August 2012

Pima County Wildlife Connectivity Assessment: Detailed Linkages

Kitt Peak Linkage Design

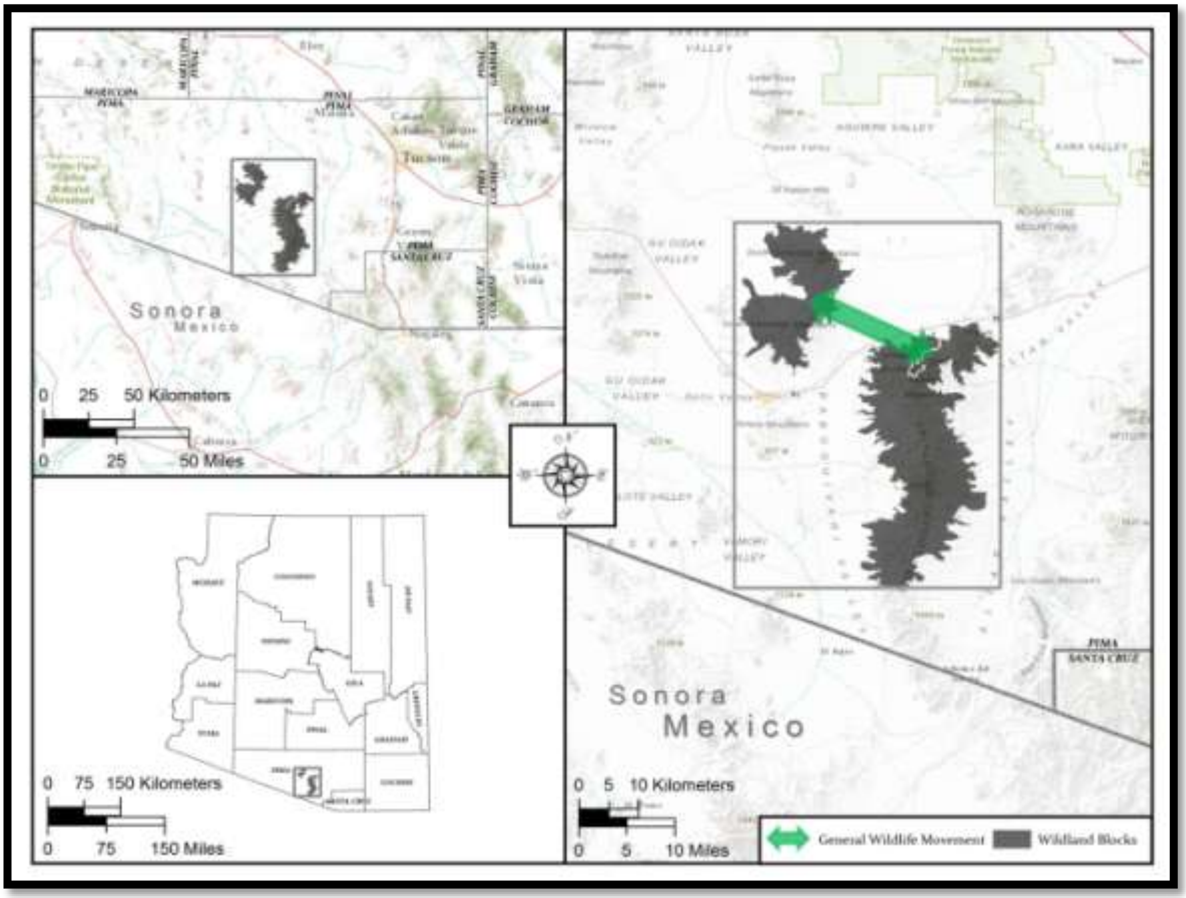
Towards Kitt Peak
Photo courtesy George Andrejko, AGFD

Arizona Game and Fish Department

Regional Transportation Authority of Pima County

Kitt Peak

Linkage Design



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Arizona Wildlife Linkages Workgroup:
Arizona Department of Transportation, Arizona Game and Fish Department, AZTEC Engineering, Bureau of Land Management, Defenders of Wildlife, Northern Arizona University, Sky Island Alliance, U.S. Department of Transportation Federal Highway Administration, U.S. Fish and Wildlife Service, U.S. Forest Service

Pima County Wildlife Connectivity Workgroup:
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Terminology

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: A group of species chosen to represent the movement needs of all wildlife species in the linkage planning area. Focal species should include (a) species narrowly dependent on a single habitat type, (b) area-sensitive species, and (c) species most sensitive to barriers. Focal species should also include both passage species (able to travel between wildland blocks in a few days or weeks) and corridor dwellers (requiring multiple generations to move between wildland blocks). For some focal species, GIS analysis might not include a corridor model

Habitat Connectivity: The extent to which an area of the landscape facilitates ecological processes such as wildlife movement, seed dispersal, and gene flow. Habitat connectivity is reduced by habitat fragmentation.

Habitat Fragmentation: The process through which previously intact areas of wildlife habitat are divided into smaller disconnected areas by roads, urbanization, or other barriers.

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. Permeability refers to the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, are conducive to wildlife movement and may sustain ecological processes.

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 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.

Riparian: An area that includes vegetation, habitats, or ecosystems that are associated with bodies of water (streams or lakes) or are dependent on the existence of ephemeral (rare), intermittent (infrequent), or perennial (year-round) surface or subsurface water drainage. This can include xeroriparian habitats (washes) that potentially only have surface water for a brief period (i.e. few hours a year) but may contain concentrated vegetation.

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: The "rooms" that the Linkage Design is intended to connect. The value of these lands will be eroded if we lose connectivity between them. Wildland blocks can include a variety of land owners. However, wildland blocks must be biologically important to focal species and remain in relatively natural condition for at least 50 years. 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 wild 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. A healthy ecosystem has a direct impact on the economy of an area as well. In an effort to maintain habitat connectivity in southern Arizona, the Arizona Game and Fish Department, in collaboration with the Regional Transportation Authority of Pima County, has developed this GIS-based linkage design.

Arizona is fortunate to have large conserved wildlands that have not yet been fragmented by development pressures, but there are many man-made barriers on the landscape that prevent a truly interconnected ecological system. With funding through the Regional Transportation Authority of Pima County, two workshops were held in 2011, bringing together a broad range of stakeholders with backgrounds in planning, wildlife conservation, development, academia, and government to identify and map important wildlife movement areas across Pima County. Stakeholders and partners also highlighted five linkage planning areas where wildlife connectivity is of particular importance to conserve, and that would benefit from a more detailed conservation plan which addresses wildlife permeability issues. These were areas previously not modeled in the Arizona Missing Linkages, and largely followed the Critical Landscape Connections broadly-defined in Pima County's Conservation Lands System, as part of the county's Sonoran Desert Conservation Plan.

In this report, we used a scientific modeling approach (described at http://corridordesign.org) to create a corridor (linkage design) that will conserve and enhance wildlife movement between two wildland blocks west of Tucson in Pima County, Arizona: the Quinlan (including Kitt Peak) and Baboquivari Mountains (Baboquivari), and both the North and South Comobabi Mountains (Comobabi). The linkage design consists of one main linkage for movement and reproduction of wildlife we have described as the Kitt Peak linkage (see *Figure 1* below).

This linkage design is based on a focal species approach. We identified 14 focal species to model, which are known to inhabit or which historically inhabited the previously mentioned wildland blocks, based on the recommendations of workshop participants, and other agency and academic scientists. Species of Greatest Conservation Need potential species distributions, as identified and modeled in Arizona's State Wildlife Action Plan, were also used to confirm possible focal species presence, through Habimap Arizona$_{TM}$. Focal species, in which habitat and/or corridors were modeled as part of this report, include eight mammals, five reptiles, and one amphibian (see *Table 1* below). Species selected are sensitive to habitat loss and fragmentation, and represent the range of habitat and movement requirements of wildlife found in the region. For example, species such as mule deer are averse to crossing roads. Mountain lion require very large areas to ensure population viability and successful dispersal, and Gila monster and desert tortoise require specialized habitats for survival. The 14 species used to create this linkage design thus provide for the connectivity needs of many others not modeled that are found in the region, as represented by tables of known element occurrence within the linkage design recorded in Arizona's Heritage Data Management System (see *Appendix D* at the end of this report) at the end of this report. Many of the species identified as having element occurrence within the linkage design are also recognized by Pima County's Sonoran Desert Conservation Plan as priority vulnerable, or are federally listed as threatened or endangered.

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 the Baboquivari and Comobabi wildland blocks. We also analyzed the size and configuration of potential habitat patches to verify that the final linkage design provides live-in or move-through habitat for each focal species. We detected road structures within the linkage design using aerial imagery, and we provide detailed recommendations for retrofit in the section titled Linkage Design and Recommendations.

The Kitt Peak linkage contains large barriers to wildlife movement in State Route 86 and State Route 386. An animal moving west from the Quinlan and Baboquivari Mountains towards the Comobabi Mountains may have to cross State Route 386, and will inevitably cross State Route 86. Wildlife-vehicle collisions frequently occur along both State highways and demonstrate the difficulty for wildlife to move between wildland blocks. Retrofitting existing road structures to increase permeability to wildlife, and the construction of new wildlife crossings structures, would greatly increase the permeability of this corridor.

This report contains many recommendations to increase the permeability for wildlife throughout the linkage design, ultimately enabling the movement of wildlife populations, and associated flow of genes, between the Quinlan and Baboquivari Mountains, and North and South Comobabi Mountains. This linkage design presents a vision that would maintain large-scale ecosystem processes that are essential to the continued integrity of the corridor. The needs of wildlife must be accommodated through thoughtful transportation planning, so negative wildlife-vehicle interactions can be reduced, and wildlife connectivity in this area can be maintained and enhanced.

Next Steps

This report can be particularly useful to transportation planners, such as the Regional Transportation Authority of Pima County (RTA), and work to reduce wildlife-vehicle collisions and improve wildlife connectivity, by providing planners with the following:

- Recommendations for the retrofitting of existing road structures, such as bridged underpasses, culverts, and drainage pipes, to improve use by wildlife. Modification of existing road structures or their replacement with more wildlife-compatible structures, along with the installation of associated fencing, may offer a cost-effective alternative to the construction of new wildlife crossings.

- Recommendations for the construction of new wildlife crossings and associated fencing to funnel wildlife towards structures. As always, before the commitment of substantial funding, these recommendations should be verified by on the ground wildlife research, such as telemetry and road mortality studies.

- Recommendations for new wildlife transportation research. Using this plan may help prioritize research funding proposals to the RTA, by providing particular locations along transportation routes where more wildlife research is needed. This plan may also increase efficiency of research projects, by focusing study areas to within the modeled linkage design.

Ultimately, we hope this linkage conservation plan will be used to protect an interconnected system of natural space, where suitable habitats for wildlife can remain intact, and be combined with effective mitigation measures, which will allow our native biodiversity to thrive, at minimal cost to other human endeavors.

Table 1: *Focal species selected for the Kitt Peak linkage design*

Mammals	Amphibians	Reptiles
*Badger	*Sonoran Desert Toad	*Black-tailed Rattlesnake
*Black-tailed Jackrabbit		*Giant Spotted Whiptail HDMS/SDCP
*Desert Bighorn Sheep		*Gila Monster HDMS
*Jaguar HDMS/SDCP		*Sonoran Desert Tortoise HDMS
*Javelina		*Sonoran Whipsnake
*Kit Fox		
*Mountain Lion		
*Mule Deer		

: Species in which habitat and/or corridors were 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 historically occur in both wildland blocks, or because the species probably can travel (e.g., by flying) across unsuitable habitat. The modeling parameters for these species were provided by the CorridorDesign Team at Northern Arizona University (see *Acknowledgements* at the beginning of this report), and were included in the Arizona Missing Linkages.

HDMS: Species in which element occurrence data is collected as part of Arizona's Heritage Data Management System managed by the Arizona Game and Fish Department. Element occurrence data, or data of breeding importance to a species, is collected and managed as part of Heritage Data Management System for animal and plant species of concern in Arizona, for management actions on the ground (See *Appendix D* at the end of this report).

SDCP: Species which were specifically identified as priority vulnerable, or federally listed as threatened or endangered, or other special status as recognized by the Pima County Sonoran Desert Conservation Plan (See *Appendix D* at the end of this report).

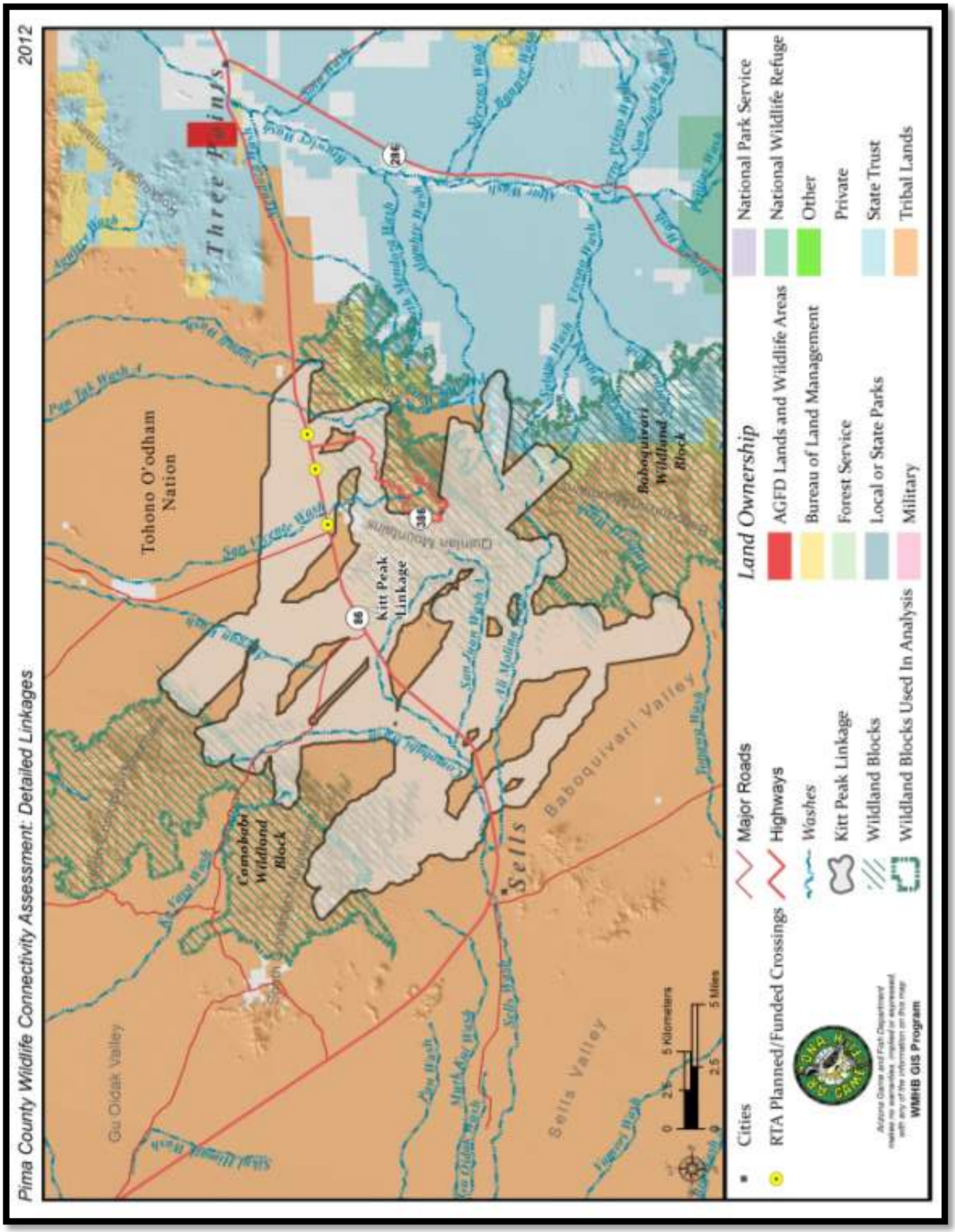


Figure 1: *The Kitt Peak linkage design*

Introduction

Nature Needs Room to Move

Arizona's growing human population and expanding infrastructure has consequences for Pima County's wildlife species and the habitats on which they depend. While human development and disturbance can adversely affect wildlife by causing direct loss or degradation of habitat, the disruption of wildlife movement patterns is a less obvious, but equally important, consequence. All wildlife move across the landscape to varying extents in order to acquire the resources necessary for survival: food, water, protective cover, and mates. Mountain lions, black bears, and mule deer roam over vast expanses that can encompass thousands of acres, while smaller animals such as Chiricahua leopard frogs engage in essential movements in a much smaller area. There is also variation in the temporal patterns of animal movement: some animal movements occur on a daily basis, while seasonal migrations may occur annually, and the dispersal of young from their natal sites to secure new breeding territories happens only once in an individual's lifetime. These diverse movement patterns ensure individual survival and in doing so help protect local populations from extinction (Laurance 1991; Beier and Loe 1992), ensure genetic diversity and reduce the risk of inbreeding via gene flow (Beier and Loe 1992; Bennett 1999), and facilitate critical ecological processes such as pollination and seed dispersal.

Habitat fragmentation, or the process through which previously intact areas of habitat are divided into smaller disconnected areas by roads, urbanization, and other barriers, decreases the degree of habitat connectivity of the landscape for wildlife that once moved freely through a mosaic of natural vegetation types. Habitat fragmentation is a major reason for regional declines in native species and can have consequences for Arizona's wildlife, ranging from direct mortality on roadways to the genetic isolation of fragmented populations. This disruption of animal movement patterns also negatively affects human welfare by increasing the risk of wildlife-vehicle collisions and the frequency of unwanted "close encounters" with wildlife.

However, the effects of habitat fragmentation can often be mitigated by identifying and protecting areas that wildlife use for movement, known as wildlife linkages or wildlife corridors (Beier and Noss 1998; Bennett 1999; Haddad et al. 2003; Eggers et al. 2009; Gilbert-Norton et al. 2010). Ridgelines, canyons, riparian areas, cliffs, swaths of forest or grassland, and other landscape or vegetation features can serve as wildlife linkages. Wildlife linkages are most effective when they connect (or are located within) relatively large and unfragmented areas referred to as wildland blocks. Habitat blocks are areas large enough to sustain healthy wildlife populations and support essential biological processes into the future (Noss 1983; Noss and Harris 1986; Noss 1987; Noss et al. 1996).

Wildlife linkage planning should include conservation of wildlife linkages and the habitat blocks they connect, and, in most cases, require the implementation of multiple strategies such as land acquisition, community planning for developments, open space conservation, and habitat restoration. Installation of roadway mitigation features including wildlife crossing structures and fencing to funnel wildlife to crossing structures are important considerations that are best incorporated into the early planning stages of transportation and development projects.

Benefits of Wildlife Linkage Planning

Identifying and conserving habitat connectivity by maintaining wildlife linkages can provide many important benefits for both humans and wildlife.

Benefits to Wildlife

By preserving the ability of wildlife species to move between or within habitat blocks, linkages allow animals to access essential resources such as food and water during their daily activities. They also allow longer seasonal migratory movements between summer and winter habitats and facilitate the dispersal movements of animals in search of mates or breeding sites. Linkages that connect otherwise isolated populations help prevent small populations from extinction (Laurance 1991; Beier and Loe 1992), help maintain genetic diversity, and reduce the risk of inbreeding (Beier and Loe 1992; Bennett 1999). Habitat connectivity also helps ensure that critical ecological processes such as pollination and seed dispersal, which often depend on animal intermediaries, are maintained. In some cases the linkages themselves may sustain actively reproducing wildlife populations (Perault and Lomolino 2000; Beier et al. 2007). Linkages are also expected to play an important role in helping animal populations adapt to and endure the effects of climate change by allowing animals to shift their range with latitude or elevation as vegetation communities change their distribution and suitable environmental conditions shift on the landscape (Hannah et al. 2002; Glick et al. 2009).

Knowledge of wildlife linkage locations helps inform project planners about what appropriate mitigation needs to occur for roads that affect many wildlife species. Roadway mitigation features such as crossing structures and parcel acquisitions, can be expensive and should be designed and implemented to accommodate "umbrella species" which will, by proxy, serve many species' movements (Beier et al. 2008; Lowery and Blackman 2007). However, certain species may require specific landscape features (i.e. ridgelines, stream corridors, etc.), vegetation composition and structure, crossing structure designs (i.e. specific height), and certain thresholds of human disturbance/activity in order to be functional. Planning for effective wildlife crossings must also consider what is going to happen on those lands in the immediate proximity of the crossing, which may also influence priorities for rural and urban open space planning and acquisition. Allowing development to occur near crossing structures and placing structures in locations that do not provide suitable habitat for the target species generally affects their use by wildlife (Beier and Loe 1992).

Benefits to People

Maintaining an interconnected network of wildland blocks will provide benefits to the local human communities as well, perhaps most obviously by improving public safety. It has been estimated that approximately 20% of the land area in the United States is ecologically affected by the country's road network (Forman et al. 2003). The implications of this widespread impact include threats to connectivity and hazards to motorists (Forman and Alexander 1998). One study estimated that each year more than 200 motorists are killed and approximately 29,000 are injured as a result of deer-vehicle collisions in the United States (Conover 1995). Such collisions can cost $2 billion annually (Danielson and Hubbard 1998). Identifying important wildlife movement areas that traverse transportation corridors prior to the construction of new roads or road improvements allows for the informed siting of wildlife-friendly over- and underpasses that can greatly reduce the likelihood of collisions (Clevenger et al. 2001; Forman et al. 2003; Dodd et al 2007). Along Arizona State Route 260, for example, a combination of wildlife underpasses and ungulate-proof fencing reduced elk-vehicle collisions by 80% (Dodd et al. 2007).

As the optimal objective of providing wildlife linkages is to maintain the connectivity between wildland blocks, there are circumstances where it is important to accommodate a linkage that, either partially or in its entirety, crosses through urban and suburban environments where open spaces invite (intended or not) passive recreation activities. In such situations, the linkage may also serve as a buffer between developed areas and wildland blocks and can help protect the wildland network from potentially damaging external influences. Incorporating and designing rural and urban greenways and/or open spaces that support wildlife movement into municipal planning efforts also helps retain the natural vistas and aesthetic attributes that Arizona residents and visitors value. Since evidence suggests that some species are sensitive to the presence of humans (Clevenger and Waltho 2000; Taylor and Knight 2003), multi-use buffer zones should be made wide enough to maintain separation between human recreation activities and the needs of the wildlife species using the corridor.

Maintaining linkages that facilitate the ecological health of wildland blocks can also be a significant investment in contributing to the diversity and vitality of an area's economy. The economic value associated with fish and wildlife-related recreation is significant for Pima County and contributes greatly to Arizona's economy. A national survey of fishing, hunting, and wildlife-associated recreation has been conducted about every five years since 1955 to evaluate national trends. The survey provides information on the number of participants in fishing, hunting, and wildlife watching (observing, photographing, and feeding wildlife), and the amount of time and money spent on these activities. In the most recent survey, it was reported that in 2006, state resident and nonresidents spent $2.1 billion on fishing, hunting, and watchable wildlife related recreation in Arizona (U.S. Department of the Interior 2006). In 2001, a county-level analysis of the national survey data revealed that in Pima County watchable wildlife activities generated a total economic effect of $327 million, supporting 3,196 jobs, providing residents with $91 million in salary and wages, and generating $2.3 million in state tax revenue (Southwick Associates 2003). Fishing and hunting recreation generated a total economic effect of $105 million for the County, supporting 1,187 jobs, providing residents with $18 million in salary and wages and generating $5.4 million in state tax revenue (Silberman 2003). These economic benefits illustrate that conserving our wildlife populations, through efforts such as maintaining or restoring habitat connectivity is also good for business in the County.

Overview of Regional Planning Efforts That Acknowledge the Importance of Conserving Wildlife Linkages

There is a long-standing appreciation among local governments, land management agencies, transportation departments, conservation organizations, energy and utility companies, and citizens across Pima County of the importance of conserving wildlife linkages and mitigating the impacts of barriers on wildlife movement.

Open space planning efforts substantively began in Pima County in 1928 with the establishment of Tucson Mountain Park (Pima County 2009). In 1976, the Trails Access Plan was formed to maintain access to existing public lands through parcel acquisition. In 1986, the Critical and Sensitive Wildlife Habitats Study marked the first effort in Pima County to help guide conservation planning by incorporating considerations for wildlife habitat and biology. In 2001, this effort was greatly refined when Pima County's Maeveen Marie Behan Conservation Lands System (CLS) was created based on comprehensive scientific and planning input (Pima County 2011; see *Figure 2* below). The CLS represents the conservation reserve design of the widely-acclaimed Pima County Sonoran Desert Conservation Plan (SDCP) and was adopted into Pima County's Comprehensive Plan to provide sustainable development guidelines (Pima County 2009). It is noteworthy to point out that in implementing the CLS, the County's evaluation of comprehensive plan amendments and land uses requiring rezoning must consider potential effects to Critical Landscape Connections/CLS designated areas where preserving and enhancing wildlife movement is a primary concern, shown by the purple arrows in the map below (see *Figure 2* below).

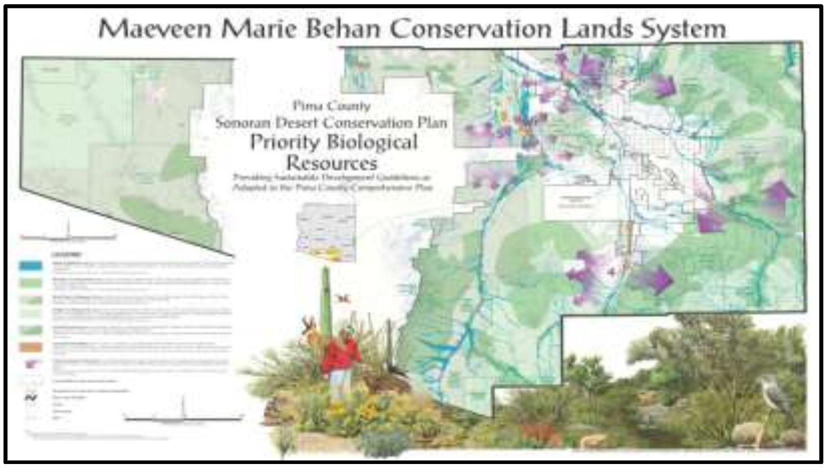


Figure 2: *The Maeveen Marie Behan Conservation Lands System shows the biologically preferred reserve design and works to provide sustainable guidelines for future development. Critical Landscape Connections, or broadly-defined areas where wildlife connectivity is significantly compromised, but can still be improved, are shown by the purple arrows (Pima County 2009).*

To aid the implementation of the SDCP, a committee appointed by the Pima County Board of Supervisors developed a Conservation Bond Program which recommended the acquisition of certain properties to conserve community open space and important habitat within the CLS. This $174 million bond package was approved by Pima County voters in 2004 by an overwhelming majority (Pima County 2011). Subsequent to the voters' approval, Pima County began acquisition of these properties; to date, upwards of 175,000 acres have been conserved (48,000+ acres acquired and 127,000+ acres held as grazing leases). These bond acquisitions actively protect a diverse array of biologically-rich areas and maintain the landscape network of habitat connectivity throughout Pima County.

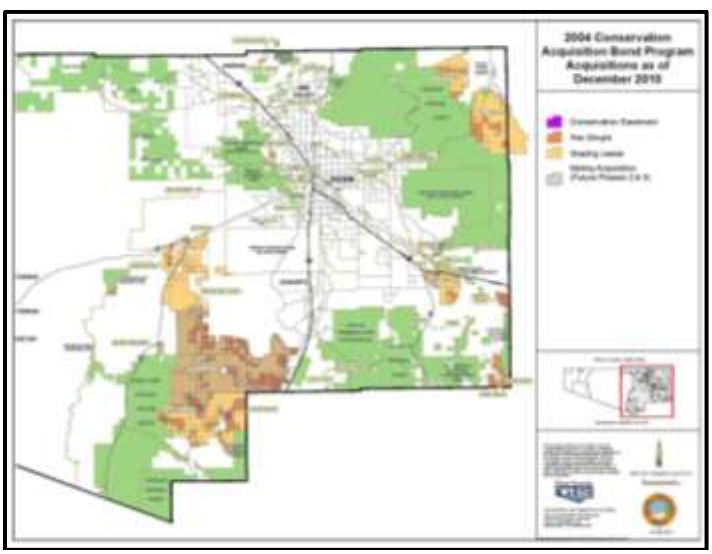


Figure 3: *The 2004 Conservation Acquisition Bond Program was approved to help implement the Sonoran Desert Conservation Plan (Pima County 2011). Multi-use lands are important for habitat and wildlife conservation in the region.*

In 2006, Pima County voters approved a sales tax increase that allowed the formation of the Regional Transportation Authority of Pima County (RTA) to address transportation planning across Pima County (Regional Transportation Authority 2011). As part of that approval, county voters specifically ear-marked $45 million to be used to incorporate wildlife linkage conservation into transportation projects. Over the 20-year timeframe of the RTA, these funds will mitigate barriers to wildlife movement and reduce wildlife-vehicle collisions.

RTA projects have been successful in coordinating with broader efforts to facilitate wildlife movement. For example, in 2009, two significant events occurred—the Town of Oro Valley incorporated the Tucson – Tortolita – Santa Catalina Mountains Linkage Design (Beier et al. 2006a) through the Arroyo Grande planning area as an amendment to its General Plan (Town of Oro Valley 2008); and the RTA approved the funding to construct one overpass and two underpasses as part of the Arizona Department of Transportation's improvement to State Route 77 near the Arroyo Grande planning area (Regional Transportation Authority 2011). In addition, a project proposed by the Tohono O'odham Nation and supported by data from the Arizona Wildlife Linkages Assessment gained final approval for RTA funding in December 2011. Through this funding, one overpass and two underpasses will be built along State Route 86 near Kitt Peak.

The need to maintain habitat connectivity for wildlife will only grow as Arizona becomes more fragmented in coming decades as development continues to meet the needs of an expanding human population. Given the relatively undeveloped status of many areas of Pima County at present, we must continue to integrate knowledge of wildlife linkages and mitigation strategies into land-use and transportation planning in the region.

Linkage Planning in Arizona: A Statewide-to-Local Approach

Habitat connectivity can be represented at various spatial scales. In Arizona, we have found it valuable to identify statewide, county-wide, and fine-scale habitat blocks and wildlife linkages to serve different conservation and planning objectives. The linkage planning tools created at each scale have led to a progressive refinement of our knowledge of wildlife movement areas and threats to habitat connectivity across the state, and the fine-scale linkage design presented in this report owes much to the broader-scale efforts that preceded it.

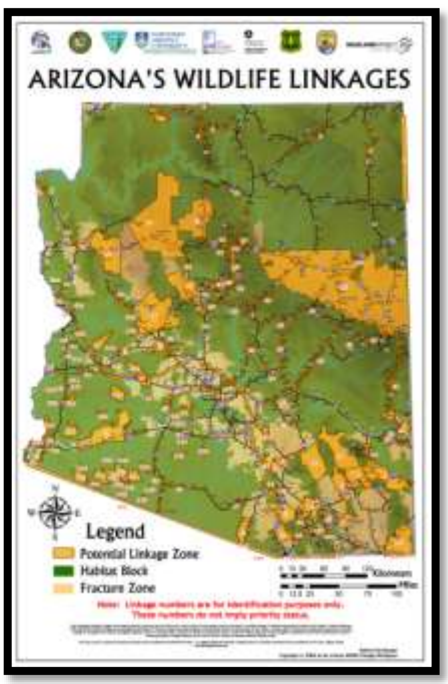
Arizona's statewide wildlife linkage planning efforts began in 2004 when federal, state, municipal, academic, and non-governmental biologists, and land managers participated in a workshop to map important habitat blocks, linkages, and potential threats to connectivity across the state. This workshop was convened by the Arizona Wildlife Linkages Workgroup, a collaboration that included the Arizona Game and Fish Department (AGFD), Arizona Department of Transportation, Federal Highways Administration, Northern Arizona University (NAU), Sky Islands Alliance, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Forest Service, and the Wildlands Network, and resulted in Arizona's Wildlife Linkages Assessment (AWLA; Arizona Wildlife Linkages Workgroup 2006; see *Figure 4* below). The AWLA provides a vision for maintaining habitat connectivity in a rapidly growing state and has served as the foundation for subsequent regional and local efforts, including the creation of fine-scale GIS linkage designs by scientists at NAU (available at http://corridordesign.org) which provided the template for this report.

The statewide assessment was followed by an effort to map wildlife linkages and potential barriers within individual Arizona counties. Beginning in 2008 the AGFD partnered with county planners to organize workshops which gathered stakeholders with backgrounds in planning, wildlife conservation, transportation, academia and government.

Overview of the Pima County Wildlife Connectivity Assessment

Continuing with the statewide strategy to identify and prioritize linkages at the county level for GIS modeling of wildlife connectivity, AGFD received funding from the Regional Transportation Authority of Pima County. This funding allowed AGFD to assemble current knowledge of wildlife linkages and barriers to wildlife movement across Pima County and to help build collaborative partnerships with local jurisdictions for eventual implementation efforts. To accomplish these tasks, AGFD joined with partner organizations (please see *Acknowledgments* for a list of members of the Pima County Wildlife Connectivity Workgroup) to initiate the Pima County Wildlife Connectivity Assessment. This project built on prior initiatives including the SDCP and AWLA. The Pima County Wildlife Connectivity Assessment (available at http://www.azgfd.gov/w_c/conn_Pima.shtml) represented a continuation of these previous efforts by identifying wildlife linkages at a finer scale that may have been overlooked in the earlier products, as well as those that will be useful for regional and local transportation or land-use planning efforts (see *Figure 5* below). With input gathered by the stakeholders at the workshops and with additional input by the Pima County Wildlife Connectivity Workgroup, five areas encompassing numerous wildlife linkages were suggested as priorities for the development of detailed linkage designs with specific recommendations for implementation. These priority areas largely followed the broadly-defined Critical Landscape Connections from the SDCP. However, additional areas not previously considered as Critical Landscape Connections were also added as a priority to model, due to their biological resources, and threats to wildlife. The Kitt Peak linkage planning area was one of those prioritized areas. Other areas modeled include Coyote – Ironwood – Tucson, Mexico – Tumacacori – Baboquivari, Santa Catalina/Rincon - Galiuro, and Sierrita – Santa Rita.

4)



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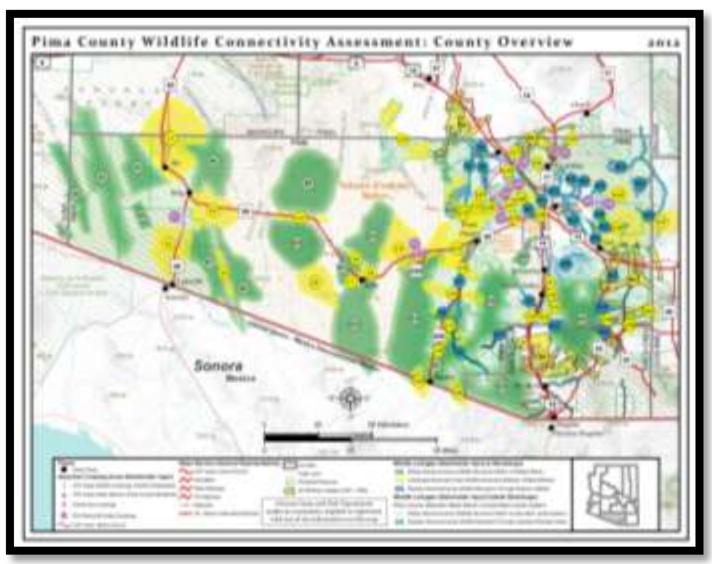

Figure 4 and Figure 5: *Statewide map of wildlife linkages and barriers created by the Arizona Wildlife Linkages Workgroup (2006). County-wide map of wildlife linkage created for the Pima County Wildlife Connectivity Assessment: Report on Stakeholder Input (2012 (Maps: Courtesy Arizona Wildlife Linkages Workgroup and Arizona Game and Fish Department).*

Ecological Significance and Existing Conservation Investments of the Kitt Peak Linkage Planning Area

In this section, we describe the ecology and conservation investments of the linkage planning area, including the wildland blocks, and the potential linkage area between them:

Ecological Significance of the Kitt Peak Linkage Planning Area

The Kitt Peak linkage planning area in Pima County lies almost entirely within the Sonoran Desert, which has the most precipitation of North America's warm deserts. Bajadas sloping down from the mountains support forests of ancient saguaro cacti, palo verde, and ironwood; creosote bush and bursage desert scrub dominate the lower desert. 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). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of 233 of the earth's most biologically valuable ecoregions, whose conservation is critical for maintaining the earth's biodiversity.

This diversity supports many mammals, reptiles, birds, and amphibian species. Wide-ranging mammals include among others, and badger, mountain lion, and mule deer. Many of these animals move long distances to gain access to suitable foraging or breeding sites, and would benefit significantly from corridors that link large areas of habitat (Turner et al. 1995). Less-mobile species and habitat specialists such as 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.

Two wildland blocks exist here: the Quinlan and Baboquivari Mountains (Baboquivari), and the North and South Comobabi Mountains (Comobabi). These wildland blocks are separated by various topographic features, including the flat lands of the Baboquivari Valley. Man-made features separating the blocks include: major roads, State Route 86 and State Route 386. Sells, the capital of the Tohono O'odham Nation is west of the linkage.

Connectivity between these wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in the Sonoran Desert. Providing connectivity is paramount in sustaining this unique area's diverse natural heritage. Recent and future human activities could sever natural connections and alter the functional integrity of this natural system. Conserving and restoring linkages will ensure that wildlife will thrive in the wildland blocks and the potential linkage area.

Below is a description of the ecological significance of each wildland block (see *Figure 6* below for a map of land cover categories):

Baboquivari Wildland Block

The Baboquivari wildland block encompasses over 141,000 acres of the Quinlan and Baboquivari Mountains bordering and within the Tohono O'odham Nation, east of Sells, Arizona and south of State Route 86. These mountains are dominated by encinal oak woodland, which comprise the largest percentages of its land cover classification. The wildland block is also comprised of mesquite upland scrub, palo-verde mixed cacti desert scrub, pinyon-juniper woodlands, and riparian mesquite bosque, among various other land cover types. Elevation here ranges from 2,772 feet to 7,713 feet.

Comobabi Wildland Block
The Comobabi wildland block includes over 57,000 acres of land encompassing the North and South Comobabi Mountains north of State Route 86 and Sells, Arizona. The majority of the land cover within the wildland block is comprised of paloverde-mixed cacti desert scrub, with much of the rest being comprised of miscellaneous desert scrub. Elevation in this block ranges from 2,349 feet to 4,777 feet.

Conservation Investments in the Kitt Peak Linkage Planning Area

Much of the Baboquivari and Comobabi wildland blocks are not protected by conventional conservation investments, but do offer some protection of habitat for different wildlife species in the linkage planning area. Connectivity between these wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in the Sonoran Desert.. Providing connectivity is paramount in sustaining this unique area's diverse natural heritage. Recent and future human activities could sever natural connections and alter the functional integrity of this natural system. Conserving and restoring linkages will ensure that wildlife will thrive in the wildland blocks and the potential linkage area:

Below is a description of the conservation investments of each wildland block (see *Figure 7* below for a map of conservation investments):

Baboquivari Wildland Block
The Baboquivari wildland block includes the Coyote Mountains Wilderness which is over 5,000 acres managed by the U.S. Bureau of Land Management (BLM). Further south, The Baboquivari Peak Wilderness, over 2,000 acres in size, is also located within the wildland block. The Baboquivari Peak Wilderness is also administered by the BLM. Much of the wildland block is located within the Tohono O'odham Nation. Since much of this wildland block is not conventionally protected by conservation areas, it was useful in this analysis to define its boundaries by also referencing the Pima County Hillside Development Overlay Zone Ordinance, and digitizing lands that meet ordinance criteria. This zone ordinance requires a permit for grading land with slope $\geq$ 15% and may offer some conservation protection for mountainous areas located within State Trust and Private lands. This zone ordinance also includes the Initiation of Protection for Peaks and Ridges, which designates protection for peaks and ridges meeting certain criteria (Pima County 2012). While this ordinance does not apply to lands within the Tohono O'odham Nation, the steep topography that innately exists by using this method to define the block is resistant to many types of development, and offers a topographical protection of the block. Tribal sovereignty includes the right to develop tribal lands within a wildland block.

Comobabi Wildland Block
The Comobabi wildland block is entirely within the Tohono O'odham Nation. Again, this block was defined by referencing the Pima County Hillside Development Overlay Zone Ordinance, and digitizing lands that meet the $\geq$ 15% slope criteria. Tribal sovereignty includes the right to develop tribal lands within a wildland block.

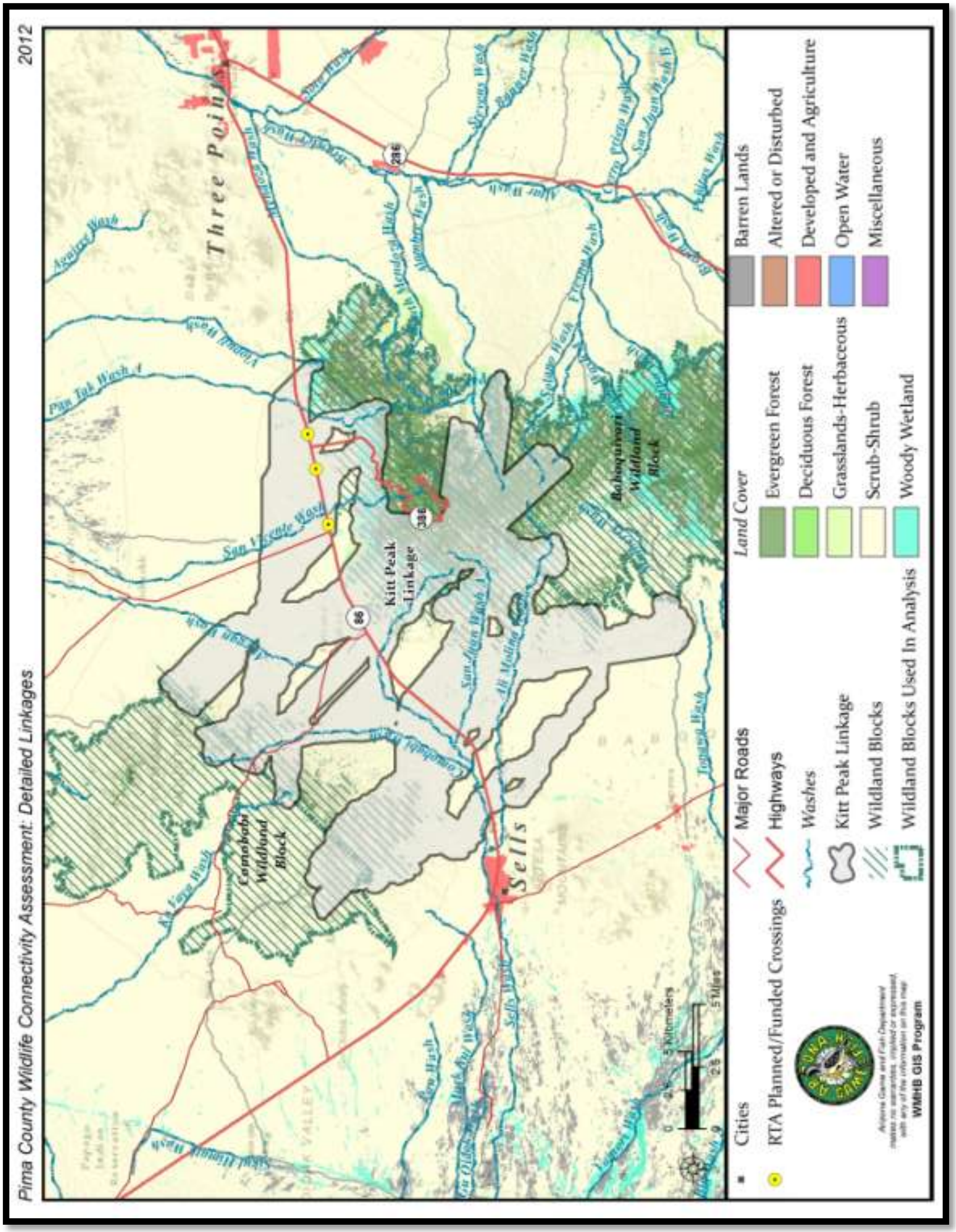

Figure 6: *Land cover in the Kitt Peak linkage design*

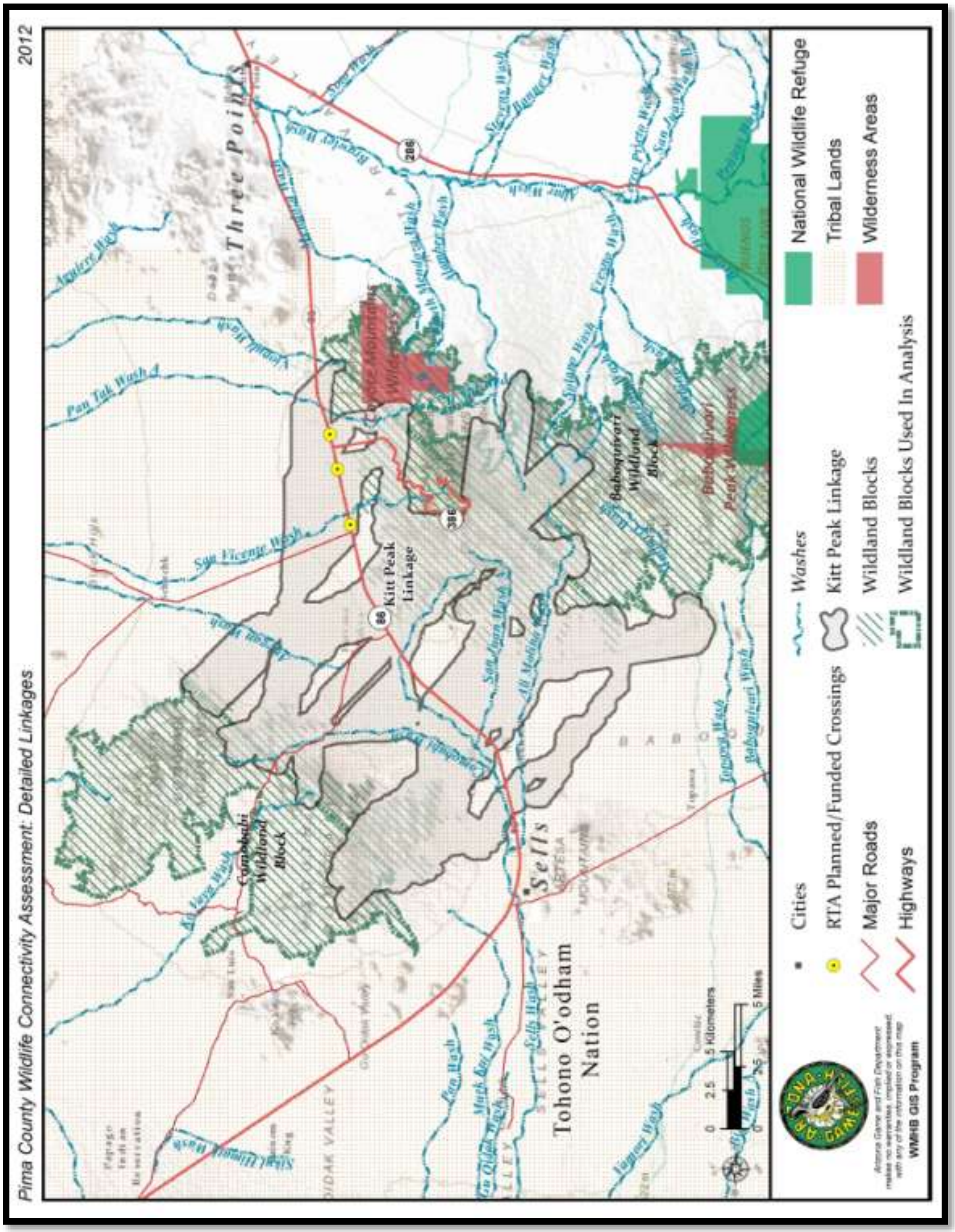

Figure 7: *Existing conservation investments in the Kitt Peak linkage design*

The Kitt Peak Linkage Design

In this section, we describe the linkage design and summarize the barriers to animal movement it encompasses. Methods for developing the linkage design are described in *Appendix A*.

One Linkage Provides Connectivity Across a Diverse Landscape

The Kitt Peak Linkage

The Kitt Peak linkage runs between the Baboquivari wildland block and the Comobabi wildland block, across State Route 386 and State Route 86. It spans about 22 km (14 mi) in a straight-line between each wildland block used in this analysis. The linkage design encompasses 123,370 acres (49,926 ha) of land, of which over 97% is within the Tohono O'odham Nation (see *Figure 1* for a map of the linkage design and land ownership at the beginning of this report). It is primarily composed of paloverde-mixed cacti desert scrub (54.5%), mesquite upland scrub (12.7%), encinal oak woodland (8.2%), and miscellaneous desert scrub (5.2%; see *Table 2* below). A range of topographic diversity exists within the linkage design, providing for the ecological needs of the focal species, as well as creating a buffer against a potential shift in ecological communities due to climate change (see *Figure 8* below). This linkage has an average slope of 12.6% (Range: 0 – 113.0%, SD: 17.0). Most of the land (67.5%) is flat-gently sloped, and steep sloped (21.2%), with the rest a mix of canyon bottom and ridgetop. There is a variety of land aspects represented, most of which are north, northwest, southwest, and west.

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 and parasitism, and invasive species
- Allow animals and plants to move in response to climate change

This Kitt Peak linkage is a relatively undeveloped and intact landscape. However, major barriers to wildlife connectivity still exist:

State Route 86

An animal moving terrestrially between the Baboquivari wildland block and the Comobabi wildland block must eventually must cross State Route 86 (SR 86). ADOT's standardized statewide crash database recorded 33 wildlife-vehicle collisions from SR 86 mile posts 120 – 140 between the years 2000 – 2010, though these numbers are probably underreported (Tohono O'odham Nation 2011). These wildlife-vehicle collisions span directly across the linkage design (see *Figure 9* below). Recently, three wildlife crossings, including two under-crossings, and one overpass, proposed by the Tohono O'odham Nation (2011), were approved by the Pima County Regional Transportation Authority (RTA) for funding. These wildlife crossings could greatly improve the utility of this corridor and reduce wildlife-vehicle collisions along SR 86.

State Route 386

Another major barrier to wildlife movement in the linkage design is State Route 386. This highway has been documented by stakeholders, including the Tohono O'odham Nation, as having a high volume of herpetofauna road kills (Arizona Game and Fish Department 2012b).

***Table 2:** Approximate land cover found within the Kitt Peak linkage design*

Land Cover Group	Land Cover Class	% of Linkage Design
Evergreen Forest	Encinal (Oak Woodland)	8.2%
Evergreen Forest	Pine-Oak Forest and Woodland	0.2%
Evergreen Forest	Pinyon-Juniper Woodland	3.4%
Grasslands-Herbaceous	Semi-Desert Grassland and Steppe	1.4%
Scrub-Shrub	Chaparral	0.6%
Scrub-Shrub	Creosotebush, Mixed Desert and Thorn Scrub	1.3%
Scrub-Shrub	Creosotebush-White Bursage Desert Scrub	4.7%
Scrub-Shrub	Desert Scrub (misc)	5.2%
Scrub-Shrub	Mesquite Upland Scrub	12.7%
Scrub-Shrub	Paloverde-Mixed Cacti Desert Scrub	54.5%
Woody Wetland	Riparian Mesquite Bosque	3.6%
Woody Wetland	Riparian Woodland and Shrubland	0.4%
Barren Lands	Bedrock Cliff and Outcrop	0.8%
Barren Lands	Wash	2.9%

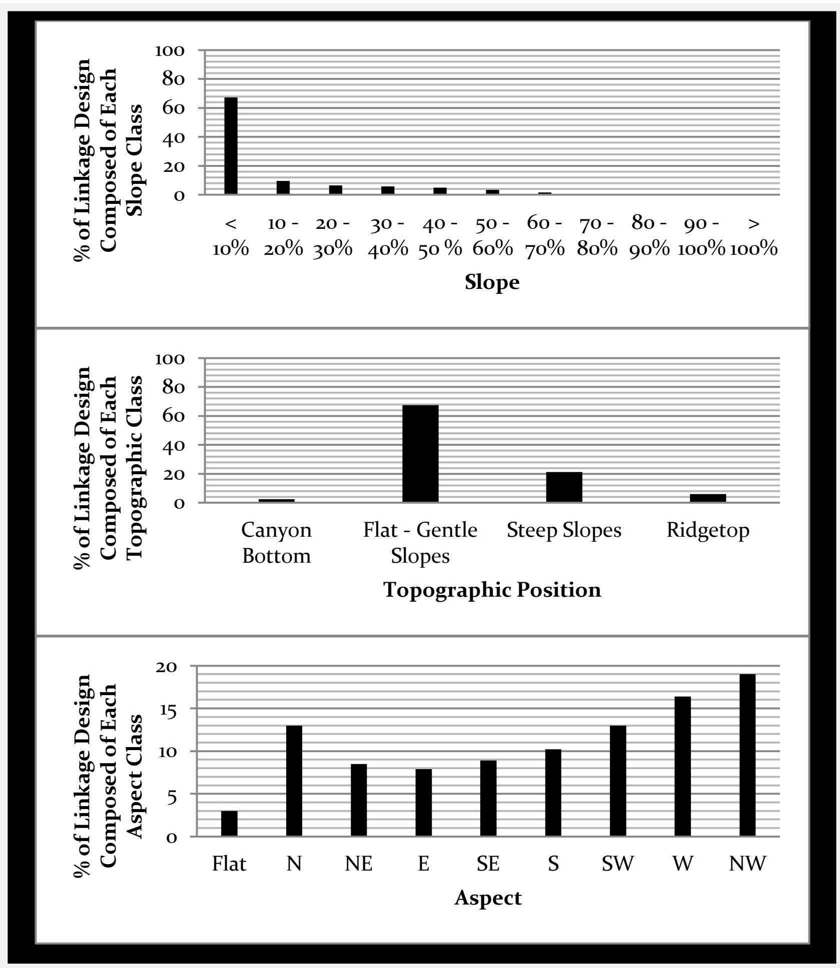

***Figure 8:** Topographic diversity encompassed by the Kitt Peak linkage design: a) Topographic position, b) Slope, c) Aspect*

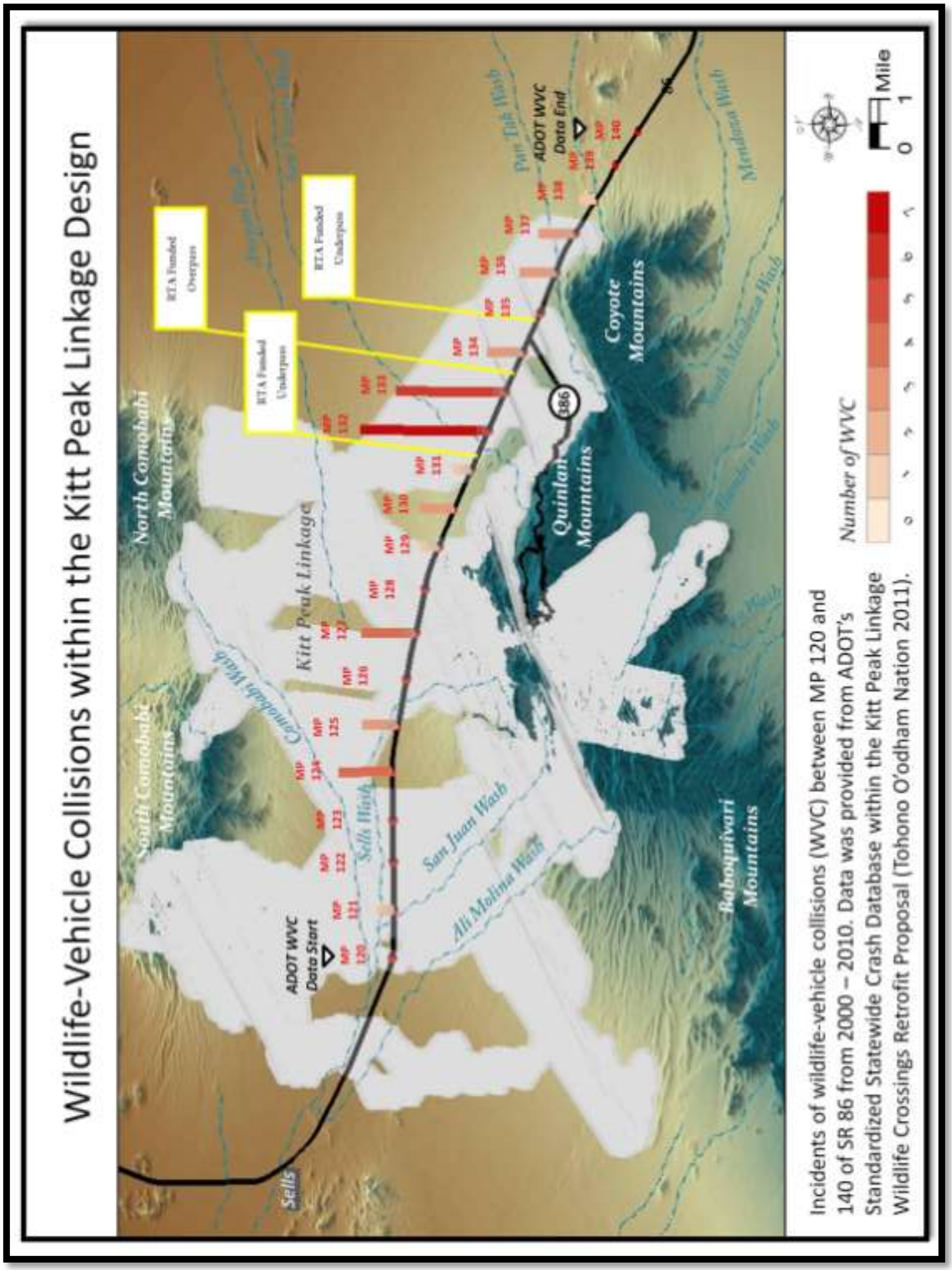

Figure 9: *Wildlife-vehicle collisions within the Kitt Peak linkage design*

Removing and Mitigating Barriers to Movement

Although roads occupy only a small fraction of the linkage design, their impacts threaten to block animal movement between wildland blocks. In this section, we review the potential impacts of these roads on ecological processes, identify specific transportation barriers in the linkage design, and suggest appropriate mitigations.

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

All of the waypoints referenced for each section on barriers refer to the following maps (see *Figure 10* and *Figure 11* below):

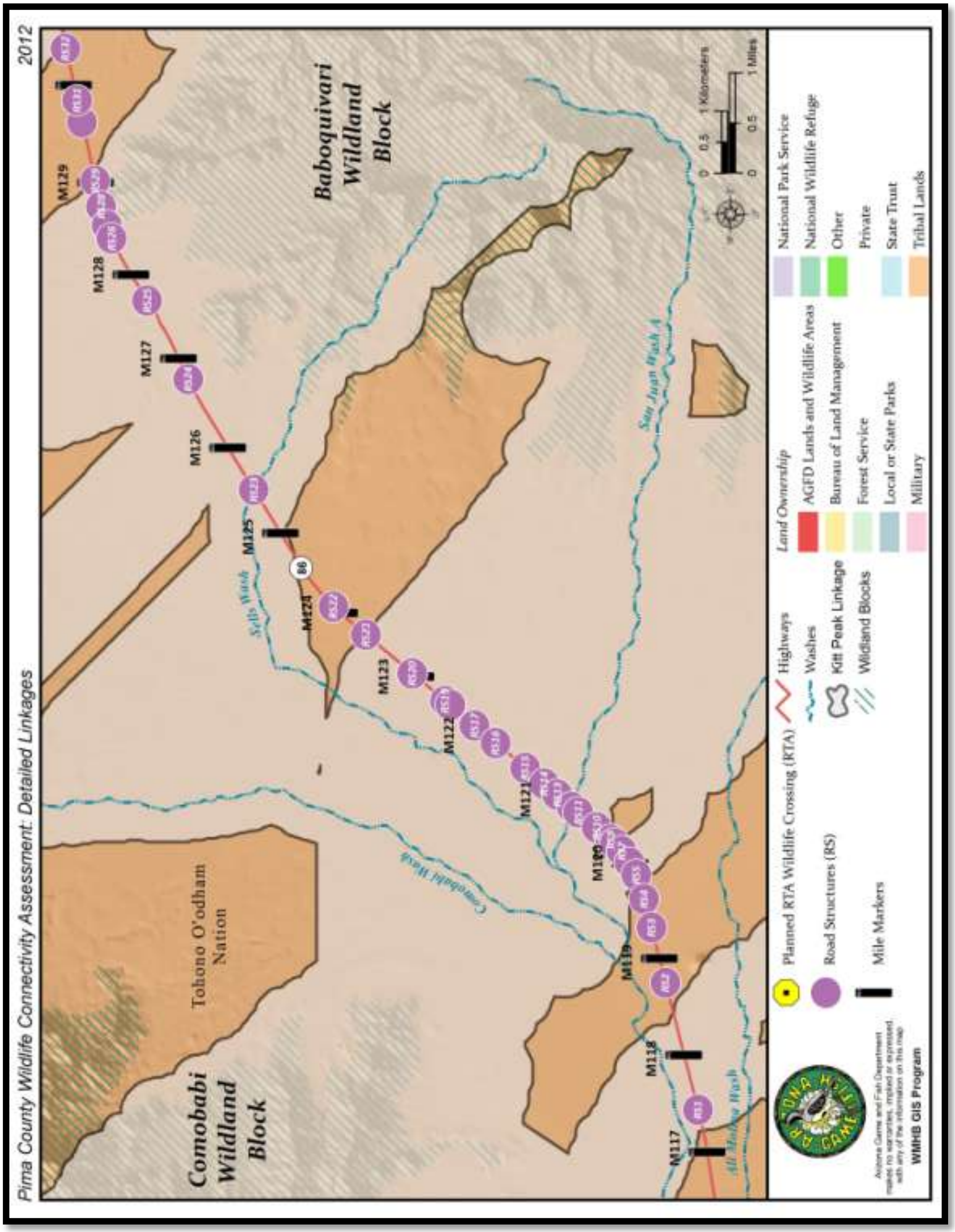

Figure 10: *Road structures within the western portion of the Kitt Peak linkage design*

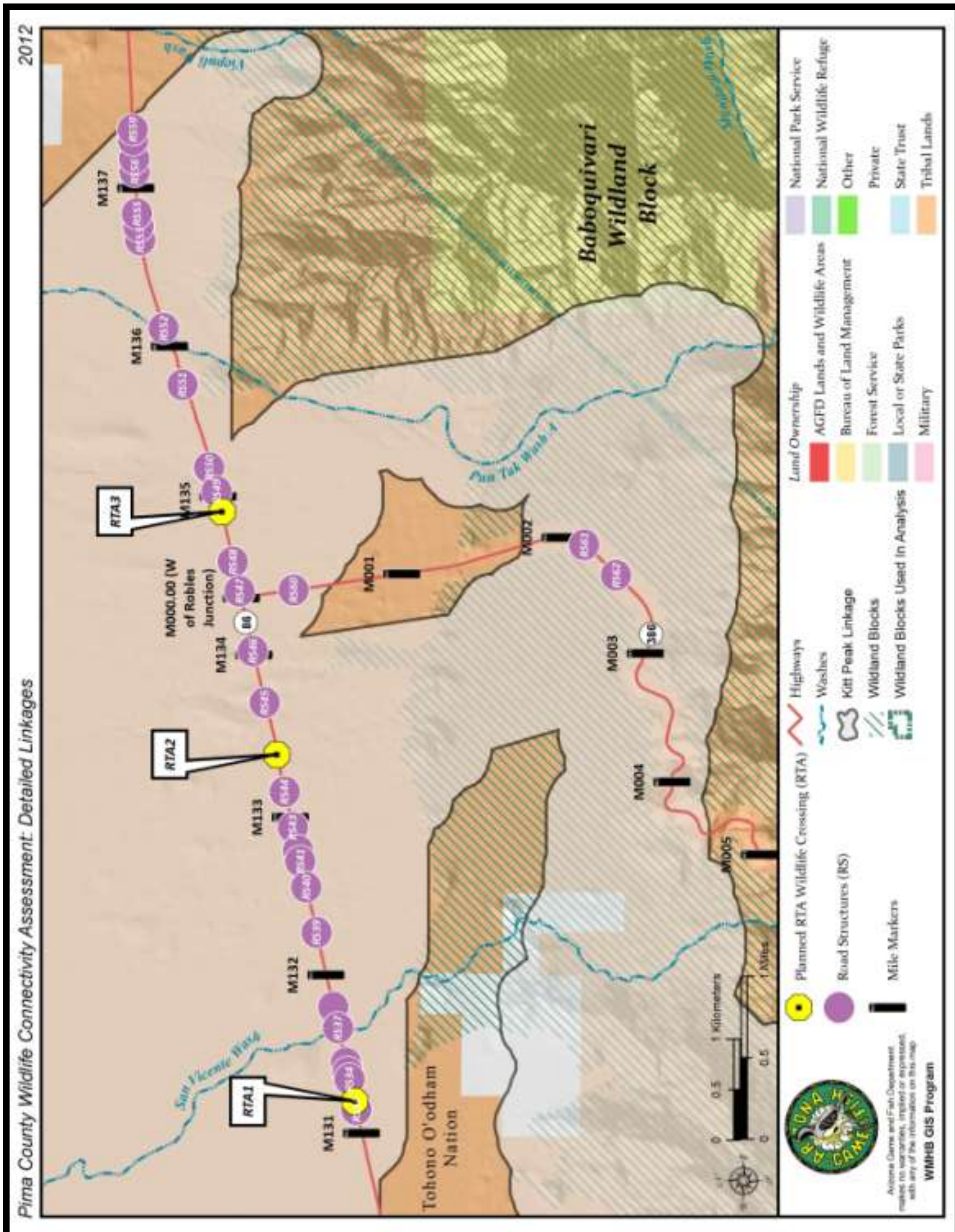

Figure 11: *Road structures within the eastern portion of the Kitt Peak linkage design*

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 (see *Table 3* below). Direct road kill 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)*

	Effects of Roads		
Characteristics making a species vulnerable to road effects	Road mortality	Habitat loss	Reduced connectivity
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		
Multiple-resource needs	★		★
Large area requirements/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, bridges, culverts, and pipes (see *Figure 12* below). 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 and St Clair 2004).

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. Forman et al. (2003) documented approximately 50 overpasses that have been built in the world, with only 6 of these occurring in North America. Recently, three overpasses were constructed over

U.S. Highway 93 in northwestern Arizona to improve permeability of the highway for desert bighorn sheep and prevent negative wildlife-vehicle interactions based on McKinney and Smith's (2007) desert bighorn movement study. 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 and 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 and 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 12: *Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (bottom) should be used to guide animals into crossing structures (Photographs courtesy George Andrejko and Dean Pokrajac, AGFD)*

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 and 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 and 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 culverts 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.

General Standards and Guidelines for Wildlife Crossing Structures

Based on the 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.

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 and St Clair 2004, Clevenger and 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 and 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 and 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 ft 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 road kill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Along Arizona State Route 260, a combination of wildlife underpasses and ungulate-proof fencing reduce elk-vehicle collisions by 80% (Dodd et al. 2007). 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 and 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.

Specifications for Wildlife Crossing Structures

Based on local on the ground wildlife research, we offer the following specifications for culverts and overpasses. Our recommendations for crossings structures follow these specifications.

The following recommendations are based on culvert design specifications from Lowery et al. (2010):

Small culverts (small mammals; herpetofauna):

- Culverts should be at least 0.3 m (1.5 ft) high.
- Culverts should be spaced every 50 m and contain vegetation cover for predation avoidance.
- For small mammals, fencing made of impenetrable mesh and 3-4 ft high is the most appropriate to reduce road kills and funnel animals.
- For herpetofauna, the crossing structures should include a sandy substrate (reptiles) or moist substrate (amphibians) on the bottom, and have an open top fitted with an open grate positioned flush with the road surface. The grate should allow for adequate rain, light, and air circulation.
- For herpetofauna, fencing of approximately 1.5 – 2.5 ft with a preventative fence top, such as a lipped wall or overhang 6 inches wide is the most appropriate to reduce road kills and funnel animals.

Medium culverts (mid-size mammals):

- Culverts should be at least 2 m (6 ft) high with an openness index (culvert height x width)/ length) of at least 0.4.
- Culverts should be spaced every 100 m.
- Fencing should be chain link and approximately 3 – 6 ft high to reduce road kills and funnel animals.

Large culverts (large-size mammals):

- Culverts should be at least 3 m (9 ft) high with an openness index (culvert height x width)/ length) of at least 0.9.
- Culverts should be spaced every 500 – 1000 m.
- Fencing should be chain link or woven wire and at least 8 ft high to reduce road kills and funnel animals.

The following overpass specifications are based on Highway 93 overpass specifications recommended by McKinney and Smith (2007):

- Overpasses should connect elevated habitats on both sides of the highway.
- Overpasses should measure approximately 160 feet wide and have roughly six feet of topsoil to promote growth of native vegetation.
- Fencing to funnel large-sized mammals into should follow recommendations for fencing by the Arizona Game and Fish Department (2012) for desert bighorn sheep and mule deer, and should be tied into existing culverts to allow use by wildlife.

Existing Roads in the Linkage Design Area

There are about 33 km (21 mi) of highways in the linkage design (See *Table 4* below). We were unable to conduct field investigations as part of this linkage design. However, we used aerial imagery where possible to document road structures within the linkage design.

Table 4: *Roads greater than 1 kilometer in length in the Kitt Peak linkage design*

Road Name	Kilometers	Miles
State Route 86	25.9	16.1
State Route 386	7.2	4.5

Recommendations for Crossing Structures in Kitt Peak Linkage Design

As mentioned in the Kitt Peak Linkage Design section above, State Route 86 (SR 86) and State Route 386 (SR 386) have been indicated to be a major barrier to wildlife connectivity. However, constructing new crossing structures is sometimes difficult due to topography or expense (Gagnon et al. 2010). Retrofitting existing crossing structures with fencing along highways has shown to be an effective method of increasing highway permeability to some species of wildlife and decreasing negative wildlife-vehicle interactions (Gagnon et al. 2010).

The following recommendations for retrofitting of existing structures are based on Lowery et al. (2010) culvert design specifications. These recommendations will help restore wildlife connectivity across the major highways in the linkage design, and refer to waypoints on the maps at the beginning of this section (see *Figure 10 and Figure 11* above):

State Route 86

- Road structures RS1 – RS59 and planned Pima County Regional Transportation Authority (RTA) wildlife crossing structures RTA1 – RTA3 located within the Kitt Peak linkage between SR 86 mile posts 117 – 138 were not able to be visited due to their location within the Tohono O'odham Nation, but were detected from 2010 aerial imagery, and digitized using GIS. While these structures were unable to be evaluated during field observations, they remain a priority to retrofit using the recommendations below:
    - Road structure RS1 between SR 86 mile posts 117 – 118, should be retrofitted during road widening projects to accommodate medium-size mammal movement preferences, based on biologically best corridors for badger. This culvert and associated fencing should follow recommendations for medium-size mammals referenced above.
    - Road structures RS5 – RS7 between SR 86 near SR 86 mile post 120, should be retrofitted during road widening projects to accommodate small mammal and herpetofauna (amphibian) movement preferences, based on biologically best corridors for black-tailed jackrabbit, and Sonoran desert toad. These culverts and associated fencing should also follow recommendations for small-sized mammals and herpetofauna referenced above.
    - Road structures RS11 – RS13 near SR 86 mile posts 121, should be retrofitted during road widening projects to accommodate large-sized mammal movement preferences based on the biologically best corridor for mule deer. These culverts should also be able to accommodate herpetofauna and medium-sized mammal

movement preferences, based on biologically best corridors for Sonoran desert toad and javelina. These culverts and associated fencing should follow recommendations for large-sized mammals and herpetofauna referenced above.

- Road structures RS14 – RS20 between SR 86 mile posts 121 – 124 should be retrofitted during road widening projects to accommodate large-sized mammal movement preferences based on the biologically best corridor for desert bighorn sheep. These culverts should also be able to accommodate herpetofauna movement preferences, based on biologically best corridors for Gila monster and Sonoran desert tortoise. These culverts and associated fencing should follow recommendations for large-sized mammals and herpetofauna referenced above.
- Road structure RS23 between SR 86 mile posts 125 – 126 should be retrofitted during road widening projects to accommodate large-sized mammal and herpetofauna movement preferences based on the biologically best corridor for mule deer and giant spotted whiptail. This culvert and associated fencing/barrier should follow recommendations for large-sized mammals and herpetofauna referenced above.
- Road structure RS25 – RS28 between SR 86 mile posts 127 – 129 should be retrofitted during road widening projects to accommodate large-sized mammal movement preferences based on the biologically best corridor for mountain lion. These culverts should follow recommendations for large-sized mammals referenced above.
- Road structures RS33 – RS59 between SR 86 mile posts 131 – 138 should be retrofitted during road widening projects to accommodate medium-sized mammal movement preferences based on the biologically best corridor for javelina. RTA structures RTA1 – RTA3 between SR 86 mile posts 131 – 135 should also accommodate large-sized mammal movement preferences based on recommendations from the Tohono O'odham Nation (2011). These culverts/wildlife crossings and associated fencing should follow recommendations for large-sized mammals referenced above.

State Route 386

- Road structures RS60 – RS62 located within the Kitt Peak linkage between SR 386 mile posts 0 – 3 were not able to be visited due to their location within the Tohono O'odham Nation, but were detected from 2010 aerial imagery, and digitized using GIS. While these structures were unable to be evaluated during field observations, they remain a priority to retrofit using the recommendations below:
    - Road structure RS60 between SR 386 mile posts 0 – 1, should be retrofitted during road widening projects to accommodate medium-size mammal movement preferences, based on biologically best corridors for javelina. This culvert and associated fencing should follow recommendations for medium-size mammals referenced above.
    - Road structures RS61 – RS62 between SR 386 mile posts 2 – 3, should be retrofitted during road widening projects to accommodate herpetofauna movement preferences, based on the biologically best corridor for giant spotted whiptail. These culverts and associated barriers should follow recommendations for herpetofauna referenced above.

Unfortunately, the existing road structures may not be adequate to serve the movement needs of the various focal species of wildlife recognized in this report and important to the Sonoran Desert Ecosystem. Every animal moving terrestrially between wildland blocks must traverse SR 86, so wildlife crossing structures along the highway that accommodate the needs of the different focal species recognized in this plan, are crucial to the success of this linkage, and may require the construction of a wildlife overpass.

We recommend the construction of overpasses as follows:

- At least one overpass in addition to the RTA approved overpass between SR 86 mile posts 133 – 134 should be constructed to facilitate movement of large-sized mammals across SR 86 within the Kitt Peak linkage. A Preliminary location for construction should be near SR 86 mp 121, due to its proximity near mule deer and desert bighorn sheep biologically best corridor models. On the ground wildlife research should be conducted before construction to determine the exact location of current large-sized mammal movements or road mortality within the linkage. Also, on the ground wildlife research should be conducted post construction to determine wildlife use of the overpass and effectiveness of reducing SR 86 road mortality.

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 and 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). Focal species were originally chosen by the CorridorDesign Team at Northern Arizona University and Regional biologists familiar with species across the State that had one or more of the following characteristics:

- Habitat specialists, especially habitats that may be relatively rare.
- 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* at the beginning of this report, 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

[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.

narrowed the list of identified focal species to 14 that could be adequately modeled using the available GIS layers. For a list of focal species not modeled, but having Heritage Data Management System (HDMS) element occurrence records within the linkage design, see *Appendix D*.

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 (*see Figure 13 below*):

- *Vegetation and land cover.* We used the Southwest Regional GAP Analysis (ReGAP) data, merging some classes to create 46 vegetation and land cover classes as described in Appendix E. This dataset was originally classified in 2001 using imagery from previous years. Since, significant development occurred since ReGAP was published, the dataset was updated to represent development using imagery from 2010. This was done by digitizing developed areas on privately owned lands located in areas previously classified in ReGAP as non-developed classes. The digitized areas were then appended to the land cover raster dataset.
- *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 0 (worst) to 100 (best), where 0-30 is strongly avoided (0 = absolute non-habitat), 30 - 60 may be occasionally used by cannot sustain a breeding population (30 = lowest value associated with occasional use for non-breeding activities), 60-80 is suboptimal but used (60 = lowest value associated with consistent use and breeding), and 80-100 is optimal (80 = lowest score typically associated with successful breeding and 100 = best habitat, highest survival and reproductive success). 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 0 to 100. We then weighted each of the four 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:

$$HabitatSuitabilityScore = Veg^{W1} * Elev^{W2} * Topo^{W3} * Road^{W4}$$

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

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

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

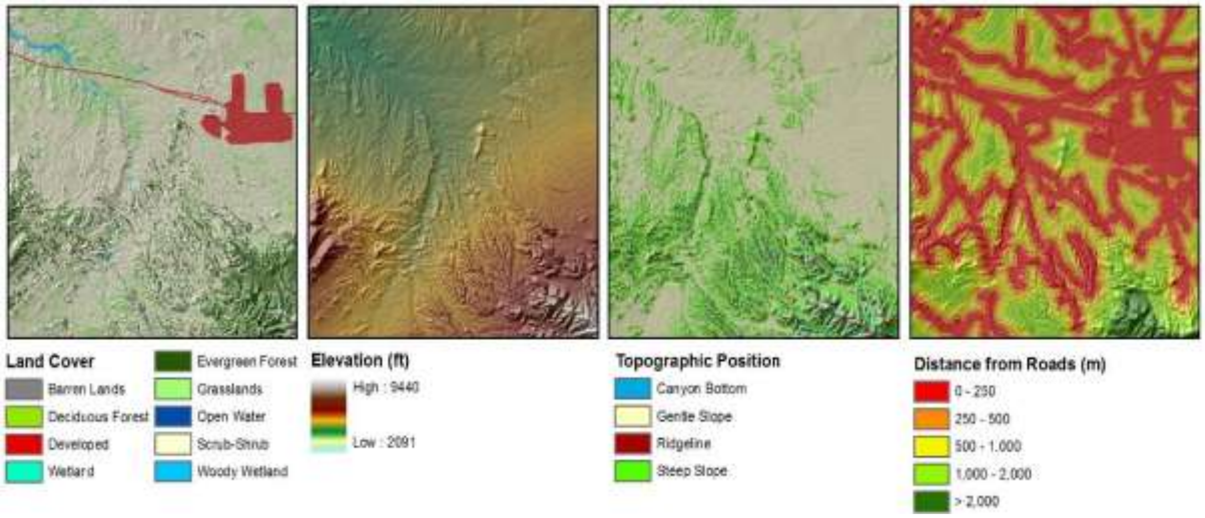

Figure 13*: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window*.

Identifying Potential Breeding Patches and 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 habitat 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. 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.

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.

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 wildland block. If potential population cores existed within each block, we used these potential cores as the starting and 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 1000m (See *Figure 14* below). After developing a biologically best corridor for each species, we combined biologically best corridors to form a union of biologically best corridors (UBBC). If a species had two or more distinct we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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[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.

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

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 3rd 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*.

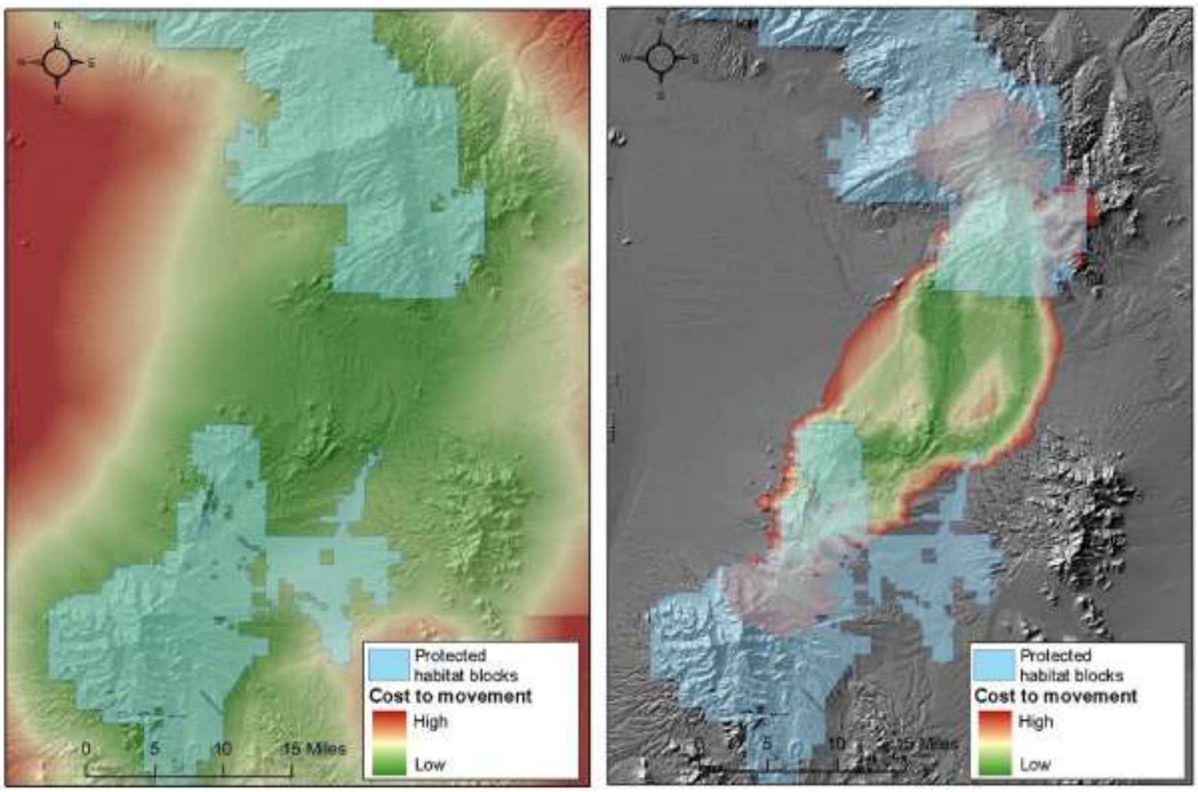

***Figure 14**: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape*

[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.

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 and 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 (0.62 mi) along the length of each branch of the preliminary linkage design, except where existing urbanization precluded such widening. Beier et al. (2006a and 2006b) widened bottlenecks first by adding natural habitats, and then by adding agricultural lands if no natural areas were available. Our Linkage Design was at least 1 km (0.62 mi) wide throughout, and so no widening due to bottlenecks was needed.

Minimum widths for individual species corridors were estimated based on home range values used to calculate potential habitat patch sizes, and whether or not the species was classified as a *corridor dweller* or *passage species* (see definition for focal species). Based on recommendations from Beier et al. (2008), individual models for corridor dwellers were more than 2 times the width of their home range over 90% of the length of the model, while passage species model widths were less than the width of their home range. Minimum widths for passage species were also maintained over 90% of the corridor model where possible. A few species were kept slightly below this width due to bottlenecks that remained after largely increasing the biologically best corridor slice. Home range widths were estimated from home range area assuming a 2:1 rectangle. 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. Some widening of the UBBC was needed to increase the width of a few merged biologically best corridor strands.

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 and 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.

Appendix B: Individual Species Modeling Parameters

***Table 5**: Habitat suitability scores and factor weights for each species (Majka et al. 2007). Scores range from 0 (worst) to 100 (best), with > 30 indicating avoided habitat, 30 – 59 occasionally used for non-breeding activities, 60 – 79 consistent use and breeding, and 80 – 100 highest survival and reproductive success.*

	Badger	Black-tailed Jackrabbit	Black-tailed Rattlesnake	Desert Bighorn Sheep	Giant Spotted Whiptail
Factor Weights					
Land Cover	65	70	0	30	70
Elevation	7	10	0	10	30
Topography	15	10	90	50	0
Distance from Roads	13	10	10	10	0
Land Cover					
Conifer-Oak Forest and Woodland	48	28		11	0
Encinal	48	50		11	44
Mixed Conifer Forest and Woodland	44	11		11	0
Pine-Oak Forest and Woodland	52	50		11	0
Pinyon-Juniper Woodland	67	67		11	0
Ponderosa Pine Woodland	52	44		11	0
Spruce-Fir Forest and Woodland	44	17		11	0
Aspen Forest and Woodland	41	22		11	0
Juniper Savanna	89	78		22	0
Montane-Subalpine Grassland	93	33		44	0
Semi-Desert Grassland and Steppe	100	72		56	33
Big Sagebrush Shrubland	78	89		33	0
Blackbrush-Mormon-tea Shrubland	74	67		44	0
Chaparral	52	50		11	67
Creosotebush, Mixed Desert and Thorn Scrub	89	94		44	67
Creosotebush-White Bursage Desert Scrub	89	94		44	0
Desert Scrub (misc)	74	100		89	0
Gambel Oak-Mixed Montane Shrubland	59	56		11	0
Mat Saltbush Shrubland	63	67		22	0
Mesquite Upland Scrub	74	72		33	33
Mixed Low Sagebrush Shrubland	74	89		44	0
Paloverde-Mixed Cacti Desert Scrub	63	100		78	0
Pinyon-Juniper Shrubland	70	78		22	0
Sand Shrubland	70	78		33	0
Stabilized Coppice Dune and Sand Flat Scrub	67	78		22	0
Greasewood Flat	41	61		33	0
Riparian Mesquite Bosque	41	61		11	67
Riparian Woodland and Shrubland	41	67		11	100
Arid West Emergent Marsh	26	11		0	89
Active and Stabilized Dune	22	61		0	0
Badland	37	22		0	0
Barren Lands, Non-specific	33	28		22	0
Bedrock Cliff and Outcrop	15	28		89	0
Cliff and Canyon	11	28		100	0
Mixed Bedrock Canyon and Tableland	11	22		89	0
Playa	15	22		11	0
Volcanic Rock Land and Cinder Land	0	17		33	0
Warm Desert Pavement	11	17		11	0
Wash	22	56		11	56

	Badger	Black-tailed Jackrabbit	Black-tailed Rattlesnake	Desert Bighorn Sheep	Giant Spotted Whiptail
Invasive Grassland or Forbland	63	61		44	0
Invasive Riparian Woodland and Shrubland	26	56		11	0
Recently Mined or Quarried	7	0		0	0
Agriculture	48	50		0	67
Developed, Medium - High Intensity	0	11		0	67
Developed, Open Space - Low Intensity	30	44		0	78
Open Water	7	11		0	89
Elevation (ft)					
	0 - 1676: 100	0 - 1829: 100		0 - 899: 89	0 - 610: 0
	1676 - 2438: 78	1829 - 2438: 67		899 - 1006: 100	610 - 701: 56
	2438 - 4000: 44	2438 - 4000: 22		1006 - 2134: 78	701 - 1219: 100
				2134 - 4000: 33	1219 - 1402: 67
					1402 - 1524: 11
Topographic Position					1524 – 4000: 0
Canyon Bottom	56	72	100	22	
Flat - Gentle Slopes	100	94	11	33	
Steep Slope	26	67	100	100	
Ridgetop	37	67	100	56	
Distance from Roads					
	0 - 250: 44	0 - 250: 11	0 - 35: 0	0 - 1000: 44	
	250 - 15000: 100	250 - 500: 44	35 - 500: 56	1000 - 15000: 100	
		500 - 1000: 78	500 - 15000: 100		
		1000 - 15000: 100			

	Gila Monster	Jaguar	Javelina	Kit Fox	Mountain Lion
Factor Weights					
Land Cover	10	60	50	75	70
Elevation	35	5	30	0	0
Topography	45	15	20	15	10
Distance from Roads	10	20	0	10	20
Land Cover					
Conifer-Oak Forest and Woodland	0	89	33	22	100
Encinal	56	89	67	33	100
Mixed Conifer Forest and Woodland	0	78	44	17	78
Pine-Oak Forest and Woodland	0	78	33	17	100
Pinyon-Juniper Woodland	44	89	56	22	100
Ponderosa Pine Woodland	0	67	44	17	67
Spruce-Fir Forest and Woodland	0	67	22	0	67
Aspen Forest and Woodland	0	44	0	6	78
Juniper Savanna	0	78	33	78	67
Montane-Subalpine Grassland	0	67	22	22	44
Semi-Desert Grassland and Steppe	56	100	89	100	56
Big Sagebrush Shrubland	0	67	11	67	44
Blackbrush-Mormon-tea Shrubland	0	56	0	67	44
Chaparral	44	67	78	44	78
Creosotebush, Mixed Desert and Thorn Scrub	78	89	78	100	44
Creosotebush-White Bursage Desert Scrub	33	67	67	100	44
Desert Scrub (misc)	78	67	89	100	44
Gambel Oak-Mixed Montane Shrubland	0	78	22	56	78
Mat Saltbush Shrubland	0	56	0	72	44
Mesquite Upland Scrub	67	67	89	56	67
Mixed Low Sagebrush Shrubland	0	44	0	67	44
Paloverde-Mixed Cacti Desert Scrub	100	56	100	78	33
Pinyon-Juniper Shrubland	44	67	0	67	89
Sand Shrubland	0	44	0	89	56
Stabilized Coppice Dune and Sand Flat Scrub	0	44	33	100	56
Greasewood Flat	0	78	0	83	44
Riparian Mesquite Bosque	56	100	100	61	67
Riparian Woodland and Shrubland	56	100	89	50	89
Arid West Emergent Marsh	89	89	56	11	22
Active and Stabilized Dune	0	11	22	72	22
Badland	0	11	11	11	44

	Gila Monster	Jaguar	Javelina	Kit Fox	Mountain Lion
Barren Lands, Non-specific	0	0	11	11	22
Bedrock Cliff and Outcrop	0	44	22	11	44
Cliff and Canyon	89	0	33	11	44
Mixed Bedrock Canyon and Tableland	89	0	0	11	44
Playa	89	0	22	11	0
Volcanic Rock Land and Cinder Land	0	11	11	22	11
Warm Desert Pavement	100	11	22	11	11
Wash	44	22	100	44	33
Invasive Grassland or Forbland	78	56	56	67	33
Invasive Riparian Woodland and Shrubland	67	78	56	44	56
Recently Mined or Quarried	0	0	0	0	22
Agriculture	0	11	33	33	0
Developed, Medium - High Intensity	11	0	33	11	0
Developed, Open Space - Low Intensity	100	0	67	33	22
Open Water	0	33	0	0	11
Elevation (ft)					
	0 - 518: 67	0 - 1219: 78	0 - 1524: 100		
	518 - 1219: 100	1219 - 1829: 100	1424 - 2134: 78		
	1219 - 1463: 67	1829 - 2438: 78	2134 - 4000: 0		
	1463 - 1737: 33	2438 – 4000: 67			
	1737 - 4000: 0				
Topographic Position					
Canyon Bottom	100	100	100	33	100
Flat - Gentle Slopes	56	56	100	100	78
Steep Slope	100	89	33	56	78
Ridgetop	100	67	67	67	67
Distance from Roads					
	0 - 1000: 56	0 - 250: 1		0 - 50 : 33	0 - 200: 22
	1000 - 3000: 78	250 - 500: 33		50 - 250: 78	200 - 500: 44
	3000 - 15000: 100	500 - 1000: 56		250 - 500: 89	500 - 1000: 56
	67	1000 - 2000: 89		500 - 15000: 100	1000 - 1500: 89
	0	2000 - 15000: 100			1500 - 15000: 100

	Mule Deer	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake
Factor Weights				
Land Cover	80	5	30	30
Elevation	0	50	25	10
Topography	15	25	40	45
Distance from Roads	5	20	5	15
Land Cover				
Conifer-Oak Forest and Woodland	67	0	0	0
Encinal	78	33	33	100
Mixed Conifer Forest and Woodland	78	0	0	0
Pine-Oak Forest and Woodland	78	0	0	100
Pinyon-Juniper Woodland	56	0	0	100
Ponderosa Pine Woodland	56	0	0	56
Spruce-Fir Forest and Woodland	22	0	0	0
Aspen Forest and Woodland	100	0	0	0
Juniper Savanna	67	67	0	78
Montane-Subalpine Grassland	67	0	0	0
Semi-Desert Grassland and Steppe	89	89	22	89
Big Sagebrush Shrubland	78	0	0	0
Blackbrush-Mormon-tea Shrubland	44	0	0	0
Chaparral	67	67	0	100
Creosotebush, Mixed Desert and Thorn Scrub	44	89	44	89
Creosotebush-White Bursage Desert Scrub	44	67	56	33
Desert Scrub (misc)	44	89	67	78
Gambel Oak-Mixed Montane Shrubland	67	0	0	0
Mat Saltbush Shrubland	22	0	0	0
Mesquite Upland Scrub	78	100	33	89
Mixed Low Sagebrush Shrubland	56	0	0	0
Paloverde-Mixed Cacti Desert Scrub	78	100	100	100
Pinyon-Juniper Shrubland	56	67	0	100
Sand Shrubland	33	89	0	0
Stabilized Coppice Dune and Sand Flat Scrub	44	89	0	0
Greasewood Flat	44	0	44	0
Riparian Mesquite Bosque	78	100	56	89
Riparian Woodland and Shrubland	78	89	0	89
Arid West Emergent Marsh	56	56	0	78
Active and Stabilized Dune	0	33	0	0
Badland	11	0	0	0
Barren Lands, Non-specific	0	33	0	0
Bedrock Cliff and Outcrop	22	56	0	78
Cliff and Canyon	33	56	0	56
Mixed Bedrock Canyon and Tableland	33	56	0	0
Playa	44	78	22	0

	Mule Deer	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake
Volcanic Rock Land and Cinder Land	22	0	0	67
Warm Desert Pavement	11	56	44	0
Wash	89	78	78	67
Invasive Grassland or Forbland	56	78	11	22
Invasive Riparian Woodland and Shrubland	78	78	0	0
Recently Mined or Quarried	44	67	0	0
Agriculture	44	67	0	0
Developed, Medium - High Intensity	11	44	0	0
Developed, Open Space - Low Intensity	56	67	33	56
Open Water	0	67	0	0
Elevation (ft)				
		0 - 1402: 100	0 - 610: 78	0 - 427: 56
		1402 - 1600: 67	610 - 914: 100	427 - 610: 78
		1600 - 1768: 56	914 - 1524: 78	610 - 1707: 100
		1768 - 4000: 22	1524 - 2134: 33	1707 - 2286: 56
			2134 - 4000: 0	2286 - 4000: 0
Topographic Position				
Canyon Bottom	89	100	100	100
Flat - Gentle Slopes	89	100	100	33
Steep Slope	67	44	44	100
Ridgetop	44	44	44	100
Distance from Roads				
	0 - 250: 33	0 - 200: 5	O - 250: 56	0 - 500: 56
	250 - 1000: 78	200 - 1000: 67	250 - 500: 67	500 - 1000: 67
	1000 - 15000: 100	1000 - 3000: 89	500 - 1000: 78	1000 - 2000: 78
		3000 - 15000: 100	1000 - 15000: 100	2000 - 15000: 100

Appendix C: Individual Species Analysis

Badger, *Taxidea taxus*

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Badgers prefer grasslands and other open habitats on flat terrain at lower elevations. They do not show an aversion to roads (Apps et al. 2002), which makes them sensitive to high road mortality. Vegetation received an importance weight of 65%, while elevation, topography, and distance from roads received weights of 7%, 15%, and 13%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – We defined minimum potential habitat patch size as 2 km^2, which is an average of the home range found for both sexes by Messick and Hornocker (1981), and equal to the female home range estimated by Goodrich and Buskirk (1998), minus 1 standard deviation. Minimum potential population core size was defined as 10 km^2, approximately enough area to support 10 effective breeders, allowing for a slightly larger male home range size and 20% overlap of home ranges (Messick and Hornocker 1981). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Badgers were classified as a passage species based on recorded dispersal distances (Messick and Hornocker 1981) and the distance between wildland blocks used in this analysis.

Results and Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for badger in the Kitt Peak linkage. Habitat scores ranged from 33.6 to 92.7, with an average suitability score of 82.0 (S.D: 10.4; see *Figure 15* below). Almost the entire BBC in the Kitt Peak linkage (99.8%) is occupied by a potential population core, with the rest occupying non-suitable habitat (see *Figure 16* below). Most of the BBC (97.0%) was greater than its estimated needed minimum width (see *Figure 17* below). The BBC was measured at 26.2 km (16.5 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more suitable habitat and potential population cores for badger. Because there is ample habitat for this species, the greatest threats to its connectivity and persistence are most likely high-traffic roads such as State Route 86.

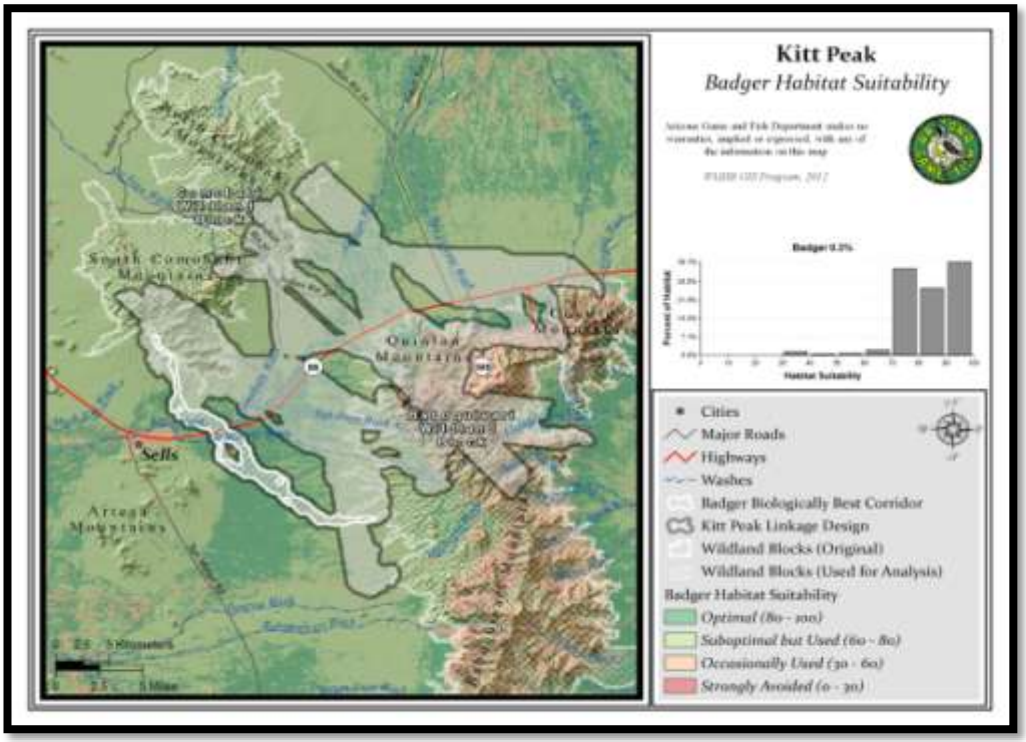

Figure 15: *Map of Kitt Peak modeled habitat suitability for badger*

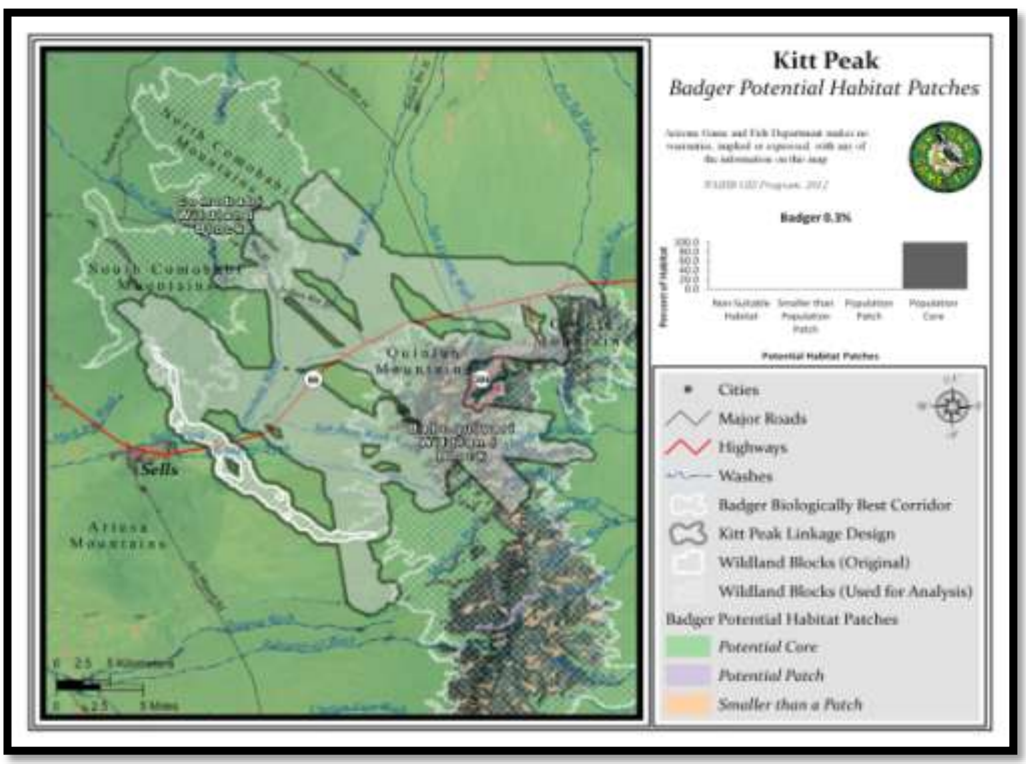

Figure 16: *Map of Kitt Peak potential habitat patches for badger*

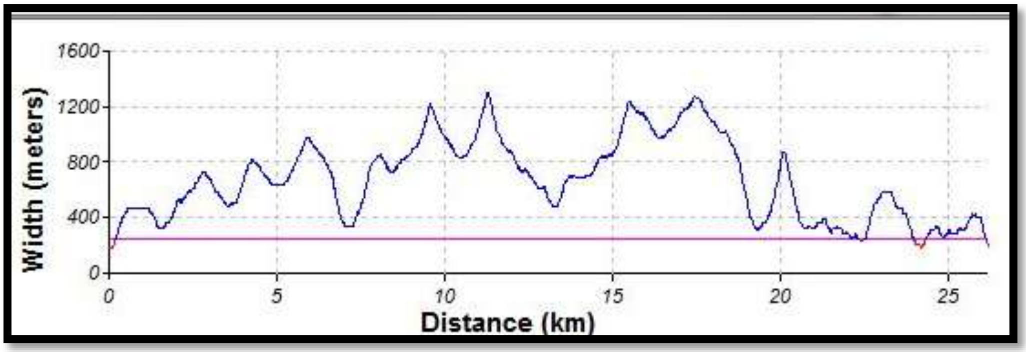

Figure 17: *Width along the Kitt Peak badger biologically best corridor*

Black-tailed Jackrabbit, *Lepus californius*

Justification for Selection

Photo courtesy George Andrejko, AGFD

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

Distribution

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

Habitat Associations

This species primarily prefers open country, and will typically avoid areas of tall grass or forest where visibility is low (Best 1996). In Arizona, black-tailed jackrabbits prefer mesquite, sagebrush, pinyon juniper, and desert scrub (Hoffmeister 1986). They are also found in sycamore, cottonwood, and rabbitbrush habitats (New Mexico Department of Game and Fish 2002). Dense grass and/or shrub cover is necessary for resting (New Mexico Department of Game and Fish 2002). Black-tailed jackrabbits are known to avoid standing water, making large canals and rivers possible population barriers (Best 1996).

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong vegetation preferences, vegetation received an importance weight of 70%, while elevation, topography, and distance from roads each received weights of 10%. For specific costs of classes within each of these factors used for the modeling process, see *Table 5*.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Black-tailed jackrabbit were considered a passage species based on the length of daily movement patterns in southern Arizona (Hoffmeister 1986) and distance between wildland blocks used in analysis.

Results and Discussion

Initial biologically best corridor – Modeling results indicate significant amounts of suitable habitat for black-tailed jackrabbits within the Kitt Peak linkage. Habitat suitability scores ranged from 63.3 to 99.4, with an average suitability of 97.3 (S.D: 6.0; see *Figure 18* below). The entire BBC (100.0%) is occupied by a potential population core (see *Figure 19* below). Most of the BBC (89.5%) was greater than its estimated needed minimum width (see *Figure 20* below). The BBC was measured at 26.4 km (16.4 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more suitable habitat and potential population cores for black-tailed jackrabbit.

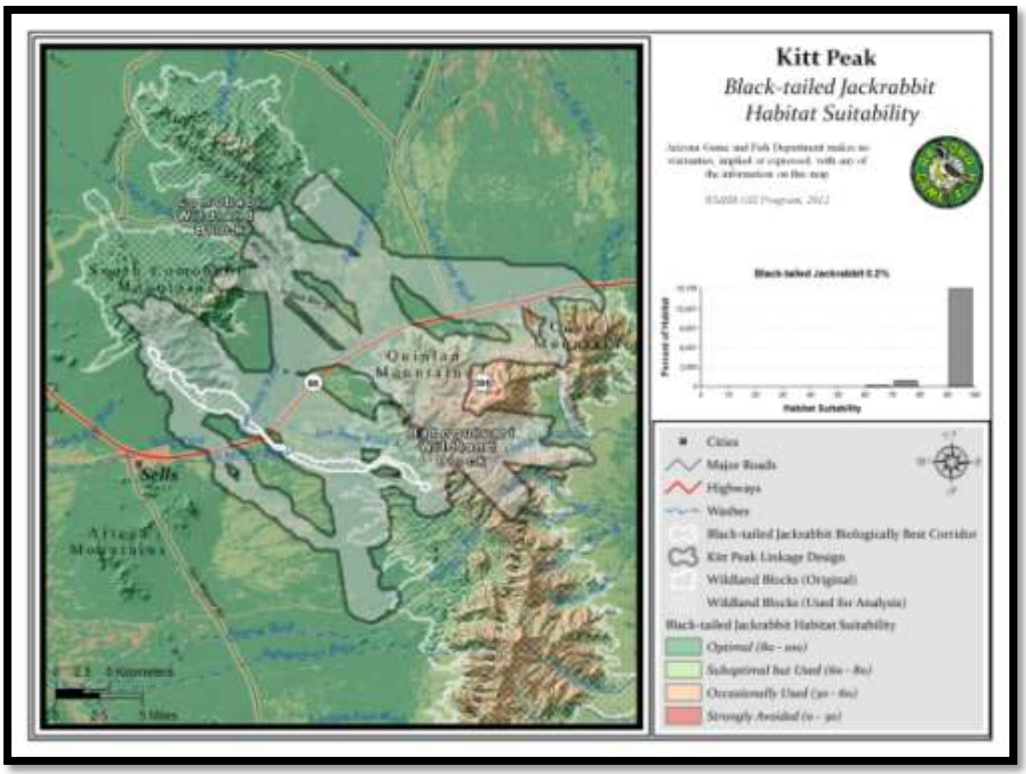

Figure 18: *Map of Kitt Peak modeled habitat suitability for black-tailed jackrabbit*

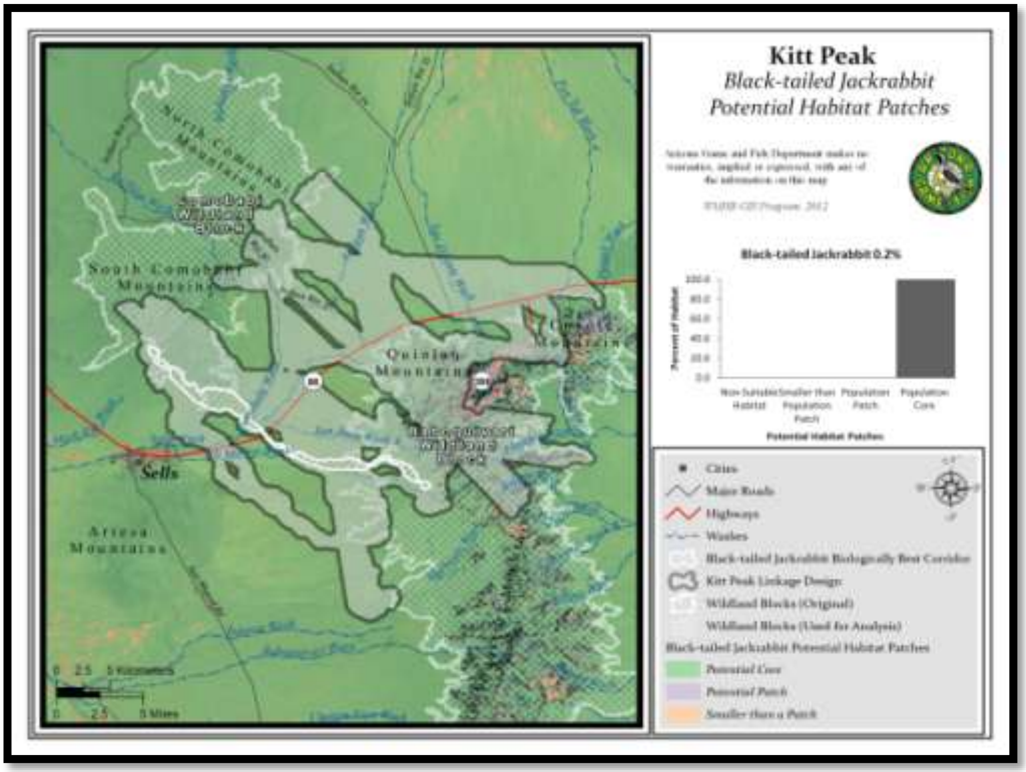

Figure 19: *Map of Kitt Peak potential habitat patches for black-tailed jackrabbit*

Figure 20: *Width along the Kitt Peak black-tailed jackrabbit biologically best corridor*

Black-tailed Rattlesnake, *Crotalus molossus*

Justification for Selection

Ecologically, the black-tailed rattlesnake is a generalist, able to live in a variety of habitats, making this species an important part of many ecosystems throughout Arizona. This rattlesnake requires various habitat types during different times of the year (Beck 1995), and relies on connectivity of these habitat types during its life cycle.

Photo courtesy Randy Babb, AGFD

Distribution

This rattlesnake is found from central and west-central Texas northwest through the southern two-thirds of New Mexico to northern and extreme western Arizona, and southward to the southern edge of the Mexican Plateau and Mesa del Sur, Oaxaca (Degenhardt et. al 1996).

Habitat Associations

Black-tailed rattlesnakes are known as ecological generalists, occurring in a wide variety of habitats including montane coniferous forests, talus slopes, rocky stream beds in riparian areas, and lava flows on flat deserts (Degenhardt et. al 1996). In a radiotelemetry study conducted by Beck (1995), these snakes frequented rocky areas, but used arroyos and creosote bush flats during late summer and fall. Pine-oak forests, boreal forests, mesquite-grasslands, chaparral, tropical deciduous forests, and thorn forests are also included as habitats for this species (New Mexico Department of Game and Fish 2002). In New Mexico, black-tailed rattlesnakes occur between 1000 and 3150 meters in elevation (New Mexico Department of Game and Fish 2002).

Spatial Patterns

The home range size for black-tailed rattlesnakes has been reported as 3.5 hectares, in a study within the Sonoran desert of Arizona (Beck 1995). These snakes traveled a mean distance of 15 km throughout the year, and moved an average of 42.9 meters per day (Beck 1995). No data is available on dispersal distance for this species, but a similar species, Tiger rattlesnake (*Crotalus tigris*), has been found to disperse up to 2 km (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team).

Conceptual Basis for Model Development

Habitat suitability model – While this species is a vegetation generalist, it is strongly associated with rocks and outcrops on mountain slopes, and rarely seen at any distance from these environments (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team). Because of this strong topographic association, topography received an importance weight of 90%, while distance from roads received a weight of 10%. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Beck (1995) found home ranges from 3-4 ha in size; however, it is thought that home ranges for most black-tailed rattlesnakes are slightly larger (Phil Rosen, personal comm. to CorridorDesign Team) so minimum patch size was defined as 10 ha. Minimum core size was defined as 100 ha. 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. Black-tailed rattlesnakes were considered a corridor dweller due to limited travel distanced found by Beck (1995), limited dispersal of similar species (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team) and the distances of wildland blocks used in this analysis. The original biologically best corridor for this species was trimmed to eliminate "bubble" areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for black-tailed rattlesnakes within the trimmed BBC used in the Kitt Peak linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 89.6 (S.D: 28.0; see *Figure 21* below). Most of the trimmed BBC, 88.9%, is occupied by a potential population core, with 0.5% occupied by a potential habitat patch, 0.1% occupied by suitable habitat smaller than a patch, and the remainder by non-suitable habitat (see *Figure 22* below). Most of the trimmed BBC (90.7%) was greater than its estimated needed minimum width (see *Figure 23* below). The trimmed corridor was measured at 24.4 km (15.2 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures little suitable habitat in addition to the BBC.

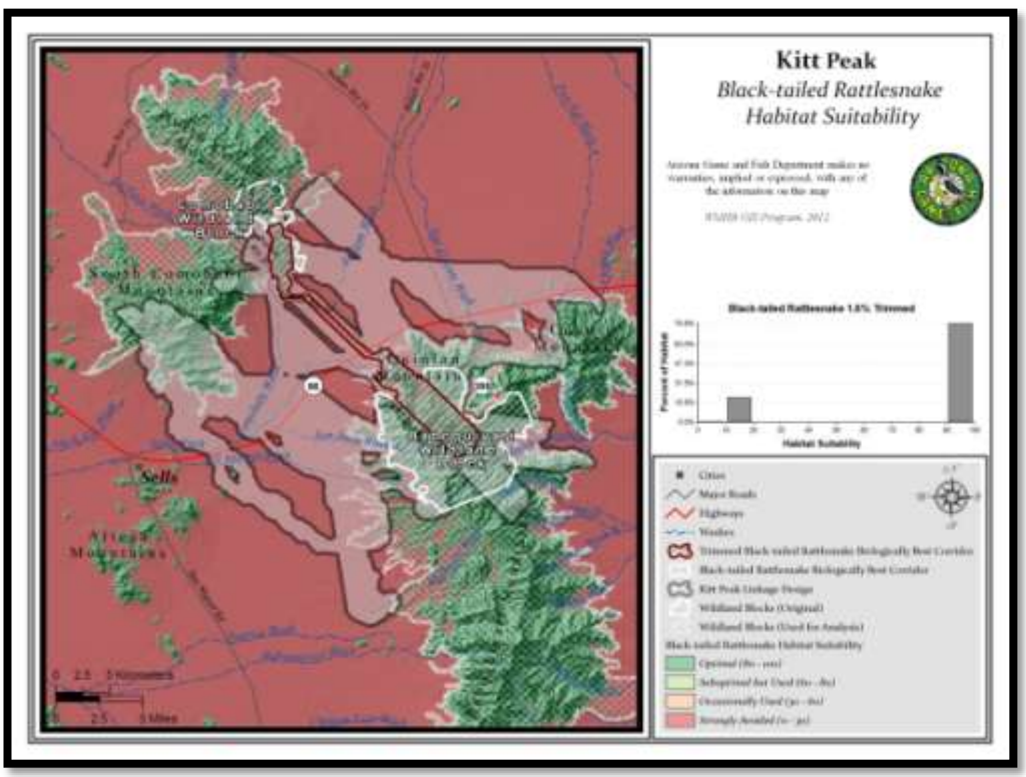

Figure 21: *Map of Kitt Peak linkage modeled habitat suitability for black-tailed rattlesnake*

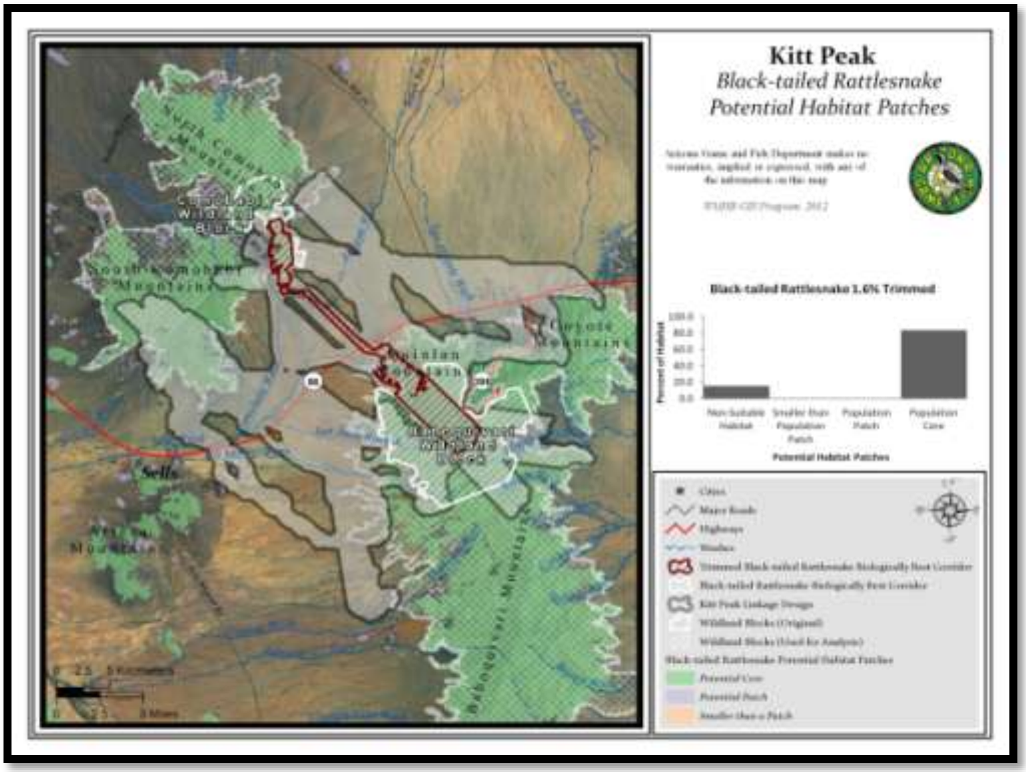

Figure 22: *Map of Kitt Peak linkage potential habitat patches for black-tailed rattlesnake*

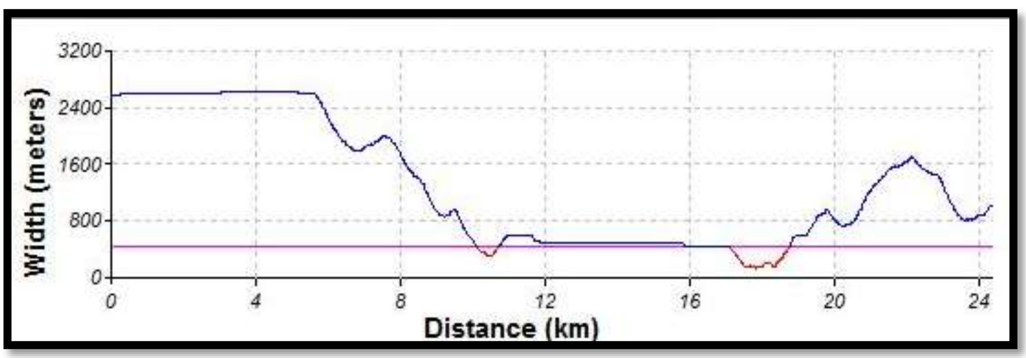

Figure 23: *Width along the Kitt Peak trimmed black-tailed rattlesnake biologically best corridor*

Desert Bighorn Sheep, *Ovis canadensis nelsoni*

Justification for Selection

Photo courtesy George Andrejko, AGFD

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).

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, desert bighorns can be found from Kanab Creek and the Grand Canyon west to Grand Wash, as well as in westernmost Arizona eastward to Aravaipa Canyon. Rocky Mountain bighorn sheep are located near Morenci, AZ, north towards Alpine, AZ, and in West Clear Creek near Camp Verde, AZ. Desert bighorn sheep used both the Quinlan/Baboquivari and Comobabi wildland blocks as habitat historically (see *Figure 24* below; Brown 1993).

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 2002). 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 2002). Elevation range for bighorn sheep varies across their range from 0 – 3660 m (New Mexico Department of Game and Fish 2004), but in Arizona the desert bighorn subspecies is found from 100 – 1000m elevation, with the best habitat found from 900 – 1000 m in the jojoba communities (Hoffmeister 1986; Alvarez-Cardenas et al. 2001).

Spatial Patterns

Home ranges for bighorn sheep vary depending upon population size, availability and connectivity of suitable habitat, and availability of water resources (Singer et al. 2001). Home ranges have been reported to range from 6.1 km² to 54.7 km² (Singer et al. 2001). One desert bighorn sheep study in Arizona reports an average home range of 16.9 ± 3.38 km² for ewes, and home ranges for males that increased with age from 11.7 km² for a one year old to 37.3 km² for a 6 year old (Shackleton 1985). Bighorn sheep that live in higher elevations are known to migrate between an alpine summer range to a lower elevation winter range in response to seasonal vegetation availability and snow accumulation in the higher elevations (Shackleton 1985; NatureServe 2005). Maximum distances for these seasonal movements are about 48 km (Shackleton 1985). Desert bighorns on low desert ranges do not have separate seasonal ranges (Shackleton 1985). Bighorns live in groups, but for most of the year males over 3 years of age live separate from maternal groups consisting of females and young (Shackleton 1985).

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong topographic preferences, topographic position received an importance weight of 50%, while vegetation, elevation, and distance from roads received weights of 30%, 10%, and 10%. For specific costs of classes within each of these factors used for the modeling process, see *Table 5*.

Patch size and configuration analysis – We defined minimum potential habitat patch size as 16.9 km2 (Shackleton 1985), and minimum potential habitat core size was defined as 84.5 km2, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Desert bighorn sheep were considered a passage species due movement distances capable during seasonal movements at higher elevations (Shackleton 1985) and the distances of wildland blocks used in this analysis.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for desert bighorn sheep within the BBC used in the Kitt Peak linkage. Habitat suitability scores ranged from 23.3 to 95.4, with an average suitability of 70.2 (S.D: 20.8) (see *Figure 25* below). Some, 39.2%, of the BBC is occupied by a potential population core, with 2.2% occupied by a potential habitat patch, 41.4% occupied by suitable habitat smaller than a patch, and the remainder by non-suitable habitat (see *Figure 26* below). Most of the trimmed BBC (94.8%) was greater than its estimated needed minimum width (see *Figure 27* below). The trimmed corridor was measured at 25.1 km (15.6 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures some additional optimal habitats in the Comobabi and Quinlan Mountains. However, most additional habitat for bighorn sheep that the linkage design captures on more gentle slopes would only be occasionally used.

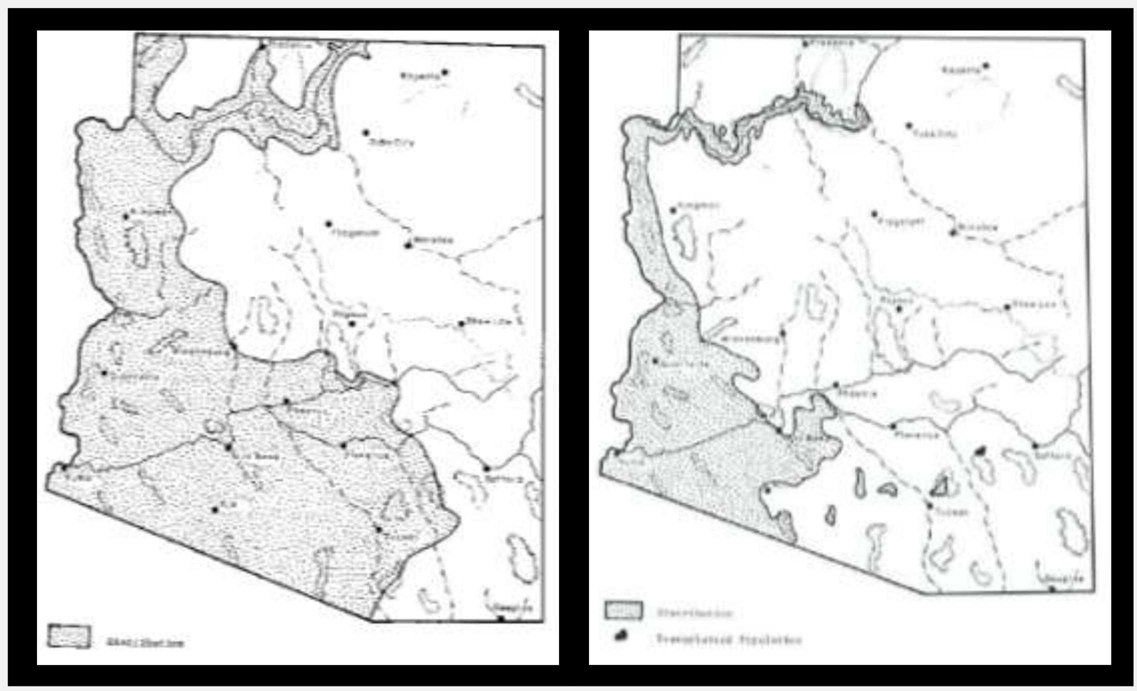

Figure 24: *Desert bighorn sheep known and suspected distribution in 1900 (left) and known distribution in 1960 (right) from (Brown 1993)*

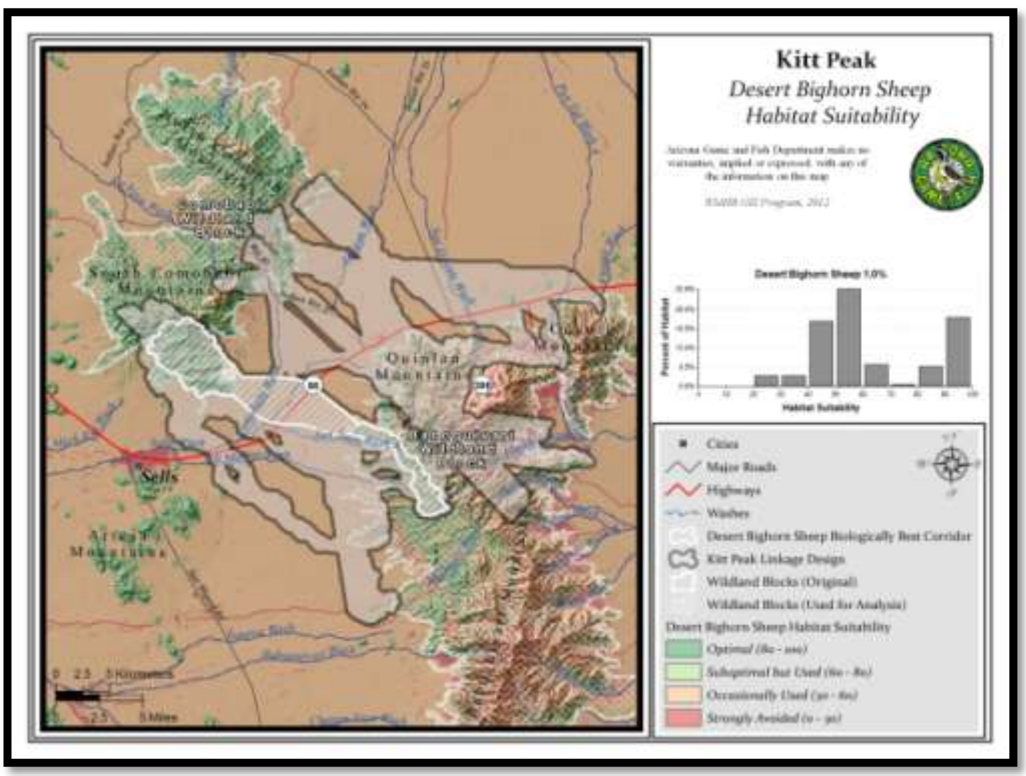

Figure 25: *Map of Kitt Peak modeled habitat suitability for desert bighorn sheep*

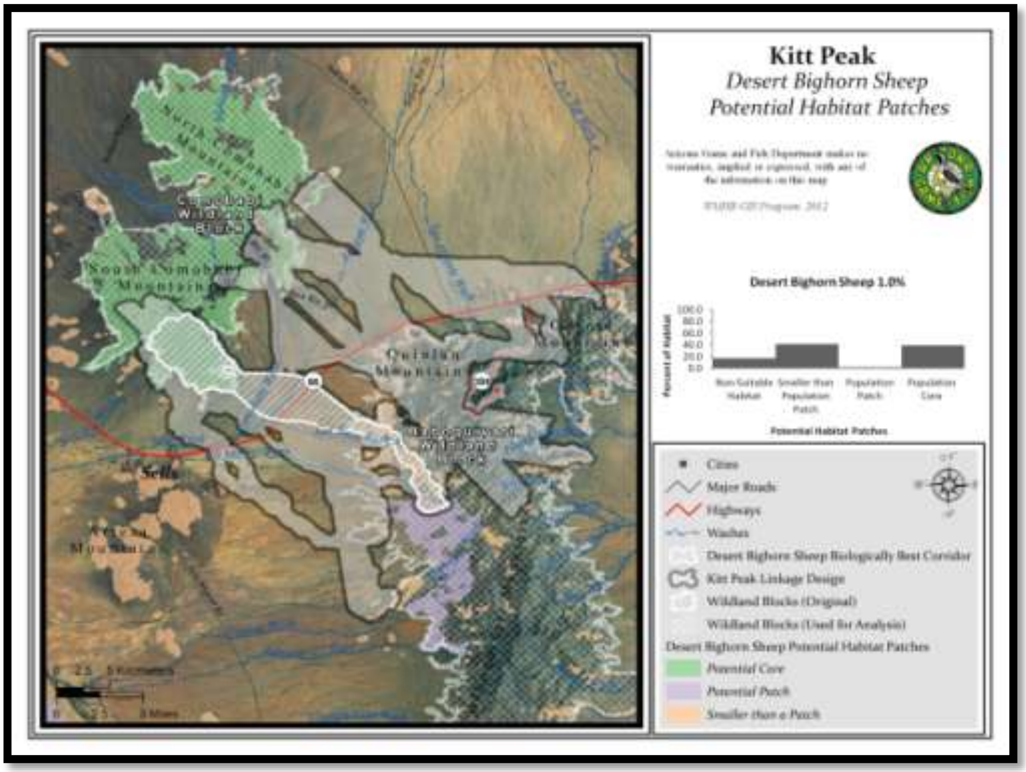

Figure 26: *Map of Kitt Peak potential habitat patches for desert bighorn sheep*

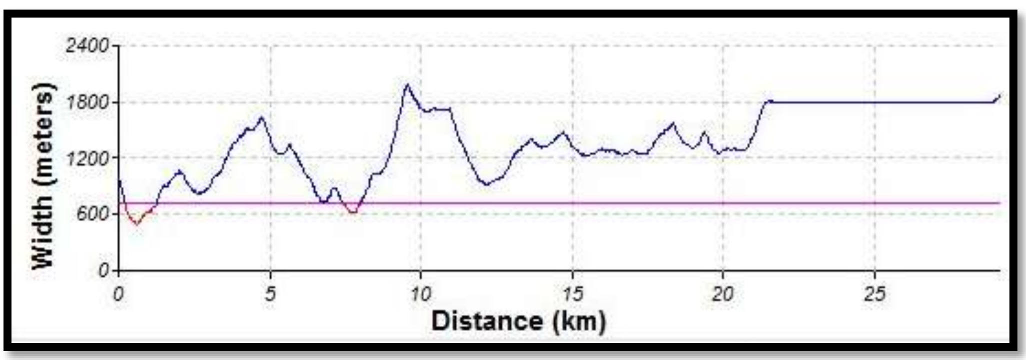

Figure 27: *Width along Kitt Peak desert bighorn sheep biologically best corridor*

Giant Spotted Whiptail, *Aspidoscelis burti stictogrammus*

Justification for Selection

The giant spotted whiptail is thought to be stable; however, little is known of its population trends (Arizona Game and Fish Department 2001). This species has a limited distribution, and is listed as Forest Service Sensitive (1999) and Bureau of Land Management Sensitive (2000; Arizona Game and Fish Department 2001). Although the giant spotted whiptail is not considered to be migratory, corridors are needed to connect disjunct populations (Pima Co., Arizona 2001). They are adversely impacted by habitat alteration due to overgrazing of riparian vegetation (Pima Co., Arizona Game and Fish Department 2001).

Photo courtesy Randy Babb, AGFD

Distribution

This lizard's range is limited to southeastern Arizona including the Santa Catalina, Santa Rita, Pajarito, and Baboquivari Mountains. It is also known to exist in the vicinity of Oracle, Pinal County, and Mineral Hot Springs, Cochise County. Outside of Arizona, the giant spotted whiptail is found in Guadalupe Canyon in extreme southwest New Mexico and northern Sonora, Mexico (Arizona Game and Fish Department 2001).

Habitat Associations

Giant spotted whiptails are found in the riparian areas of lower Sonoran life zones, as well as mountain canyons, arroyos, and mesas in arid and semi-arid regions (Pima Co., Arizona 2001). These lizards inhabit dense shrubby vegetation, often among rocks near permanent and intermittent streams, as well as open areas of bunch grass within these riparian habitats (Arizona Game and Fish Department 2001).They are able to access lowland desert along stream courses (Pima Co., Arizona 2001). Elevation ranges of suitable habitat are from 2,200 to 5,000 feet (670 to 1,500m) (Pima Co., Arizona 2001).

Spatial Patterns

Giant spotted whiptails require only 2-4 ha for their home range (Rosen et al. 2002). Within this area, they rely on a mosaic of open spaces and cover of dense thickets of thorny scrub while foraging (Pima Co., Arizona 2001). These lizards are not migratory, and hibernate in winter.

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 70%, while elevation received a weight of 30%.

Patch size and configuration analysis – Minimum patch size was defined as 4 ha, while minimum core size was defined as 25 ha. 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. Giant spotted whiptail were considered a corridor dweller due to their small home range size (Rosen et al. 2002).

Results and Discussion

Initial biologically best corridor – Modeling results indicate some suitable habitat for giant spotted whiptail within the BBC used in the Kitt Peak linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 45.6 (S.D: 32.5) (see *Figure 28* below). Some, 39.0%, of the BBC is occupied by a potential population core, with 0.8% occupied by a potential habitat patch, 0.9% occupied by suitable habitat smaller than a patch, and the remainder by non-suitable habitat (see *Figure 29* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 30* below). The corridor was measured at 32.0 km (19.9 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures little additional habitat for giant spotted whiptail.

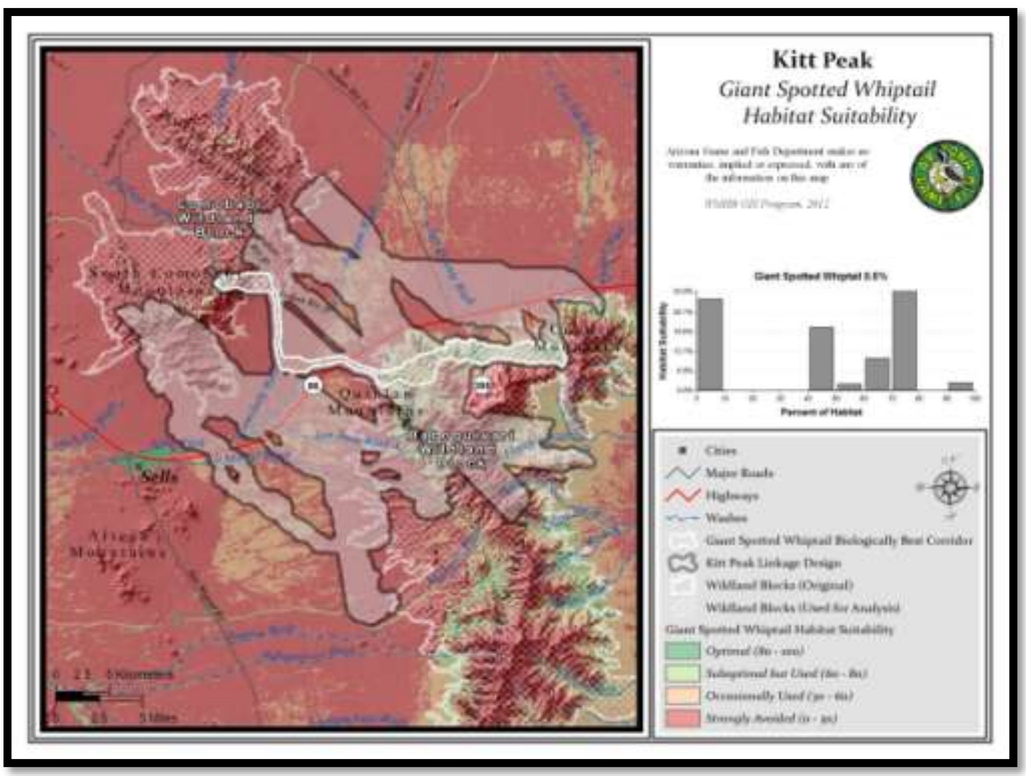

Figure 28: *Map of Kitt Peak habitat suitability for giant spotted whiptail*

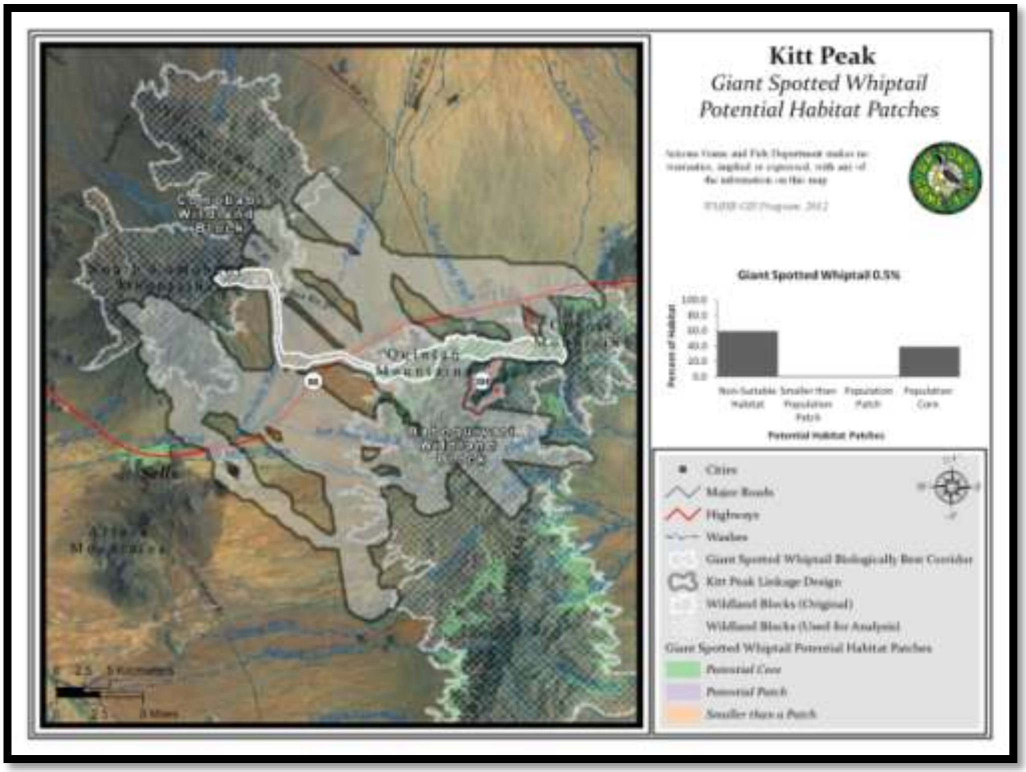

Figure 29: *Map of Kitt Peak potential habitat patches for giant spotted whiptail*

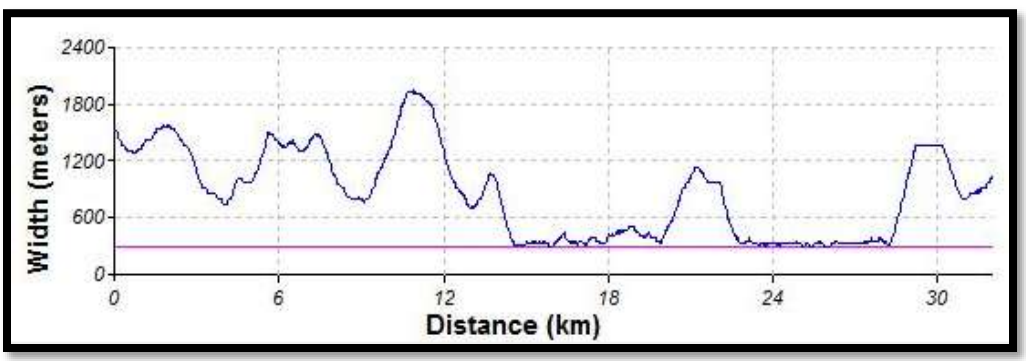

Figure 30: *Width along the Kitt Peak giant spotted whiptail biologically best corridor*

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 (Arizona Game and Fish Department 2002; New Mexico Department of Game and Fish 2002).

Photo courtesy Randy Babb, AGFD

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 (New Mexico Department of Game and Fish 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 and Matt Goode, personal comm. with CorridorDesign Team). 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 and Goode, personal comm. with CorridorDesign Team).

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 and configuration analysis – Minimum potential habitat patch size was defined as 100 ha, and minimum potential core size was defined as 300 ha (Rosen and Goode, personal comm. with CorridorDesign Team, 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. Although Gila monsters are assumed to disperse up to 8 km or more (Rose and Goode, personal comm. with CorridorDesign Team), modeled single species corridor lengths were much longer, and so Gila monster were considered corridor dwellers in both linkages. The original biologically best corridor for this species was trimmed to eliminate "bubble" areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for Gila monster within the trimmed BBC used in the Kitt Peak linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 86.6 (S.D: 12.8; see *Figure 31* below). All of the trimmed BBC is occupied by a potential population core (see *Figure 32* below). Most of the trimmed BBC (92.7%) was greater than its estimated needed minimum width (see *Figure 32* below). The trimmed corridor was measured at 23.8 km (14.8 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures more optimal and suboptimal but used habitat.

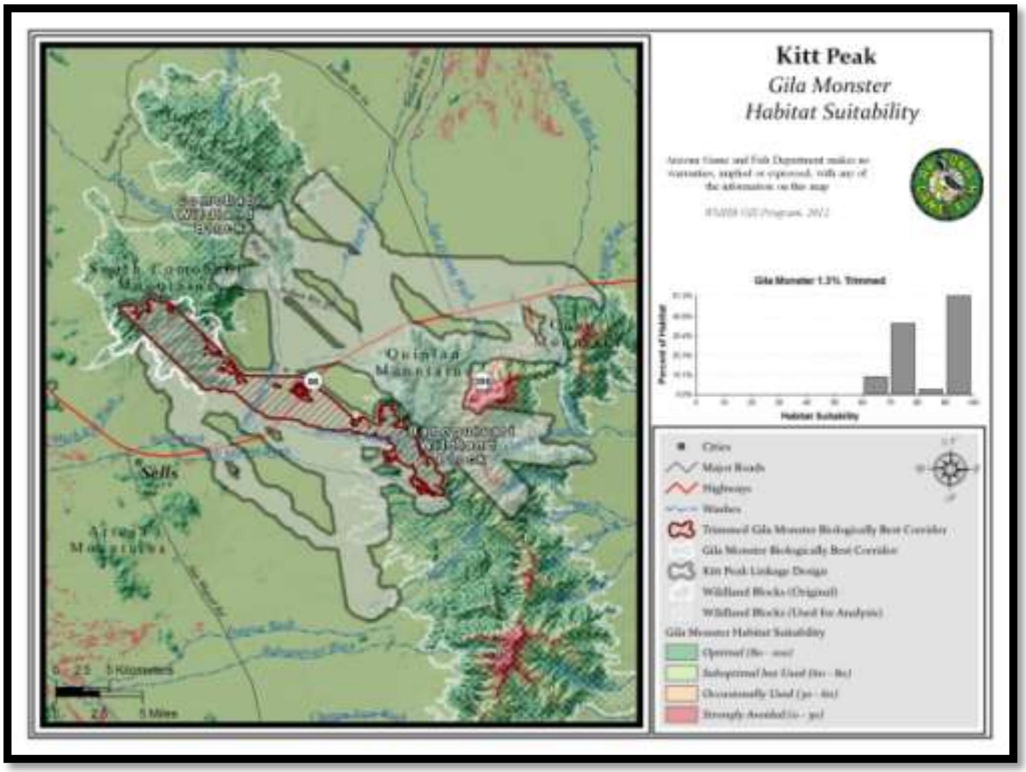

Figure 31: *Map of Kitt Peak modeled habitat suitability for Gila monster*

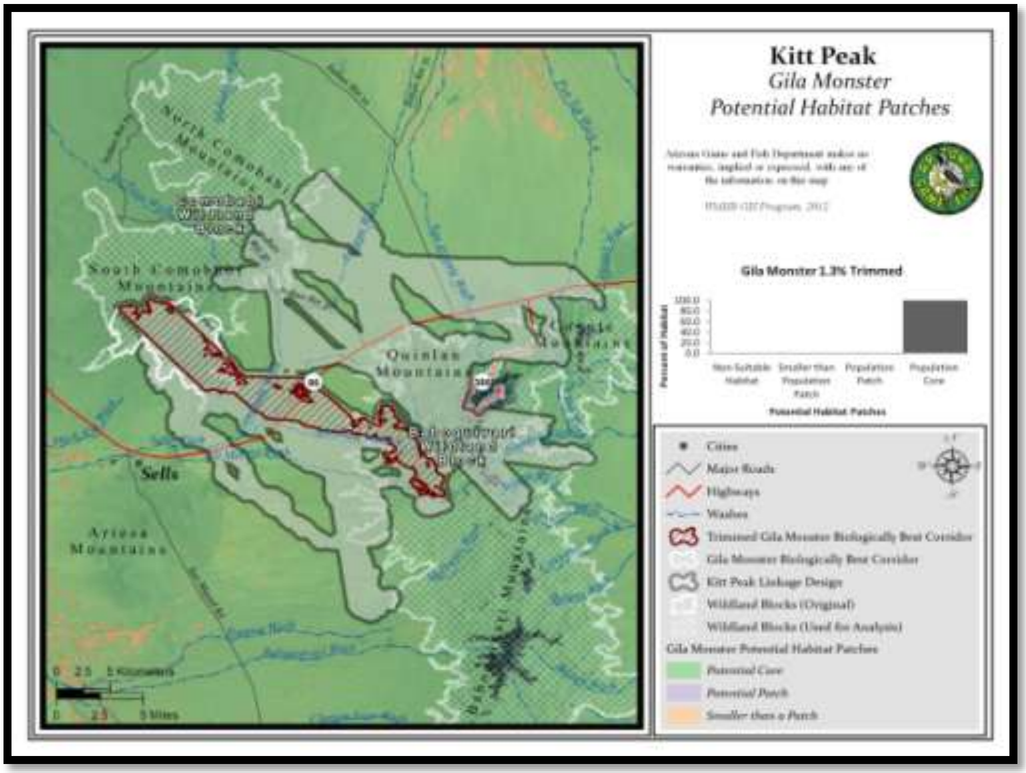

Figure 32: *Map of Coyote – Ironwood potential habitat patches for Gila monster*

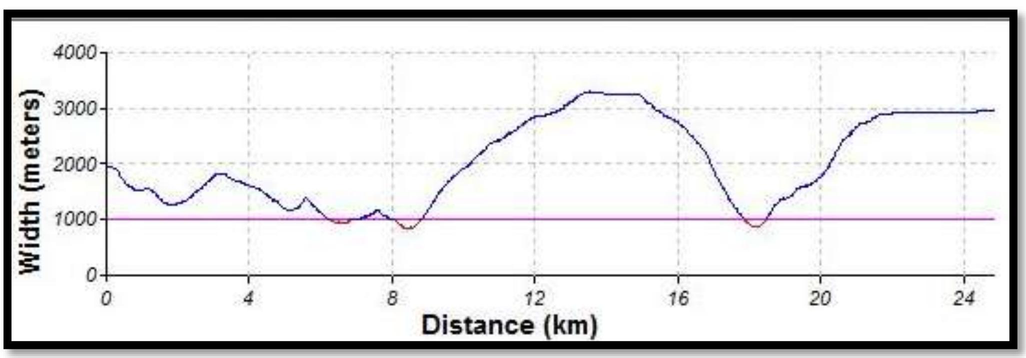

Figure 33: *Width along the Kitt Peak trimmed Gila monster biologically best corridor*

Jaguar, *Panthera onca*

Justification for Selection

Photo courtesy George Andrejko, AGFD

Jaguars are listed both as a federally endangered species without critical habitat, and as Wildlife Special Concern species by the state of Arizona. They have suffered from a loss of habitat and hunting by ranchers, and persistence in Arizona is contingent on habitat corridors which allow movement from source populations in Mexico (Arizona Game and Fish Department 2004).

Distribution

Jaguars have a limited range in Mexico, Guatemala, and Argentina, and are rare in the United States, Bolivia, Panama, Costa Rica, and Honduras, Peru, Colombia, and Venezuela (Seymour 1989). The largest known populations of jaguars exist in the Amazonian rainforest of Brazil. Within Arizona, they historically occurred in the southeastern part of the state, with several recorded sightings in central Arizona and as far north as the south rim of the Grand Canyon (Hoffmeister 1986).

Habitat Associations

Jaguars are adaptable to a variety of conditions, and are most often found in areas with sufficient prey, cover, and water supply (Seymour 1989). Within Arizona, habitat preferences are not clear; however, the species appears to prefer scrub and grasslands, evergreen forest, and conifer forest & woodlands (Hatten et al. 2003). It has been suggested that their apparent preference for grasslands may reflect movement corridors from the Sierra Madres of Mexico into southeast Arizona, rather than a preference for this habitat type (Hatten et al. 2003). Jaguars have a strong preference for water, and are often found within several kilometers of a water source such as perennial rivers or cienegas (Hatten et al. 2003; AZGFD 2004). They also appear to prefer intermediate to rugged terrain, and seem to be especially sensitive to human disturbance (Hatten et al. 2003; Menke & Hayes 2003).

Spatial Patterns

The home range of jaguars may vary from 10 to 170 km2, with smaller home ranges in rain forests, and larger home ranges recorded in open habitats (Arizona Game and Fish Department 2004). In Brazil, the average density of jaguars was approximately one animal per 25 km2, with one female ranging up to 38 km2, and one male ranging more than 90 km2 (Schaller & Crawshaw 1980).

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 60%, while elevation, topography, and distance from roads received weights of 5%, 15%, and 20%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum patch size for jaguar was defined as 41 km2 and minimum core size as 205 km2. 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. However, a biologically best corridor for this species was not included in the linkage design, due to its limited element occurrence data in the Comobabi wildland block. Habitat suitability and potential habitat patches were modeled due to known occurrences of jaguar near in the Baboquivari wildland block

Results and Discussion

Union of biologically best corridors – The linkage design captures mostly suboptimal but usable habitat (see *Figure 34* below) and is within a potential population core (see *Figure 35* below).

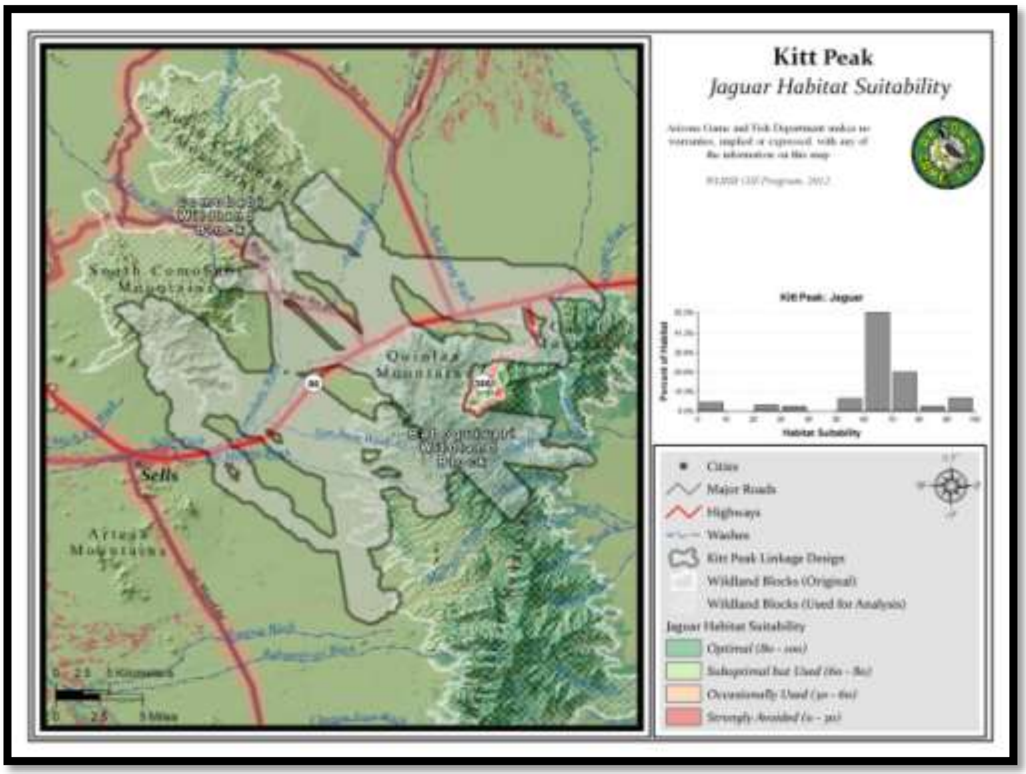

Figure 34: *Map of Kitt Peak modeled habitat suitability for jaguar*

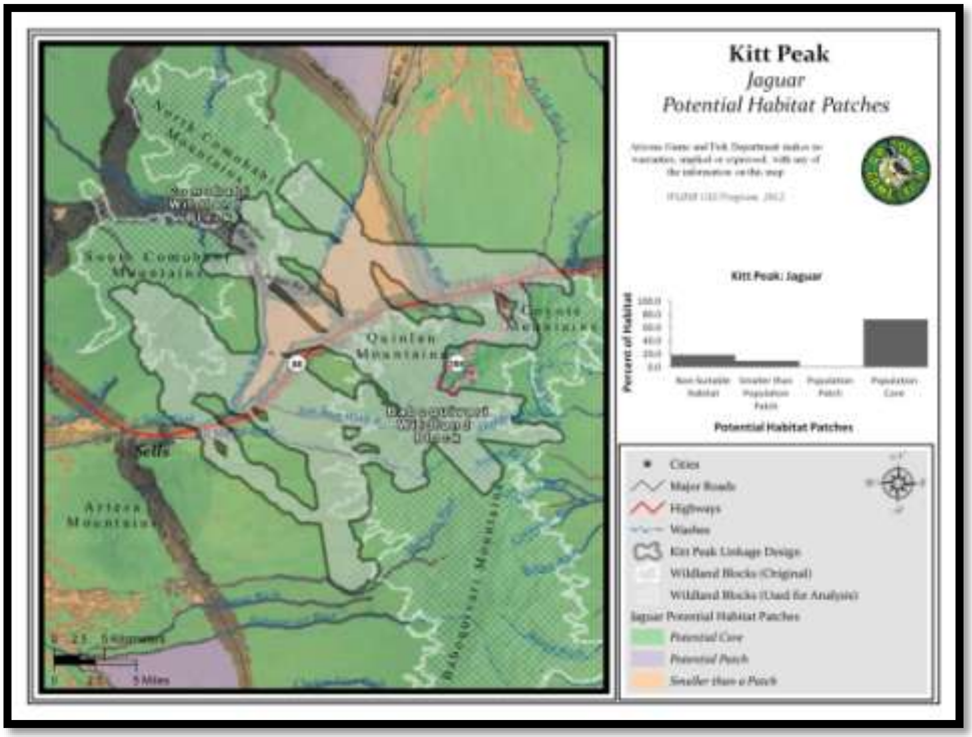

Figure 35: *Map of Kitt Peak potential habitat patches for jaguar*

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).

Photo courtesy George Andrejko, AGFD

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 Game and Fish 2002).

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size and 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. with the CorridorDesign Team). 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. Javelina were classified as a passage species based on known extensive movements of several kilometers (NatureServe 2005).

Results and Discussion

Initial biologically best corridor – Modeling results indicate mostly optimal habitat for javelina within the Kitt Peak BBC. Habitat suitability scores ranged from 0 to 100, with an average suitability of 98.3 (S.D: 5.5; see *Figure 36* below). The entire BBC is occupied by a potential population core (see *Figure 37* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 38* below). The BBC was measured at 24.4 km (15.2 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more optimal habitat for javelina.

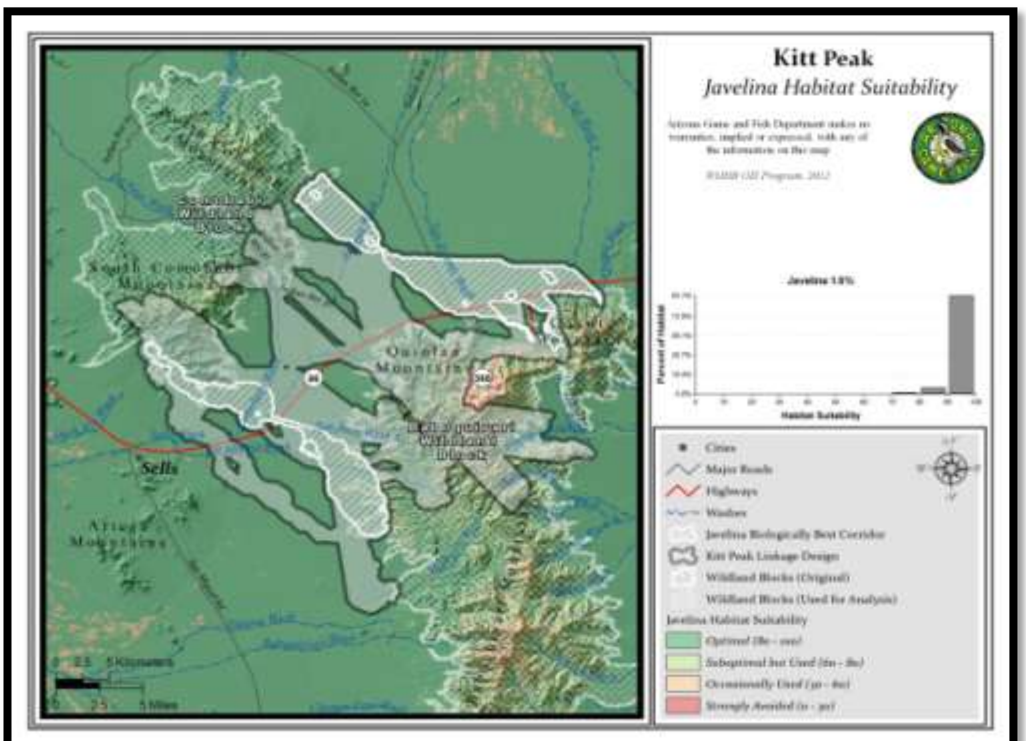

Figure 36: *Map of Kitt Peak modeled habitat suitability for javelina*

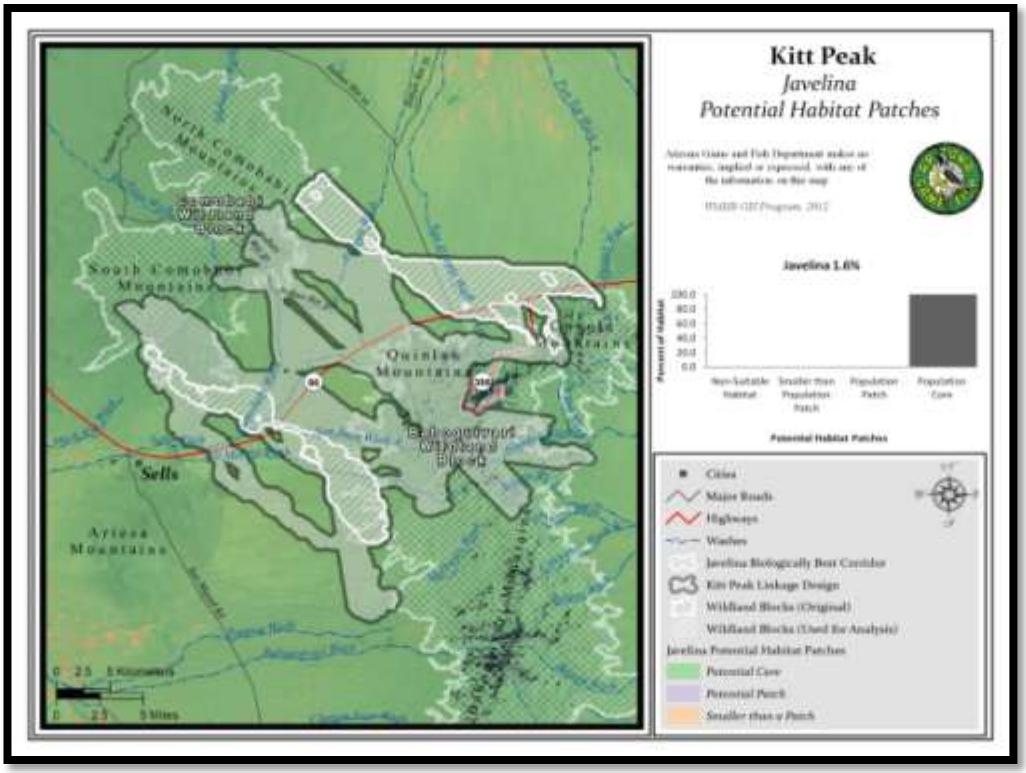

Figure 37: *Map of Kitt Peak potential habitat patches for javelina*

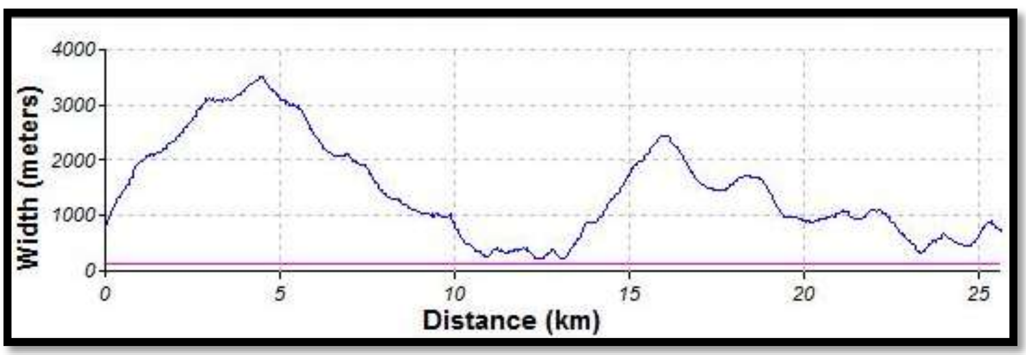

Figure 38: *Width along the Kitt Peak javelina biologically best corridor*

Kit Fox, *Vulpes macrotis*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution and Status

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model –Vegetation received an importance weight of 75%, while topography and distance from roads received weights of 15% and 10%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. However, a BBC for kit fox was not included, due to its length and suitable habitat for the species in the rest of the Kitt Peak linkage design.

Results and Discussion

Initial biologically best corridor – A BBC for kit fox was not included in the Kitt Peak linkage. This was due to the long distances the modeled BBC traveled, and the suitable habitat in other portions of the Kitt Peak linkage design for kit fox.

Union of biologically best corridors – As mentioned above, the linkage design captures considerably more optimal and suboptimal but used habitat (see *Figure 39* below), and potential population cores for kit fox (see *Figure 40* below).

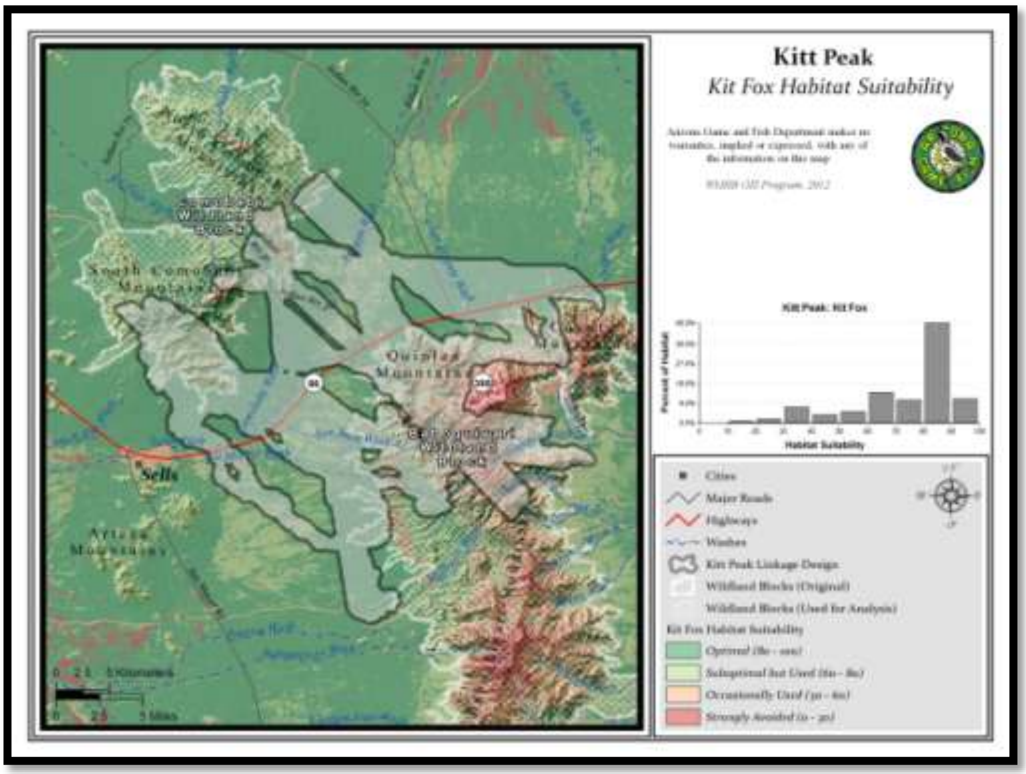

Figure 39: *Map of Kitt Peak modeled habitat suitability for kit fox*

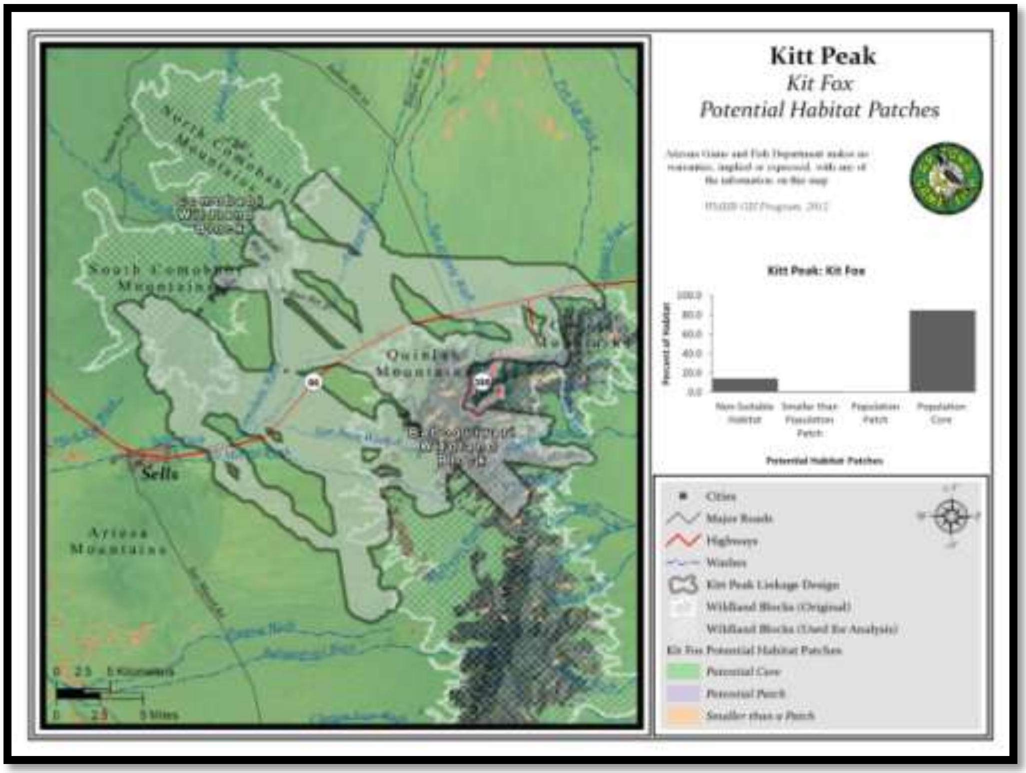

Figure 40: *Map of Kitt Peak potential habitat patches for kit fox*

Mountain Lion, *Puma concolor*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

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 Department of Game and Fish 2002). 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 Department of Game and Fish 2002). 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 and 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 and Sweanor 2001;

Dickson and 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. Mountain lion were classified as a passage species based on larger dispersal distances recorded by Logan and Sweanor (2001). The original biologically best corridor for this species was trimmed to eliminate "bubble" areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate a mix of habitat suitability for mountain lion throughout the Kitt Peak linkage, although some optimal and suboptimal but used habitat is present. Habitat suitability scores ranged from 20.8 to 100.0, with an average suitability of 70.4 (S.D: 21.6; see *Figure 41* below). The majority of the trimmed BBC, 58.4%, is within a potential population core, while 12.5% is occupied by suitable habitat smaller than a patch, and the rest occupied by less than suitable habitat (see *Figure 42* below). Most of the trimmed BBC (92.7%) was greater than its estimated needed minimum width (see *Figure 43* below). The trimmed corridor was measured at 25.2 km (15.7 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design offers some additional suboptimal but used, and occasionally used habitat for mountain lion.

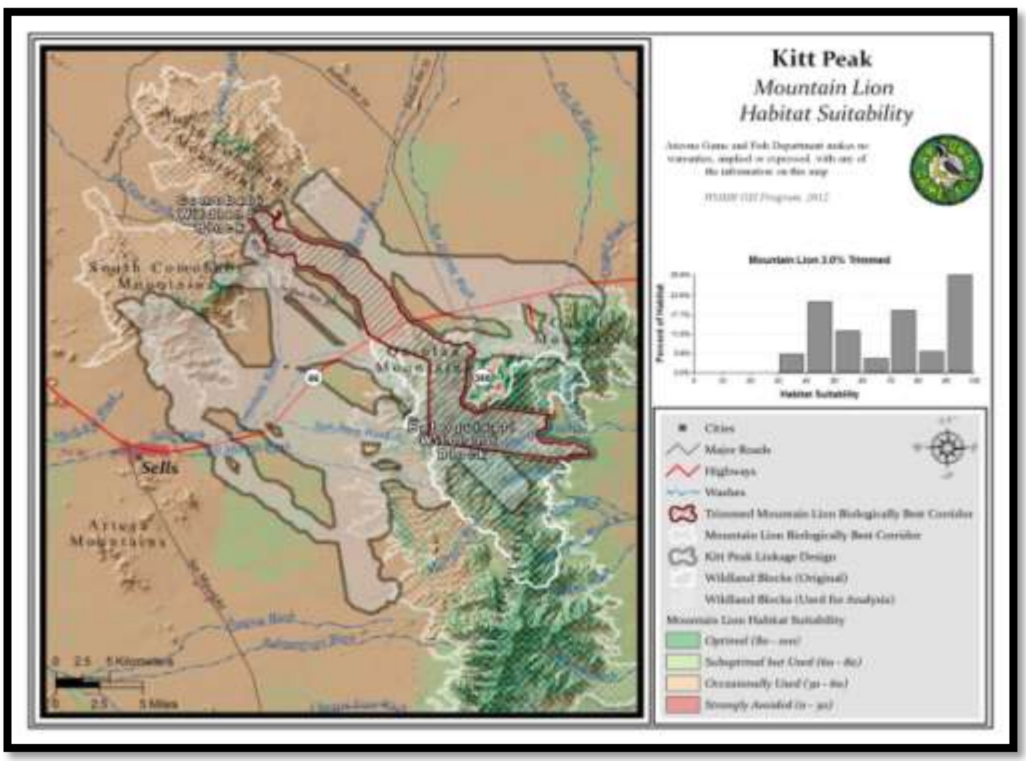

Figure 41: *Map of Kitt Peak modeled habitat suitability for mountain lion*

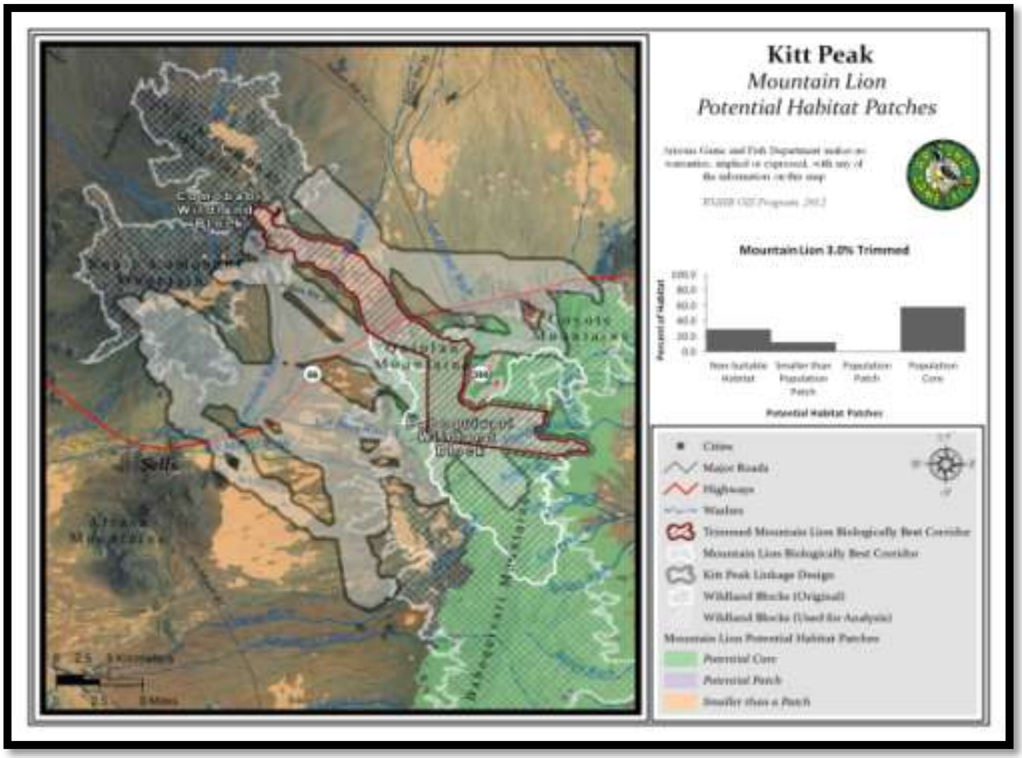

Figure 42: *Map of Kitt Peak potential habitat patches for mountain lion*

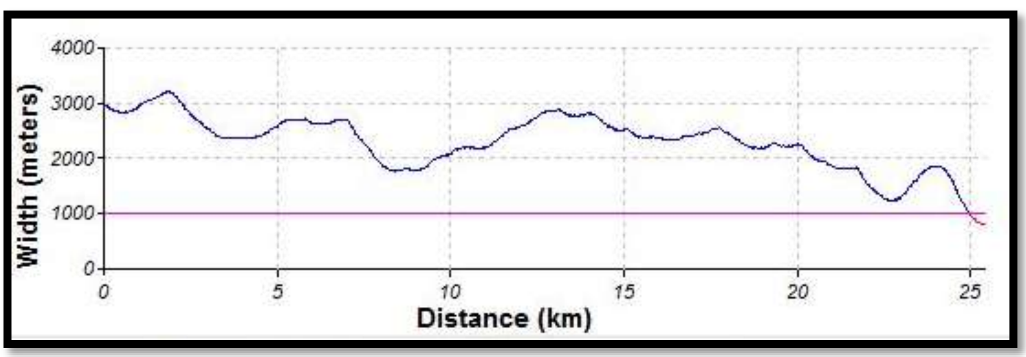

Figure 43: *Width along the Kitt Peak trimmed mountain lion biologically best corridor*

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 and Wallmo 1984). Road systems may affect the distribution and welfare of mule deer (Sullivan and Messmer 2003).

Photo courtesy George Andrejko, AGFD

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 and 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 and Wallmo 1984). Dispersal distances for male mule deer have been recorded from 97 to 217 km, and females have moved 180 km (Anderson and Wallmo 1984). Two desert mule deer yearlings were found to disperse 18.8 and 44.4 km (Scarbrough and 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. with CorridorDesign Team). 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 and 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. Mule deer were classified as a passage species based on larger dispersal distances recorded by Anderson and Wallmo (1984).

Results and Discussion

Initial biologically best corridor – Modeling results indicate mostly optimal and suboptimal but used habitat for mule deer within the Kitt Peak BBC. Habitat suitability scores ranged from 26.3 to 89.5, with an average suitability of 77.7 (S.D: 10.4; see *Figure 44* below). Almost the entire BBC (98.6%) is located within a potential population core (see *Figure 45* below). Most of the BBC (96.3%) was greater than its estimated needed minimum width (see *Figure 46* below). The corridor was measured at 25.2 km (15.7 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more optimal and suboptimal but used habitat for mule deer. The majority of public safety concerns along highways and major roads in this area most likely come from negative mule deer-vehicle interactions. It is important for both public safety and mule deer connectivity that road mitigation recommendations in this report be implemented.

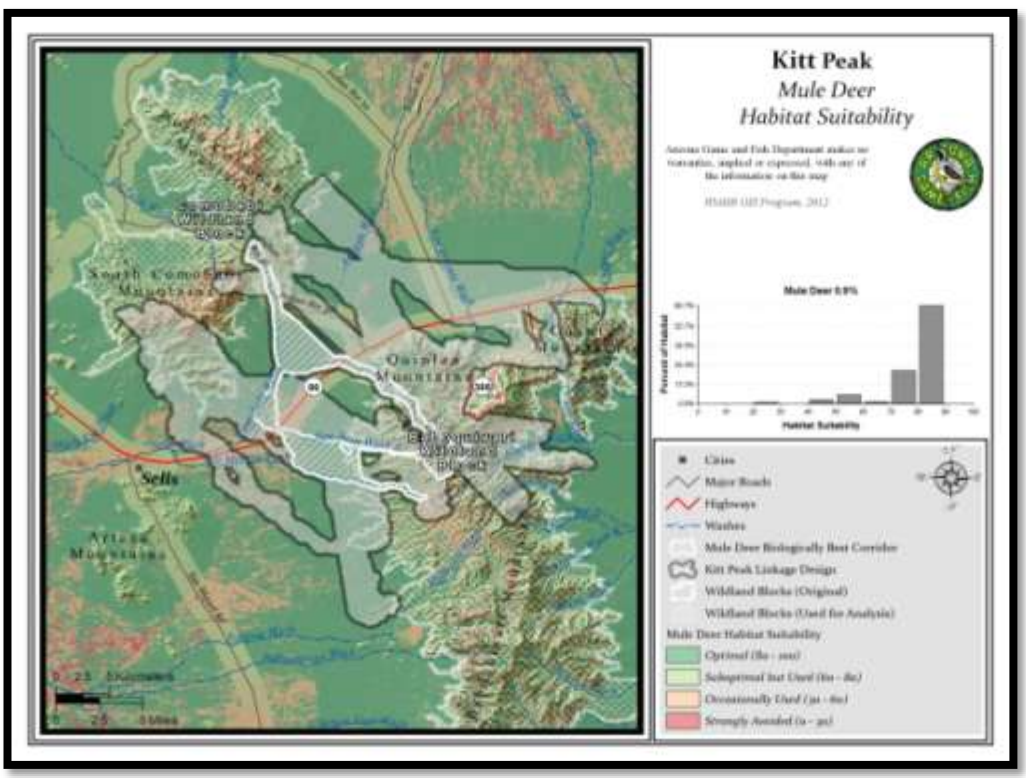

Figure 44: *Map of Kitt Peak modeled habitat suitability for mule deer*

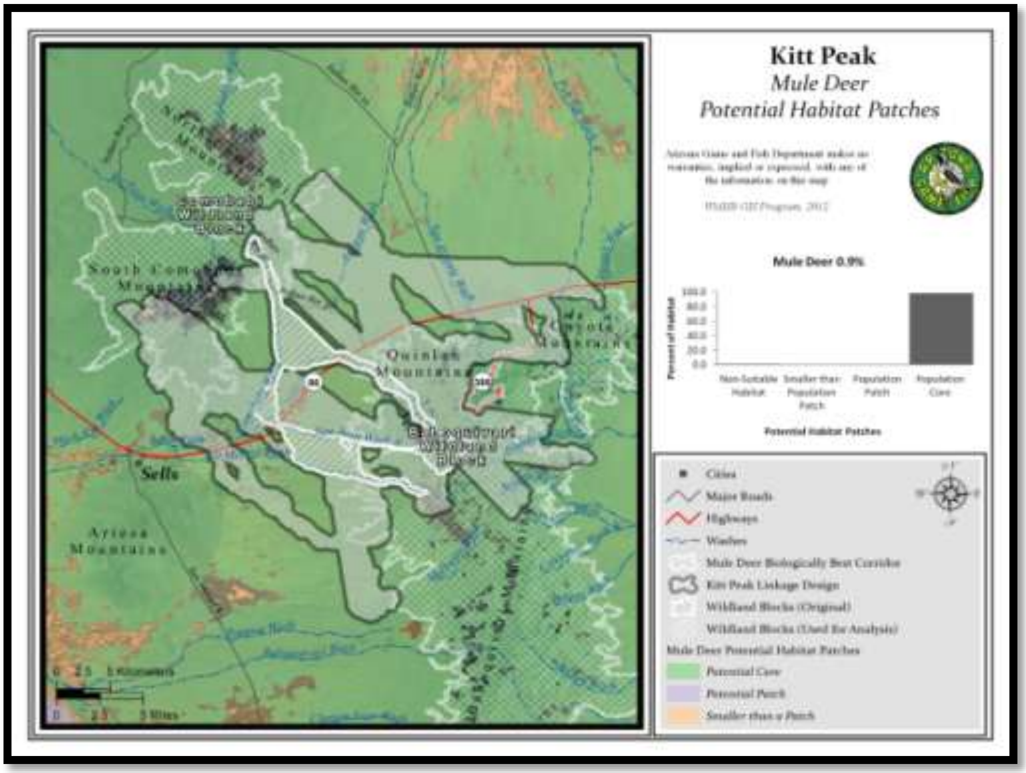

Figure 45: *Map of Kitt Peak potential habitat patches for mule deer*

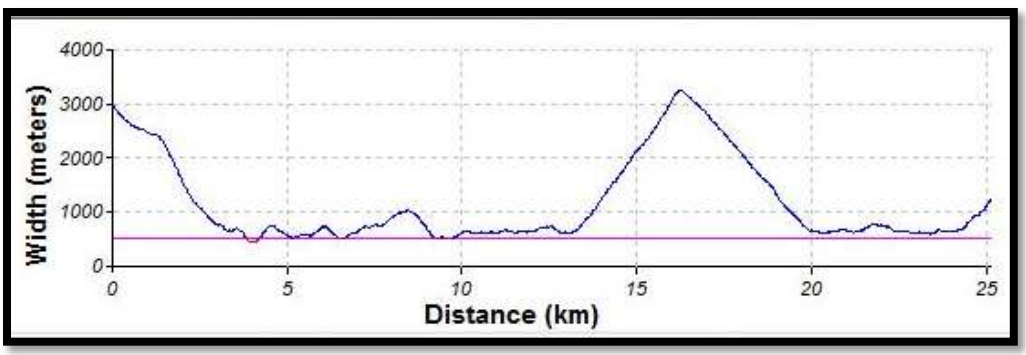

Figure 46: *Width along the Kitt Peak mule deer biologically best corridor*

Sonoran Desert Toad, *Incilius alvarius* (Formerly *Bufo alvarius*)

Justification for Selection

This species is thought to be potentially susceptible to extirpation or demographic impact from road mortality due to its large size, conspicuous activity, numerous observations of road-killed adults, presumed long natural lifespan, and apparent declines in road-rich urban zones (Phil Rosen, personal comm. with CorridorDesign Team).

Photo courtesy Randy Babb, AGFD

Distribution

Sonoran desert toads range from southeastern California to southwestern New Mexico (New Mexico Department of Game and Fish 2002).

Habitat Associations

Sonoran desert toads appear capable of occupying any vegetation type, from urbanized park to their maximum elevation. Roads can have a massive mortality impact and presumed population impact, but some populations live near roads that may be peripheral or marginal to the core habitat (P. Rosen, personal comm. with CorridorDesign Team). Breeding is naturally concentrated in canyons and upper bajada intermittent streams, and on valley floors in major pools, but not naturally frequent on intervening bajadas. With stock ponds, breeding can occur anywhere on the landscape, but valley centers and canyons likely remain as the core areas (P. Rosen, personal comm. with CorridorDesign Team).

Spatial Patterns

Little is known about spatial patterns for this species. Rosen (personal comm. with CorridorDesign Team) estimates the smallest area of suitable habitat necessary to support a breeding group for 1 breeding season to be 25 ha, based on limited knowledge of movements and smallest occupied patches in Tucson. Based on unpublished data by Cornejo, adults appear to be highly mobile, and long distance movements (5 km to be conservative) seem likely (P. Rosen, personal comm. with CorridorDesign Team).

Conceptual Basis for Model Development

Habitat suitability model –Vegetation received an importance weight of 5%, while elevation, topography, and distance from roads received weights of 50%, 25%, and 20%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha (Rosen and Mauz 2001; Phil Rosen, personal comm. with CorridorDesign Team).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. Although adults appear to be highly mobile, and long distance movements of 5 km seem likely (P. Rosen, personal comm. with CorridorDesign Team), Sonoran desert toad were classified as a corridor dweller based on longer distances required to move between wildland blocks in both linkage strands. The original biologically best corridor for this species was trimmed to eliminate "bubble" areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate mostly optimal habitat for Sonoran desert toad within the trimmed BBC used in the Kitt Peak linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 96.6 (S.D: 11.1; see *Figure 47* below). Almost the entire trimmed BBC (99.2%) is located within a potential population core (see *Figure 48* below). Most of the BBC (89.6%) was greater than its estimated needed minimum width (see *Figure 49* below). The corridor was measured at 32.2 km (20.0 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more suitable habitat for Sonoran desert toad, most of which is optimal.

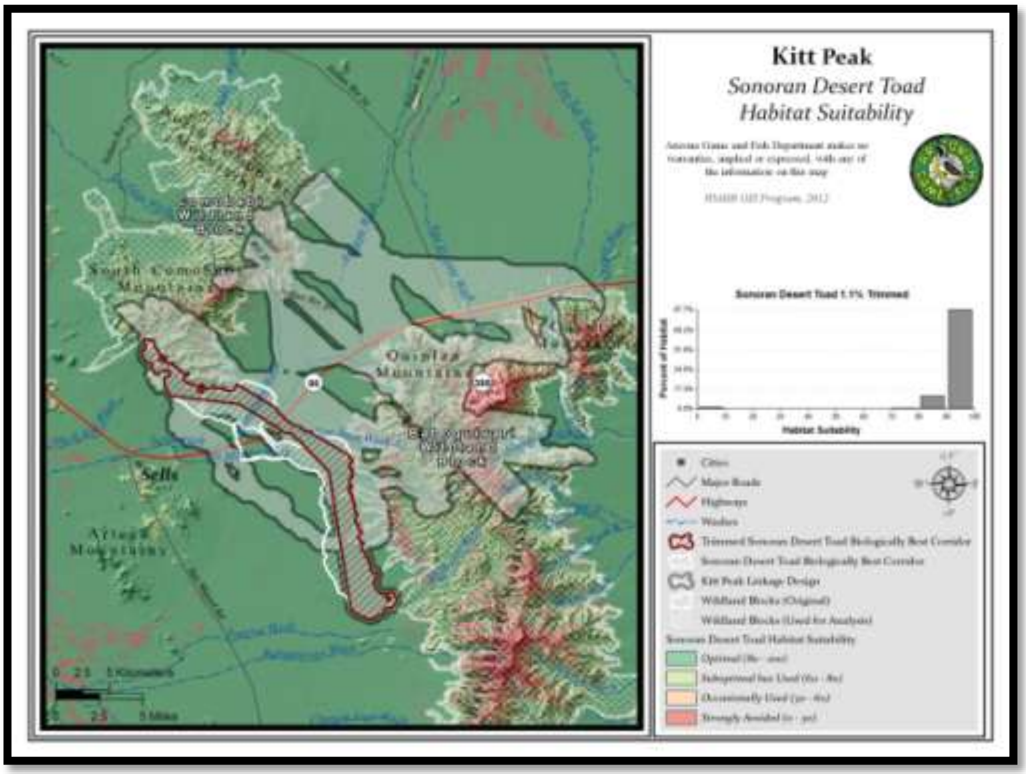

Figure 47*: Map of Kitt Peak modeled habitat suitability for Sonoran desert toad*

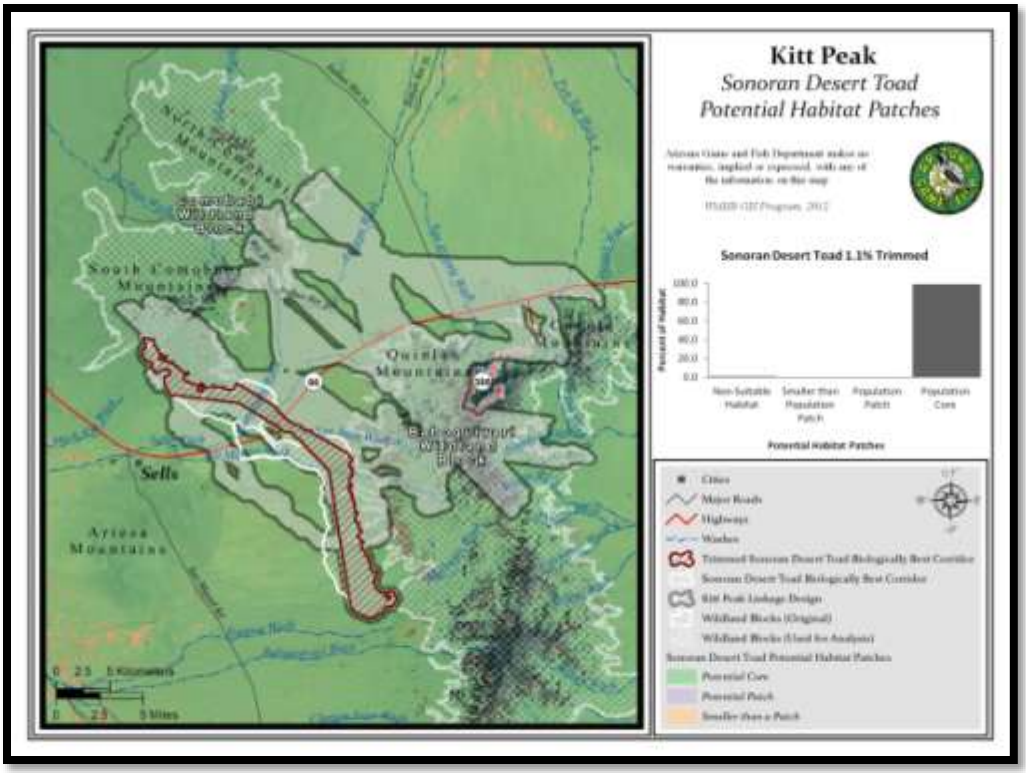

Figure 48: *Map of Coyote – Ironwood potential habitat patches and cores for Sonoran desert toad*

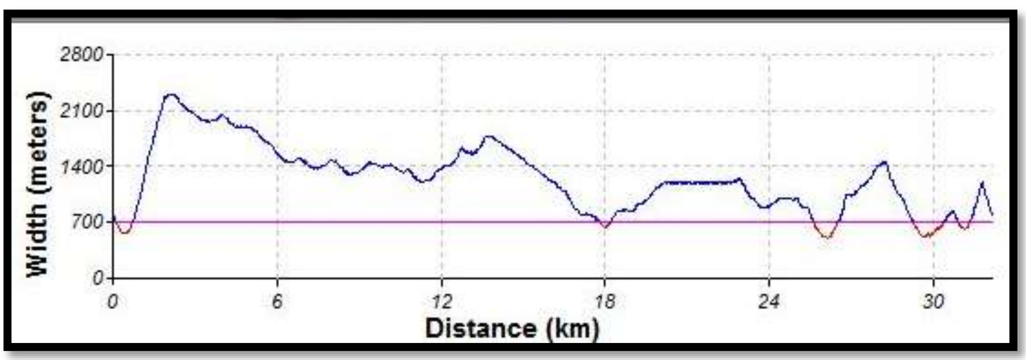

Figure 49: *Width along the Kitt Peak Sonoran desert toad trimmed biologically best corridor*

Sonoran Desert Tortoise, *Gopherus morafkai* (Formerly *Gopherus agassizii*)

Justification for Selection

The Mojave desert tortoise is listed as Threatened by the Fish and Wildlife Service, and the Sonoran desert tortoise was listed as a Candidate species on December 14, 2010 (FR75No239). Both desert tortoise species are vulnerable to habitat fragmentation, and need connectivity to maintain genetic diversity. Their ability to survive may be limited because of the potential for adult road-kill mortality (Edwards et al. 2003).

Photo courtesy Audrey Owens, AGFD

Distribution

Desert tortoises are found in deserts throughout California, southeastern Nevada, southwestern Utah, and Arizona. Although once referred to as separate populations of the same species (*Gopherus agassizii*), desert tortoises have now been recognized as two distinct species: the Mojave desert tortoise (*Gopherus agassizii*), which occurs north and west of the Colorado River, and the Sonoran desert tortoise (*Gopherus morafkai*), which occurs south and east of the Colorado River. Murphy et al. (2011), referred to these species with the common names Agassiz's desert tortoise (Mojave desert tortoise), and Morafka's desert tortoise (Sonoran desert tortoise), though AGFD currently does not utilize these common names. Sonoran desert tortoises occur in Pima, Pinal, Yavapai, Mohave, La Paz, Graham, Santa Cruz, Maricopa, Gila, and Yuma Counties within Arizona.

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) and bajadas. Zylstra and Steidl (2008) found that tortoises occupied east-facing slopes, and are less likely to occupy north facing slopes. However, AGFD unpublished data has found juveniles mostly on north-facing slopes, and adults on west-facing slopes. Desert tortoises also use burrows excavated into hardened caliche along incised washes (Averill-Murray et al. 2002a). 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 annual and perennial plants. Diets of Sonoran desert tortoises vary among populations in response to seasonal availability of plan species and in response to precipitation amounts (Martin and van Devender 2002). They have even been observed consuming dried plant materials during periods of drought (Averill-Murray et al. 2002b). Optimal habitat is within Arizona Upland Sonoran desert scrub and Move desert scrub, between elevations of 900 and 4,200 feet. However, there have been populations observed in an oak woodland forest at 5,200 feet in the Rincon, Atascosa and Pajarito mountains (van Devender 2002, U.S. Fish and Wildlife Service 2010a), and one in the ponderosa pine dominated coniferous community in the Rincon Mountains at 7,808 feet (Aslan et al. 2003).

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. 2002b). Density of tortoise populations can range from 20 to upwards of 150 individuals per square mile (from 23 Sonoran Desert populations, Averill-Murray et al. 2002b). Desert tortoises are a long-lived species, with estimates of longevity between 60 and 100 years, and a generation time of 12 to 15 years (U.S. Fish and Wildlife Service 2010a). While long-distance movements of desert tortoises appear uncommon, but a few have been observed and are likely important for the long-term viability of populations (Edwards et al. 2004). Desert tortoises may move more than 30km during long-distance movements (Barrett et al. 1990; Averill-Murray and Klug 2000; Edwards 2003).

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 and configuration analysis – Minimum potential habitat patch size was defined as 15 ha, and minimum potential core size was defined as 50 ha (Rosen and Mauz 2001, Phil Rosen, personal comm.. with CorridorDesign Team).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. Although long distance movements have been observed and are important for the species (Edwards et al. 2004), Sonoran desert tortoise were classified as a corridor dweller based on small home range sizes and limited mobility.

Results and Discussion

Initial biologically best corridor – Modeling results indicate mostly suboptimal but used habitat for Sonoran desert tortoise within the Kitt Peak linkage BBC. Habitat suitability scores ranged from 0 to 100, with an average suitability of 71.9 (S.D: 19.0; see *Figure 50* below). Most of the BBC (81.2%) is located within a potential population core, with a small portion (0.9%) within a potential habitat patch and suitable habitat smaller than a patch (0.4%), with the remainder being non-suitable habitat (see *Figure 51* below). Most of the trimmed BBC (93.1%) was greater than its estimated needed minimum width (see *Figure 52* below). The corridor was measured at 25.9 km (16.1 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more suboptimal but used habitat, and occasionally used habitat for Sonoran desert tortoise.

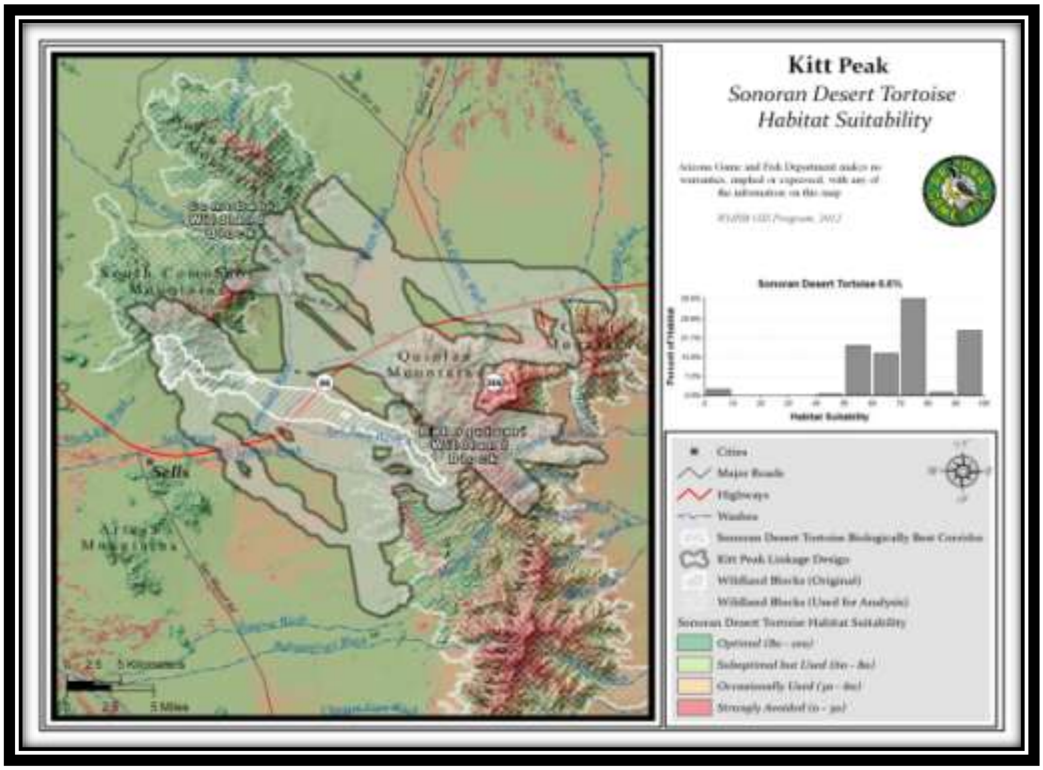

Figure 50: Map of Kitt Peak modeled habitat suitability for Sonoran desert tortoise

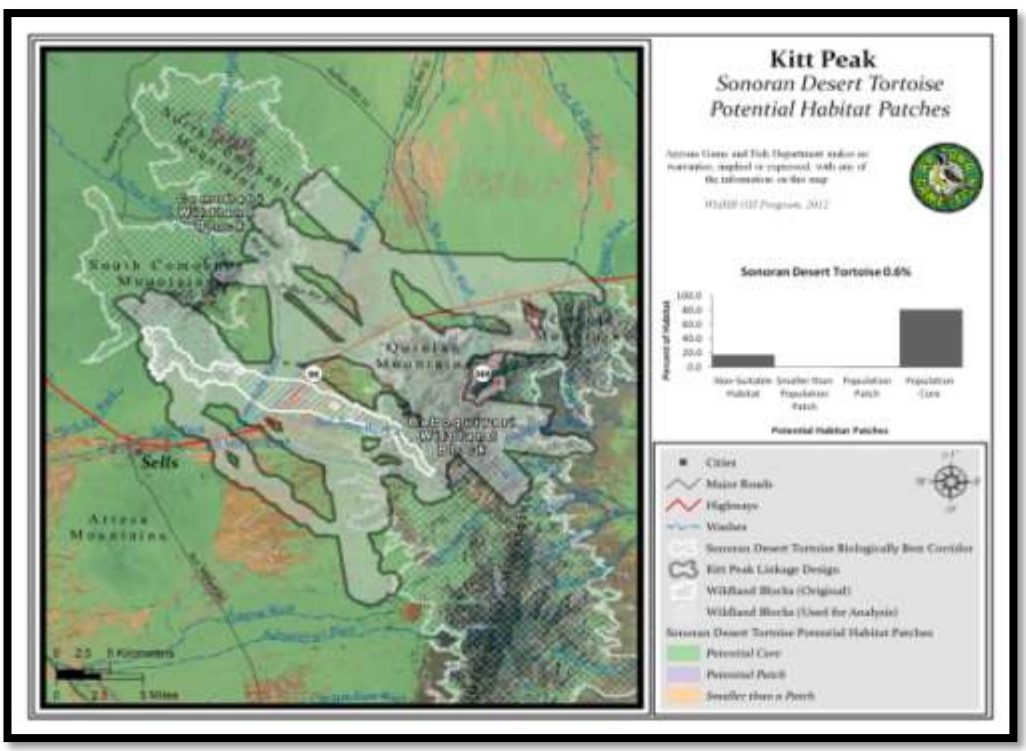

***Figure 51:** Map of Kitt Peak potential habitat patches for Sonoran desert tortoise*

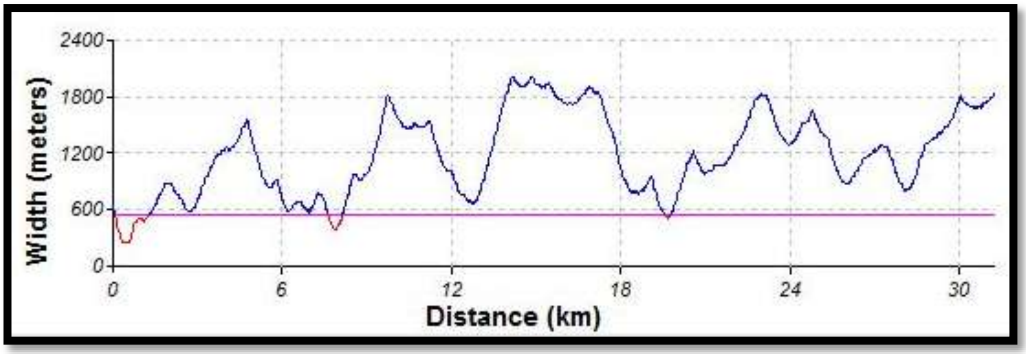

Figure 52: *Width along the Kitt Peak Sonoran desert tortoise biologically best corridor*

Sonoran Whipsnake, *Masticophis bilineatus*

Justification for Selection

Wide-ranging, active, diurnal snakes including whipsnakes and racers are usually observed to disappear when urban road networks become dense, and the assumption is that road mortality plays a large role (Phil Rosen, personal comm. with CorridorDesign Team).

Photo courtesy Randy Babb, AGFD

Distribution

The Sonoran whipsnake is mainly found in the Sonoran desert of Mexico, but also occurs within southern Arizona and New Mexico.

Habitat Associations

This species tends to prefer areas with rugged topography, and will also use mid-to-high elevation riparian flats. This species is mobile, may occur along or move along desert and grassland washes, and thus might occasionally traverse areas of flat non-habitat between mountains, like some other larger reptiles. Preferred land cover types include Encinal, Pine-Oak Forest, Pinyon-Juniper Woodland, Chaparral, Creosotebush - Mixed Desert and Thorn Scrub, and Paloverde-Mixed-Cacti Desert Scrub.

Spatial Patterns

Home range has been estimated as 50 ha for this species (Parizek et al. 1995). Little is known about dispersal distance, but a telemetry study found one large male to move up to 1 km per day (Parizek et al. 1995). Based on observations of other whipsnakes, movement events of up to 4.5 km may be feasible (Phil Rosen, personal comm. with CorridorDesign Team).

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 10%, 45%, and 15%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 50 ha, and minimum potential core size was defined as 250 ha (Phil Rosen, personal comm. with CorridorDesign Team). 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. Sonoran whipsnake were classified as a corridor dweller based on assumed distance of movement events (Phil Rosen, personal comm. with CorridorDesign Team) and length between wildland blocks. The original biologically best corridor for this species was trimmed to eliminate “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate a variety of habitats within the linkage design for Sonoran whipsnake. Habitat suitability scores ranged from 39.9 to 100, with an average suitability of 86.2 (S.D: 18.0; see *Figure 53* below). Mostof the trimmed BBC (79.3%) is located within a potential population core, with a small portion (0.2%) occupying suitable habitat smaller than a patch, and the remainder within non-suitable habitat (see *Figure 54* below). Most of the trimmed BBC (84.2%) was greater than its estimated needed minimum width (see *Figure 55* below). The trimmed corridor was measured at 24.1 km (15.0 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures considerably more optimal, suboptimal but used, and occasionally used habitat for Sonoran whipsnake.

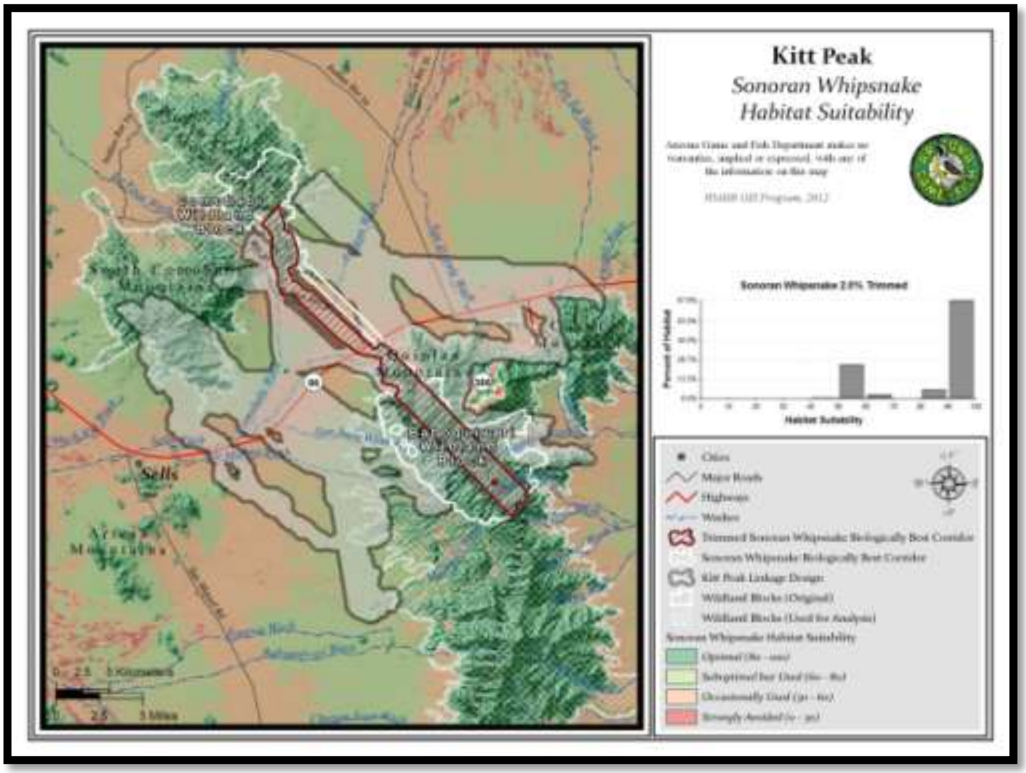

Figure 53: *Map of Kitt Peak modeled habitat suitability for Sonoran whipsnake*

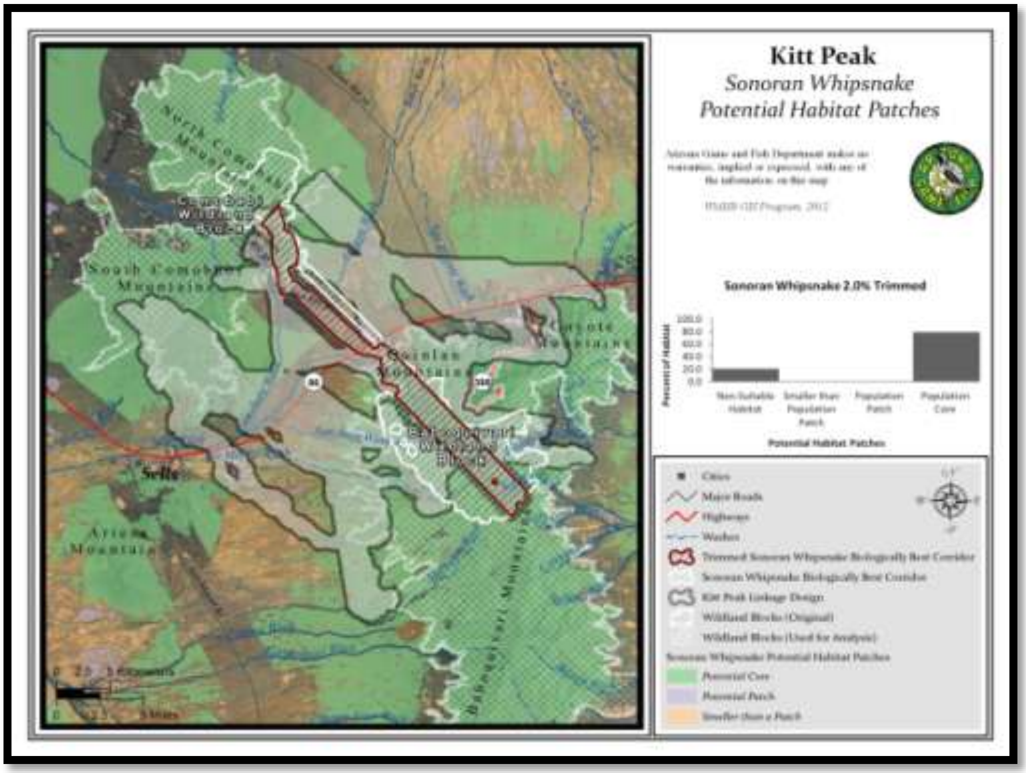

Figure 54: *Map of Kitt Peak potential habitat patches for Sonoran whipsnake*

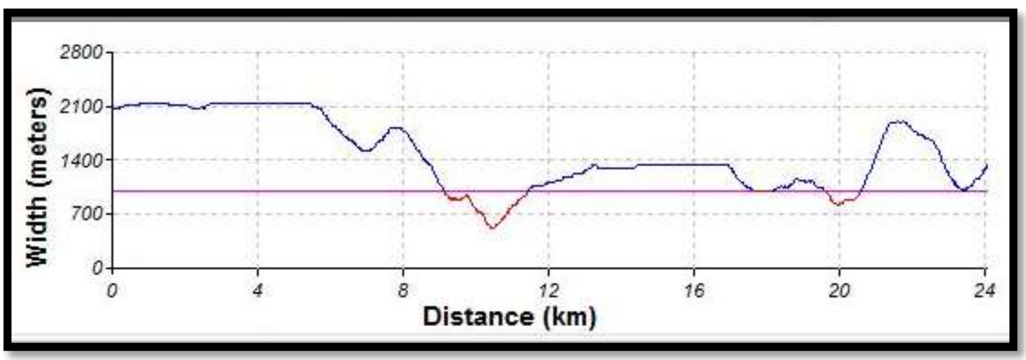

Figure 55: *Width along the Kitt Peak trimmed Sonoran whipsnake biologically best corridor*

Appendix D: HDMS Element Occurrence

The following table represents Heritage Data Management System (HDMS) element occurrence data within the linkage design. This element occurrence data represents observations which are of a reproductive significance to the species, and thus indicate biologically important observations which are crucial for management decisions. (Key: ESA = Federal Endangered Species Act, USFS = US Forest Service, BLM = US Bureau of Land Management, State = Arizona Game and Fish Department, SC = Species of Concern, LT = Listed as threatened, S = Sensitive, WSC = Wildlife Species of Concern, SR = Salvage restricted, collection only with permit. CorridorDesign species are those species previously modeled by the CorridorDesign Team of Northern Arizona University in Arizona Missing Linkages reports. SDCP species are those considered priority vulnerable, or federally listed as threatened and endangered and included in Pima County's Sonoran Desert Conservation Plan).

Table 6: *HDMS Species Occurrence in the Kitt Peak linkage design*

Taxonomic Group	Common Name	Scientific Name	FWS	USFS	BLM	STATE	Corridor Design	SDCP
Amphibian	Sonoran Green Toad	*Anaxyrus retiformis*			S			
Bird	Crested Caracara	*Caracara cheriway*				WSC		
Bird	Harris's Hawk	*Parabuteo unicinctus*						
Invertebrate	Baboquivari Talussnail	*Sonorella baboquivariensis*						Yes
Plant	Arid Throne Fleabane	*Erigeron arisolius*		S				
Plant	Arizona Passionflower	*Passiflora arizonica*		S				
Plant	Baboquivari Giant Hyssop	*Agastache rupestris*						
Plant	Lemmon's Lupine	*Lupinus lemmonii*		S				
Plant	Lemmon's Stevia	*Stevia lemmonii*		S				
Plant	Lobed Fleabane	*Erigeron lobatus*						
Plant	Thornber Fishhook Cactus	*Mammillaria thornberi*				SR		
Plant	Wiggins Milkweed Vine	*Metastelma mexicanum*	SC	S				
Reptile	Giant Spotted Whiptail	*Aspidoscelis burti stictogrammus*	SC	S			Yes	Yes
Reptile	Sonoran Desert Tortoise	*Gopherus agassizii* (Sonoran Population)	C	S		WSC	Yes	
Reptile	Northern Green Ratsnake	*Senticolis triaspis intermedia*		S				
Reptile	Saddled Leaf-nosed Snake	*Phyllorhynchus browni*		PS				

Appendix E: Creation of Linkage Design

To create the final Linkage Design, we combined biologically best corridors for all focal species modeled, and made several adjustments to the union of biologically best corridors (see *Figure 56* below):

- We trimmed biologically best corridors with "bubble areas" created from widening the strands to meet width requirements over 90% of the corridor where possible. Some corridor dwellers were slightly below the ideal width kept along 90% of the corridor. This was due to certain habitat limitations that did not increase bottlenecks. Trimming biologically best corridors had little effect on the mean habitat suitability located within each corridor.
- We buffered the union of biologically best corridors 300m to remove modeling relicts and edge effects based on recommendations from Majka et al. (2007).
- We widened the buffered union of biologically best corridors to meet the 1km minimum width requirement throughout the linkage design. This was done using natural lands adjacent to the linkage design.

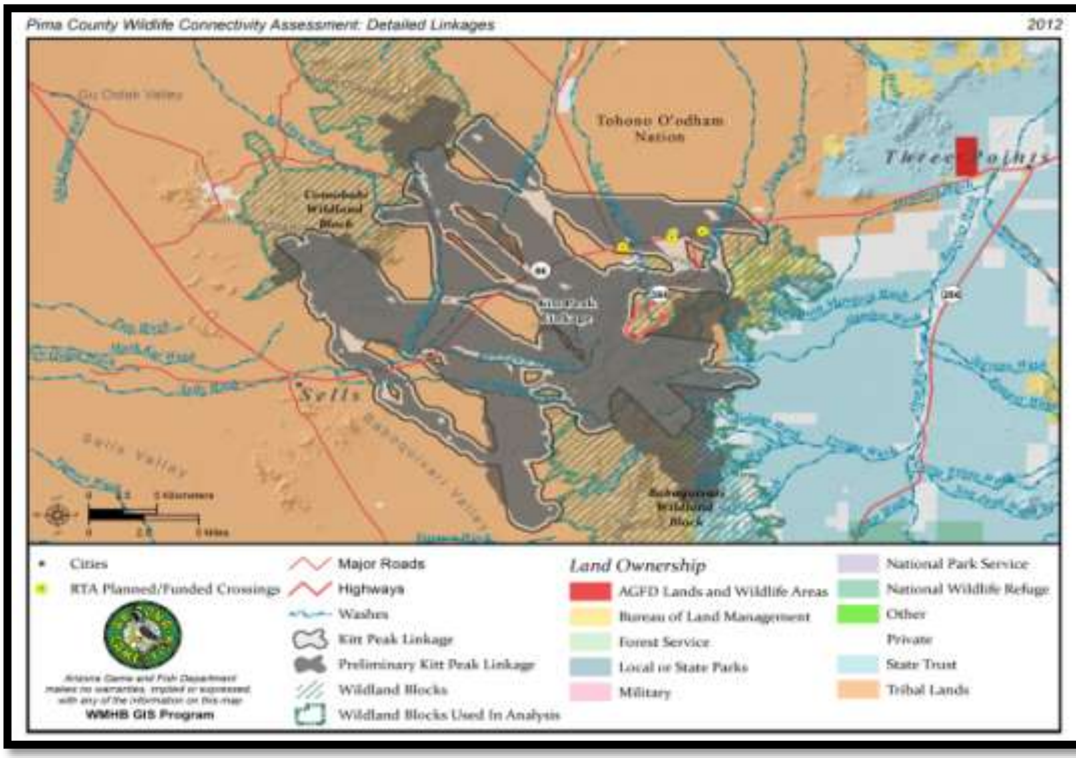

Figure 56: *Progression of the Kitt Peak linkage design*

Appendix F: Update and Description of Land Cover

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).

As mentioned in the Linkage Design Methods (Appendix A), ReGAP was originally classified in 2001 using imagery from previous years. However, significant development had occurred throughout the State since that time. Since development can impact wildlife by fragmenting habitat, and is a major category in ReGAP driving these corridor models, using this dataset for analysis without addressing this issue would have ignored the impact of development in our linkage design. In order to properly address recent levels of development, private lands where development is most likely to occur, previously categorized as non-developed in ReGAP were examined. Areas with development present were digitized and categorized according to ReGAP as Developed, Open Space – Low Intensity, or Developed, Open Space – High Intensity based on ReGAP descriptions (see below). These areas were then appended to the land cover raster used in the analysis. Since the majority of this linkage design is outside private lands, and within the Tohono O'odham Nation, no significant updating of the land cover took place.

What follows is a description of each class found in the linkage area, taken largely from the document, Landcover Descriptions for the Southwest Regional GAP Analysis Project (Available from http://earth.gis.usu.edu/swgap)

EVERGREEN FOREST (3 CLASSES) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Encinal (Oak Woodland) – Encinal occurs on foothills, canyons, bajadas and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, extending north into Trans-Pecos Texas, southern New Mexico and sub-Mogollon Arizona. These woodlands are dominated by Madrean evergreen oaks along a low-slope transition below Madrean Pine-Oak Forest and Woodland (CES305.796) and Madrean Pinyon-Juniper Woodland (CES305.797). Lower elevation stands are typically open woodlands or savannas where they transition into desert grasslands, chaparral or in some cases desertscrub. Common evergreen oak species include *Quercus arizonica*, *Quercus emoryi*, *Quercus intricata*, *Quercus grisea*, *Quercus oblongifolia*, *Quercus toumeyi*, and in Mexico *Quercus chihuahuensis* and *Quercus albocincta*. Madrean pine, Arizona cypress, pinyon and juniper trees may be present, but do not codominate. Chaparral species such as *Arctostaphylos pungens*, *Cercocarpus montanus*, *Purshia spp*., *Garrya wrightii*, *Quercus turbinella*, *Frangula betulifolia* (= *Rhamnus betulifolia*), or *Rhus spp*. may be present but do not dominate. The graminoid layer is usually prominent between trees in grassland or steppe that is dominated by warm-season grasses such as *Aristida spp*., *Bouteloua gracilis*, *Bouteloua curtipendula*, *Bouteloua rothrockii*, *Digitaria californica*, *Eragrostis intermedia*, *Hilaria belangeri*, *Leptochloa dubia*, *Muhlenbergia spp*., *Pleuraphis jamesii*, or *Schizachyrium cirratum*, species typical of Chihuahuan Piedmont Semi-Desert Grassland (CES302.735). This system includes seral stands dominated by shrubby Madrean oaks typically with a strong graminoid layer. In transition areas with drier chaparral systems, stands of chaparral are not dominated by Madrean oaks, however, Madrean Encinal may extend down along drainages.

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.

GRASSLANDS-HERBACEOUS (1 CLASS) – Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation.

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 (6 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 – Mixed Desert and Thorn Scrub – This cover type includes xeric creosotebush basins and plains and the mixed desert scrub in the foothill transition zone above, sometimes extending up to the lower montane woodlands. Vegetation is characterized by *Larrea tridentata* alone or mixed with thornscrub and other desert scrub such as *Agave lechuguilla*, *Aloysia wrightii*, *Fouquieria splendens*, *Dasylirion leiophyllum*, *Flourensia cernua*, *Leucophyllum minus*, *Mimosa aculeaticarpa var. biuncifera*, *Mortonia scabrella* (= *Mortonia sempervirens ssp. scabrella*), *Opuntia engelmannii*, *Parthenium incanum*, *Prosopis glandulosa*, and *Tiquilia greggii*. Stands of *Acacia constricta Acacia neovernicosa* or *Acacia greggii* dominated thornscrub are included in this system, and limestone substrates appear important for at least these species. Grasses such as *Dasyochloa pulchella*, *Bouteloua curtipendula*, *Bouteloua eriopoda*, *Bouteloua ramosa*, *Muhlenbergia porteri* and *Pleuraphis mutica* may be common, but generally have lower cover than shrubs.

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.

Bedrock Cliff and Outcrop – This ecological system is found from subalpine to foothill elevations and includes barren and sparsely vegetated landscapes (generally <10% plant cover) of steep cliff faces, narrow canyons, and smaller rock outcrops of various igneous, sedimentary, and metamorphic bedrock types. Also included are unstable scree and talus slopes that typically occur bellow cliff faces. Species present are diverse and may include *Bursera microphylla*, *Fouquieria splendens*, *Nolina bigelovii*, *Opuntia bigelovii*, and other desert species, especially succulents. Lichens are predominant lifeforms in some areas. May include a variety of desert shrublands less than 2 ha (5 acres) in size from adjacent areas.

Wash

Appendix G: Literature Cited

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Appendix H: Data Requests

To obtain a copy of the GIS data or field investigation photographs for use in your local planning efforts please contact the Habitat Program at AGFD's Tucson regional office at (520) 628-5376 or the Department's GIS Program at gis@azgfd.gov.

Additional tools are available from AGFD to help planners identify wildlife resources in a project planning area. These tools include the *Species and Habitat Conservation Guide* (SHCG), a model depicting areas of wildlife conservation potential, and *HabiMap™ Arizona*, an online data viewing platform that serves as an exploration tool for AGFD's wildlife datasets. Site-specific reports on wildlife species of concern and federally-listed threatened and endangered species are available through the *Online Environmental Review Tool*. All of these tools, along with additional resources such as helpful guidelines documents, can be accessed on AGFD's "Planning for Wildlife" web page at http://www.azgfd.gov/WildlifePlanning.

For a more in depth description of GIS wildlife corridor modeling approaches and to download ArcGIS modeling tools developed by scientists at Northern Arizona University please see the CorridorDesign website at http://corridordesign.org. Here you will also find a number of completed Arizona Missing Linkage designs (2007 – 2008) produced by the CorridorDesign team through funding provided by the Arizona Game and Fish Department's Heritage Fund.