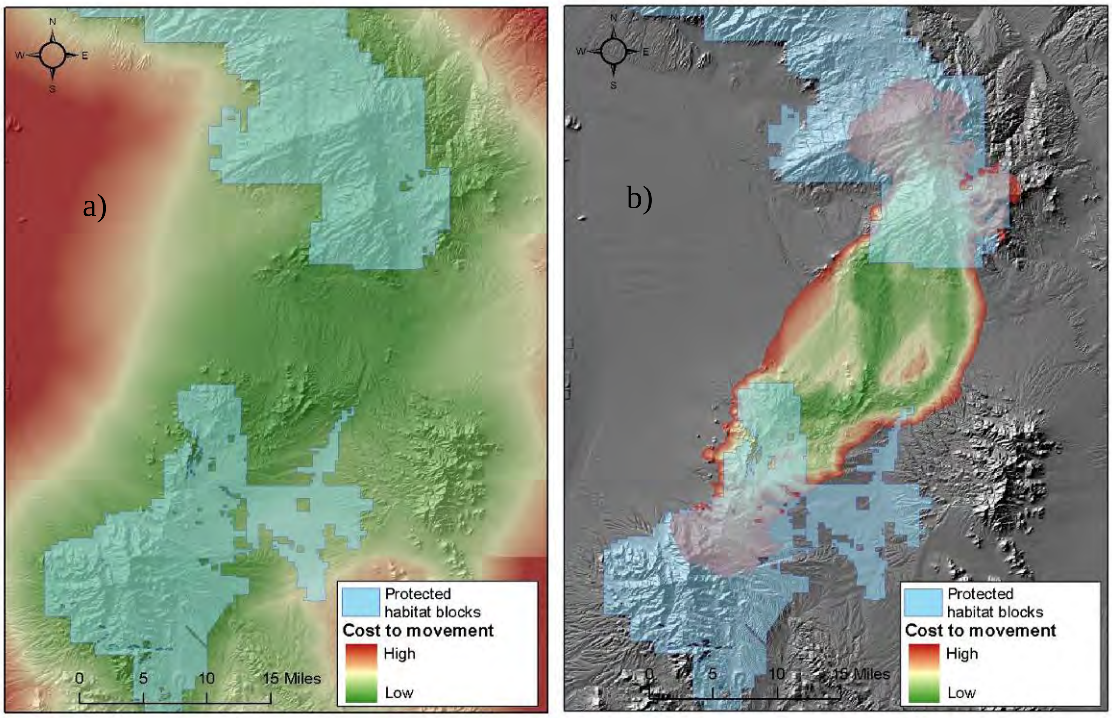


Figure 17: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape.

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 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.

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

Field Investigations

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

Appendix B: Individual Species Analyses

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

	Bobcat	Bighorn Sheep	Desert Tortoise	Gila Monster	Javelina
Factor weights					
Land Cover	95	50	50	10	50
Elevation	5	10	15	35	30
Topography	0	30	35	45	20
Distance from Roads	0	10	0	10	0
Land Cover					
Pine-Oak Forest and Woodland	2	9	10	10	7
Pinyon-Juniper Woodland	2	9	10	6	5
Ponderosa Pine Woodland	2	9	10	10	6
Juniper Savanna	4	8	10	10	7
Semi-Desert Grassland and Steppe	4	5	8	5	2
Chaparral	2	9	10	6	3
Creosotebush, Mixed Desert and Thorn Scrub	4	6	6	3	3
Creosotebush-White Bursage Desert Scrub	4	6	5	7	4
Desert Scrub (misc)	4	2	4	3	2
Gambel Oak-Mixed Montane Shrubland	2	9	10	10	8
Mesquite Upland Scrub	4	7	7	4	2
Paloverde-Mixed Cacti Desert Scrub	4	3	1	1	1
Pinyon-Juniper Shrubland	2	8	10	6	10
Riparian Mesquite Bosque	3	9	5	5	1
Riparian Woodland and Shrubland	3	9	10	5	2
Barren Lands, Non-specific	6	8	10	10	9
Bedrock Cliff and Outcrop	6	2	10	2	8
Cliff and Canyon	6	1	10	2	7
Mixed Bedrock Canyon and Tableland	6	2	10	2	10
Warm Desert Pavement	6	9	6	6	8
Recently Mined or Quarried	6	10	10	10	10
Agriculture	9	10	10	10	7
Developed, Medium - High Intensity	9	10	10	9	7
Developed, Open Space - Low Intensity	7	10	7	1	4
Open Water	10	10	10	10	10
Elevation (ft)					
	0-7500: 1 7500-10000: 5 10000-11000: 9	0-2950: 2 2950-3300: 1 3300-7000: 3 7000-11000: 7	0-5000: 1 5000-7000: 7 7000-11000: 10	0-1700: 4 1700-4000: 1 4000-4800: 4 4800-5700: 7 5700-11000: 10	0-5000: 1 5000-7000: 3 7000-11000: 10
Topographic Position					
Canyon Bottom		8	8	1	1
Flat - Gentle Slopes		7	5	5	1
Steep Slope		5	3	1	7
Ridgetop		1	7	1	4
Distance from Roads (m)					
		0-1000: 6 1000-15000: 2	0-250: 5 250-500: 4 500-1000: 3 1000-15000: 1	0-1000: 5 1000-3000: 3 3000-15000: 1	

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

Bobcat (*Lynx rufus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of optimal and suitable habitat for bobcat within the potential linkage area (Figure 18 and Figure 20). With the exception of developed areas, almost the entire remainder of the potential linkage area serves as a potential population core (Figure 19 and Figure 21). Within the BBC in the eastern strand, habitat suitability ranged from 3.83 to 3.88, with an average suitability cost of 3.87 (S.D: 0.0). Within the BBC in the western strand, habitat suitability ranged from 3.4 to 8.9 in the developed areas, with an average suitability cost of 4.1 (S.D. 0.9).

Union of biologically best corridors – The eastern and western strands of the UBBC both capture additional optimal habitat for bobcat. Nearly all of the UBBC, excepting small residentially developed areas, is a potential habitat core for bobcat. The greatest threats to connectivity and persistence of bobcat populations are canals, roads, agricultural land use, continued habitat fragmentation, and urbanization.

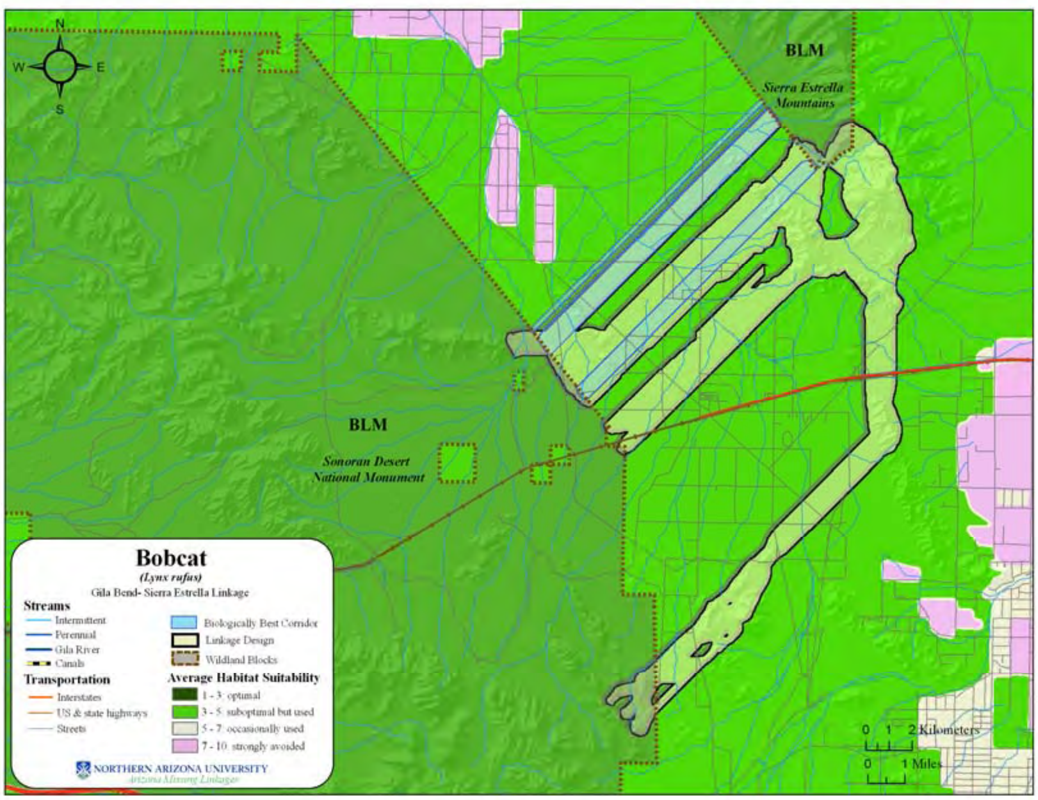


Figure 18: Modeled habitat suitability of bobcat in the SDNM-Sierra Estrella Linkage.

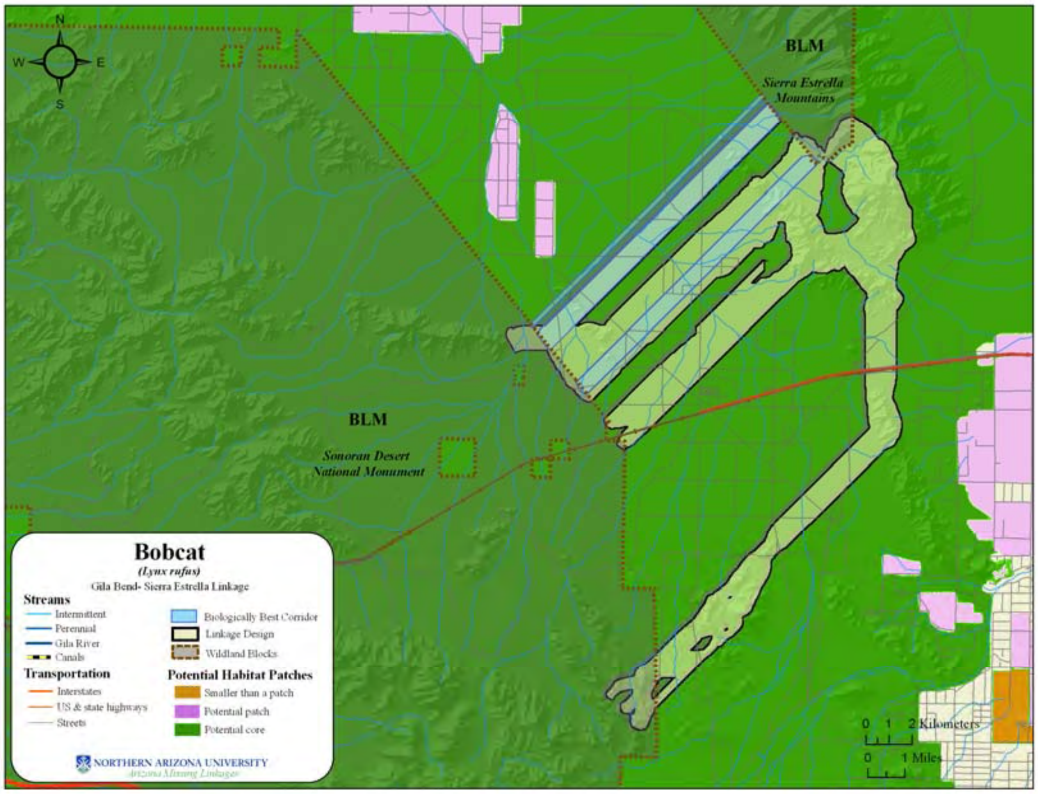


Figure 19: Potential habitat patches and cores for bobcat in the SDNM-Sierra Estrella Linkage.

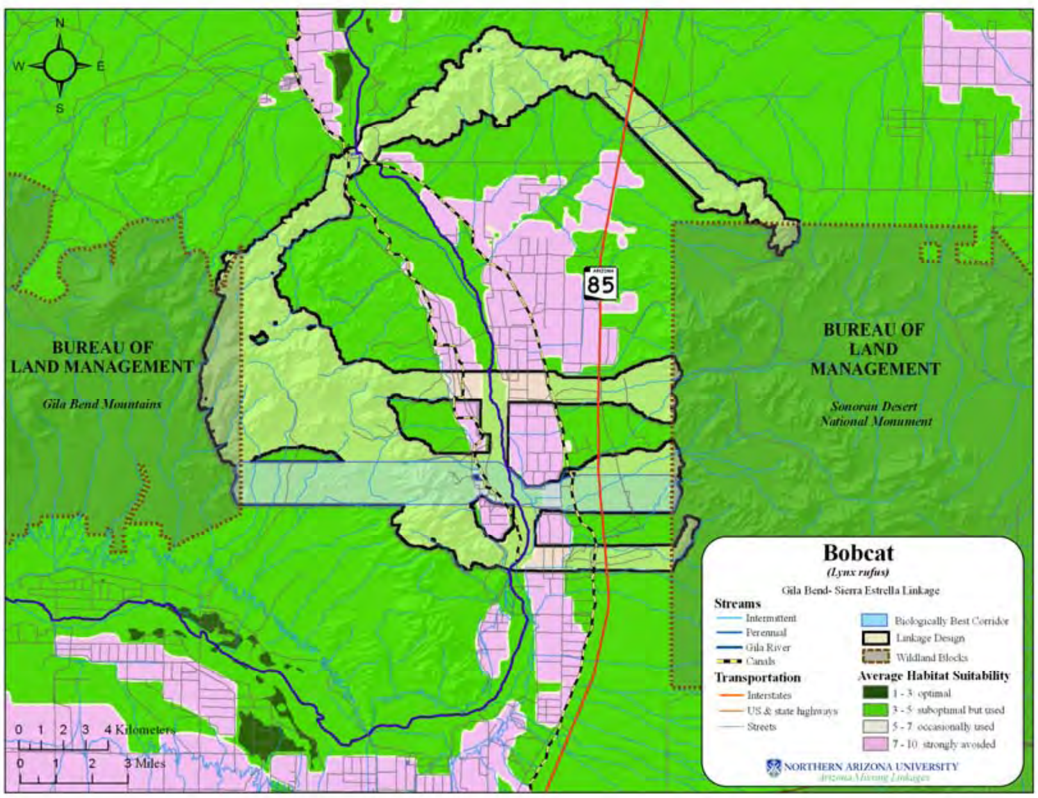


Figure 20: Modeled habitat suitability of bobcat in the Gila Bend-SDNM Linkage.

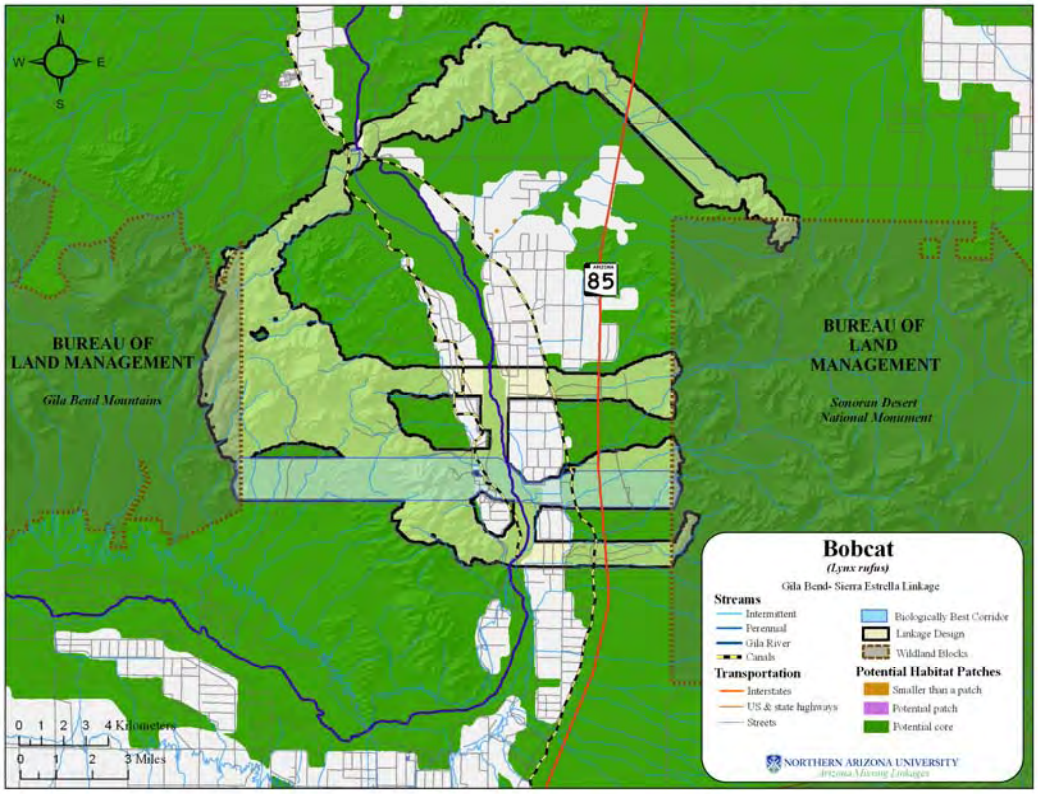


Figure 21: Potential habitat patches and cores for bobcat in the Gila Bend-SDNM Linkage.

Desert Bighorn Sheep (*Ovis canadensis nelsoni)*

Justification for Selection

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

Distribution

Bighorn sheep are found throughout western North America from the high elevation alpine meadows of the Rocky Mountains to low elevation desert mountain ranges of the southwestern United States and northern Mexico (Shackleton 1985). Specifically, their range extends from the mountains and river breaks of southwestern Canada south through the Rocky Mountains and Sierra Nevada, and into the desert mountains of the southwest United States and the northwestern mainland of Mexico (NatureServe 2005). In Arizona, bighorns can be found from Kanab Creek and the Grand Canyon west to Grand Wash, as well as in westernmost Arizona eastward to the Santa Catalina Mountains (Hoffmeister 1986). Surveys in the late 1990's (Arizona Desert Bighorn Sheep Society 2004) documented about 90 bighorn in the Gila Bend Mountains, and about 35 bighorn in the Sierra Estrella. The population in the Maricopa Mountains (SDNM) was so large that it recently served as a source of animals to transplant to other areas. However the population plummeted from over 90 in 1995 to about 15 animals in 2002.

Habitat Associations

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

1000m elevation, with the best habitat found from 900 – 1000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate potentially suitable habitat for bighorn mainly in the mountain ranges located within the wildland blocks (Figure 22 and Figure 24). Within the BBC in the eastern strand, habitat suitability ranged from 1.9 to 8.1, with an average suitability cost of 7.0 (S.D: 2.0). Within the BBC in the western strand, habitat suitability ranged from 1.9 to 10.0 in the developed areas, with an average suitability cost of 4.7 (S.D. 2.1). The largest gap between potentially suitable habitat patches is approximately 8 .5 km in the eastern strand and 7.7 km in the western strand.

Union of biologically best corridors – The UBBC captures a small portion of additional habitat for the desert bighorn sheep where the UBBC coincides with the mountain ranges that make up the sheep habitat. Major highways and developed areas have been found to completely eliminate gene flow in bighorn sheep populations (Epps et al. 2005), so connectivity between these blocks is dependent on effective crossing structures and maintenance of existing habitat. The greatest threats to connectivity and persistence of bighorn populations are canals, roads, continued habitat fragmentation, and urbanization.

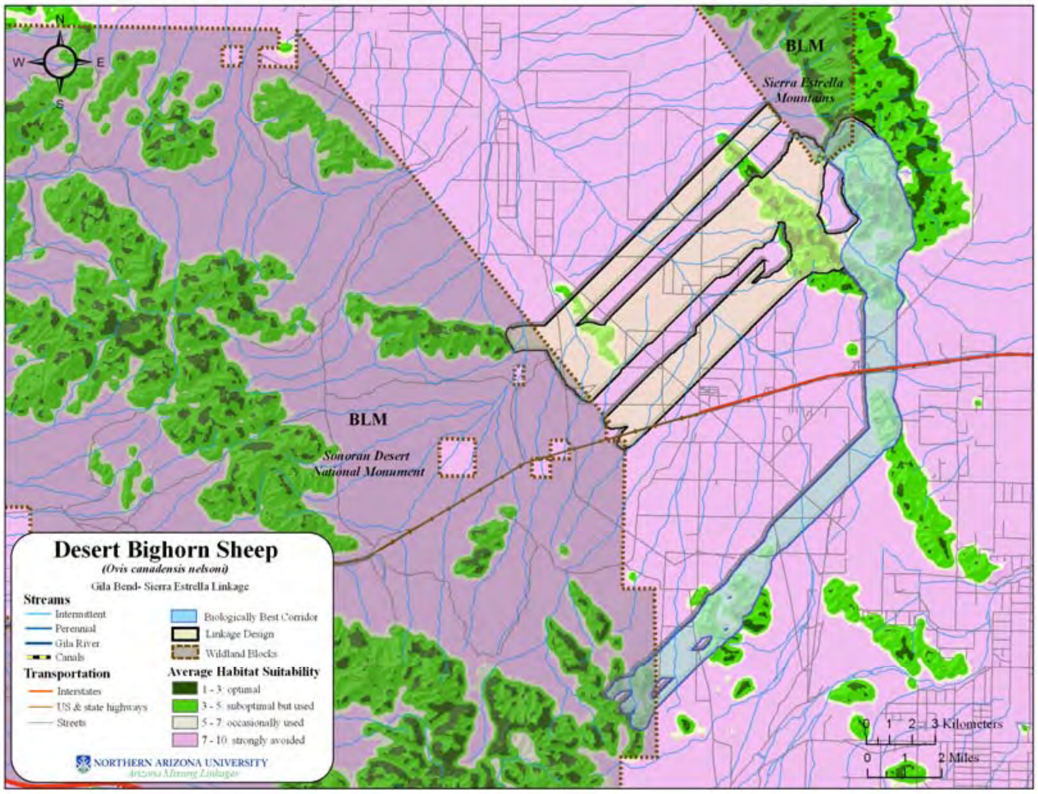


Figure 22: Modeled habitat suitability of bighorn sheep in the SDNM-Sierra Estrella Linkage.

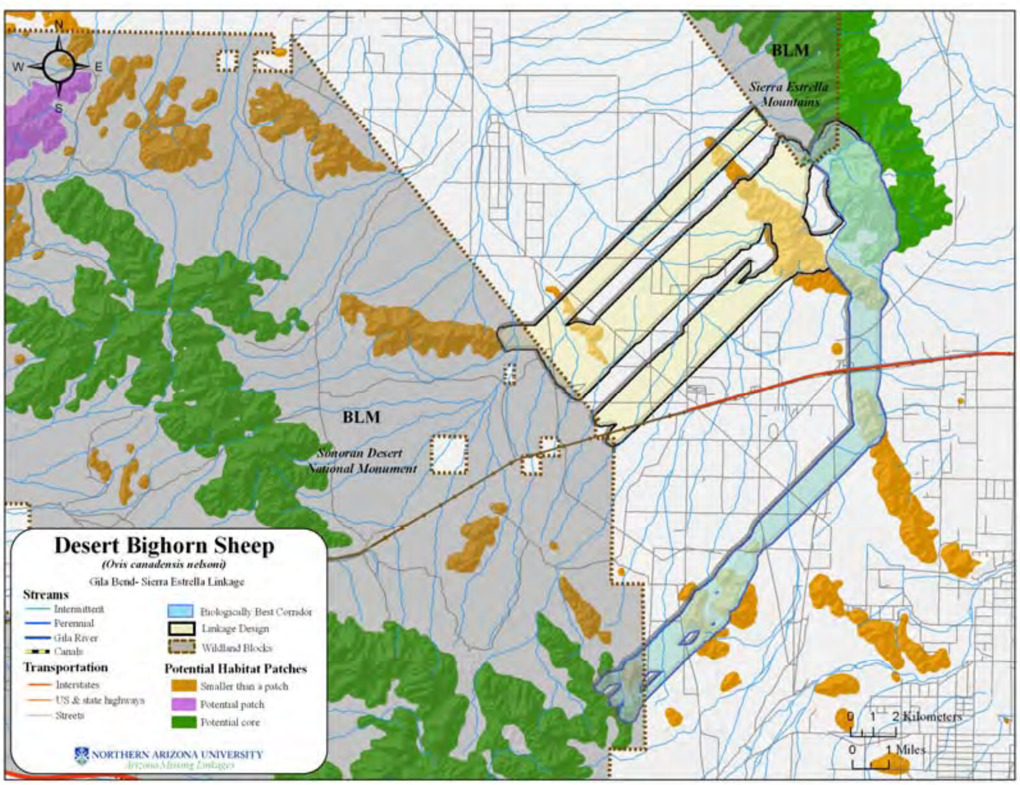


Figure 23: Potential habitat patches and cores for bighorn sheep in the SDNM-Sierra Estrella Linkage.

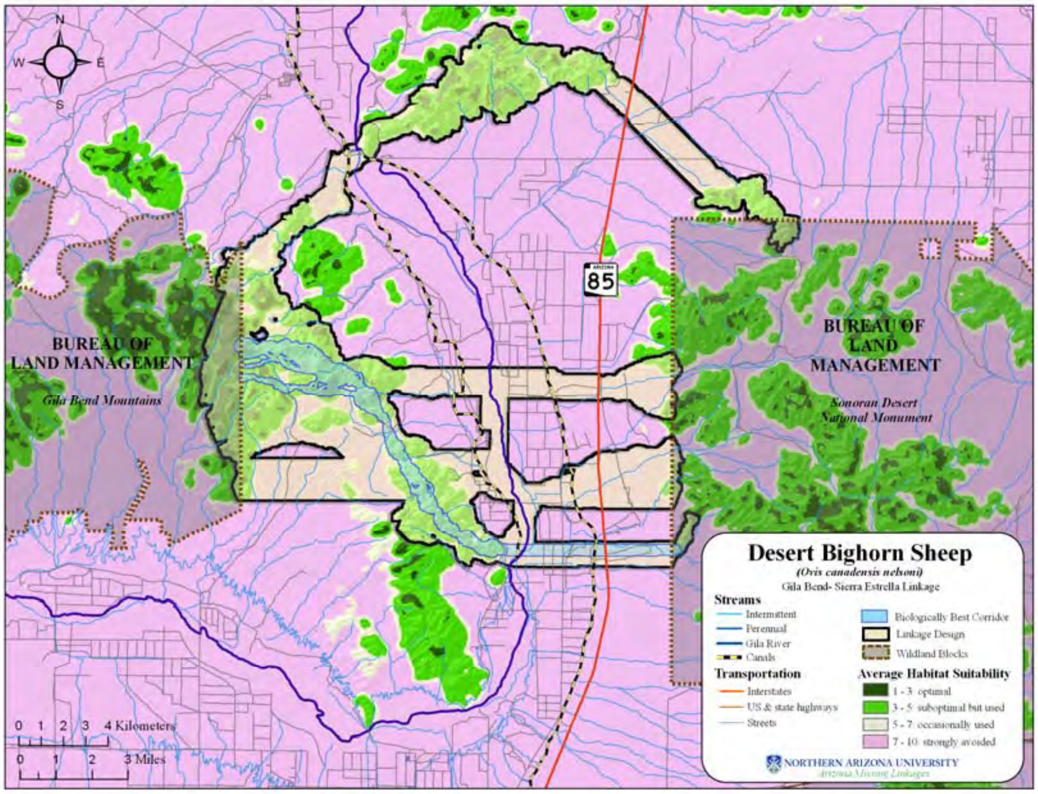


Figure 24: Modeled habitat suitability of bighorn sheep in the Gila Bend-SDNM Linkage.

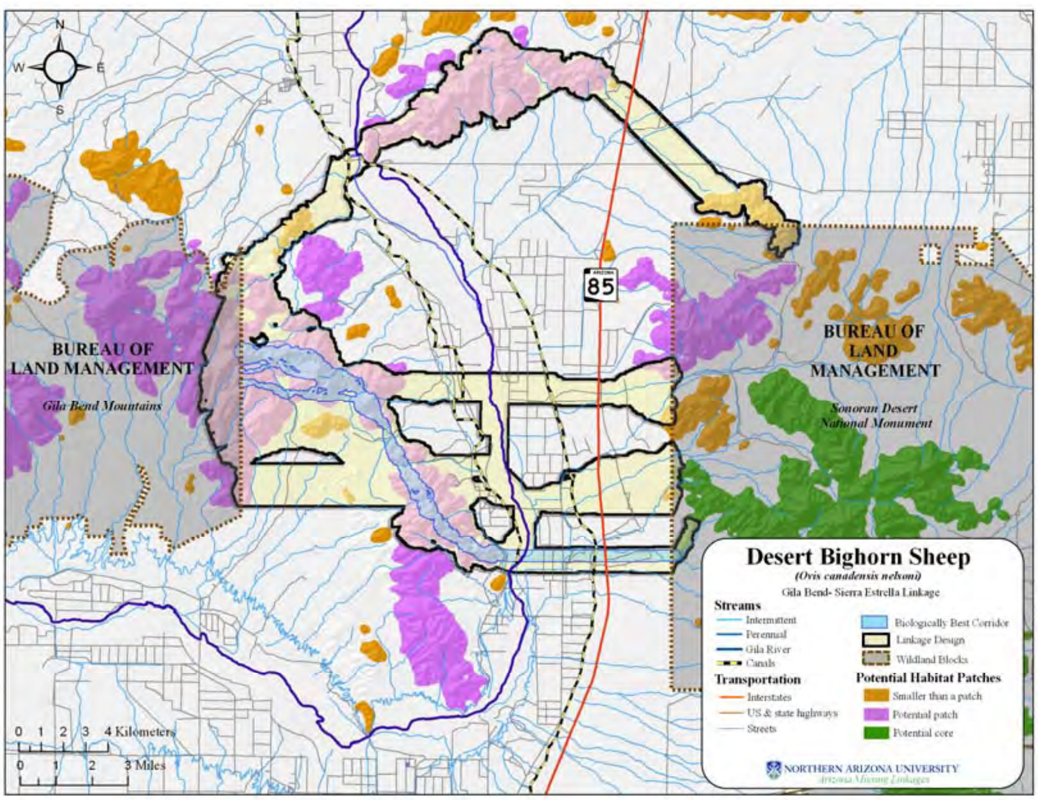


Figure 25: Potential habitat patches and cores for bighorn sheep in the Gila Bend-SDNM Linkage.

Desert Tortoise (*Gopherus agassizii*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate a significant amount of optimal and suitable habitat for this species within the potential linkage area (Figure 26 and Figure 28). Within the BBC in the eastern strand, habitat suitability ranged from 1.4 to 5.4, with an average suitability cost of 4.2 (S.D: 0.7). Within the BBC in the western strand, habitat suitability ranged from 1.1 to 10.0 in the developed areas, with an average suitability cost of 3.8 (S.D. 1.4). Most of the linkage area, except for the developed areas and lands adjacent to major roads serve as a potential habitat core (Figure 27 and Figure 29).

Union of biologically best corridors – The UBBC captures additional suitable habitat for desert tortoise throughout the eastern strand, along with optimal habitat in the mountain ranges. It captures some addition suitable and optimal habitat in the western strand, though the western strand contains more avoided habitat including developed areas that could impede tortoise movement.

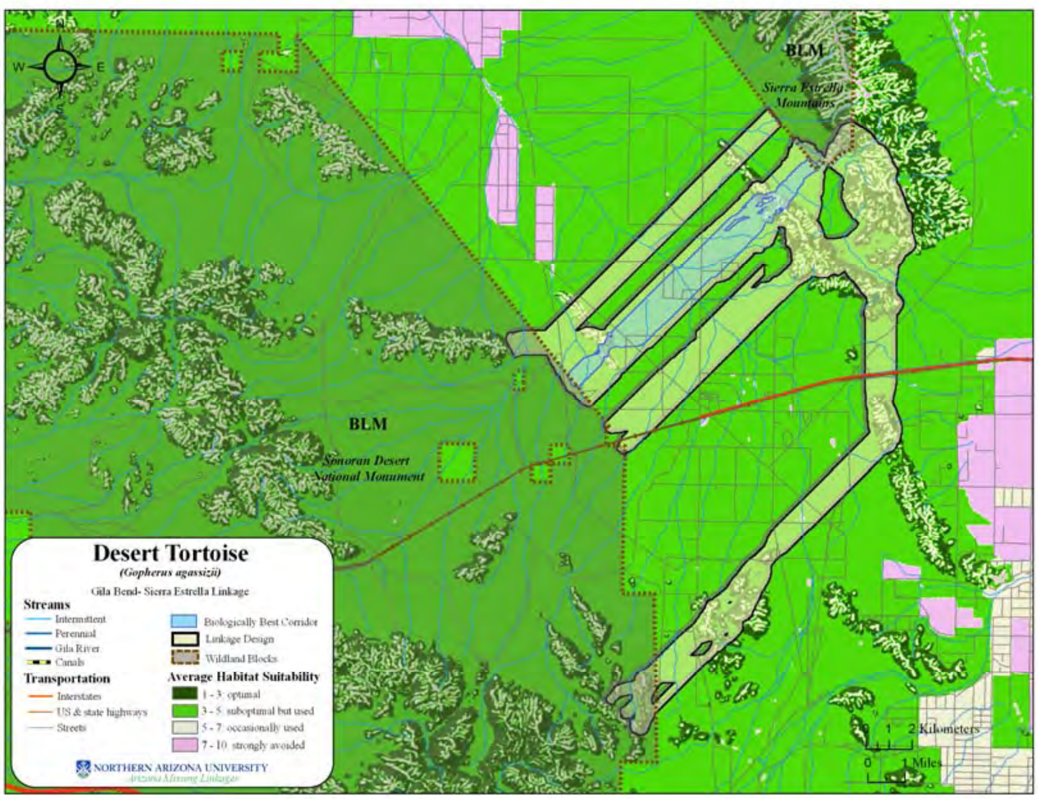


Figure 26: Modeled habitat suitability of desert tortoise in the SDNM-Sierra Estrella Linkage.

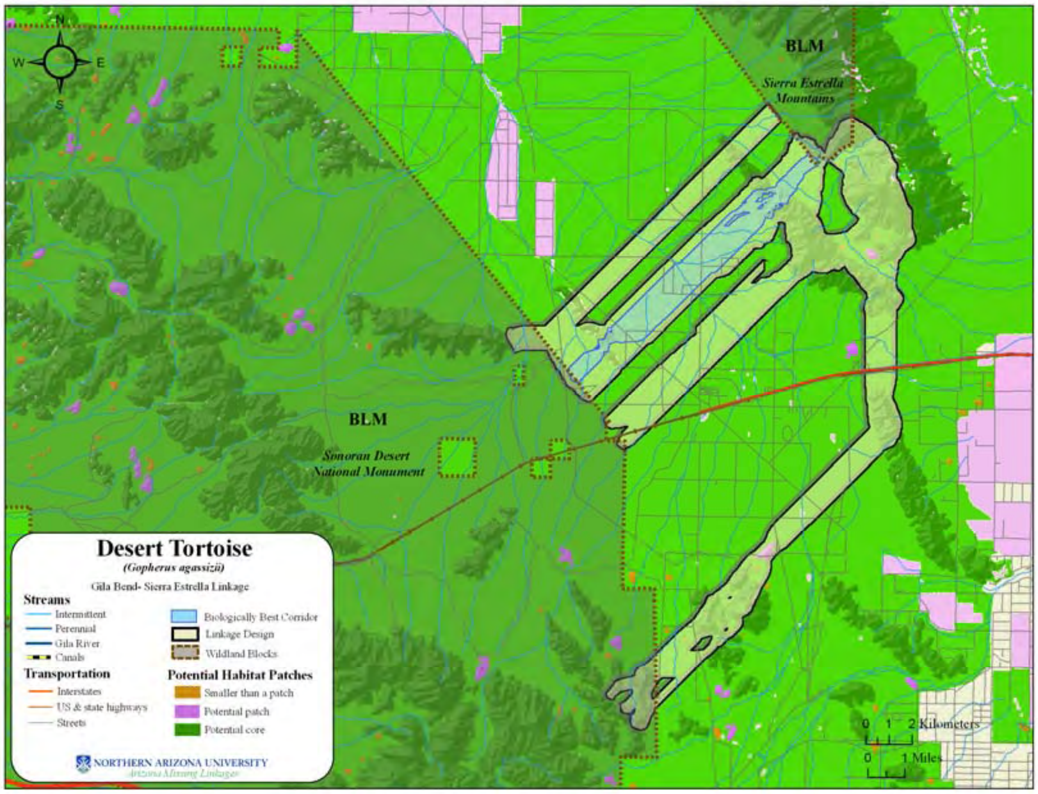


Figure 27: Potential habitat patches and cores for desert tortoise in the SDNM-Sierra Estrella Linkage.

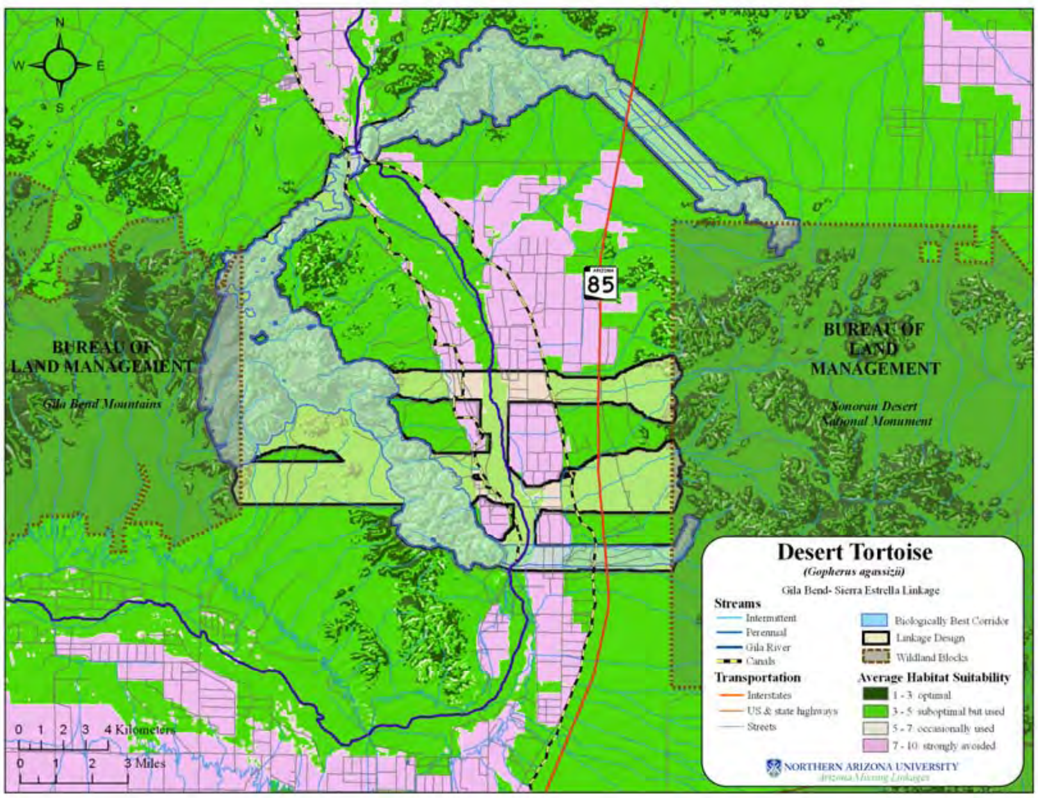


Figure 28: Modeled habitat suitability for desert tortoise in the Gila Bend-SDNM Linkage.

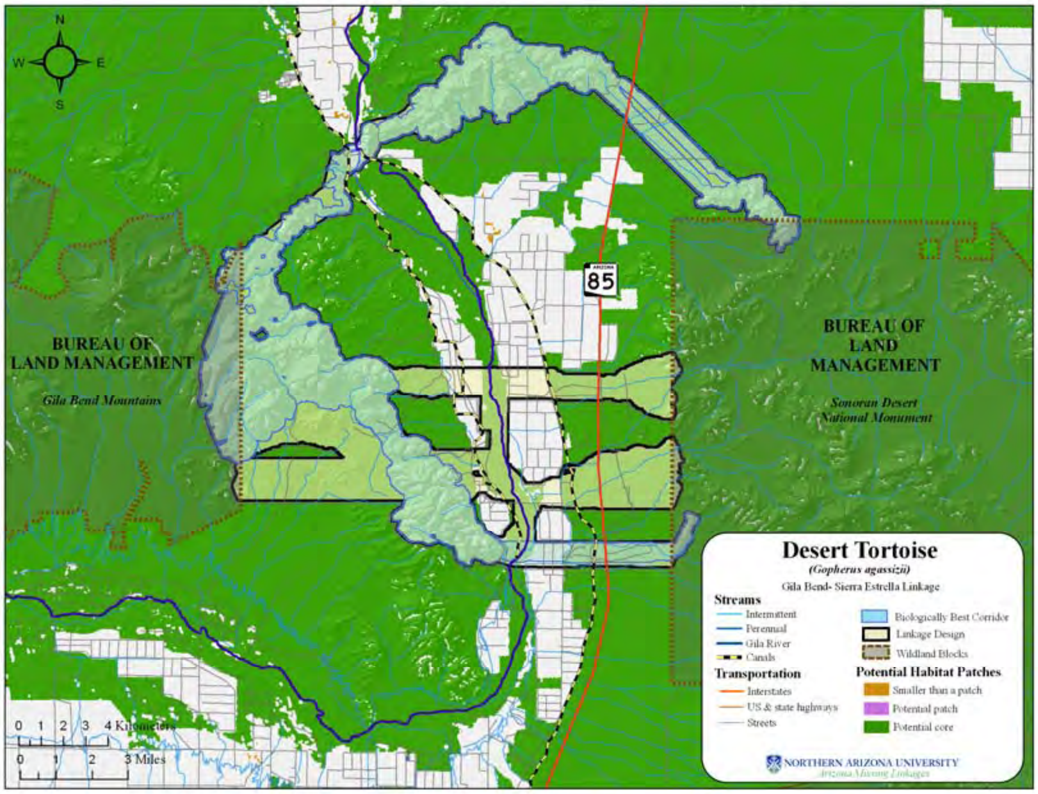


Figure 29: Potential habitat patches and cores of desert tortoise in the Gila Bend-SDNM Linkage.

Gila Monster (*Heloderma suspectum*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 10%, while elevation, topography, and distance from roads received weights of 35%, 45%, and 10%, respectively. For specific scores of classes within each of these factors, see Table 5.

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for this species within the potential linkage area (Figure 30and Figure 32). Within the BBC in the eastern strand, habitat suitability ranged from 1.0 to 4.9, with an average suitability cost of 3.8 (S.D: 1.5 Within the BBC in the western strand, habitat suitability ranged from 1.2 to 10.0 in the developed areas, with an average suitability cost of 3.9 (S.D. 1.8).

Union of biologically best corridors – The UBBC captures very little additional optimal habitat for the gila monster within the mountain ranges. It also captures some additional suitable habitat in both the eastern and western strands though the western strand passes through more avoided habitat near Highway 85.

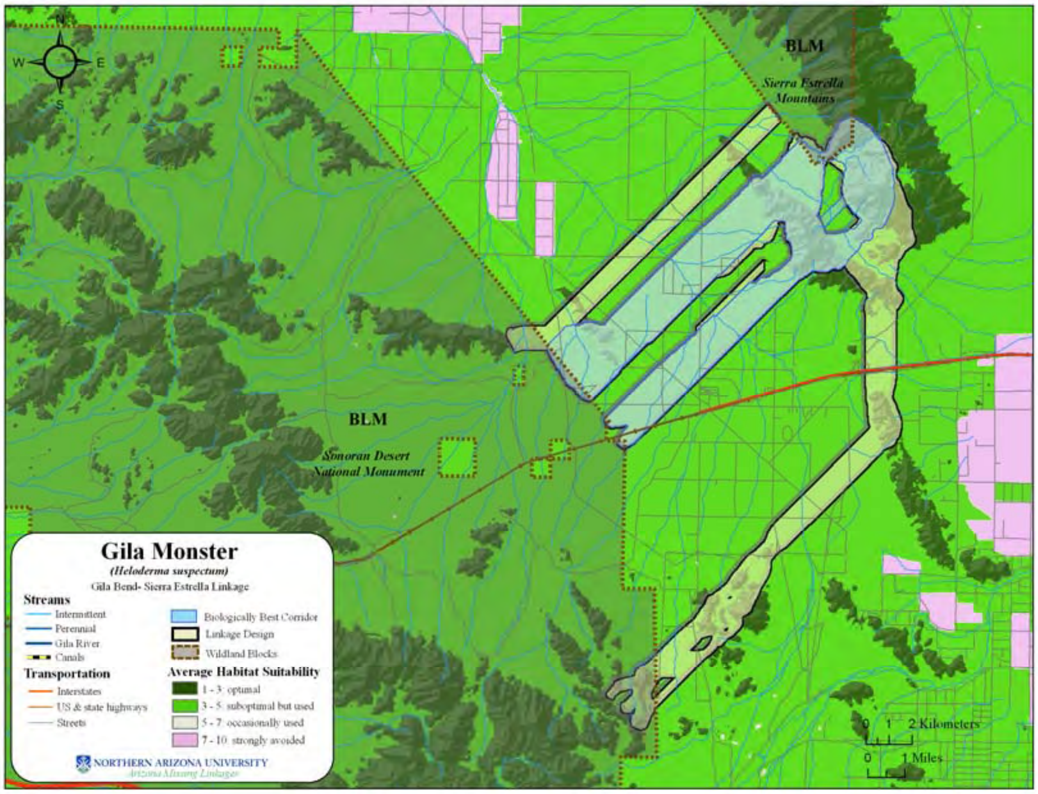


Figure 30: Modeled habitat suitability of gila monster in the SDNM-Sierra Estrella Linkage.

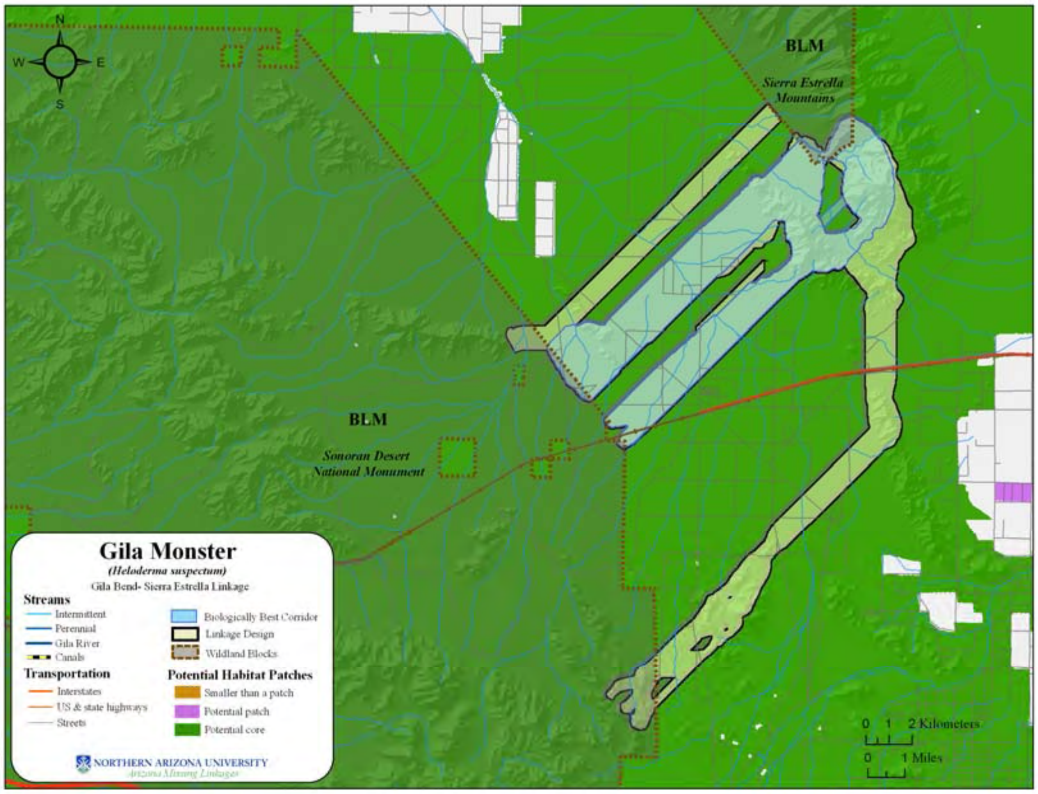


Figure 31: Potential habitat patches and cores for gila monster in the SDNM-Sierra Estrella Linkage.

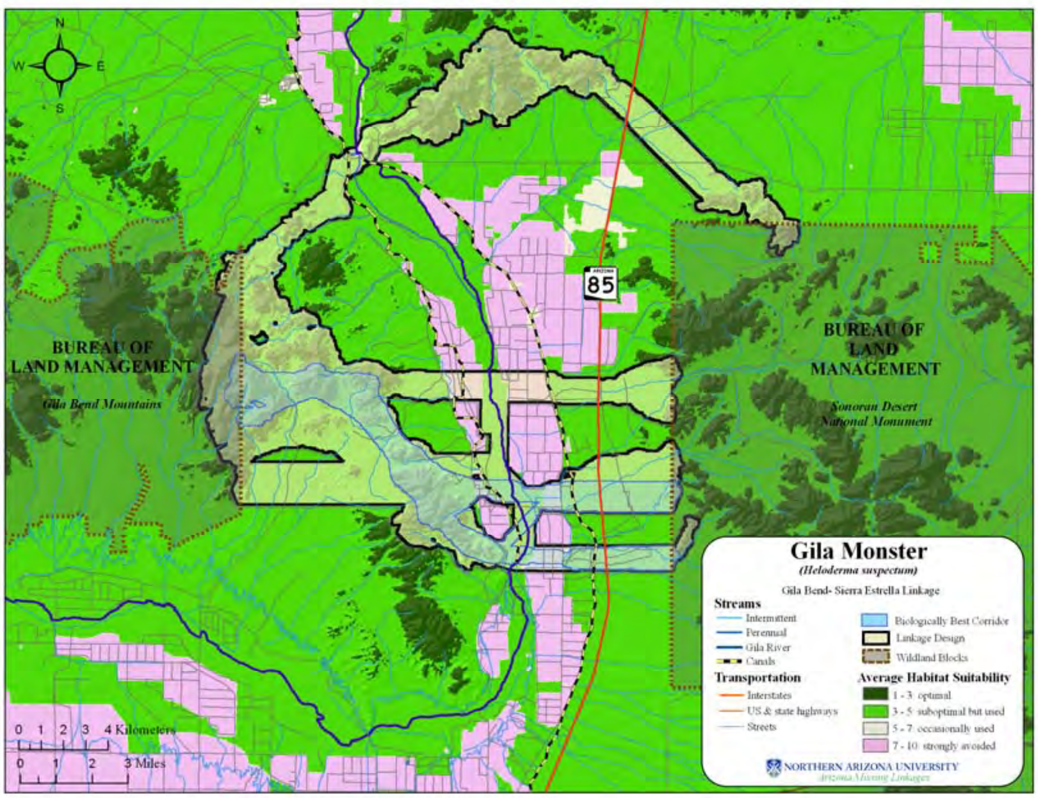


Figure 32: Modeled habitat suitability of gila monster in the Gila Bend-SDNM Linkage.

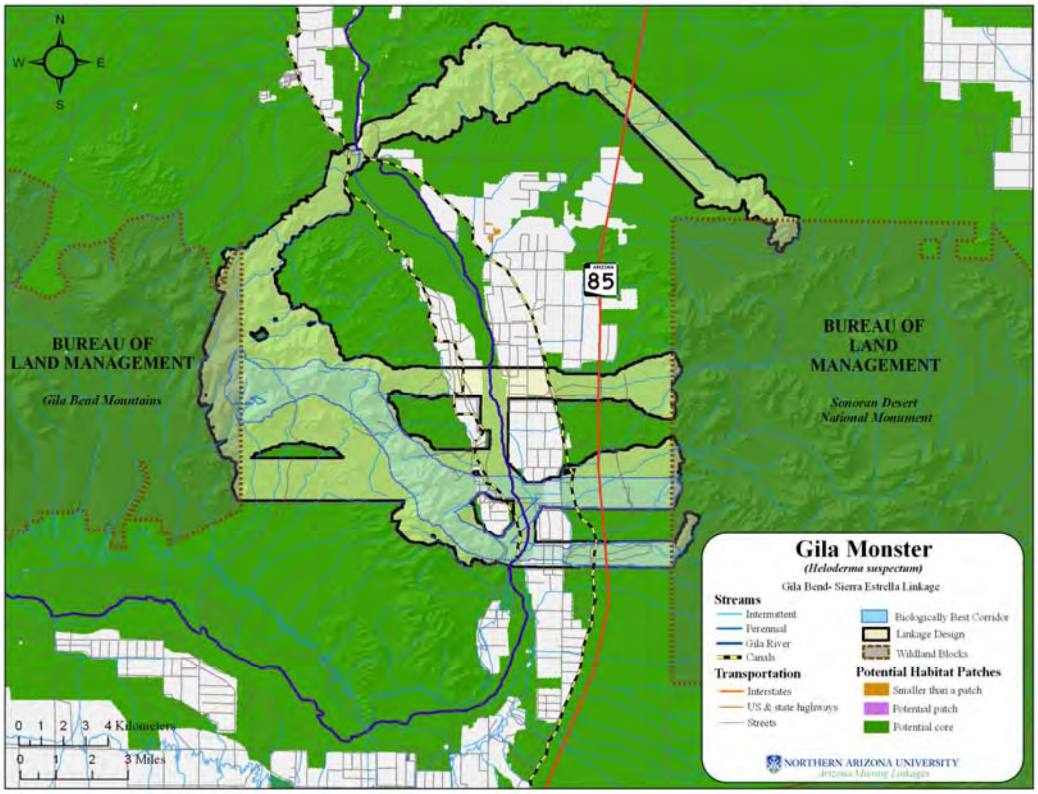


Figure 33: Potential habitat patches and cores for gila monster in the Gila Bend-SDNM Linkage.

Javelina (*Tayassu tajacu*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

Javelina live in stable herds, though occasionally some individuals may move out of the herd to join another or establish their own (Hoffmeister 1986). Home ranges for herds have been reported as 4.7 km^2 in the Tortolita Mountains (Bigler 1974), 4.93 km^2 near Prescott (Ticer et al. 1998), and between 1.9 and 5.5 ha in the Tonto Basin (Ockenfels and Day 1990). Dispersal of javelina has not been adequately studied, but they are known to be capable of extensive movements of up to several kilometers (NatureServe 2005).

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results indicate abundant optimal habitat for javelina within the linkage planning area (Figure 34 and Figure 36). Within the BBC in the eastern strand, habitat suitability ranged from 1.0 to 4.1, with an average suitability cost of 2.3 (S.D: 0.6). Within the BBC in the western strand, habitat suitability ranged from 1.0 to 4.8, with an average suitability cost of 2.5 (S.D. 0.7). The vast majority of the linkage area comprises a potential habitat core for javelina.

Union of biologically best corridors – The UBBC is comprised almost entirely of optimal javelina habitat in the eastern strand and a mixture of suitable and optimal habitat in the western strand.

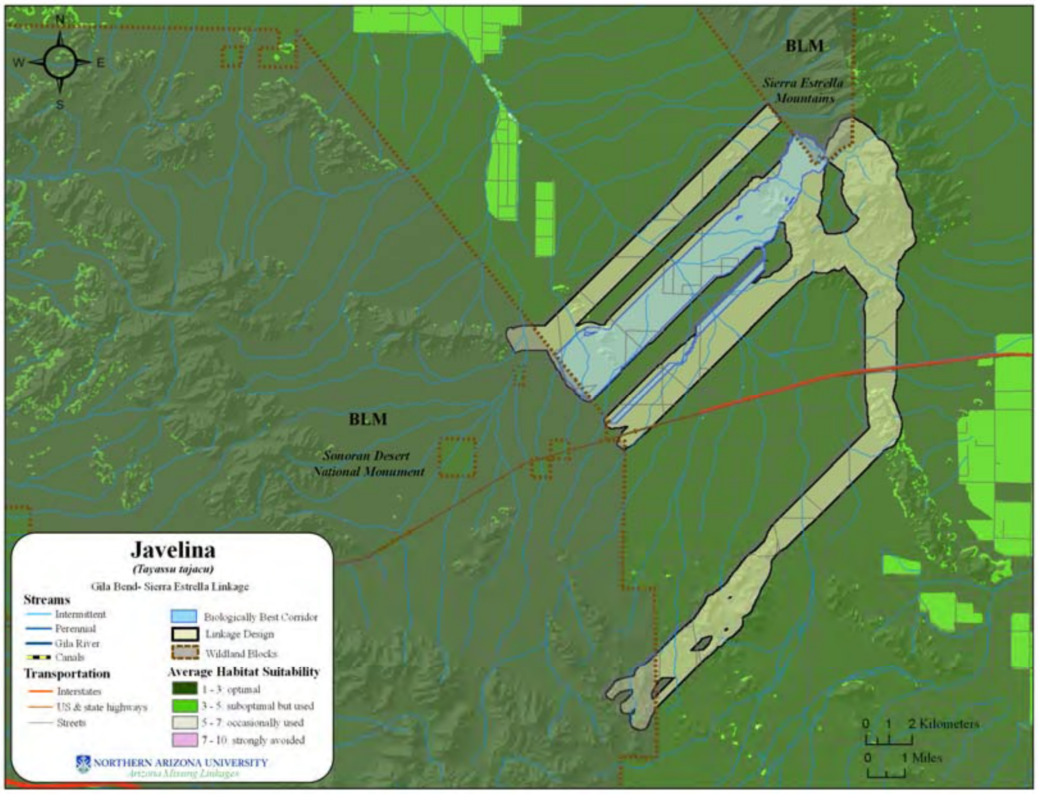


Figure 34: Modeled habitat suitability of javelina in the SDNM-Sierra Estrella Linkage.

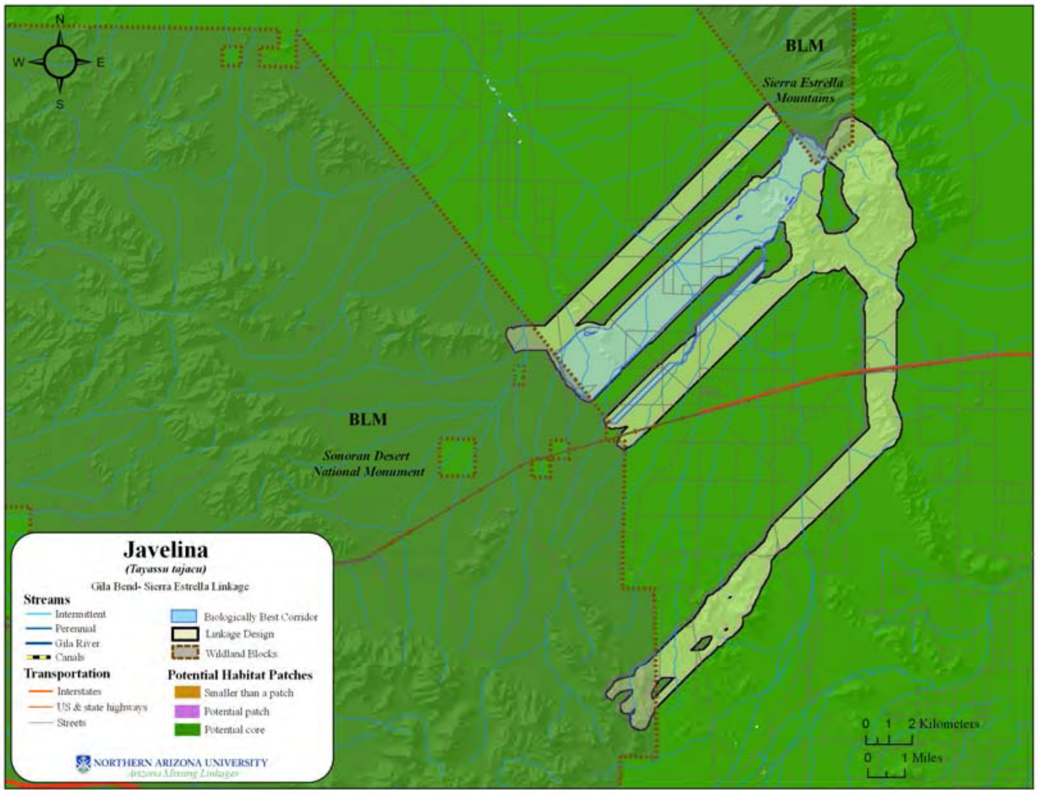


Figure 35: Potential habitat patches and cores for javelina in the SDNM-Sierra Estrella Linkage.

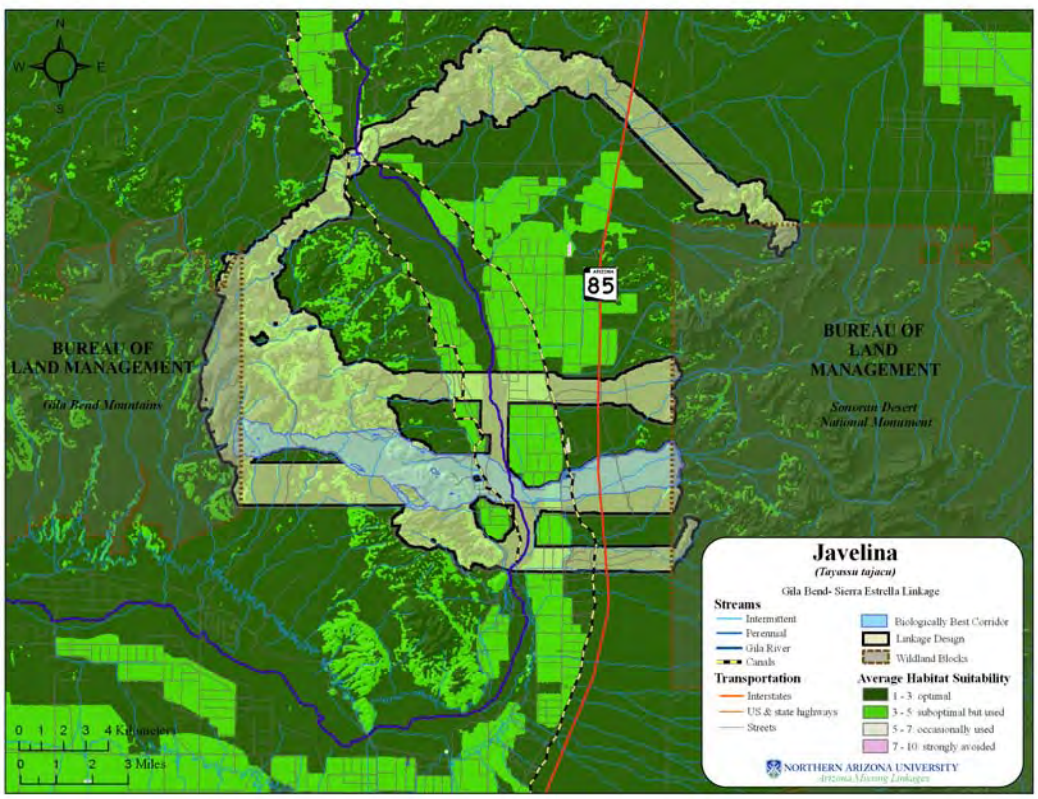


Figure 36: Modeled habitat suitability for javelina in the Gila Bend-SDNM Linkage.

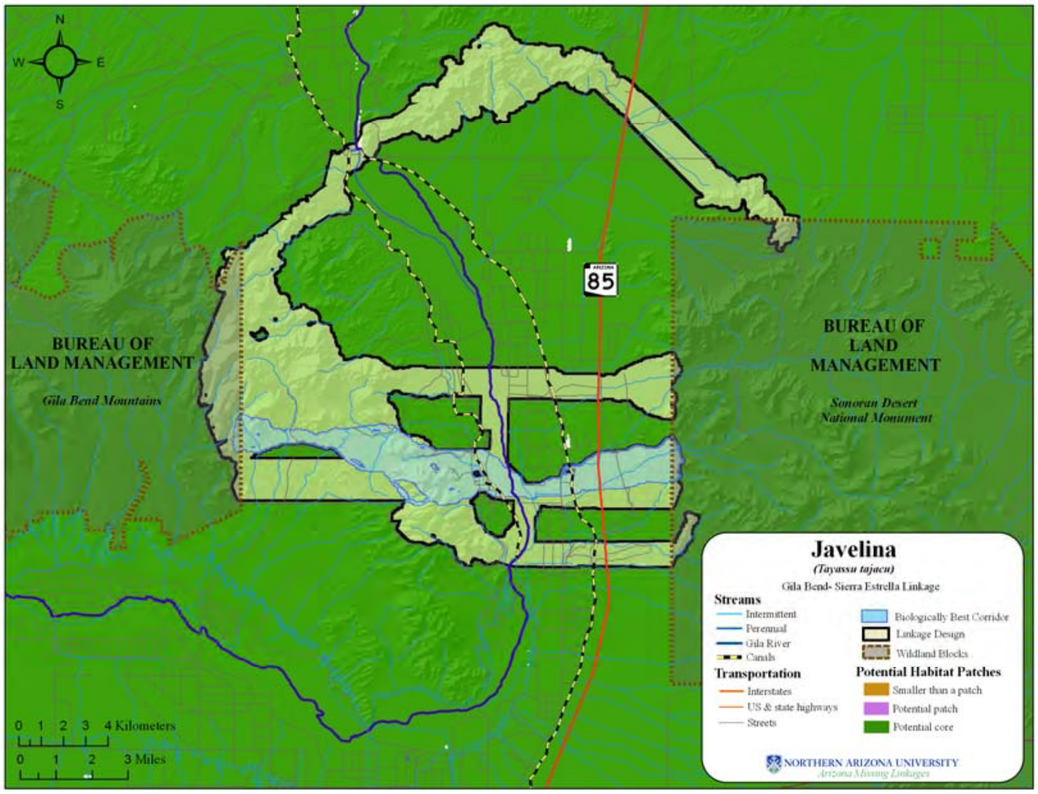


Figure 37: Potential habitat patches and cores for javelina in the Gila Bend-SDNM Linkage.

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 4,000 m (Currier 1983).

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Our modeling process did not identify a biologically best corridor for mountain lion within the linkage planning area. Because no areas with suitable habitat large enough to serve as a potential habitat core were identified, there were no starting and ending points from which to calculate a least-cost corridor analysis. Very little suitable and less optimal habitat were identified, with only small patches of either occurring along or near the Gila River (Figure 40). No potential habitat patches or cores were identified (Figure 41).

Union of biologically best corridors – The UBBC does not capture any habitat rated suitable for mountain lion.

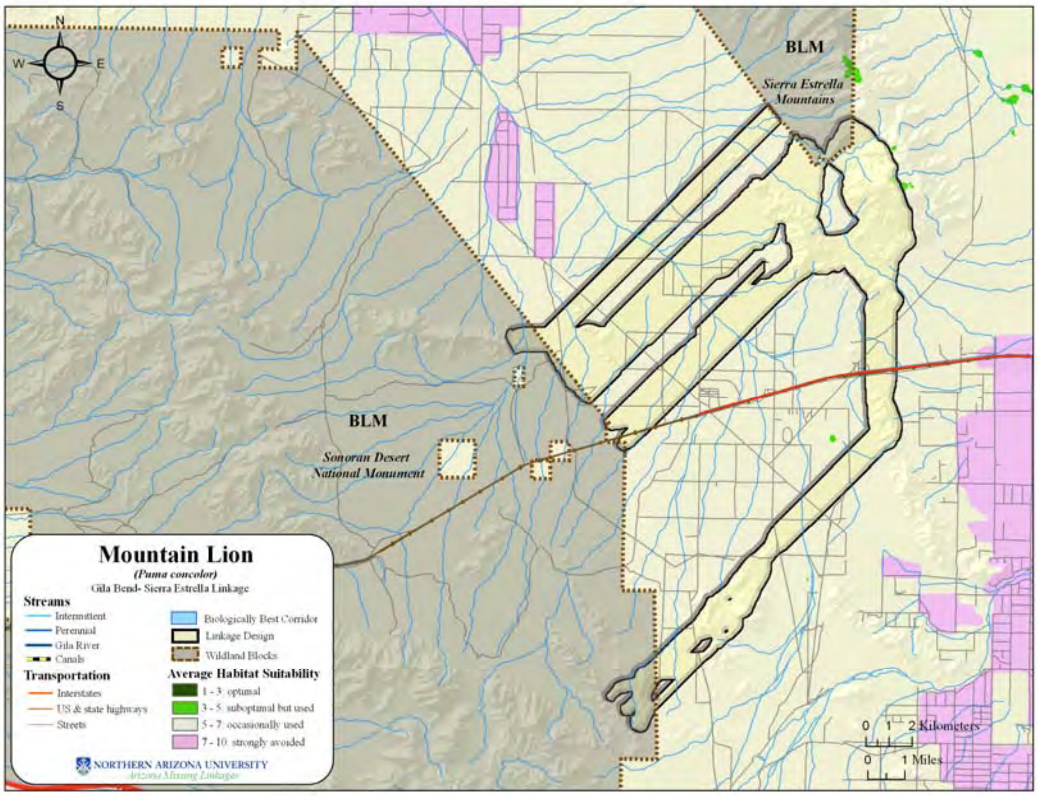


Figure 38: Potential habitat patches and cores for mountain lion in the SDNM-Sierra Estrella Linkage.

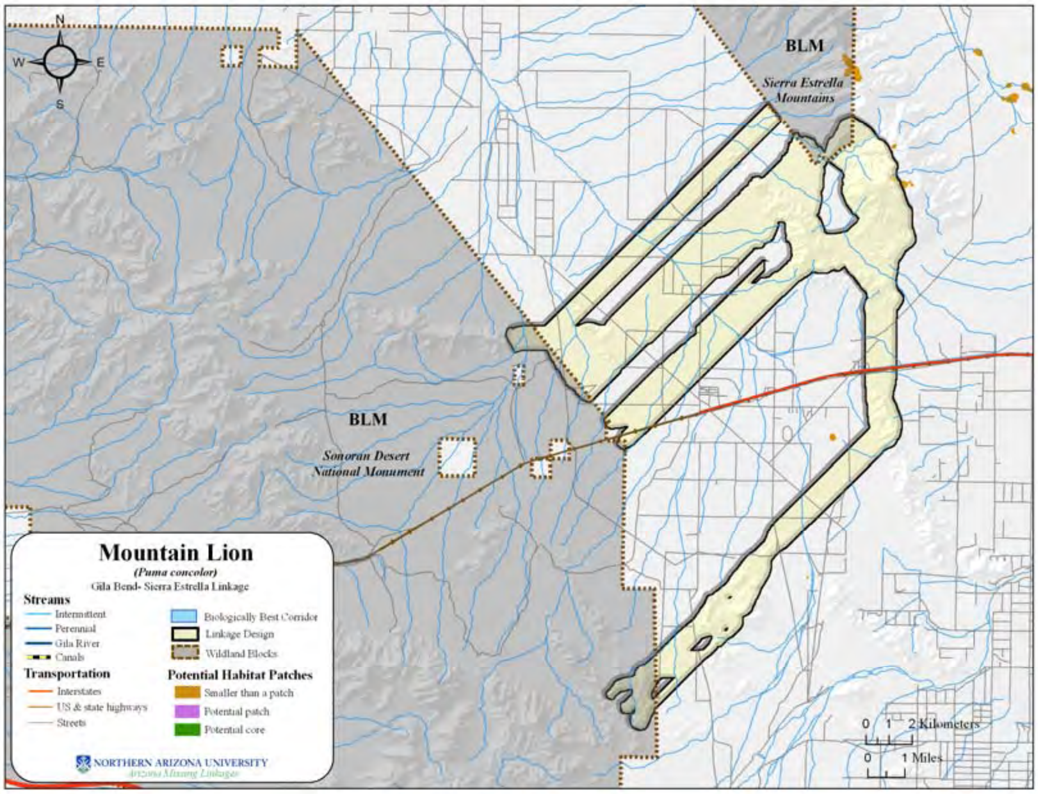


Figure 39: Modeled habitat suitability for mountain lion in the SDNM-Sierra Estrella Linkage.

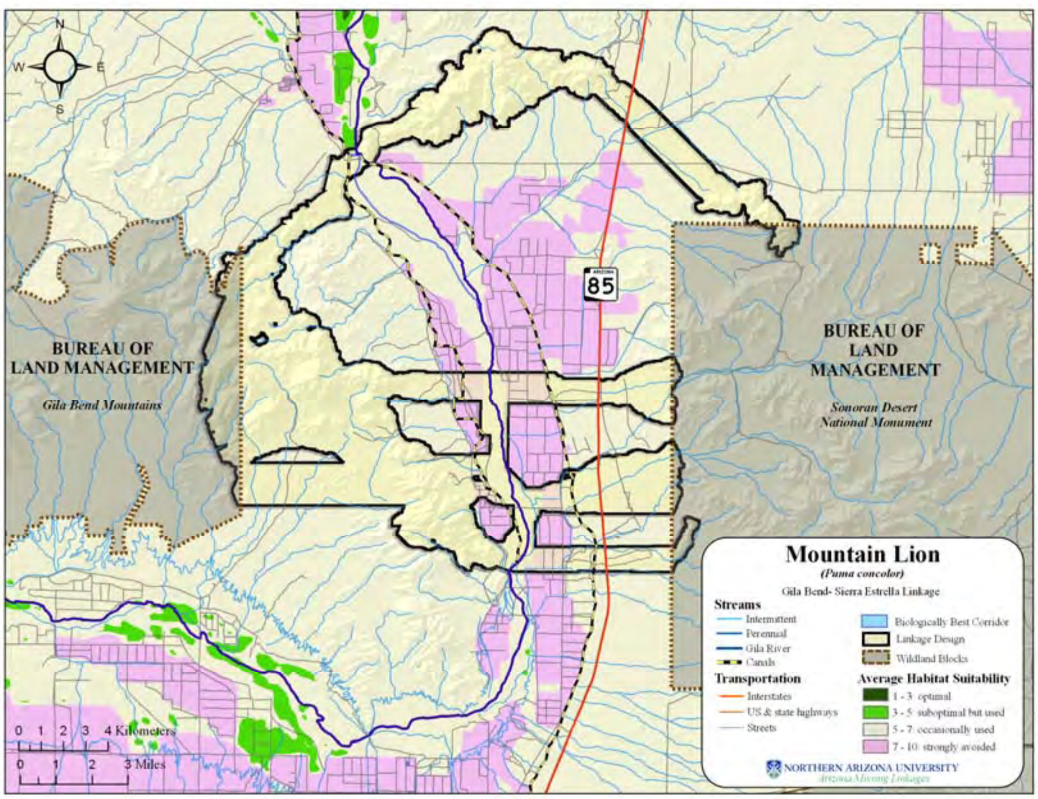


Figure 40: Modeled habitat suitability of mountain lion in the Gila Bend-SDNM Linkage.

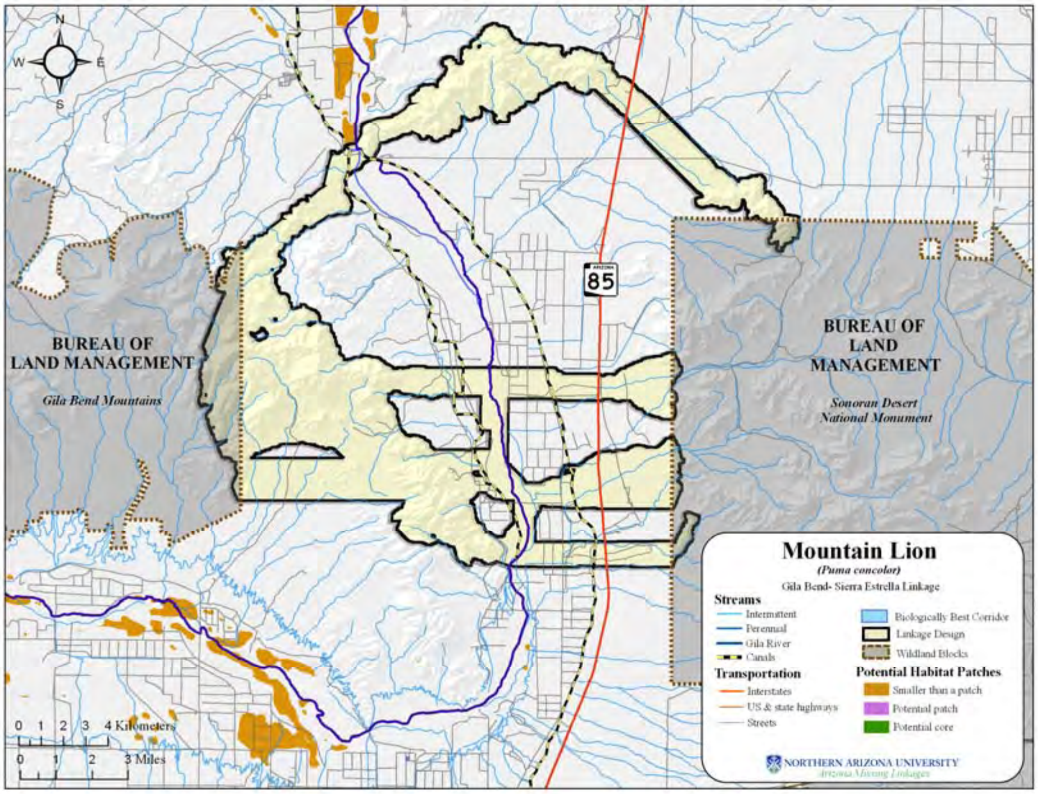


Figure 41: Potential habitat patches and cores for mountain lion in the Gila Bend-SDNM Linkage.

Mule Deer (*Odocoileus hemionus*)

Justification for Selection

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

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

Results & Discussion

Initial biologically best corridor – Modeling results identified patches and cores of suitable and optimal habitat for mule deer within the mountain ranges in the linkage planning area (Figure 43 and Figure 45). Within the BBC in the eastern strand, habitat suitability ranged from 2.8 to 5.6, with an average suitability cost of 4.8 (S.D: 1.0). Within the BBC in the western strand, habitat suitability ranged from 2.9 to 5.6 in the developed areas, with an average suitability cost of 4.5 (S.D. 1.0) (Figure 42 and Figure 45).

Union of biologically best corridors – The UBBC captures some additional habitat rated as suitable or optimal for mule deer, particularly in the Sierra Estrella mountain range and on the west side of the Gila River.

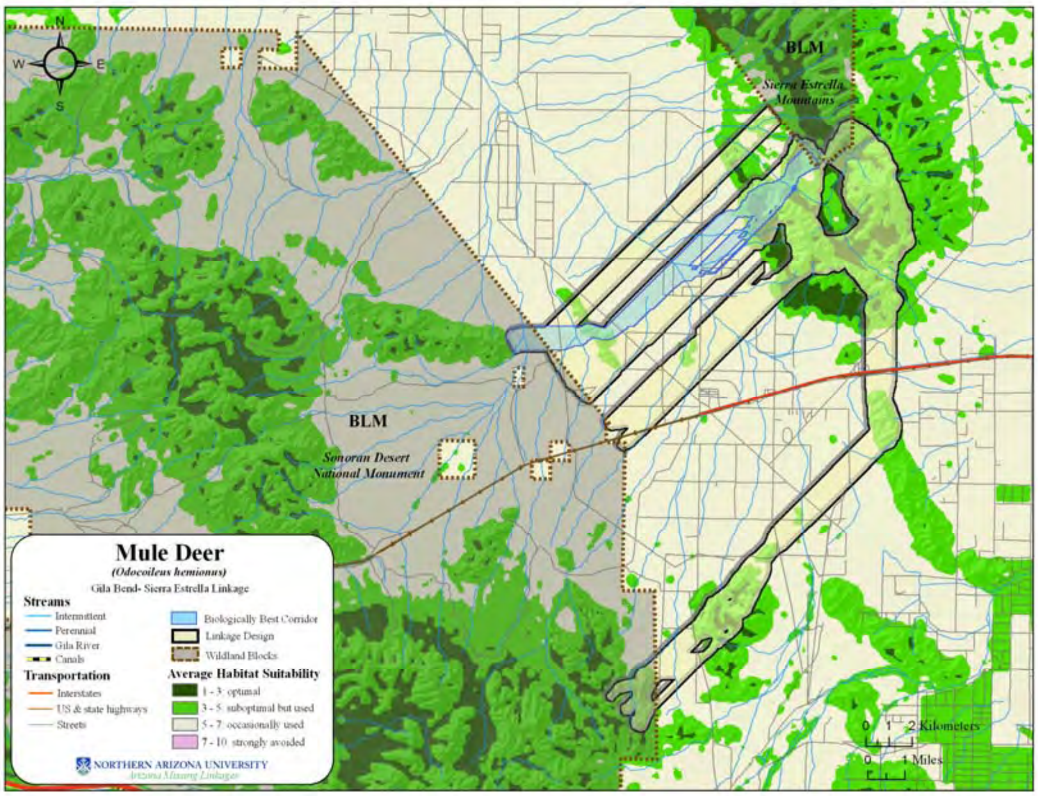


Figure 42: Modeled habitat suitability of mule deer in the SDNM-Sierra Estrella Linkage.

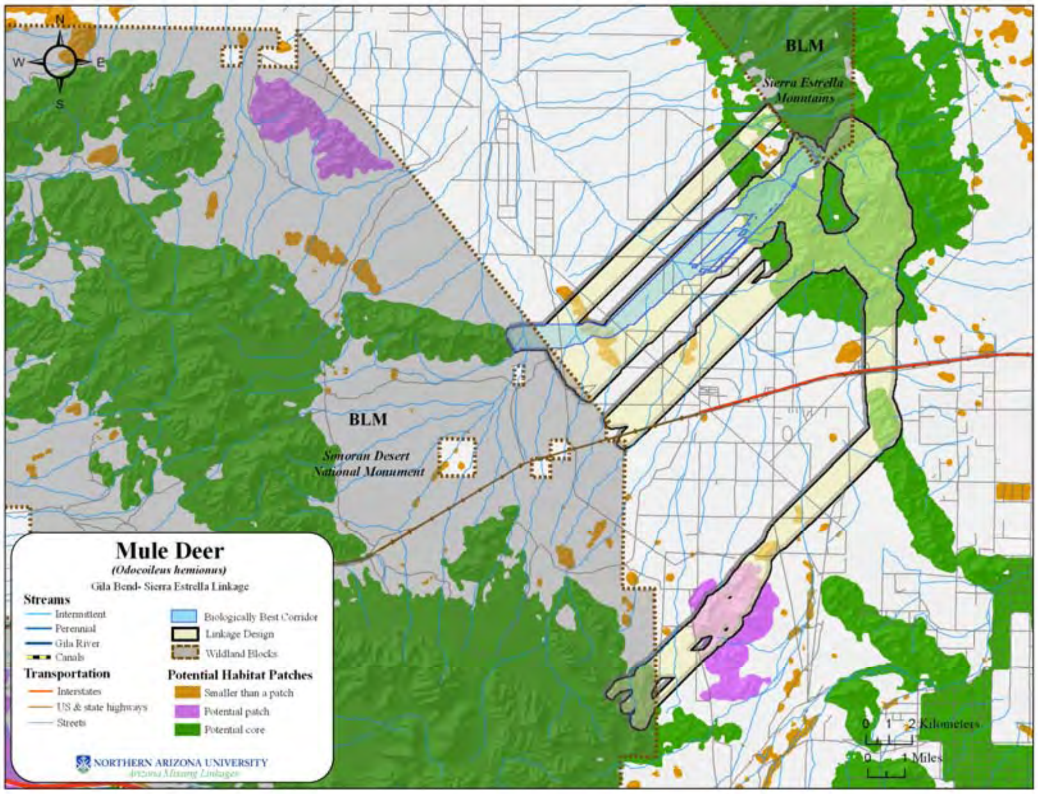


Figure 43: Potential habitat patches and cores for mule deer in the SDNM-Sierra Estrella Linkage.

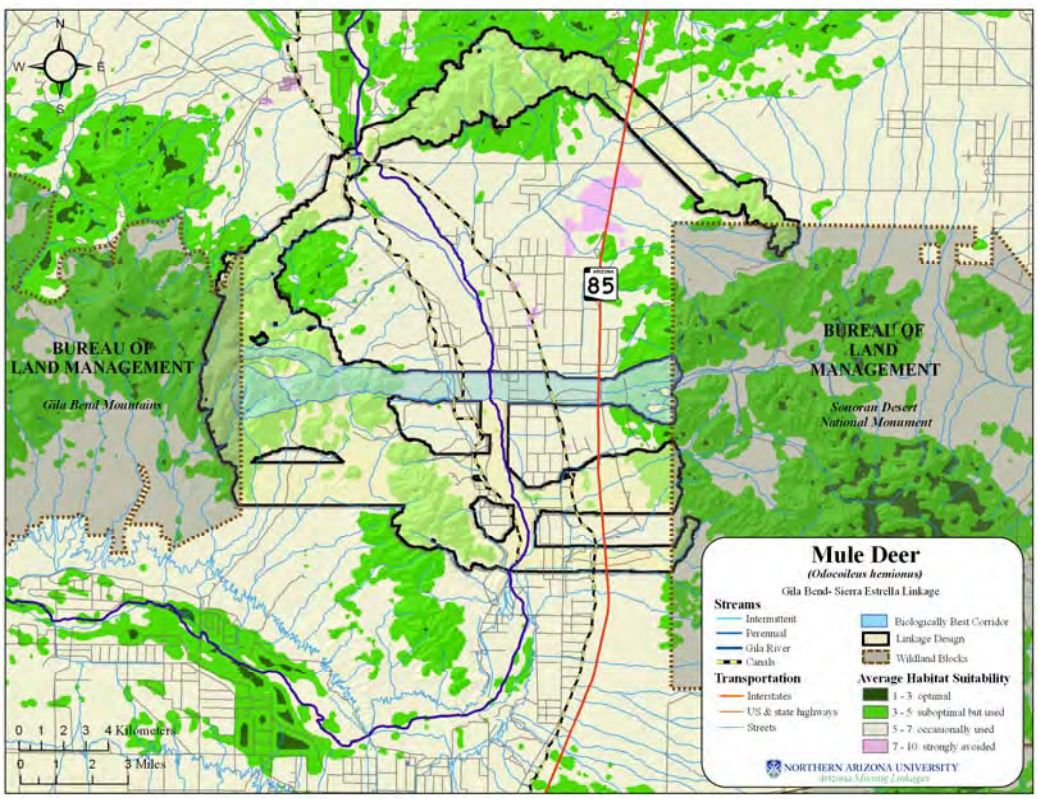


Figure 44: Modeled habitat suitability of mule deer in the SDNM-Sierra Estrella Linkage.

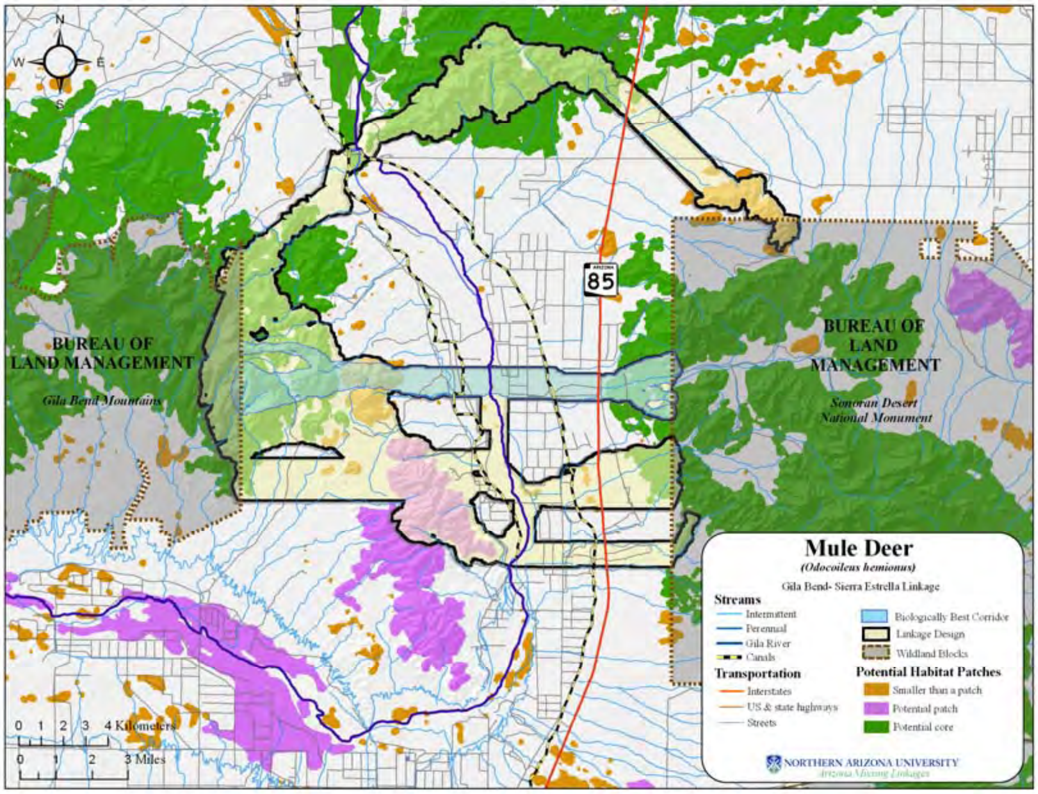


Figure 45: Potential habitat patches and cores for mule deer in the Gila Bend-SDNM Linkage.

Appendix C: Focal Species Not Modeled

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

Mammals

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

Reptiles and Amphibians

Several reptilian and amphibian species were suggested as focal species; however, their habitat preferences cannot be easily modeled using standard GIS layers. These species include:

- Desert Iguana
- Giant Spotted Whiptail Lizard
- Leopard Chuckwalla
- Long-tailed Lizard
- Red-backed Lizard
- Regal Ringneck Snake
- Rosy Boa
- Side-blotched Lizard
- Sonoran Desert Toad
- Tiger Whiptail
- Tree Lizard
- Tucson Shovel-nosed Snake
- Zebra tailed Lizard

Birds

- 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).
- Road Runner (*Geococcyx californianus*) – Road runners occur in a range of desert habitat dominated by shrubs, including paloverde and creosotebush vegetation associations (NMDGF 2005). We reasoned they would be well-covered by the remaining suite of focal species.
- Western Burrowing Owl (*Athene cunicularia hypugaea*) – Western burrowing owls are designated a sensitive species by the BLM. They prefer open, well-drained grasslands, steppes, deserts, and prairies (AZGFD 2001). Given that they are highly mobile, we could not adequately model their habitat preferences..

Plants

- Night Blooming Cerus (*Peniocereus greggi*) – This protected plant is found primarily in Sonoran desertscrub in central regions of the state, in areas where Larrea tridentata is found (Gibson and Horack 1978). Its primary threats include urban development, and construction of canals, roads, and reservoirs. Its habitat preferences could not be adequately modeled using our habitat suitability modeling process.

Appendix D: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several minor adjustments to the union of biologically best corridors (Figure 46):

The SDNM-Sierra Estrella Linkage:

- We removed the a narrow northern arm of the biologically best corridor for bobcat that did not meet minimum width requirements,
- We removed a short, narrow arm of the biologically best corridor for javelina that did not meet minimum width requirements,
- We removed a short, narrow arm of the biologically best corridor for gila monster hat did not meet minimum width requirements,
- We buffered a portion of the biologically best corridor for bighorn sheep to reach the minimum width,
- We filled-in holes that were created as an artifact of the modeling process if they were composed of natural vegetation and not high-density developed land.

The Gila Bend-SDNM Linkage:

- We buffered the eastern portion of southern most strand to reach the minimum width,
- We buffered a strand that runs north-south, connecting the two southern most strands, to meet minimum width and encompass more of the federally protected land administered by the Bureau of Land Management,
- We filled-in holes that were created as an artifact of the modeling process if they were composed of natural vegetation and not high-density developed land.

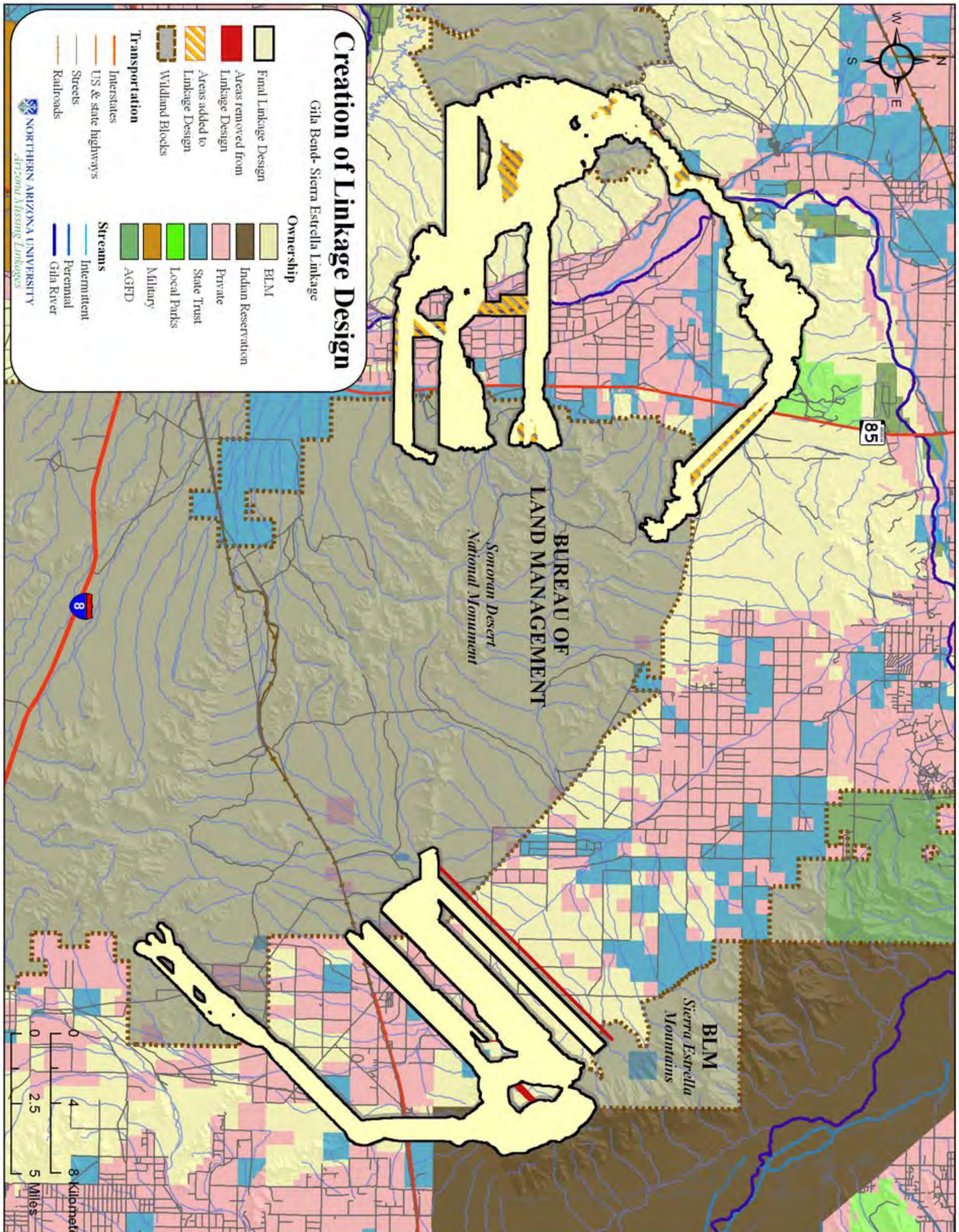


Figure 46: Adjustments to the Union of Biologically Best Corridors to create the Linkage Design.

Appendix E: Description of Land Cover Classes

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

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

Appendix F: Literature Cited

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Bleich, V.C., J.D. Wehausen, and S.A. Holl. 1990. Desert-dwelling mountain sheep: Conservation implications of a naturally fragmented distribution. Conservation Biology 4: 383-390.

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.

Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114: 189-197.

Clevenger, A.P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121: 453-464.
Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38: 1340-1349.
Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109: 15-26.
Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16:503-514.
Colby, B., and S. Wishart. 2002. Riparian areas generate property value premium for landowners. Agiculatural and Resource Economics, Arizona State University, Tucson, AZ. 15p. Available online: http://ag.arizona.edu/arec/pubs/riparianreportweb.pdf.
Conservation Biology Institute. 2005. Analysis of General Plan-2020 San Diego County. Encinitas, Ca. 27pp.
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.
Dickson, B.G., and P. Beier. 2002. Home range and habitat selection by adult cougars in southern California. Journal of Wildlife Management 66:1235-1245.
Dodd, C.K, W.J. Barichivich, and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.
Donnelly, R., and J.M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. Conservation Biology 18:733-745.
Edwards, T., E.W. Stitt, C.R. Schwalbe, and D.E. Swann. 2004. Natural History Notes: Gopherus Agassizii (Desert Tortoise). Movement. Herpetological Review 35:381-382
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Washington D.C. Available from www.elistore.org
Environmental Law Institute. 2003. Conservation thresholds for land use planners. Environmental Law Institute. Washington D.C. Available online: www.elistore.org.
Epps, C.W., D.R. McCullough, J.D. Wenausen, V.C. Bleich, and J.L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18: 102-113.
Evink, G.L. 2002. Interaction between roadways and wildlife ecology. National Academy Press, Washington, D.C.
Findley, J.S., A.H. Harris, D.E. Wilson, and C. Jones. 1975. Mammals of New Mexico. University of New Mexico Press, Albuquerque, New Mexico. xxii + 360 pp.
Fisher, R. A. and J. C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. U.S. Army Engineer Research and Development Center. ERDC-TN-EMRRPSR-24. Available online
Forman, R.T.T., et al. 2003. Road ecology: science and solutions. Island Press: Washington, D.C.
Friesen, L.E., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.
Fuller, T.K., Berendzen, S.L., Decker, D.A., & Cardoza, J.E. (1995). Survival and cause- specific mortality rates of adult bobcats *(Lynx rufus). American Midland Naturalist* 134:404-408.
Germaine, S.S., and B.F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229-237.
Germaine, S.S., S.S. Rosenstock, R.E. Schweinsburg, and W.S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson, Arizona. Ecological Applications 8:680-691.
Germano, D.J. 1992. Longevity and age-size relationships of populations of desert tortoises. Copeia 1992: 367-374.
Goodrich, J.M., and S.W. Buskirk. 1998. Spacing and ecology of North American badgers (*Taxidea taxus*) in a prairie-dog (*Cynomys leucurus*) complex. Journal of Mammalogy 78: 171-179.
Gross, J.E., F.J. Singer, and M.E. Moses. 2000. Effects of disease, dispersal, and area on bighorn sheep restoration. Restoration Ecology 8: 25-37.
Halloran, A.F.. and W.E. Blanchard. 1954. Carnivores of Yuma County, Arizona. American Midland Naturalist 51: 481-487.
Hart, D.D., T.E. Johnson, K.L. Bushaw-Newton, R.J. Horowitz, A.T. Bednarek, D.F. Charles, D.A. Kreeger, and D.J. Velinsky. 2002. Dam removal: challenges and opportunities for ecological research and river restoration. Bioscience 52: 669- 681.
Hoffmeister, D.F. 1986. Mammals of Arizona. The University of Arizona Press and The Arizona Game and Fish

Department. 602 pp.
Jennings, W.B. 1997. Habitat use and food preferences of the desert tortoise, Gopherus agassizii, in the Western Mojave Desert and impacts of off-road vehicles. Proccedings: Conservation, Restoration, and Management of Tortoises and turtles – An International Conference: pp. 42-45.
Johnson, T.L., and D.M. Swift. 2000. A test of a habitat evaluation procedure for Rocky Mountain Bighorn Sheep. Restoration Ecology 8: 47-56.
http://en.wikipedia.org/wiki/Bobcat - _ref-Kansas_1Kamler, JF; Gipson, PS. 2000. "Home Range, Habitat Selection, and Survival of Bobcats, Lynx rufus, in a Prairie Ecosystem in Kansas". Canadian Field-Naturalist 114 (3): 388-94.
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.
Kraussman, P.R. 2000. An Introduction to the restoration of bighorn sheep. Restoration Ecology 8: 3-5.
Krueper, D. J. 1993. Conservation priorities in naturally fragmented and human-altered riparian habitats of the arid West. USDA Forest Service. General Technical Report RM-43. Available online: www.birds.cornell.edu/pifcapemay/krueper.htm.
Kupferberg, S. J. 1997. Bullfrog (*Rana catesbeiana*) invasion of a California river: the role of larval competition. Ecology 78: 1736-1751.
Lambeck, R. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.
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.
Lite, S.J., and J.C. Stromberg. 2005. Surface water and ground-water thresholds for maintaining Populus - Salix forests, San Pedro River, Arizona. Biological Conservation 125:153–167.
Little, S.J. 2003. The influence of predator-prey relationships on wildlife passage evaluation. ICOET 2003.
Logan, K.A., and L.L. Sweanor. 2001. Desert Puma: Evolutionary Ecology and Conservation of an Enduring Carnivore. Island Press, Washington D.C. 463 pp.
Long, C.A. 1973. Taxidea taxus. Mammalian Species 26: 1-4.
Long, C.A., and C.A. Killingley. 1983. The badgers of the world. Charles C. Thomas Publishing, Springfield, IL.
Lowe, C.H. 1978. The Vertebrates of Arizona. The University of Arizona Press. Tuscon, Arizona. 270pp.
Luckenbach, R.A., and R.B. Bury. 1983. Effects of off-road vehicles on the biota of the Algodones Dunes, Imperial County, California. Journal of Applied Ecology 20: 265-286.
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.
McDonald, W., and C.C. St Clair. 2004. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41: 82-93.
Messick, J.P., and M.G. Hornocker. 1981. Ecology of the badger in southwestern Idaho. Wildlife Monographs 76.
Naiman, R. J., H. Decamps and M. Pollock. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.
National Academy of Sciences. 2002. Riparian areas: functions and strategies for management. National Academy Press. Washington D. C. 436 p.
NatureServe. 2005. NatureServe Explorer: An online encyclopedia of life [web application]. Version 4.6. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: November 29, 2005).
New Mexico Department of Game & Fish. 2002. Biota Information System of New Mexico. New Mexico Department of Game & Fish electronic database, BISON, Version 1/2004, Santa Fe, New Mexico.

http://nmnhp.unm.edu/bisonm/bisonquery.php. Accessed 9 September 2005.
Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115: 499-507.
Ockenfels, R.A., 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.
Odell, E.A., and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.
Oftedal, O.T. 2002. Nutritional ecology of the desert tortoise in the Mohave and Sonoran deserts. Pp. 194-241 in Van Devender, T.R. (ed) The Sonoran Desert Tortoise. Natural History, Biology, and Conservation. Univ. of Arizona Press, Tucson.
Olsen, D.M., and E. Dinnerstein. 1998. The Global 200: A Representation approach to Conserving the Earth's Most Biologically Valuable Ecoregions. Conservation Biology 12:502-515.
Parkyn, S. 2004. Review of riparian buffer zone effectiveness. MAF Technical Paper No: 2004/05. Available online: www.maf.govt.nz/publications.
Peris, S., and J. Morales. 2004. Use of passages across a canal by wild mammals and related mortality. European Journal of Wildlife Research. 50: 67-72.
Pima County, Arizona. 2001. Sonoran Desert Conservation Plan: Priority Vulnerable Species. Unpublished report by Pima County, Arizona. Available from http://www.co.pima.az.us/cmo/sdcp website. (Accessed February 13, 2006).
Riley, S. P. D., R. M. Sauvajot, D. Kamradt, E. C. York, C. Bromley, T. K. Fuller, and R. K. Wayne. 2003. Effects of urbanization and fragmentation on bobcats and coyotes in urban southern California Conservation Biology 17: 566-576 .
Riley. 2006. Spatial Ecology of Bobcats and Gray Foxes in Urban and Rural Zones of a National Park. Journal of Wildlife Management 70(5):1425–1435.
Rollins, Dale. Managing Desert Mule Deer. Wildlife Management Handbook: 41-46.
Rosen, P.C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation 68: 143-148.
Rottenborn, S.C. 1999. Predicting impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.
Rubin, E.S., W.M. Boyce, C.J. Stermer, and S.G. Torres. 2002. Bighorn sheep habitat use and selection near an urban environment. Biological Conservation 104: 251-263.
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.
Shackleton, D.M. 1985. *Ovis canadensis.* Mammalian Species 230: 1-9.
Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12: 107-123.
Singer, F.J., C.M. Papouchis, and K.K. Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8: 6-13.
Singer, F.J., M.E. Moses, S. Bellew, and W. Sloan. 2000. Correlates to colonizations of new patches by translocated populations of bighorn sheep. Restoration Ecology 8: 66-74.
Singer, F.J., V.C. Bleich, and M.A. Gudorf. 2000. Restoration of Bighorn Sheep Metapopulations in and Near Western National Parks. Restoration Ecology 8: 14-24.
Singer,F.J., L.C. Zeigenfuss, and L. Spicer. 2001. Role of Patch Size, Disease, and Movement in Rapid Extinction of Bighorn Sheep. Conservation Biology 15: 1347-1354.
Smith, W.P. 1991. Odocoileus virginianus. Mammalian Species 388: 1-13.
Sowls, L. K. 1997. Javelinas and other peccaries: their biology, management, and use. Second edition. Texas A & M University, College Station, Texas, USA.
Springer, A. E., J. M. Wright, P. B. Shafroth, J. C. Stromberg, and D. T. Patten 1999. Coupling ground-water and riparian vegetation models to simulate riparian vegetation changes due to a reservoir release. Water Resources Research 35: 3621-3630.

Stralberg, D., and B. Williams. 2002. Effects of residential development and landscape composition on the breeding birds of Placer County's foothill oak woodlands. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.
Stromberg, J. 2000. Parts 1-3: Restoration of riparian vegetation in the arid Southwest: challenges and opportunities. Arizona Riparian Council Newsletter vol. 13 no. 1-3. Arizona Riparian Council. Tempe, Arizona. Available online: http://azriparian.asu.edu/newsletters.htm.
Stromberg, J.C., J.A. Tress, S.D. Wilkins, and S. Clark. 1992. Response of velvet mesquite to groundwater decline. Journal of Arid Environments 23:45-58.
Stromberg, J.C., M.R. Sommerfield, D.T. Patten, J. Fry, C. Kramer, F. Amalfi, and C. Christian. 1993. Release of effluent into the Upper Santa Cruz River, Southern Arizona: ecological considerations. Pp. 81-92 in M. G. Wallace, ed. Proceedings of the Symposium on Effluent Use Management. American Water Resources Association, Tucson, AZ.
Stromberg, J.C. 1997. Growth and survivorship of Fremont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist 57:198-208.
Sullivan T.L., and T.A. Messmer. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. Wildlife Society Bulletin 31:163-173.
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. 1994. Desert Tortoise (Mojave Population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon, USA. 73pp.
U.S. Fish and Wildlife Service. 1981. Standards for the development of Suitability Index Models. Division of Ecological Services. Government Printing Office, Washington D.C., USA.
U.S. Fish and Wildlife Service. 2001. Gila Topminnow General Species Information. Unpublished abstract compiled by the Arizona Ecological Services Field Office, U.S. Fish and Wildlife Service, Phoenix, AZ. Available from http://www.fws.gov/arizonaes/Southwes.htm website. (Accessed January 27, 2006).
US Fish and Wildlife Service. 2005. Species Information: Threatened and Endangered Animals and Plants website: http://www.fws.gov/endangered/wildlife.html#Species (Accessed January 4, 2006).
Van Wieren, S.E., and P.B. Worm. 2001. The use of a motorway wildlife overpass by large mammals. Netherlands Journal of Zoology 51: 97-105.
Vander Haegen, W.M., G.R. Orth, and L.M. Aker. 2005. Ecology of the western gray squirrel in south-central Washington. Progress report. Washington Department of Fish and Wildlife, Olympia. 41pp.
Vohies, C.T., and W.P. Taylor. 1933. The life histories and ecology of jack rabbits, Lepus alleni and Lepus californicus spp., in relation to grazing in Arizona. University of Arizona College Agricultural Technical Bulletin 49: 471-587.
Vos, C.C., J. Verboom, P.F.M. Opdam, and C.J.F. Ter Braak. 2001. Toward ecologically scaled landscape indices. The American Naturalist 183: 24-41.
Wallmo, O.C. 1981. Mule and Black-tailed deer of North America. University of Nebraska Press. Lincoln and London. 605 pp.
Webb, R.H. and H.G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. New York : Springer-Verlag.
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.

Woolf, A and Hubert, GF. 1998. Statue and Management of Bobcats in the United States over Three Decades: 1970 – 1990. Wildlife Society Bulletin vol. 26, n 2, p 287-293.

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.

Zeigenfuss, L.C., F.J. Singer, and M.A. Gudorf. 2000. Test of a modified habitat suitability model for bighorn sheep. Restoration Ecology 8: 38-46.

Appendix G: Database of Field Investigations

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

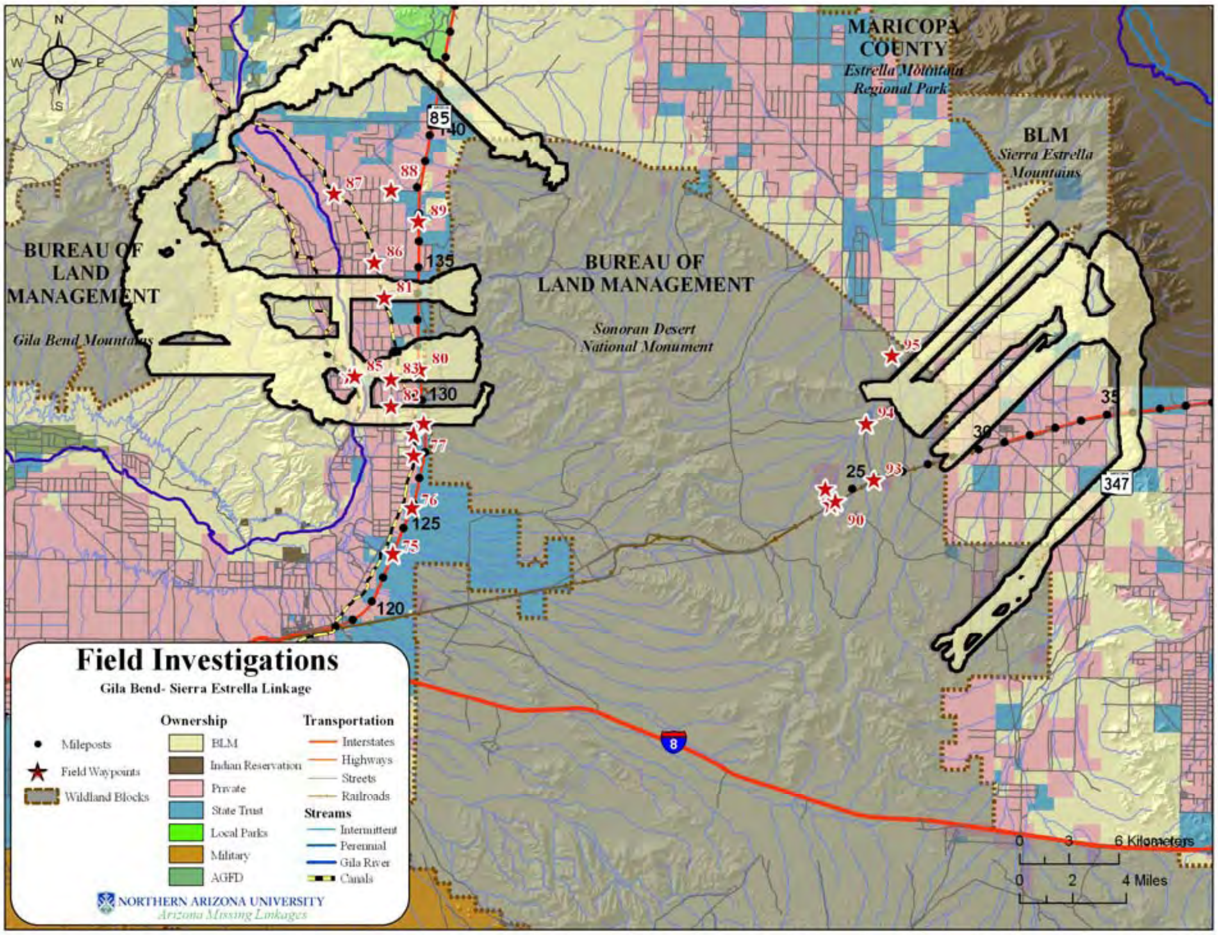
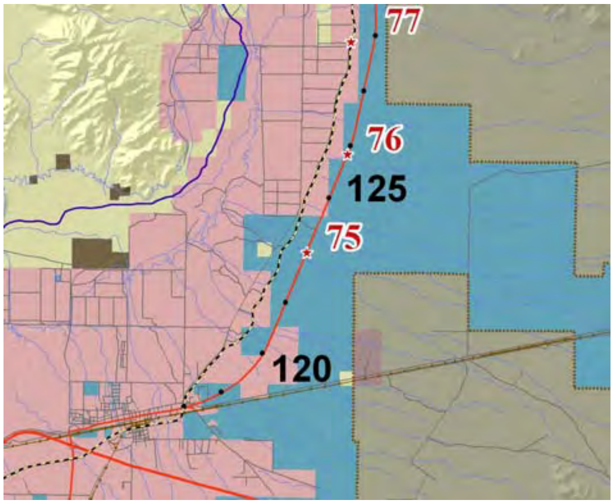


Figure 47: Waypoints marking field investigation sites within the linkage planning area

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	75		
Linkage Zone:	Gila Bend	**Latitude:**	32.99052	**Longitude:**	-112.66346
Observers:	Paul Beier	**UTM X:**	344580.9232	**UTM Y:**	3651464.664
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

SR 85, MP 124

Site Photographs

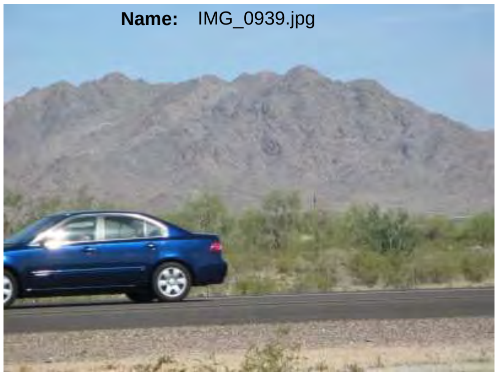
Name: IMG_0937.jpg

Notes: 5x10' Box culvert typical of crossing structures located approximately every 1/2 mile along SR 85.

Name: IMG_0938.jpg

Notes: Box culverts

Name: IMG_0939.jpg

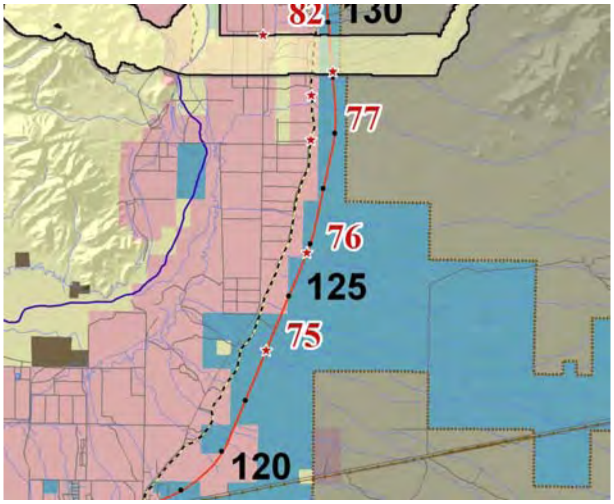


Azimuth: 285 **Zoom:** 6

Notes: Gila Bend Mountains

Linkage #:	73	**Waypoint #:**	76		
Linkage Zone:	Gila Bend	**Latitude:**	33.01585	**Longitude:**	-112.65163
Observers:	Paul Beier	**UTM X:**	345730.451	**UTM Y:**	3654255.812
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

SR 85, MP 125.9

Site Photographs

Name: IMG_0940.jpg

Azimuth: 260 **Zoom:** 3

Notes: Farms, Gila Bend Mountains, Graded land

Name: IMG_0941.jpg

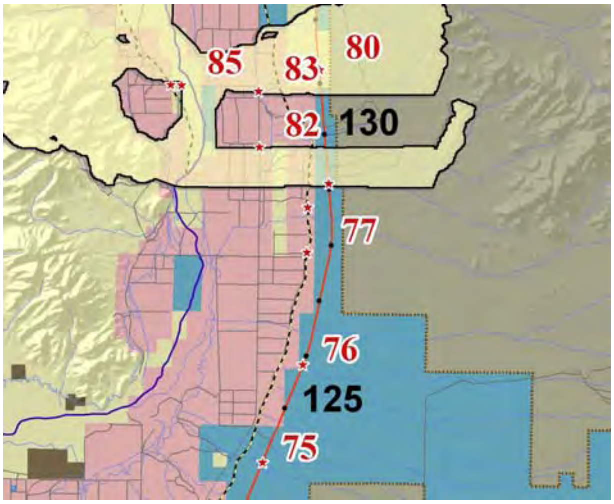
Azimuth: 260 **Zoom:** 3

Name: IMG_0942.jpg

Azimuth: 260 **Zoom:** 3

Linkage #:	73	**Waypoint #:**	77		
Linkage Zone:	Gila Bend	**Latitude:**	33.04473	**Longitude:**	-112.651
Observers:	Paul Beier	**UTM X:**	345839.6127	**UTM Y:**	3657457.087
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Canal

Site Photographs

Name: IMG_0943.jpg

Azimuth: 250 **Zoom:** 3

Notes: Enterprise Canal pictured, with farms and Gila Bend Mountains in the distance

Name: IMG_0944.jpg

Azimuth: 295 **Zoom:** 3

Notes: Enterprise Canal in the foreground and desert scrub in background

Name: IMG_0945.jpg

Azimuth: 340 **Zoom:** 3

Notes: Along the Enterprise Canal

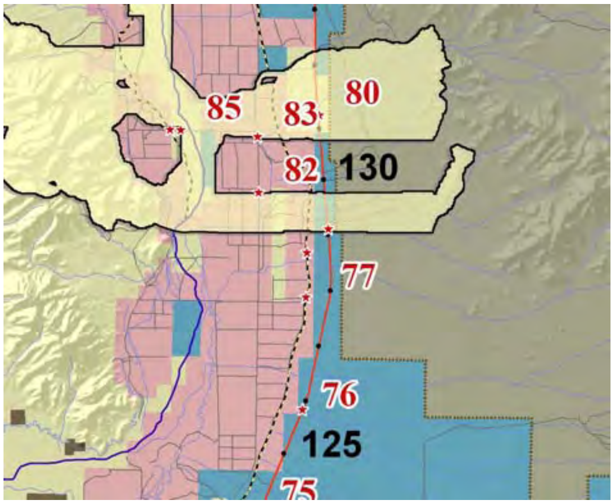
Name: IMG_0946.jpg

Notes: The canal has steep (roughly 45 degree) banks that could impede wildlife movement

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	78		
Linkage Zone:	Gila Bend	**Latitude:**	33.05626	**Longitude:**	-112.65099
Observers:	Paul Beier	**UTM X:**	345860.6431	**UTM Y:**	3658735.516
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Gap in Canal

Site Photographs

Name: IMG_0947.jpg

Notes: The downstream end of the siphon

Name: IMG_0948.jpg

Notes: A gap in the Enterprise Canal

Name: IMG_0949.jpg

Azimuth: 55 **Zoom:** 3

Notes: SR 85 and Mountains beyond

Name: IMG_0950.jpg

Azimuth: 255 **Zoom:** 4

Notes: A wash in desert scrub habitat flowing toward the gap in the canal, agricultural fields and the Gila Bend mountains in the background

Appendix G: Database of Field Investigations

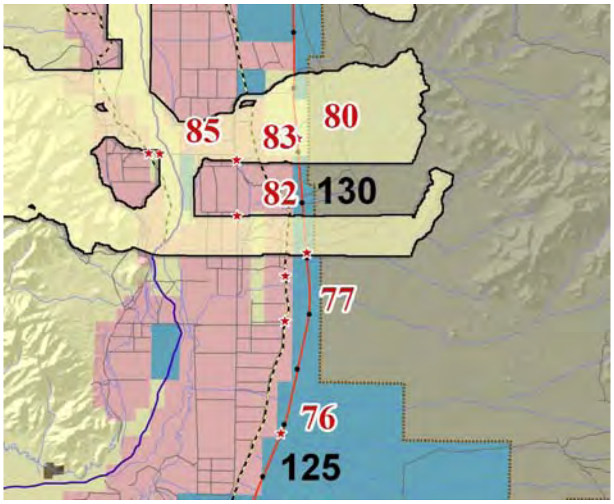
Linkage #: 73 | **Waypoint #:** 79

Linkage Zone: Gila Bend | **Latitude:** 33.06235 | **Longitude:** -112.64464

Observers: Paul Beier | **UTM X:** 346464.1334 | **UTM Y:** 3659401.47

Field Study Date: 5/11/2007 | **Last Printed:** 12/19/2007

Waypoint Map



Waypoint Notes

SR 85, MP 129, an approximately 15' high ridge is a potential location for an overcrossing

Site Photographs

Name: IMG_0952.jpg

Azimuth: 65 **Zoom:** 4

Notes: Desert to the northeast

Name: IMG_0953.jpg

Azimuth: 5 **Zoom:** 4

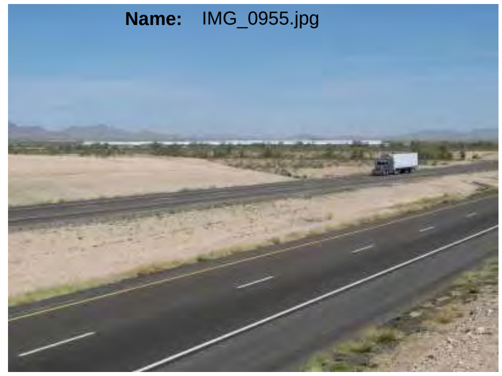
Notes: Desert to the North

Name: IMG_0954.jpg

Azimuth: 235 **Zoom:** 4

Notes: Highway, desert, and agricultual land to the west

Name: IMG_0955.jpg

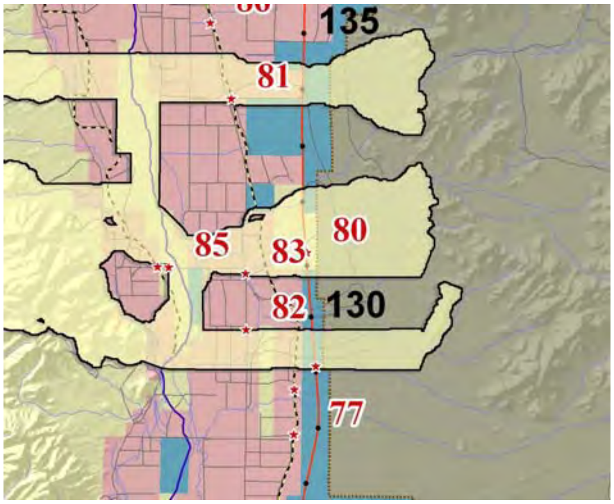


Azimuth: 305 **Zoom:** 2

Notes: Approximately 15' ridge along Highway, sheds in the distance

Linkage #:	73	**Waypoint #:**	80		
Linkage Zone:	Gila Bend	**Latitude:**	33.09153	**Longitude:**	-112.6479
Observers:	Paul Beier	**UTM X:**	346210.5621	**UTM Y:**	3662641.725
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

SR 85, MP 131.08, an approximately 10' high ridge is a potential location for an overcrossing

Site Photographs

Name: IMG_0957.jpg

Azimuth: 190 **Zoom:** 6

Notes: Ridge adjacent to road, large white sheds beyond

Name: IMG_0958.jpg

Azimuth: 155 **Zoom:** 6

Notes: SR 89 becomes a divided highway from this point south

Name: IMG_0959.jpg

Azimuth: 85 **Zoom:** 6

Notes: Desert to the east

Name: IMG_0960.jpg

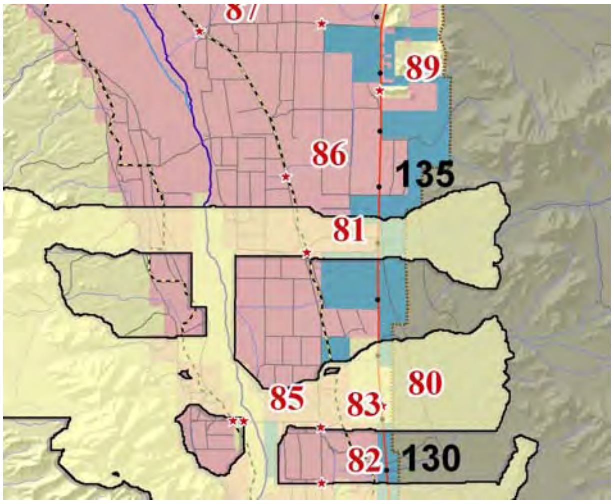
Azimuth: 10 **Zoom:** 6

Notes: Desert to the North

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	81		
Linkage Zone:	Gila Bend	**Latitude:**	33.13068	**Longitude:**	-112.67157
Observers:	Paul Beier	**UTM X:**	344070.5200	**UTM Y:**	3667017.677
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Woods Road and Old US Highway 80

Site Photographs

Name: IMG_0962.jpg

Azimuth: 270 **Zoom:** 4

Notes: Junction of canal, Woods Road, and Old US Highway 80

Name: IMG_0963.jpg

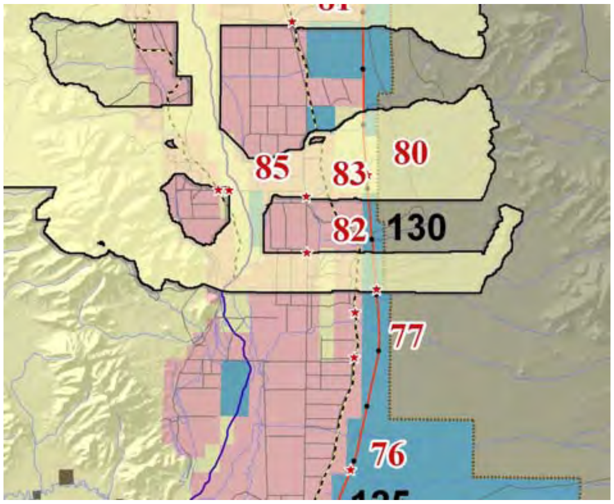
Azimuth: 250 **Zoom:** 6

Notes: Crop rows and mountains

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	82		
Linkage Zone:	Gila Bend	**Latitude:**	33.07146	**Longitude:**	-112.66598
Observers:	Paul Beier	**UTM X:**	344487.7336	**UTM Y:**	3660443.002
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Old US Highway 80, MP 9

Site Photographs

Name: IMG_0965.jpg

Azimuth: 45 **Zoom:** 3

Notes: Cottonfields and sheds

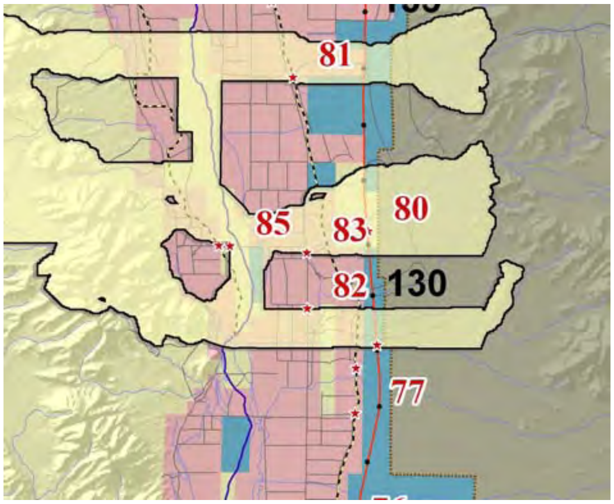
Name: IMG_0966.jpg

Azimuth: 285 **Zoom:** 6

Notes: Agriculture includes cornfields and hay, mountains in the distance

Linkage #:	73	**Waypoint #:**	83		
Linkage Zone:	Gila Bend	**Latitude:**	33.08581	**Longitude:**	-112.66645
Observers:	Paul Beier	**UTM X:**	344469.1214	**UTM Y:**	3662034.836
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map

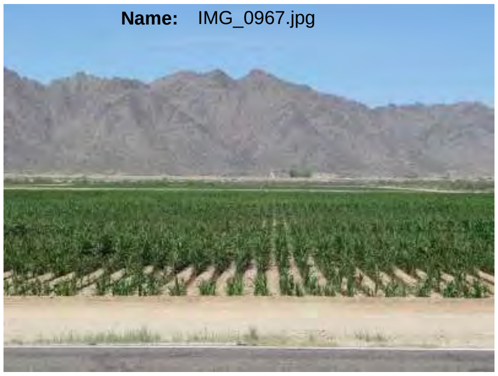


Waypoint Notes

Old US Highway 80 and Pierpoint Road

Site Photographs

Name: IMG_0967.jpg

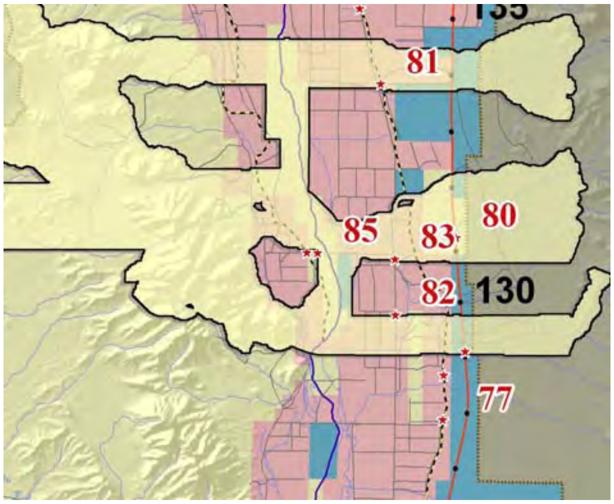


Azimuth: 270 **Zoom:** 4

Notes: Corn field, the Gila River and the Gila Bend Mountains in the distance

Linkage #:	73	**Waypoint #:**	84		
Linkage Zone:	Gila Bend	**Latitude:**	33.0872	**Longitude:**	-112.69322
Observers:	Paul Beier	**UTM X:**	341972.853	**UTM Y:**	3662228.965
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Pierpoint Road and the Gila River

Site Photographs

Name: IMG_0968.jpg

Notes: Truck loads of waste

Name: IMG_0969.jpg

Azimuth: 190 **Zoom:** 2

Notes: A pasture leading up to the Gila Bend Mountains

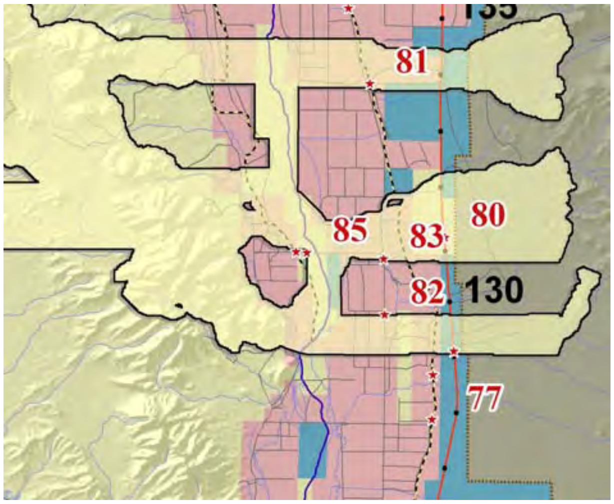
Name: IMG_0970.jpg

Azimuth: 125 **Zoom:** 2

Notes: Downstream in the Gila River

Linkage #:	73	**Waypoint #:**	85		
Linkage Zone:	Gila Bend	**Latitude:**	33.08713	**Longitude:**	-112.68991
Observers:	Paul Beier	**UTM X:**	342281.6847	**UTM Y:**	3662216.222
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Pierpoint Road and the Gila River

Site Photographs

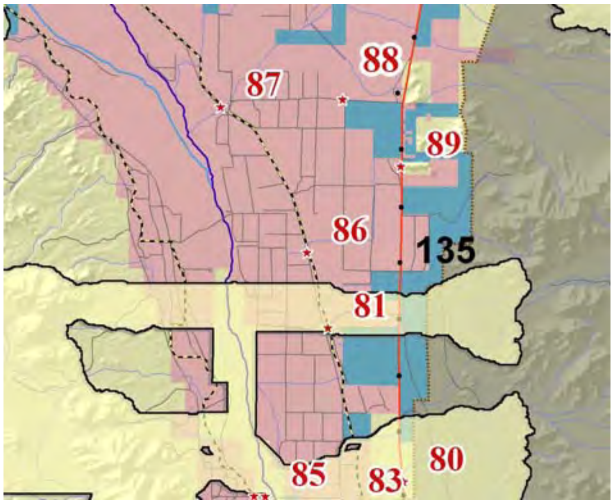
Name: IMG_0971.jpg

Azimuth: 320 **Zoom:** 6

Notes: Upstream in the Gila River

Linkage #:	73	**Waypoint #:**	86		
Linkage Zone:	Gila Bend	**Latitude:**	33.15004	**Longitude:**	-112.67839
Observers:	Paul Beier	**UTM X:**	343468.6424	**UTM Y:**	3669174.519
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Old US Highway 80 and Layton Wash

Site Photographs

Name: IMG_0972.jpg

Azimuth: 320 **Zoom:** 1
Notes: The Canal

Name: IMG_0973.jpg

Azimuth: 245 **Zoom:** 1
Notes: Downstream in Layton Wash

Name: IMG_0974.jpg

Azimuth: 45 **Zoom:** 2
Notes: Upstream in Layton Wash

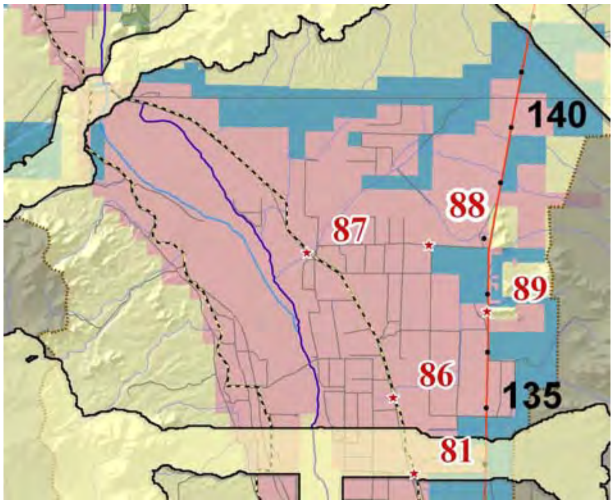
Name: IMG_0975.jpg

Azimuth: 245 **Zoom:** 2
Notes: Downstream in Layton Wash

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	87		
Linkage Zone:	Gila Bend	**Latitude:**	33.18695	**Longitude:**	-112.70536
Observers:	Paul Beier	**UTM X:**	341019.7115	**UTM Y:**	3673307.841
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

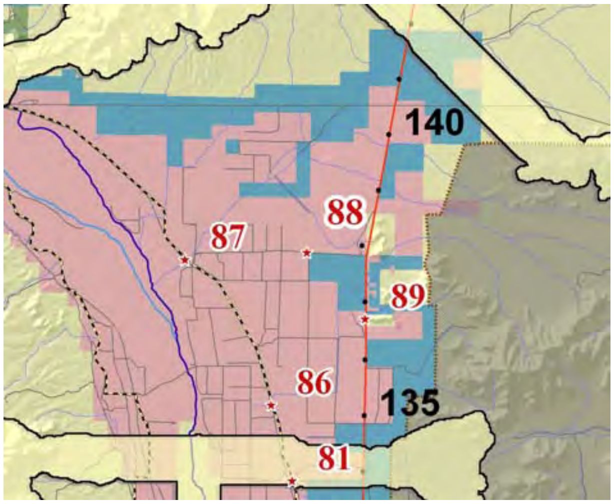
(No photo) The intersection at Old US Highway 80 and Rainbow wash was under construction.

Site Photographs

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	88		
Linkage Zone:	Gila Bend	**Latitude:**	33.18937	**Longitude:**	-112.66818
Observers:	Paul Beier	**UTM X:**	344490.4534	**UTM Y:**	3673520.300
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map

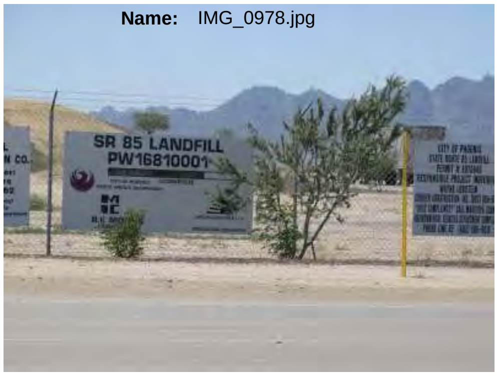


Waypoint Notes

The City of Phoenix landfill on Patterson Road

Site Photographs

Name: IMG_0978.jpg

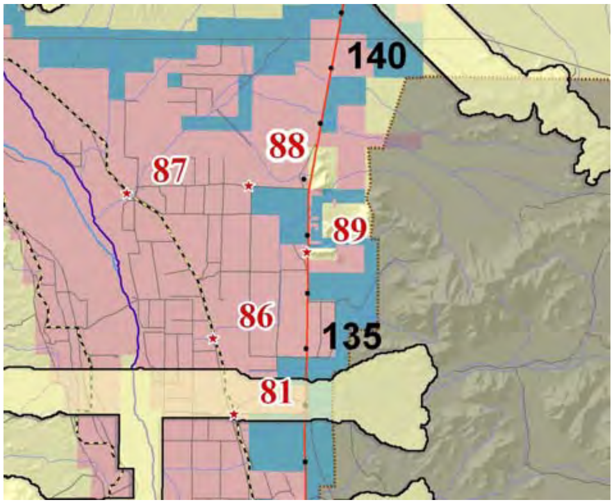


Notes: The entrance to the landfill

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	89		
Linkage Zone:	Gila Bend	**Latitude:**	33.17251	**Longitude:**	-112.65022
Observers:	Paul Beier	**UTM X:**	346135.4158	**UTM Y:**	3671624.280
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

SR 85

Site Photographs

Name: IMG_0979.jpg

Azimuth: 70 **Zoom:** 1

Notes: Foothills of Maricopa Mountains

Name: IMG_0980.jpg

Azimuth: 240 **Zoom:** 1

Notes: Landfill on the right

Name: IMG_0981.jpg

Azimuth: 225 **Zoom:** 4

Notes: Desert flats, agricultural fiels and the Gila Bend Mountains

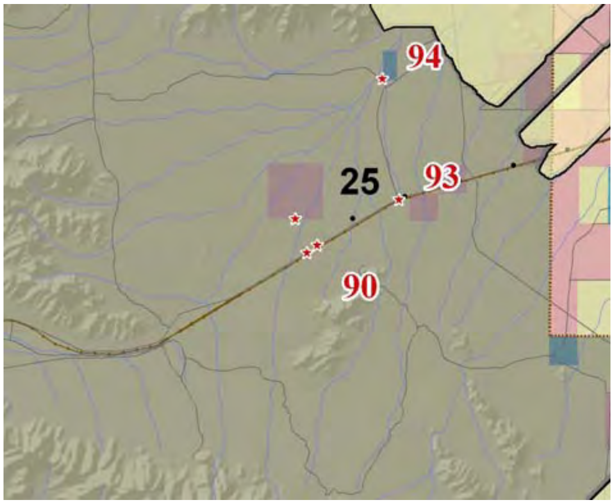
Name: IMG_0982.jpg

Azimuth: 205 **Zoom:** 3

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	90		
Linkage Zone:	Gila Bend	**Latitude:**	33.02079	**Longitude:**	-112.38034
Observers:	Paul Beier	**UTM X:**	371079.5334	**UTM Y:**	3654438.094
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map

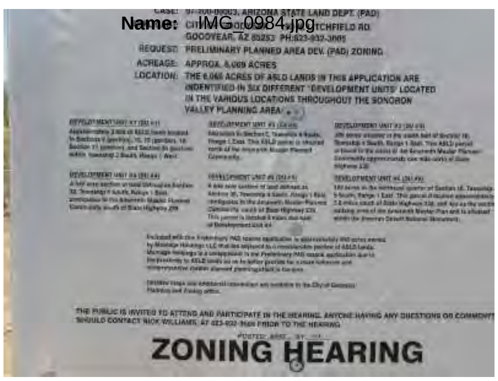


Waypoint Notes

Maricopa Road, MP 24

Site Photographs

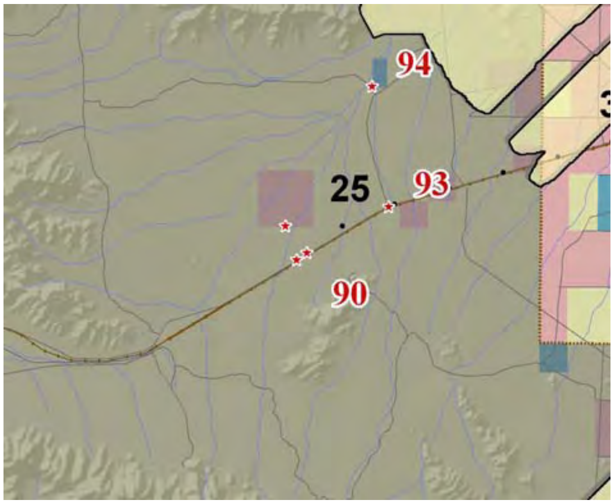
Name: IMG_0984.jpg



Notes: Sign indicating that applications have ben submitted to develop over 6,000 acres of state land.

Linkage #:	73	**Waypoint #:**	91		
Linkage Zone:	Gila Bend	**Latitude:**	33.0227	**Longitude:**	-112.37728
Observers:	Paul Beier	**UTM X:**	371368.1273	**UTM Y:**	3654646.114
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

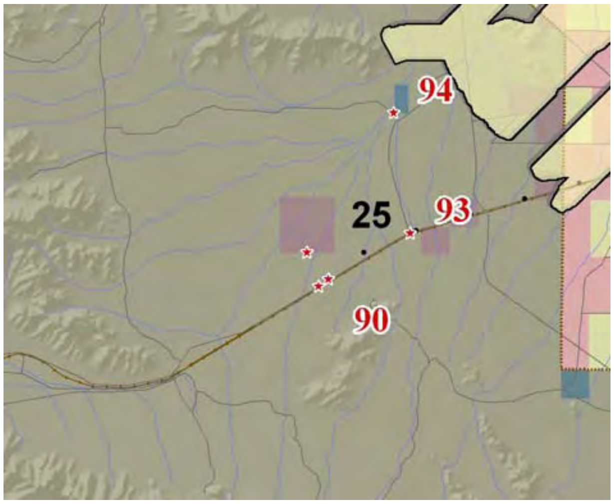
(No photo) A paved road leaves Maricopa Road towards industrial building

Site Photographs

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	92		
Linkage Zone:	Gila Bend	**Latitude:**	33.0294	**Longitude:**	-112.38395
Observers:	Paul Beier	**UTM X:**	370754.9106	**UTM Y:**	3655397.151
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Tire recycling facility

Site Photographs

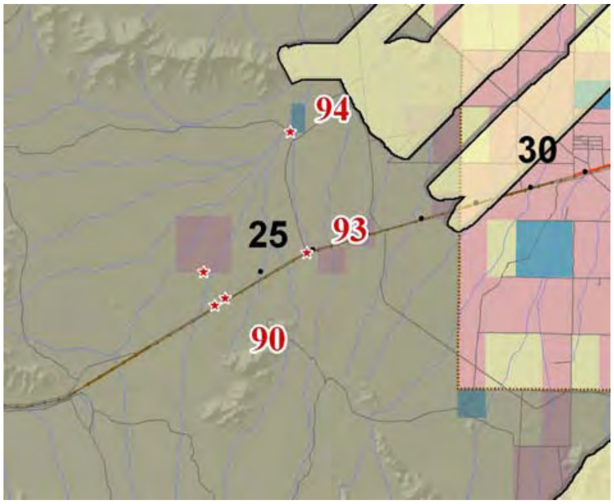
Name: IMG_0985.jpg

Name: IMG_0986.jpg

Notes: Tire recycling facility

Linkage #:	73	**Waypoint #:**	93		
Linkage Zone:	Gila Bend	**Latitude:**	33.03471	**Longitude:**	-112.3526
Observers:	Paul Beier	**UTM X:**	373690.4444	**UTM Y:**	3655947.768
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

SR 238, MP 25.9

Site Photographs

Name: IMG_0987.jpg

Azimuth: 305 **Zoom:** 4

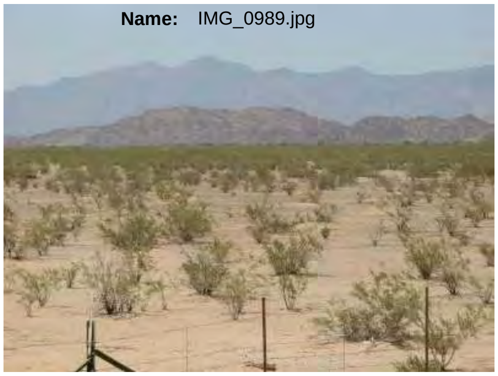
Notes: Creosote flats

Name: IMG_0988.jpg

Azimuth: 0 **Zoom:** 4

Notes: Dirt road heading north through the creosote flats

Name: IMG_0989.jpg



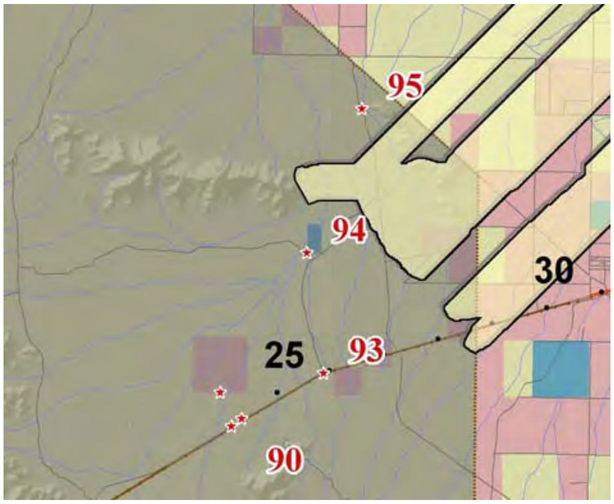
Azimuth: 30 **Zoom:** 4

Notes: Creosote flats

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	94		
Linkage Zone:	Gila Bend	**Latitude:**	33.06561	**Longitude:**	-112.35806
Observers:	Paul Beier	**UTM X:**	373224.8309	**UTM Y:**	3659380.343
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

North Tank

Site Photographs

Name: IMG_0990.jpg

Azimuth: 310 **Zoom:** 3

Notes: Stock corral and desert flats

Name: IMG_0991.jpg

Azimuth: 265 **Zoom:** 6

Notes: Desert flats

Name: IMG_0992.jpg

Notes: Stock tank and mesquite trees

Name: IMG_0993.jpg

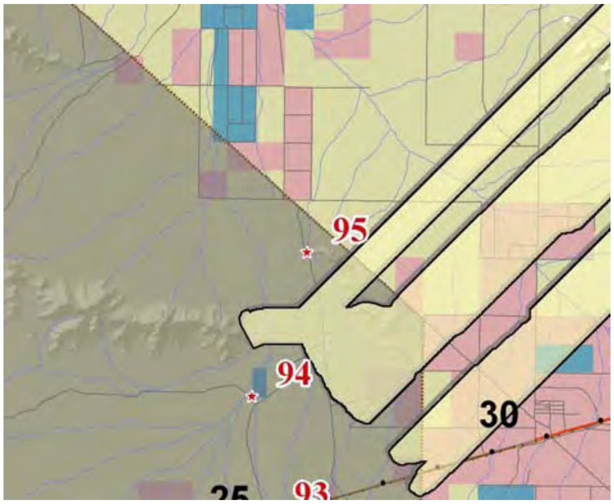
Azimuth: 45 **Zoom:** 4

Notes: Corral and desert flats, landfill off in the distance on the right

Appendix G: Database of Field Investigations

Linkage #:	73	**Waypoint #:**	95		
Linkage Zone:	Gila Bend	**Latitude:**	33.10275	**Longitude:**	-112.34192
Observers:	Paul Beier	**UTM X:**	374784.2719	**UTM Y:**	3663478.828
Field Study Date:	5/11/2007	**Last Printed:**	12/19/2007		

Waypoint Map



Waypoint Notes

Above Rainbow Valley near Espanto Mountain

Site Photographs

Name: IMG_0997.jpg

Azimuth: 205 **Zoom:** 1

Notes: Mesquite bosque in foreground, desert flats beyond

Name: IMG_0998.jpg

Azimuth: 235 **Zoom:** 3

Name: IMG_0999.jpg

Azimuth: 25 **Zoom:** 2

Name: IMG_1000.jpg

Azimuth: 335 **Zoom:** 2