

# August 2012

**Pima County Wildlife Connectivity Assessment: Detailed Linkages**

**Coyote - Ironwood - Tucson Linkage Design**



*Looking towards Ironwood Forest National Monument from Tucson Mountain Park*

Arizona Game and Fish Department

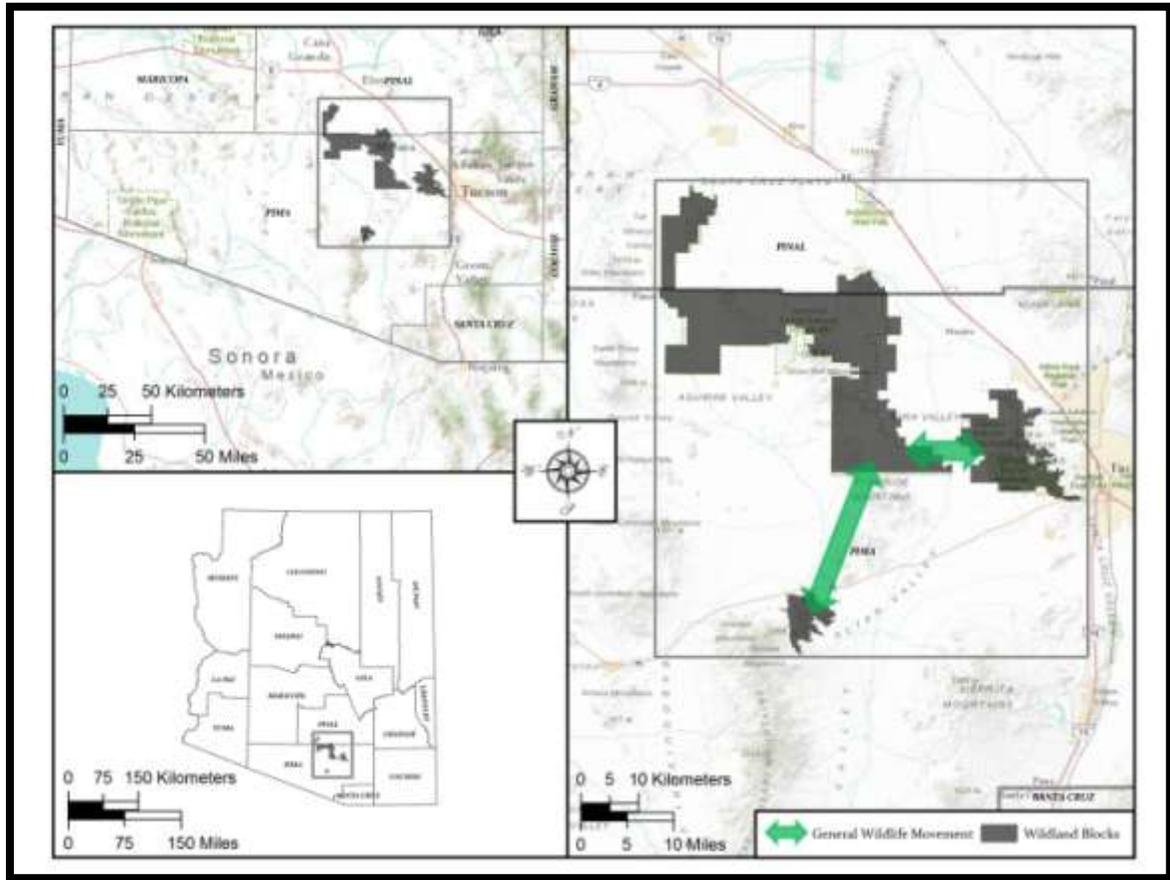


Regional Transportation Authority of  
Pima County



# Coyote - Ironwood - Tucson

## Linkage Design



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*Arizona Wildlife Linkages 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 three protected wildland blocks west of Tucson in Pima County, Arizona: the Coyote Mountains (Coyote), Ironwood Forest (Ironwood), and the Tucson Mountains (Tucson). These areas represent a large public investment in biological diversity, and the linkage design presented in this report works to maintain and increase the value of that investment. The linkage design is composed of two linkages for movement and reproduction of wildlife – one linkage between the Coyote Mountains and Ironwood Forest (Coyote – Ironwood), and another linkage between Ironwood Forest and the Tucson Mountains (Ironwood – Tucson) (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*<sup>TM</sup>. 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 Coyote, Ironwood, and Tucson 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 visited focus areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for many of these barriers in the section titled Linkage Design and Recommendations.

Both the Ironwood-Tucson and Coyote-Ironwood linkage strands contain many obstacles to wildlife movement. An animal moving east from Ironwood Forest National Monument towards the Tucson Mountains may encounter chain-link fences, major roads, urban developments, and the Central Arizona Project canal. Wildlife-vehicle collisions frequently occur along State Route 86 and demonstrate the difficulty for wildlife to move from the Coyote Mountains through the Roskrige Mountains and into Ironwood Forest. Border infrastructure and border-related activities may also be a barrier to wildlife movement between the Coyote and Ironwood wildland blocks. In addition to these barriers, the invasive buffelgrass threatens to bring fire to the entire Sonoran Desert ecosystem within the linkage design and surrounding areas.

Various enhancements would increase permeability of this area to wildlife. Retrofitting existing road structures to increase permeability to wildlife, the construction of new wildlife crossings structures, and fencing modifications to "wildlife-friendly" specifications, can improve the utility of the linkage design. Effective land-use planning, that incorporates the needs of wildlife, is also important to keep suitable habitat between wildland blocks, and on either side of road and canal crossing structures. Habitat restoration efforts that target the removal of invasive species, would work to conserve the integrity of the areas ecosystem and its high biodiversity. Border policies and infrastructure that address undocumented immigration and illegal activities, without sacrificing the needs of wildlife, would also increase wildlife connectivity.

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 Coyote Mountains, Ironwood Forest, and Tucson Mountains. This linkage design presents a vision that would maintain large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments by the Bureau of Land Management, National Park Service, Pima County and other conservation lands. The needs of wildlife must be accommodated through thoughtful land-use and transportation planning, so negative wildlife-vehicle interactions can be reduced, and wildlife connectivity in this area can be maintained and enhanced.

## Next Steps

This linkage design is a science-based starting point for conservation actions. The plan can be used as a resource for regional land managers to understand their critical role in sustaining biodiversity and ecosystem processes. Relevant aspects of this plan can be folded into management plans of agencies managing public lands. Regulatory agencies can use this information to help inform decisions regarding impacts on streams and other habitats. This report can also help motivate and inform watershed planning, habitat restoration, conservation easements, zoning, and land acquisition. Implementing this plan will take

decades, and collaboration among county planners, land management agencies, resource management agencies, land conservancies, and private landowners.

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

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 Coyote – Ironwood – Tucson linkage design

Mammals	Amphibians	Reptiles
*Badger	*Sonoran Desert Toad	*Black-tailed Rattlesnake
*Black-tailed Jackrabbit		*Gila Monster <sup>HDMS</sup>
*Desert Bighorn Sheep		*Sonoran Desert Tortoise <sup>HDMS</sup>
*Jaguar <sup>HDMS/SDCP</sup>		*Sonoran Whipsnake
*Javelina		*Tucson Shovel-nosed Snake <sup>HDMS/SDCP</sup>
*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).

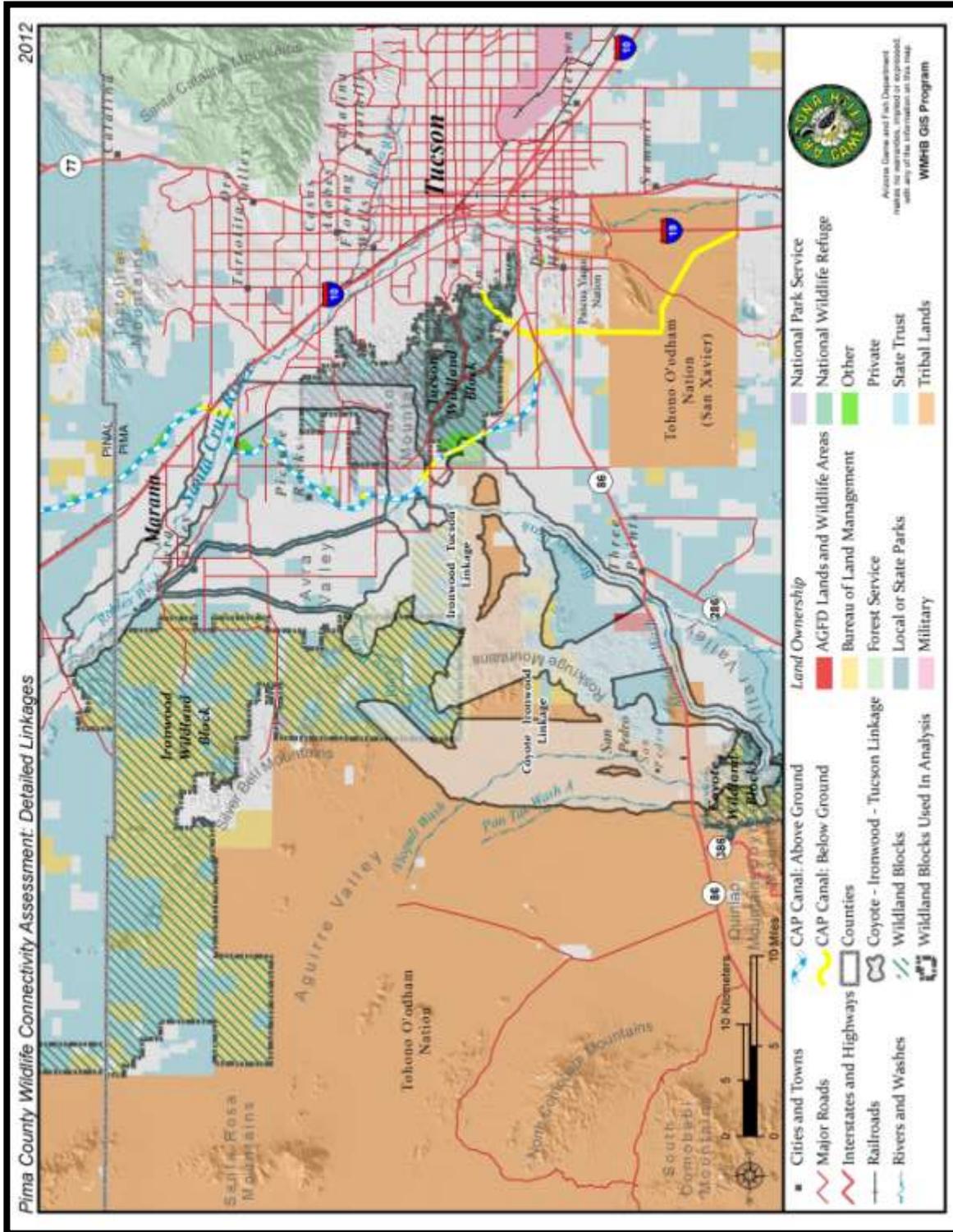


Figure 1: The linkage design between the Coyote, Ironwood, and Tucson wildland blocks includes a Coyote-Ironwood linkage and an Ironwood-Tucson linkage

# 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)

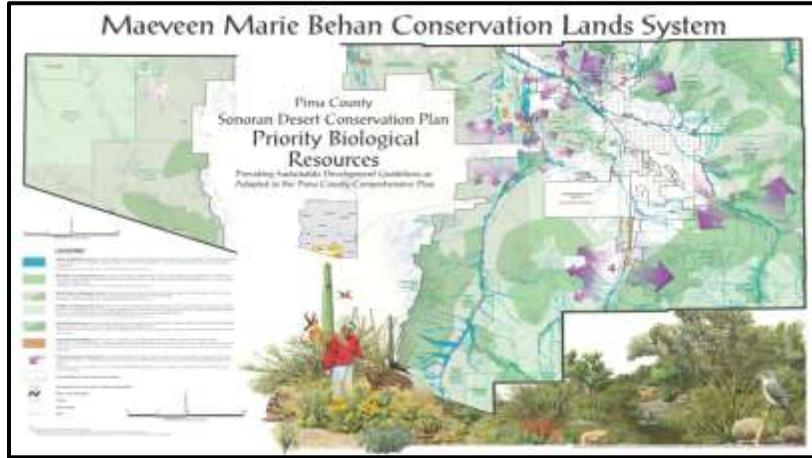
passive recreation activities. In such situations, the linkage may also serve as a buffer between developed areas and wildland blocks and can help protect the wildland network from potentially damaging external influences. Incorporating and designing rural and urban greenways and/or open spaces that 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**

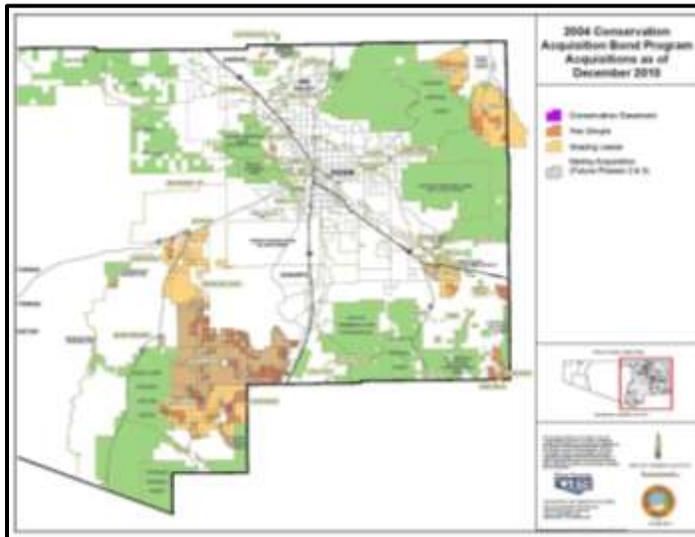
There is a long-standing appreciation among local governments, land management agencies, transportation departments, conservation organizations, energy and utility companies, and citizens across Pima County of the importance of conserving wildlife linkages and mitigating the impacts of barriers on wildlife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

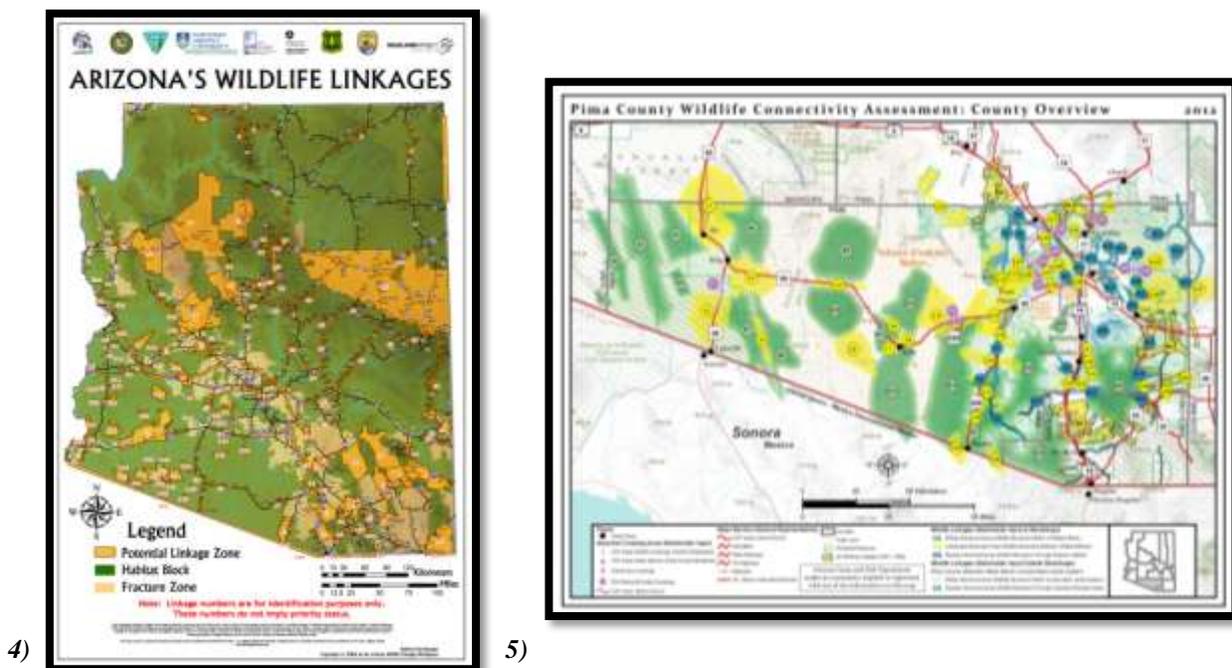
Habitat connectivity can be represented at various spatial scales. In Arizona, we have found it valuable to identify statewide, county-wide, and fine-scale habitat blocks and wildlife linkages to serve different conservation and planning objectives. The linkage planning tools created at each scale have 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://corridor design.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](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. The Coyote – Ironwood – Tucson linkage planning area was one of these prioritized areas suggested to model, and works to address Critical Landscape Connection 1, 5, and 6 (See *Overview of Regional Planning Efforts That Acknowledge the Importance of Conserving Wildlife Linkages* above). Other areas included Kitt Peak, Mexico – Tumacacori – Baboquivari, Santa Catalina/Rincon - Galiuro, and Sierrita – Santa Rita.



**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 Coyote – Ironwood – Tucson 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 Coyote – Ironwood – Tucson Linkage Planning Area

The Coyote – Ironwood - Tucson 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.

Within the Sonoran Desert Ecoregion, the linkage planning area includes a variety of habitats throughout the landscape (see *Figure 6* below). Three wildland blocks exist here: the Coyote Mountains (Coyote), Ironwood Forest National Monument (Ironwood), including part of the Roskrige, Silver Bell, and Sawtooth Mountains, and the Tucson Mountains (Tucson). These wildland blocks are separated by various topographic features, including the steep terrain of the Roskrige Mountains between the Coyote and Ironwood wildland blocks, and the flat lands of Avra Valley between the Ironwood and Tucson wildland blocks. Man-made features separating the blocks include: major roads, State Route 86 and the communities of Avra Valley, Picture Rocks, Robles Junction/Three Points, and the Town of Marana.

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, and provide the chance for important focal species, such as desert bighorn sheep, to expand their range to historically used habitats. 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 7* below for a map of land cover categories):

### *Coyote Wildland Block*

The Coyote wildland block encompasses over 12,000 acres of the Coyotes Mountains bordering the Tohono O’odham Nation, west of Robles Junction/Three Points and south of State Route 86. It is neighbored by the Quinlan Mountains to the west and the Baboquivari Mountains to the south. These mountains are dominated by oak woodlands and mesquite, which comprise the largest percentages of its land cover classification. The wildland block is also comprised of riparian mesquite bosque, semi-desert grassland and steppe, and bedrock cliff and outcrop, among various other land cover types. Elevation here ranges from 2,841 feet to 6,499 feet.

### *Ironwood Wildland Block*

The Ironwood wildland block includes over 187,000 acres of land encompassing numerous mountain ranges, including portions of the Roskrige, Silver Bell, West Silver Bell, Waterman, and Sawtooth Mountains north of State Route 86 and west of Tucson. The Ironwood Forest wildland block also includes portions of the Aguirre and Avra Valleys and borders the eastern boundary of the Tohono O’odham Nation. The majority of the land cover within the wildland block is comprised of paloverde-mixed cacti desert scrub, with creosotebush-white bursage desert scrub and barren lands comprising most of the remaining portions. This landscape is well known for its large concentrations of ironwood trees, *Olneya tesota*. The ironwood tree is also recognized as a keystone species by the Pima County SDCP (Pima County 2009). Elevation in this block ranges from 1,539 feet to 4,216 feet.

### *Tucson Wildland Block*

The Tucson wildland block encompasses over 47,000 acres of the Tucson Mountains on the west side of Tucson and Interstate 10. This rugged desert landscape is dominated by paloverde-mixed cacti desert scrub, with much of the remainder being miscellaneous desert scrub. It is known for its high concentrations of large saguaro cacti, *Cereus giganteus*. The saguaro cactus is also recognized as a keystone species by the Pima County SDCP (Pima County 2009). Elevation in the block ranges from 2,185 feet to 4,672 feet.

## **Conservation Investments in the Coyote – Ironwood – Tucson Linkage Planning Area**

The Coyote, Ironwood, and Tucson wildland blocks represent large conservation investments that protect 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, and provide the chance for important focal species, such as desert bighorn sheep, to expand their range to historically used habitats. 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 8* below for a map of conservation investments):

### *Coyote Wildland Block*

The Coyote wildland block includes the Coyote Mountains Wilderness which is over 5,000 acres managed by the U.S. Bureau of Land Management. Since the Coyote Mountains Wilderness is relatively small in size, and important wildlife habitat is located outside of these boundaries, the wildland block boundaries used for this analysis was increased in size by referencing the Pima County Hillside Development Overlay Zone Ordinance. 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).

#### *Ironwood Wildland Block*

The boundaries of this wildland block are formed by Ironwood Forest National Monument, managed by the BLM. Much of the Ironwood Forest National Monument is comprised of BLM lands, but it also includes both State Trust and Private parcels.

#### *Tucson Wildland Block*

The Tucson wildland block includes Tucson Mountain Park, a 20,000 acre preserve owned by Pima County, and Saguaro National Park West, including the 13,470-acre Tucson Mountain portion of the Saguaro Wilderness. Also included is the Tucson Mitigation Corridor (TMC), located adjacent to the west of Tucson Mountain Park. The TMC is owned by the U.S. Bureau of Reclamation and established to mitigate lost habitat from Central Arizona Project (CAP) canal construction, and to facilitate wildlife movement to habitats on either side. The CAP canal is siphoned below six washes in this area which facilitate wildlife movement east/west of the CAP canal. Tull and Krausman (2001) found that mule deer use both the TMC and the wash siphons along the CAP canal within the TMC. It is managed by Pima County as part of the Tucson Mountain Park system (Pima County 2008), and thus was included as part of the Tucson wildland block in this analysis due to its habitat value, and high land stewardship status protecting it from future development. Although wildlife movement is prevented east/west of the CAP canal outside of the six wash siphons, the TMC ultimately functions as an extension of the other conservation reserves mentioned above. The TMC is also one of the few protected areas of flat land along Avra Valley, below the Tucson Mountains. Thus, it was important to include as part of the Tucson wildland block, in order to increase the topographic diversity of the block, and accommodate the needs of the variety of focal species used in our analysis.



**Figure 6:** Varied habitats throughout the landscape of the Sonoran Desert: **A)** Coyote Mountains **B)** Ephemeral section of Brawley Wash **C)** Roskrige Mountains and Ironwood Forest National Monument **D)** Intermittent section of Brawley Wash **E)** Saguaro National Park West





# The Coyote – Ironwood Tucson Linkage Design

The linkage design (see *Figure 1* for a map of the linkage design at the beginning of this report) includes a Coyote-Ironwood linkage strand, and an Ironwood-Tucson linkage strand. 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*.

## Two Linkages Provide Connectivity Across a Diverse Landscape

### The Coyote – Ironwood Linkage

The Coyote-Ironwood linkage runs between the Coyote wildland block and the Ironwood wildland block, across State Route 86. It spans about 21 km (13 mi) in a straight-line between each wildland block used in this analysis. It is primarily composed of paloverde-mixed cacti desert scrub (73.1%), creosotebush-white bursage desert scrub (8.7%), mesquite upland scrub (7.4%), and various washes (3.1%). This linkage has an average slope of 9.4% (Range: 0 – 245.0%, SD: 15.0). Most of the land (74.4%) is flat-gently sloped, and steep sloped (17.6%), with the rest a mix of canyon bottom and ridgetop.

This linkage between the Coyote Mountains and Ironwood Forest National Monument is a relatively undeveloped and intact landscape. However, major barriers to wildlife connectivity still exist:

#### State Route 86

An animal moving terrestrially between the Coyote and Ironwood wildland blocks eventually must cross State Route 86 (SR 86). Lowery et al. (2010) documented SR 86 as a major barrier to wildlife connectivity, with 8,179 individual detections of road kill, animal sign and tracks, or direct observation, consisting of 90 different species. This study, conducted from the Kinney Road intersection to the Tohono O’odham Nation boundary, along SR 86, identified numerous focal species and taxonomic groups included in this report (see *Table 2* below).

### 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

**Table 2:** Focal species and taxonomic group mortality identified by Lowery et al. (2010) along SR 86

Common Name	Live	Road Kill	Tracks	Scat
Badger	1	3		
Bats		7		
Black-tailed Jackrabbit	3	27	5	1
Gila Monster		2		
Javelina		2	39	1
Kit Fox		1		
Mule Deer		5	74	
Sonoran Desert Toad		1,512		
Sonoran Desert Tortoise		4		

While many of these detections were not directly within the Coyote – Ironwood linkage (due to study area boundaries), the numerous detections involving a variety of species offer evidence of SR 86 as a barrier to wildlife movements in the area. This highway may also represent a population barrier to a desert bighorn sheep population in the Silver Bell Mountains within Ironwood Forest National Monument, which have been eliminated from their historical range south. Suitable habitats in the Coyote Mountains had been previously used by desert bighorn sheep populations (Brown 1993).

#### *Border Infrastructure*

The barrier SR 86 presents to wildlife is compounded further by a US Border Patrol checkpoint established near mile post 146.5, with night-time operation of large artificial lights, which may cause disturbance to wildlife.

#### *Invasive Species*

The invasive buffelgrass is present throughout the Coyote – Ironwood linkage. This grass threatens the integrity of the entire Sonoran Desert through its introduction of fire to the ecosystem. The presence of this grass consequently poses a challenge to the survival of many of the plants and animals within the linkage design and throughout this area of the Sonoran Desert.

### **The Ironwood - Tucson Linkage**

The Ironwood – Tucson linkage runs through Avra Valley from Ironwood Forest National Monument to the Tucson Mountains. The linkage spans approximately 13.6 km (8.5 mi) in a straight-line between each wildland block used in this analysis. However, a portion of protected lands are only separated by a straight-line distance of 3.3 km (2.1 mi), between the southern portion of Ironwood Forest National Monument and the Tucson Mitigation Corridor adjacent to Tucson Mountain Park. The linkage is primarily composed of paloverde-mixed cacti desert scrub (58.2%), creosotebush-white bursage desert scrub (9.9%), agriculture (9.4%), and riparian woodland and shrubland (8.9%). Low-intensity developed lands (2.4%) and high-intensity developed lands (1.3%) are both present. This strand has an average slope of 6.7% (Range: 0-148.0%, SD: 12.9). The majority of land in this strand is classified as having flat-gentle slopes (81.1%), with steep slopes occupying the second largest topographic classification (12.9%).

This area is severely fragmented and numerous barriers exist:

#### *Sandario Road*

During field observations, high traffic volume and speeds were observed along Sandario Road, representing a major barrier to wildlife movement. While numerous roads exist in the Ironwood – Tucson linkage, almost all terrestrial wildlife movement between the Ironwood and Tucson blocks must cross Sandario Road, and so it is a focus in this report.

#### *Santa Cruz River Barriers*

The Santa Cruz River provides valuable habitat connectivity between the Ironwood and Tucson blocks, and is represented as part of the Ironwood – Tucson linkage. Some riparian vegetation currently exists along this section of the Santa Cruz River within the linkage, partially due to effluent discharge from nearby wastewater treatment facilities. Natural perennial river flow has been lost in the Santa Cruz River and its riparian habitats degraded from groundwater pumping and other human activities (Fabre and Cayla 2009). Continued habitat restoration made possible from effluent flows would greatly benefit this strand of the linkage. Numerous major roads also cross this portion of the river. However, many bridged underpasses may allow the passage of a variety of species, including large mammals.

### *Twin Peaks Road*

Lowery and Blackman (2007) identified Twin Peaks Road as a major barrier to wildlife connectivity, with 630 roadway detections across 55 species, and 529 detections of direct mortalities from road kills. Numerous focal species modeled as part of the linkage design were detected along Twin Peaks Road, including black-tail jackrabbit, javelina, kit fox, mule deer, Sonoran Desert toad, and Sonoran Desert tortoise.

### *Central Arizona Project Canal*

The otherwise impermeable Central Arizona Project (CAP) canal must also be traversed through an available wildlife crossing or siphon. Four Central Arizona Water Conservation District (CAWCD) CAP wildlife crossings and a portion of an almost 2 km engineered siphon of the CAP canal exists within part of the linkage design, however, light-housing developments both west and south of the siphon represent a barrier to wildlife movement through that area. Additionally, six wash siphons exist within the Tucson Mitigation Corridor (TMC), which we considered as part of the Tucson wildland block, which allow wildlife movement east – west of the CAP canal.

### *Fences*

Many sections of double barbed-wire fencing exist along the City of Tucson Central Avra Valley Storage and Recovery Project (CAVSARP) property operated by the Tucson Water Department within the Ironwood – Tucson linkage. In addition to these stretches of fenceline, chain-link fencing around CAVSARP infiltration basins may also block wildlife movement. Gaps approximately 30 – 40 meters exist in between chain-link exclusion fences which may allow the passage wildlife through these areas.

### *Urban Development*

The Ironwood – Tucson linkage contains numerous barriers to wildlife movement associated with urban development. Numerous towns and communities exist within and near the linkage, including Avra Valley, Marana, and Picture Rocks. The most notable urban development barriers exist west and south of an almost 2 km engineered siphon of the CAP canal near the intersection of Mile Wide Road and Sandario Road, working to block wildlife movement across this buried portion of the canal. Development near the northern Tucson Mountain foothills, within the Town of Marana, is also blocking wildlife habitat connectivity between the Santa Cruz River portion of the Ironwood – Tucson linkage and the Tucson wildland block.

Compared to the Coyote – Ironwood linkage (preceding paragraphs), the Ironwood – Tucson linkage is considerably more fragmented by a variety of barriers, including the CAP canal, major roads, and urban development. In order for this linkage to properly maintain biodiversity and genetic processes, considerable land use planning, habitat restoration and barrier mitigation must take place. Connectivity between the Ironwood and Tucson wildland block has already become compromised for desert bighorn sheep, an important focal species. Surely, other focal species in this linkage will also suffer without prompt and strong action to shape development and mitigate barriers. While acknowledging the challenges and costs, we believe that restoring and enhancing this linkage is an achievable goal. Ultimately, the fate of this corridor lies with local jurisdictions and conservation investors.

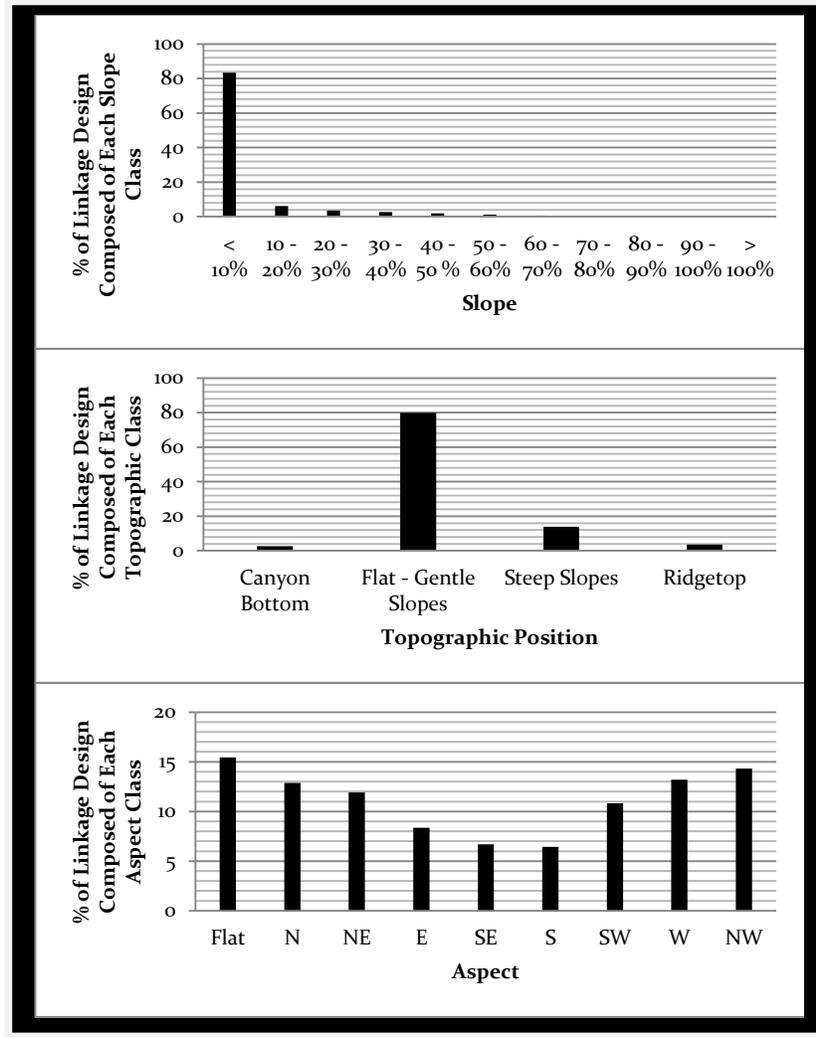
## **Characteristics of the Entire Linkage Design**

The linkage design encompasses 176,271 acres (71,335 ha) of land, of which about 23% is privately owned, 20% is State Trust land, 36% is Tribal lands, 6% is within National Park Service land, 13% is owned by BLM, and the rest is owned by miscellaneous entities (see *Figure 1* for a map of the linkage design and land ownership at the beginning of this report). Paloverde-mixed cacti desert scrub accounts for over 64% of the land cover, and developed land accounts for almost 2% of the linkage design (see *Table 3* 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 9* below). Roughly 80% of the linkage design has a slope of less than 10%. About 80% of the land is classified as gentle slopes, 14% as steep slopes, and the remaining 6% as canyon bottom or ridgetop. There is a variety of land aspects represented, most of which are flat, north, northeast, or northwest.

**Table 3: Approximate land cover found within Linkage Design**

Land Cover Group	Land Cover Class	% of Linkage Design
Evergreen Forest	Encinal (Oak Woodland)	0.5%
Evergreen Forest	Pinyon-Juniper Woodland	0.2%
Grasslands-Herbaceous	Semi-Desert Grassland and Steppe	0.8%
Scrub-Shrub	Chaparral	0.1%
Scrub-Shrub	Creosotebush, Mixed Desert and Thorn Scrub	0.4%
Scrub-Shrub	Creosotebush-White Bursage Desert Scrub	9.6%
Scrub-Shrub	Desert Scrub (misc)	1.7%
Scrub-Shrub	Mesquite Upland Scrub	4.2%
Scrub-Shrub	Paloverde-Mixed Cacti Desert Scrub	64.5%
Woody Wetland	Riparian Mesquite Bosque	1.4%
Woody Wetland	Riparian Woodland and Shrubland	4.7%
Barren Lands	Barren Lands, Non-specific	2.1%
Barren Lands	Bedrock Cliff and Outcrop	0.2%
Barren Lands	Wash	2.7%
Developed and Agriculture	Agriculture	5.2%
Developed and Agriculture	Developed, Medium - High Intensity	0.7%
Developed and Agriculture	Developed, Open Space - Low Intensity	1.3%



**Figure 9:** Topographic diversity encompassed by Linkage Design: a) Topographic position, b) Slope, c) Aspect

## Removing and Mitigating Barriers to Movement

Although roads, canals, fences, urban areas, and various other barriers 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 features on ecological processes, identify specific 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):

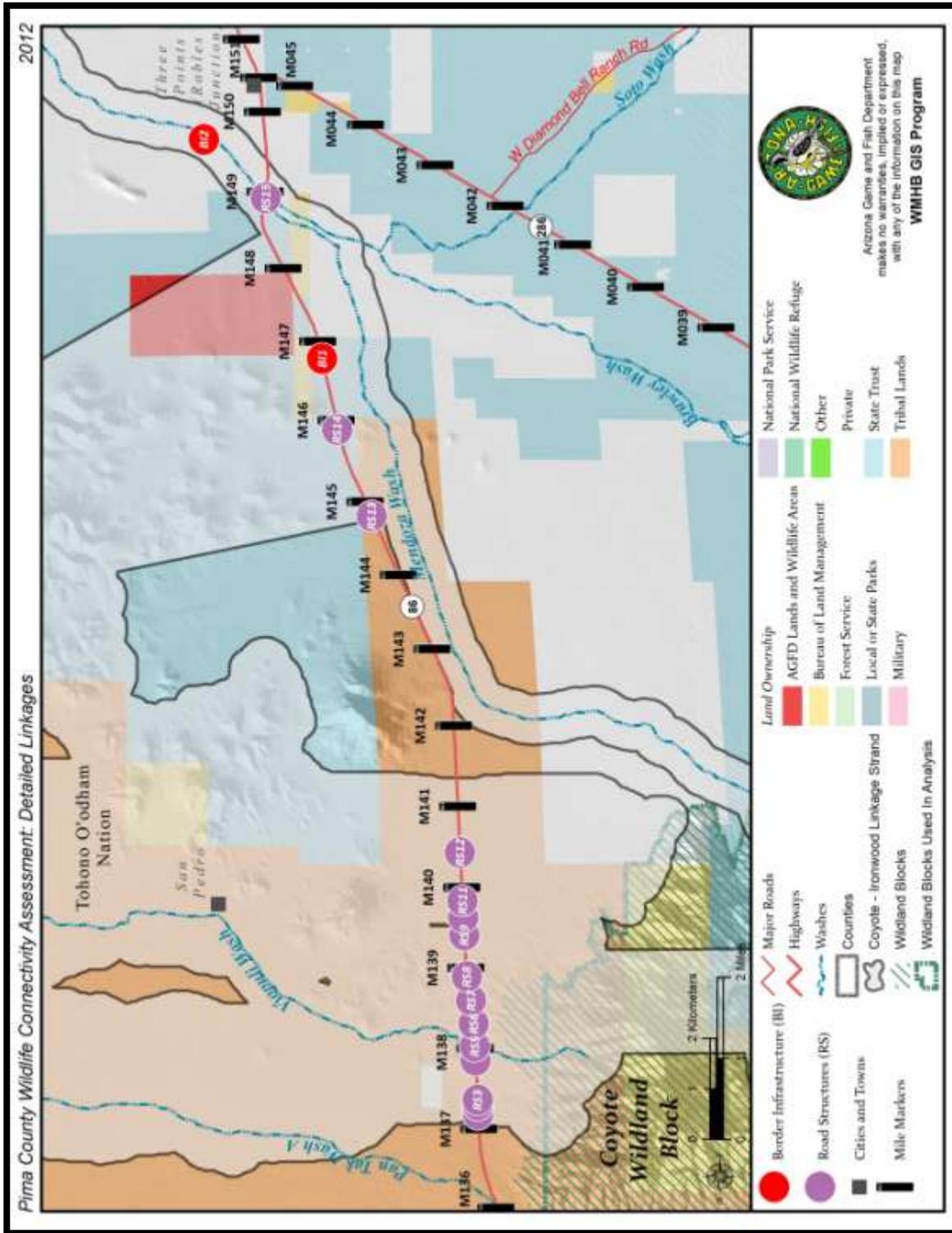


Figure 10: Field observations within the Coyote – Ironwood linkage



## 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 4* 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 4:** Characteristics which make species vulnerable to the three major direct effects of roads (from Forman et al. 2003)

Characteristics making a species vulnerable to road effects	Effects of Roads		
	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

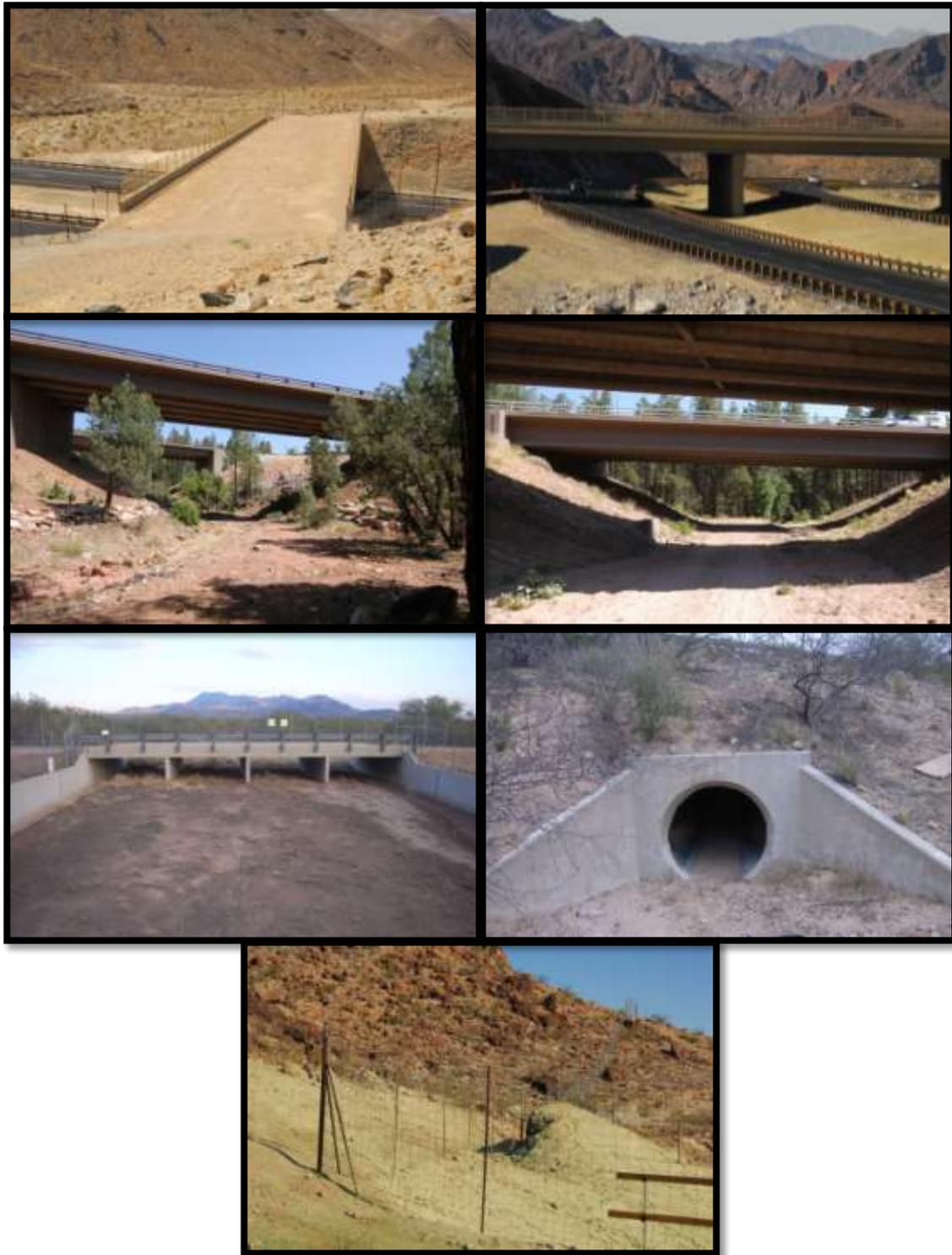
Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses, bridges, culverts, and pipes (see *Figure 12* below). While many of these structures were not originally constructed with ecological 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.

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.



**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)

## *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 491 km (305 mi) of transportation routes in the linkage design, including 10.8 km (6.7 mi) of State Route 86 (W Tucson – Ajo Hwy, W Ajo Hwy), 4.7 km (2.9 mi) of Sandario Road, 1.8 km (1.1 mi) of Twin Peaks Road, and the remainder consisting of other local roads (See *Table 5* and *Table 6* below). We conducted field investigations where possible on a selection of these roads to document existing road structures that could be modified to enhance wildlife movement through the area.

**Table 5: Roads greater than 1 kilometer in length in the Coyote – Ironwood Linkage Design strand**

Road Name	Kilometers	Miles
San Pedro Rd	7.3	4.5
Unknown	96.4	59.9
W Ajo Hwy	2.5	1.6
W Black Peak Rd	1.1	0.7
W Tucson-Ajo Hwy	4.0	2.5

**Table 6: Roads greater than 1 kilometer in length in the Ironwood – Tucson Linkage Design strand**

Road Name	Kilometers	Miles
Bajada Loop	2.8	1.8
N Aguirre Rd	3.4	2.1
N Avra Rd	1.6	1.0
N Kinney Rd	8.0	5.0
N Lockett Rd	1.6	1.0
N Reservation Rd	4.3	2.6
N Sandario Rd	1.2	0.7
N Sanders Rd	1.4	0.9
N Sassy Dr	1.4	0.8
N Silverbell Rd	1.1	0.7
Quarry Rd	1.3	0.8
S Avra Rd	1.5	0.9
S Marstellar Rd	1.4	0.8
S Sandario Rd	3.1	1.9
Unknown	66.3	41.2
W Avra Valley Rd	3.1	2.0
W Cocorague Ranch Rd	3.6	2.2
W Donaldson Ranch Rd	3.1	1.9
W Fort Lowell Rd	1.1	0.7
W Hardin Rd	1.6	1.0
W Picture Rocks Rd	1.9	1.2
W Tangerine Rd	1.2	0.8
Wasson Peak Footpath	2.1	1.3
White Stallion Ranch Rd	2.1	1.3

## *Recommendations for Crossing Structures in the Coyote – Ironwood Linkage*

As mentioned in the Coyote – Ironwood – Tucson Linkage Design section above, State Route 86 (SR 86) has been shown to be a major barrier to wildlife connectivity (Lowery et al. 2010). 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 SR 86, and refer to waypoints on the map at the beginning of this section (see *Figure 10* above):

### *State Route 86*

- Road structures RS1 – RS13 located within the Coyote – Ironwood linkage between SR 86 mile posts 137 – 145 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 structures RS1 – RS8 between SR 86 mile posts 137 – 139, should be retrofitted during road widening projects to accommodate large-size mammal movement preferences, based on biologically best corridors for desert bighorn sheep, mountain lion, and mule deer. These culverts and associated fencing should follow recommendations for large-size mammals referenced above. Models indicate that road structures RS5 – RS8 between SR 86 mile posts 138 – 139, are also within or near biologically best corridors for various reptiles, including black-tailed rattlesnake, Gila monster, Sonoran desert tortoise, and Sonoran whipsnake focal species. These culverts and associated fencing should also follow recommendations for herpetofauna referenced above.
  - Road structures RS9 – RS11 between SR 86 mile posts 139 – 141, should be retrofitted during road widening projects to accommodate medium mammal movement preferences, based on biologically best corridors for black-tailed jackrabbit, javelina, and badger. These culverts and associated fencing should also follow recommendations for mid-sized mammals referenced above.
  - Road structure RS12 between SR 86 mile posts 140 – 141, should be retrofitted during road widening projects to accommodate amphibian movement preferences based on the biologically best corridor for Sonoran desert toad. This culvert and associated fencing should follow recommendations for herpetofauna (amphibians) referenced above.
  - Road structure RS13 between SR 86 mile posts 144 – 145, was not within a modeled biologically best corridor. However, this structure should be retrofitted to meet specifications for small culverts and fencing (small mammals; herpetofauna) referenced above, based on Lowery et al. (2010) recommendations based on SR 86 road mortality research.
- Road structure RS14 between SR 86 mile posts 145 – 146, was not within a modeled biologically best corridor. However, this structure should be retrofitted to meet specifications for large culverts (large-size mammals) and large-sized mammal fencing referenced above, based on recommendations from Lowery et al. (2010). This structure was visited during field observations,

and is currently a concrete box culvert consisting of four cells, each measuring 1.5 m (5 ft) in height and approximately 3 m (9 ft) in width (see *Figure 13* below).

- Road structure RS15 near SR 86 mile post 149, was within the riparian portion of the linkage design. This structure should be retrofitted with fencing to meet specifications for large-sized mammals referenced above, based on recommendations from Lowery et al. (2010) road mortality research. Road structure RS15, SR 86 Brawley Wash Bridge, was visited during field observations, and is a large bridged underpass that spans Brawley Wash (see *Figure 14* below). This road structure should be viewed as a priority structure for wildlife movement across SR 86.

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 should be constructed to facilitate movement of large-sized mammals across SR 86 within the Coyote – Ironwood linkage. A Preliminary location for construction should be between SR 86 mp 137 – 139 indicated by 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.

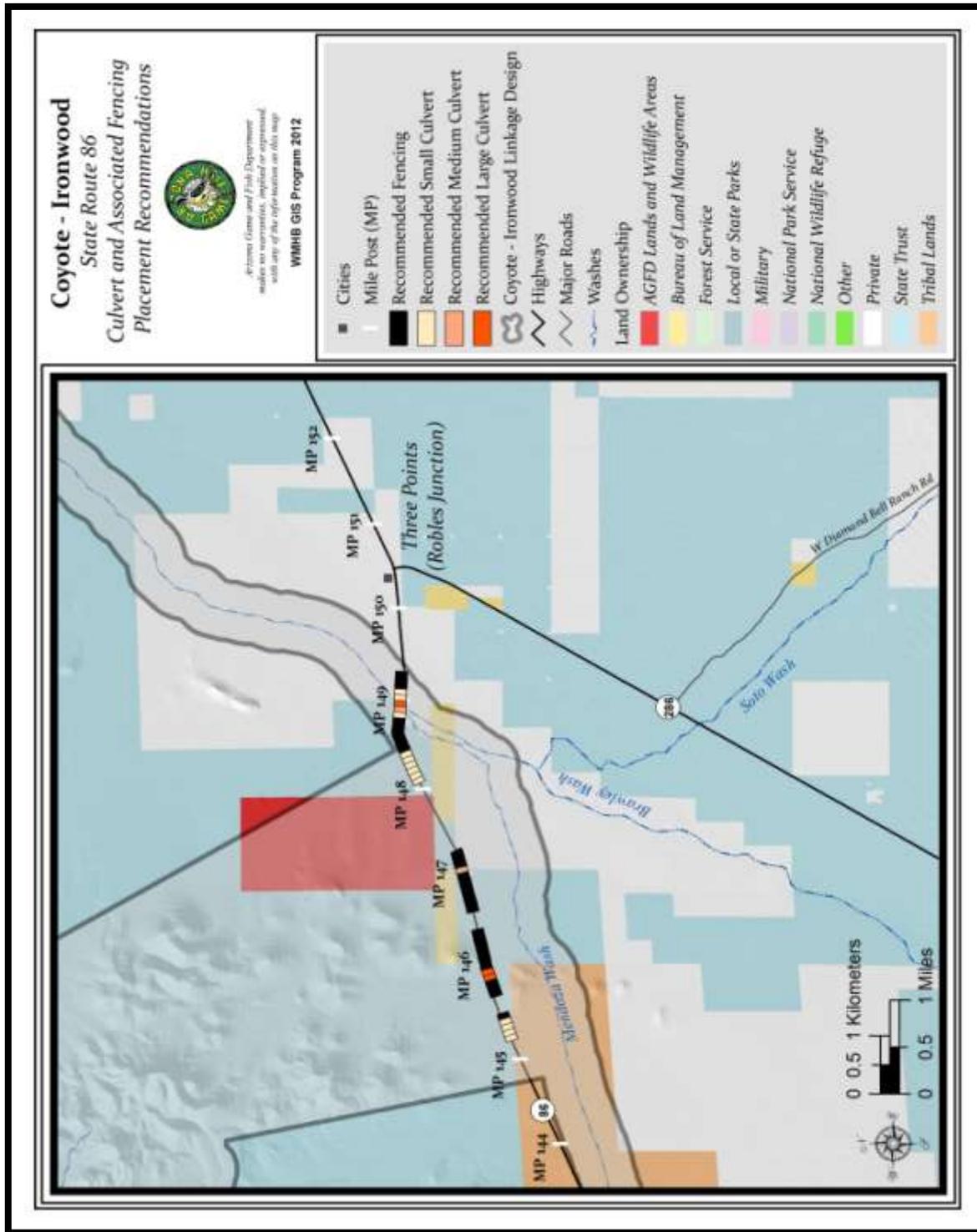
Additional retrofitting and new wildlife construction recommendations have been made from on the ground wildlife mortality research conducted by Lowery et al. (2010) for SR 86 between the Tohono O’odham Nation boundary and Kinney Road. These recommendations should be followed to increase wildlife connectivity across SR 86. Recommendations that occur within the linkage design can be visualized in the map below (see *Figure 15* below).



*Figure 13: SR 86 concrete box culvert below State Route 86 (RS14)*



*Figure 14: SR 86 bridged underpass spanning Brawley Wash (RS15)*



**Figure 15:** State Route 86 recommended wildlife crossing and fencing placement east of the Tohono O’odham Nation boundary within the linkage based on wildlife mortality research (Lowery et al. 2010). Note: this map reflects recommended crossing location and not numbers of culverts recommended, which should follow spacing specifications based on culvert type in Lowery et al. (2010)

## *Recommendations for Crossing Structures in the Ironwood – Tucson Linkage*

As mentioned in the Coyote – Ironwood – Tucson Linkage Design section above, Sandario Road and major roads across the Santa Cruz River, are major barriers in the Ironwood – Tucson linkage. Twin Peaks Road has also been shown to be a major barrier to wildlife connectivity (Lowery and Blackman 2007).

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 Sandario Road and through the Santa Cruz River, and refer to waypoints on the map at the beginning of this section (see *Figure 11* above):

### *Sandario Road*

- Road structure RS16 should be retrofitted during road projects to accommodate large-sized mammal movement preferences, based on the biologically best corridor for mountain lion. This structure was visited during field observations and is a concrete box culvert, consisting of one cell, measuring approximately 2m (6 ft) in height, and 4 m (12 ft) in width (see *Figure 16* below).

### *Santa Cruz River Barriers*

- Road structure RS17 should be viewed as a priority structure for wildlife movement through Avra Valley Road along the Santa Cruz River, based on the biologically best corridor for mountain lion. Road structure RS17, Avra Valley Road Bridge, was visited during field observations, and is a large bridged underpass spanning the Santa Cruz River (see *Figure 17* below). Additional on the ground research should be conducted to determine if retrofitting this structure with fencing is necessary, and what type of fencing should be used.
- Road structure RS18 should be viewed as a priority structure for wildlife movement through Sanders Road, along the Santa Cruz River, based on the biologically best corridor for mountain lion. Road structure RS18, Sanders Road Bridge, was visited during field observations, and is a large bridged underpass spanning the Santa Cruz River (see *Figure 18* below). Additional on the ground research should be conducted to determine if retrofitting this structure with fencing is necessary, and what type of fencing should be used.
- Road structure RS19 should be viewed as a priority structure for wildlife movement through Marana Road along the Santa Cruz River, based on the biologically best corridor for mountain lion. Road structure RS19, Marana Road Bridge, was visited during field observations and is a large bridged underpass spanning the Santa Cruz River (see *Figure 19* below).

These structures within the linkage 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. For example, many of the animals moving terrestrially between the Ironwood and Tucson wildland blocks must traverse Sandario Road, and wildlife crossing structures which accommodate needs of different focal species recognized in this plan, are crucial. This may require the construction of new wildlife crossings. Twin Peaks Road has also been recognized as a significant barrier to wildlife movement (Lowery and Blackman 2007), and must also be mitigated.

We recommend constructing new crossing structures and associated improvements as follows using culvert design specifications by Lowery et al. (2010), and overpass specifications by McKinney and Smith (2007):

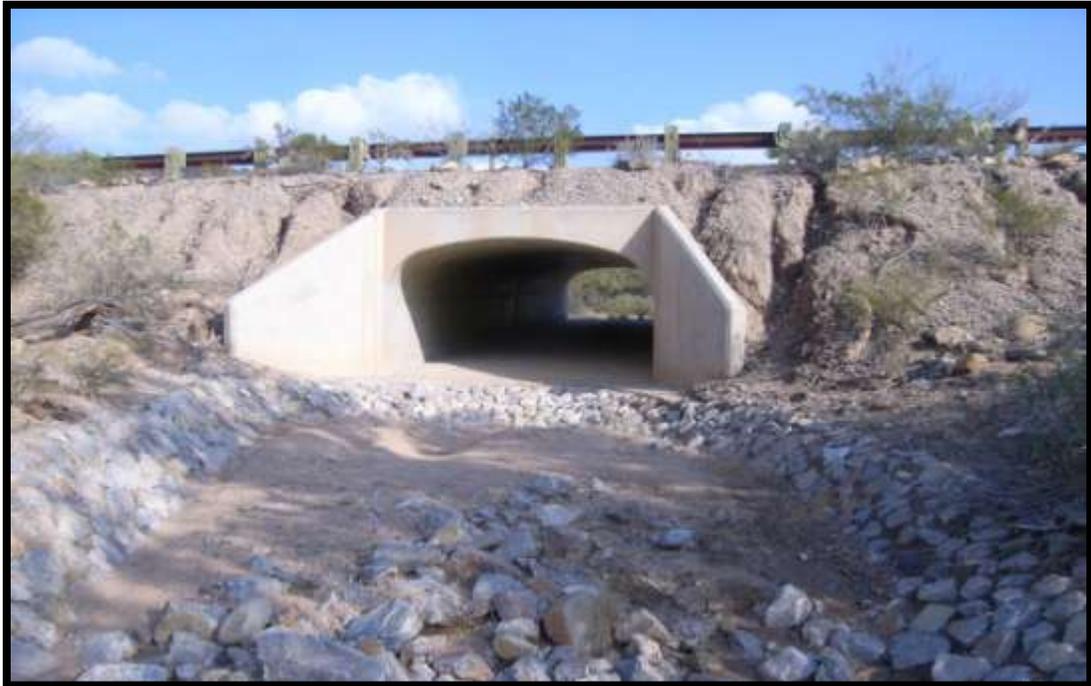
### *Sandario Road*

- Additional culverts should be constructed which follow recommendations for large mammal passage along Sandario Road during future road improvement projects. The preliminary locations of new culvert construction should be located along Sandario Road just south of Kinney Road, based on the biologically best corridor for mountain lion. Additional on the ground wildlife research is needed in this area to verify model results before construction.
- Additional culverts should be constructed which follow recommendations for small, mid, and large-sized mammal, as well as herpetofauna passage along Sandario Road during future road improvement projects in a second location. The preliminary locations of new culvert construction should be located along Sandario Road from where the north boundary of the Tucson Mitigation Corridor (TMC) to just south of the southern boundary of the Garcia Strip within the linkage. This is based on the modeled biologically best corridors for badger, black-tailed jackrabbit, Gila monster, mule deer, javelina, kit fox, mule deer, Sonoran desert toad, Sonoran desert tortoise, Sonoran whipsnake, and Tucson shovel-nosed snake. Fencing and herpetofauna barrier walls, or road grade increases should accompany crossing structure construction to help funnel animals. Again, additional on the ground wildlife research is needed in this area to verify model results before construction.
- Ideally, at least one overpass would be constructed within this linkage, based on the design specifications suggested by McKinney and Smith (2007), to allow passage of large ungulates. A preliminary location based on the modeled corridor for mule deer suggests construction along Sandario Road near the northern boundary of the Garcia Strip. Again, additional on the ground research is needed in this area to verify model results before construction.

### *Twin Peaks Road*

- Twin Peaks Road should receive mitigation within the linkage based on recommendations from Lowery and Blackman (2007). Road mortality and detection research can be visualized within the linkage by referencing the map below (see *Figure 20* below)

Pima County is fortunate to have a progressive transportation planning process, and funding to implement projects to enhance wildlife connectivity. We hope RTA will be a major implementer of this Linkage Design.



*Figure 16: Culvert under Sandario Road (RS16)*



*Figure 17: Avra Valley Road underpass spanning the Santa Cruz River (RS17)*



*Figure 18: Sanders Road underpass spanning the Santa Cruz River (RS18)*



*Figure 19: Marana Road underpass spanning the Santa Cruz River (RS19)*

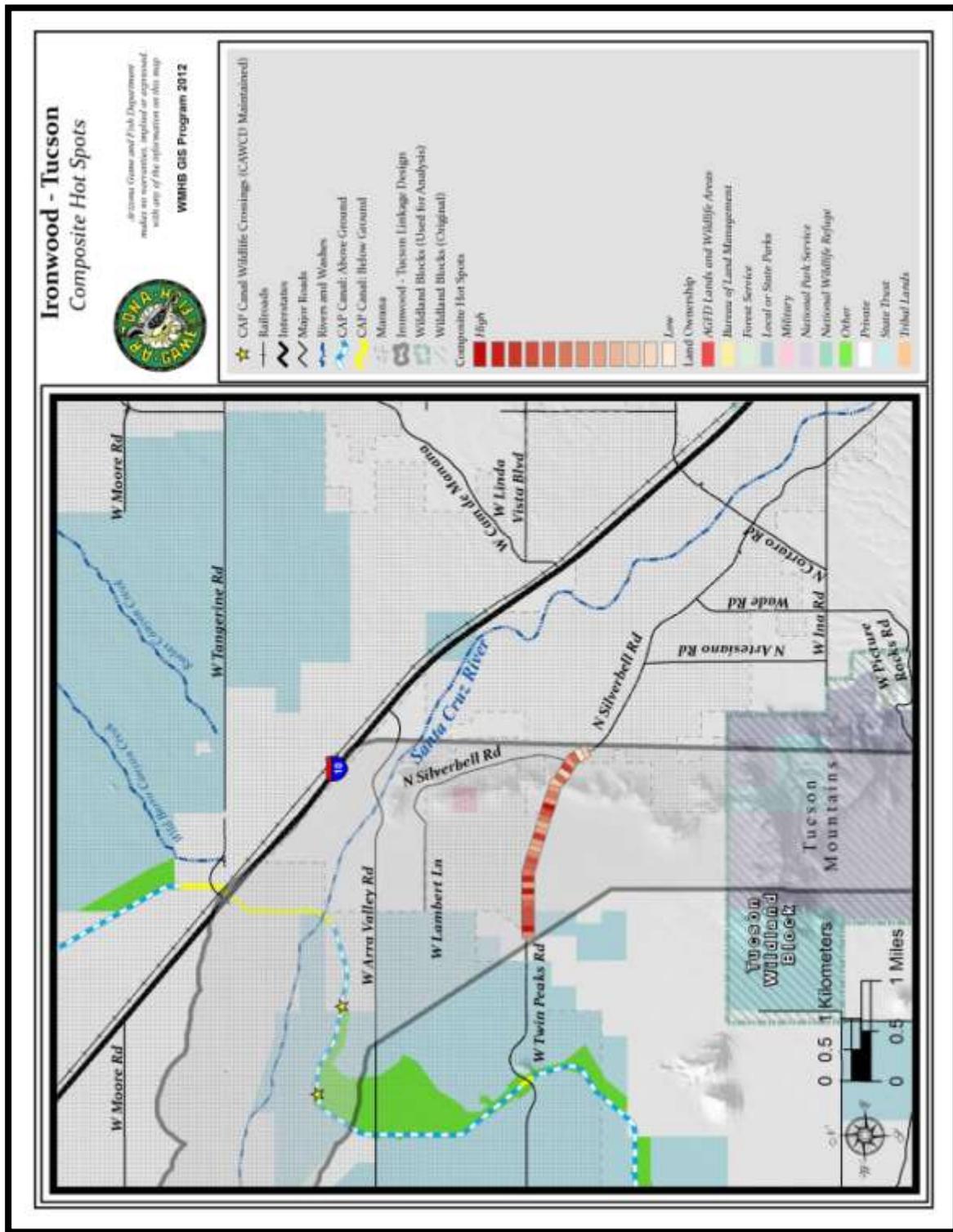


Figure 20: Twin Peaks Road wildlife mortality and detection research within the linkage design from Lowery and Blackman (2007).

## Impacts of Border Activity on Wildlife

A large portion of the southern boundary of Pima County is shared by an international border with Mexico. As described in Arizona's State Wildlife Action Plan (Arizona Game and Fish Department 2012), undocumented human immigration and drug smuggling across the Arizona-Mexico border increased dramatically in the last decade, resulting in a cumulative impact to wildlife habitats. However, apprehensions have declined 61 percent since 2005, and in 2010 apprehension numbers were at their lowest level since 1972 (Department of Homeland Security 2011). Border security measures are being stepped up throughout the Arizona-Mexico borderlands region in an attempt to address border traffic (Roberts et al. 2010). A security fence stretching along 1,125 km, more than one third of the U.S.-Mexico border, has been constructed. Fence structure segments are mostly  $\geq 4$  m tall, have vertical gaps 5-10 cm wide and are associated with vegetation clearing and roads  $\geq 25$  m wide (Flesch et al. 2010). In addition to habitat fragmentation caused by this barrier and areas cleared of vegetation for patrol roads, the increased traffic near the border from enforcement patrols and pursuits, as well as artificial night lighting, as seen below (*Figure 37*), are also of concern due to their potential to affect wildlife habitat quality and functional transboundary habitat connectivity (Arizona Game and Fish Department 2012b).

Impacts of border activity and border infrastructure (BI) are evident within the linkage design. A U.S. Customs and Border Protection (CBP) checkpoint, and associated artificial lighting, exists along State Route 86 within the linkage (see *Figure 21 below*). Humane Borders also maintains a water station, evident by its recognizable blue flag within the linkage design (see *Figure 22 below*). The waypoints referenced in the figure descriptions below refer to *Figure 11* at the beginning of this section titled Removing and Mitigating Barriers.

## Guidelines and Recommendations for Mitigation of Artificial Lighting

Artificial lighting should follow the Arizona Game and Fish Department's Wildlife Friendly Guidelines (2009b) for mitigation of artificial lighting below:

- 1) **Eliminate all bare bulbs and any lighting pointing upward.** This is especially true for decorative lighting, and would reduce contributions to overall light pollution.
- 2) **Use only the minimum amount of light needed for safety.**
- 3) **Use narrow spectrum bulbs as often as possible** to lower the range of species affected by lighting.
- 4) **Shield, canter or cut lighting** to ensure that light reaches only areas needing illumination. This will significantly reduce sky glow.
- 5) **Light only high-risk stretches of roads**, such as crossings and merges, allowing headlights to illuminate other areas. Where possible, use embedded road lights to illuminate the roadway.
- 6) In Flagstaff and Coconino County, the desire to maintain dark skies for the Flagstaff Naval Observatory and Lowell Observatory has led to city and county ordinances protecting dark skies. These ordinances have coincidentally offered wildlife relief from the negative impacts of light pollution. For more information visit <http://flagstaffdarkskies.org/>.
- 7) **All new developments should use the latest management technologies** so that continued growth and expansion leads to no increase in the impact of light pollution (Salmon 2003).

A report from Defenders of Wildlife (2006), details border activity impacts on wildlife and habitat. The report offers their recommendations for minimizing border infrastructure and border policies on wildlife. It is available online here: [http://www.defenders.org/publications/on\\_the\\_line\\_report.pdf](http://www.defenders.org/publications/on_the_line_report.pdf)



*Figure 21: U.S. Border Patrol checkpoint and associated lighting along State Highway 86 (B11)*



*Figure 22: Looking towards Humane Borders water station, marked by a blue flag (B12)*

## Impacts of Canals on Wildlife

Canals can have both positive and negative impacts on desert wildlife. Some species may use canals as a water source, but the steep banks make it impossible or dangerous for most animals to do so. Desert mule deer, bighorn sheep, and Sonoran pronghorn have drowned in canals (Rautenstrauch and Krausman 1989). Canals serve as significant barriers to movement by preventing species from moving to viable habitat on the other side of the canal, drowning species, and rerouting natural movement patterns.

### *Existing Canals in the Linkage Design*

The Central Arizona Project (CAP) canal acts as a major barrier to wildlife movement within the Ironwood – Tucson linkage. The CAP canal is approximately 12 meters (39 ft) wide, and is lined with eight-foot fences on both sides to keep large animals out.

The waypoints referenced in the text and figure descriptions below refer to *Figure 11* at the beginning of this section titled Removing and Mitigating Barriers:

The establishment of the Tucson Mitigation Corridor (TMC) by the U.S. Bureau of Reclamation (USBR), and its management by Pima County as part of the Tucson Mountain Park system, has greatly increased the permeability of the CAP canal and wildlife connectivity within the TMC. Numerous CAP canal siphons, one just south of the TMC (see *Figure 23* below), and six within the TMC (see *Figure 24 – 29* below), span through large washes and allow movement of various species of wildlife. For example, mule deer have been found to use both the TMC and wash siphons (Tull and Krausman 2001). Because the TMC now functions as part of the Tucson mountain park system, and the CAP canal is relatively permeable in this area, the TMC was included as part of the Tucson wildland block in order to focus modeling in areas without conservation protection.

An additional CAP canal siphon under the intersection of Sandario Road and Mile Wide Road, is approximately two kilometers in length, much longer than the previously mentioned TMC CAP canal siphons (see *Figure 30* below). Due to the length of this siphon, this portion of the CAP canal represents one of the most permeable areas to wildlife. However, development south, and west of the Sandario/Mile Wide siphon, threatens to decrease wildlife permeability in this area. Land use planning here must address wildlife movement to salvage the opportunity for permeability of the canal here.

The Central Arizona Water Conservation District (CAWCD) maintains nine canal crossing structures (CS) in and near the linkage design (CS9 – CS17). Four of these canal crossing structures exist within the linkage, two of which were visited and are pictured below (see *Figure 31* and *Figure 32* below).

## *Guidelines and Recommendations for Mitigation of Canals*

We provide the following recommendations for mitigation of canals:

- 1) **Ensure opportunities for wildlife to cross every canal in the linkage area.** This can be accomplished by several methods. The most permeable, yet most expensive method is to bury any canal within the linkage design below ground. For wide canals, such as the CAP, vegetated overpasses should be installed. While no studies have examined optimal crossing structures for canals, information can be gleaned from the literature on the determinants of success for road mitigation

structures. For example, Van Wieren and Worm (2001) recommend wildlife overpasses over roads be at least 40-50 m wide for optimal wildlife usage. For narrow canals, an affordable solution would be to cover the canal with metal plates, and cover these plates with an earthen substrate. Crossings at dirt roads are helpful, but lack vegetation needed for some wildlife species to find them attractive. To ensure usability by an array of species, the grade of the entrance and exit to these crossing structures should provide a gentle approach to the canal.

- 2) **Install fencing on all areas of the canal which do not have crossing structures.** This fencing must completely seal the canal in order for it to effectively restrict wildlife use (Rautenstrauch and Krausman 1989), and be sufficiently high to prevent deer from jumping the fence (Peris and Morales 2004).
- 3) **Provide alternative water sources adjacent to crossing structures** (Rautenstrauch and Krausman 1989). To discourage use of the canals as a water supply by deer and other species, a small amount of water should be diverted to water catchments to allow wildlife to drink without risk of drowning.
- 4) **Provide escape structures** for deer and other species along any area of the canal which does not have a crossing structure or fencing. Cable-and-float directors in conjunction with stairs or ramps should be installed in the canal to provide deer and other species means of escaping the canal. In a study of Desert mule deer use of the Mohawk Canal, Rautenstrauch and Krausman (1989) found that deer swam an average of 947 meters before escaping via escape structures. They recommend escape structures should be spaced 2 km apart or less. Every canal section with a dam, siphon, or other hazard should have at least 2 escape structures, at least 1 of them upstream from the hazard.



*Figure 23: CAP canal wash siphon just south of the TMC (CS1)*



*Figure 24: CAP canal wash siphon within the TMC (CS2)*



*Figure 25: CAP canal wash siphon within the TMC (CS3)*



*Figure 26: CAP canal wash siphon within the TMC (CS4)*



*Figure 27: CAP canal wash siphon within the TMC (CS5)*



*Figure 28: CAP canal wash siphon within the TMC (CS6)*



*Figure 29: CAP canal wash siphon within the TMC (CS7)*



*Figure 30: Southern start of extensive CAP canal siphon near the Sandario and Mile Wide Intersection (CS8)*



*Figure 31: CAWCD CAP wildlife crossing structure (CS9)*



*Figure 32: CAWCD CAP wildlife crossing structure (CS10)*

## Impacts of Fences on Wildlife

Fencing is located throughout the Southwest and is generally intended to restrict movement of livestock, but may also impede wildlife access to critical resources, restrict migratory and escape routes, and fragment wildlife populations (Arizona Game and Fish Department 2012c). Harrington and Conover (2006) estimated an average annual mortality of ungulates (mule deer, pronghorn, and elk) of 0.25 mortalities/km of wire fence. Fence damage from wildlife-fence conflicts and ungulate deaths also causes economic loss to both land owners and governments (Harrington and Conover 2006).

### *Existing fences in the Linkage Design*

Stretches of double barbed-wire fences and chain-link fences are concentrated on the City of Tucson Central Avra Valley Storage and Recovery Project (CAVSARP) property maintained by the Tucson Water Department. Exclusionary chain-link fencing exists around infiltration basins within the CAVSARP, and is a barrier to wildlife movement (see *Figure 33* below). Some openings exist in between chain-link fences that may allow passage of some wildlife in-between exclusionary fencing (see *Figure 34* and *Figure 35* below). Numerous stretches of double-wired and chain-link fencing also exists along the CAVSARP property boundary, and are a hazard to wildlife (see *Figure 36 – Figure 38* below).

## Recommendation and Guidelines for Mitigation of Fences

The following recommendations, summarized from the Arizona Game and Fish Department Wildlife Compatible Fencing Guidelines (2012c) are designed to minimize wire fence impacts to wildlife, and should be used whenever possible:

- 1) **Remove any stretches of fence that are not necessary (this includes double fences).** Consider using natural barriers (boulder, hedges etc.) where possible instead of a fence. Removing fencing is especially important to allow access to resources (water etc.), crossings, low-traffic areas, and areas of mortality.
- 2) **Where fencing is unavoidable, the maximum height of the top wire should be less than 42 in. The minimum height should be 18 in wherever possible** (or a minimum of 16 in when required by ADOT right-of-way standards).
- 3) **Top and bottom wires should be smooth instead of barbed whenever possible.**
- 4) **“Goat bars”, or pvc pipe placed around the top two and bottom two wires, should be used wherever possible to facilitate wildlife crossings.** Installing piping in this manner lowers the height of the top strand of fence, and increases the height of the bottom strand of fence. It also provides a mechanism for wildlife to recognize sections of fencing that are more permeable.
- 5) **Accumulated brush along sections of fence decrease fence permeability, and should be removed regularly.**

For more information regarding wildlife compatible fencing and fence designs, please access AGFD (2012c), available online: [http://www.azgfd.gov/hgis/documents/110125\\_AGFD\\_fencing\\_guidelines.pdf](http://www.azgfd.gov/hgis/documents/110125_AGFD_fencing_guidelines.pdf)



*Figure 33: CAVSARP chain link fencing (F1)*



*Figure 34: Gap between CAVSARP chain-link fencing (F3)*



**Figure 35:** Gap between CAVSARP chain-link fencing (F4)



**Figure 36:** CAVSARP double fencing (F2)



*Figure 37: CAVSARP double fencing (F5)*



*Figure 38: CAVSARP double fencing (F6)*

## Impacts of Invasive Species on Wildlife

Numerous invasive species have been recognized as problematic in Pima County. Salt cedar, Giant reed, Bermuda grass, fountain grass, bullfrog, green sunfish, mosquitofish, crayfish, honey bee, horses, cattle burros, pigs, tiger salamander, non-native snails, and fire ants, were initially recognized by Pima County as potentially having adverse impacts on priority vulnerable species in the Sonoran Desert Conservation Plan (Pima County 2002a). Various plant species additionally including, buffelgrass, Johnson grass, Lehmann lovegrass, Mediterranean grass, Arabian grass, Natal grass, red brome, African rue, filaree, crystal iceplant, Malta starthistle, Sahara or African mustard, camelthorn, African sumac, Eurasian watermilfoil, giant salvinia, hydrilla, and water hyacinth, were also recognized by the Sonoran Institute as problematic invasive species of the Sonoran Desert (Pima County 2002a).

### *Existing invasive species in the Linkage Design*

Buffelgrass is present throughout the Coyote – Ironwood – Tucson Linkage Design, as seen below in experimental treatment plots near the Coyote – Ironwood linkage (see *Figure 39* below). Buffelgrass poses an immediate threat to the integrity of the Sonoran Desert by altering natural ecological processes, competing with and excluding native plants, reducing critical habitat, and introducing fire (NPS 2008). Arizona Statue R3-4-244 has approved listing of buffelgrass as a Regulated and Restricted Noxious Weed (Southern Arizona Buffelgrass Coordination Center 2007).

Eradication efforts for buffelgrass can include mechanical removal and herbicide applications (NPS 2008). The linkage design may offer a focused area for buffelgrass and other exotic species eradication efforts. A group of volunteers, the Sonoran Desert Weedwackers, has had particular success of mechanical removal of buffelgrass in focused areas, such as Tucson Mountain Park (Southern Arizona Buffelgrass Coordination Center 2007).

For more information on eradication of buffelgrass visit the Southern Arizona Buffelgrass Coordination Center at: <http://www.buffelgrass.org/>.



**Figure 39:** Buffelgrass and flagging looking towards the Coyote and Roskruge Mountains

## Impacts of Stream and Riparian Impediments on Wildlife

### *Importance of Riparian Systems in the Southwest*

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Santa Cruz River (see *Figure 40* below), Brawley, Robles, and Blanco Washes provide important habitat for many species in the linkage area, including the cactus ferruginous pygmy-owl.

### *Stream Impediments in the Linkage Design*

Most streams in Arizona have areas without surface water or riparian vegetation, and thus are naturally fragmented from the perspective of many wildlife species. But nearly all riparian systems in the Southwest also have been altered by human activity (Stromberg 2000) in ways that increase fragmentation. For example, the Santa Cruz River, and its riparian ecosystems in the linkage design have been heavily degraded due to groundwater pumping, flood control measures, water diversions, and other human activities (Fabre and Cayla 2009). In this stretch, the Santa Cruz River is usually dry most of the year, with flows only occurring from effluent discharged from wastewater treatment plants, and storm runoff (Fabre and Cayla 2009). For animals associated with streams or riparian areas, impediments are presented by road crossings, vegetation clearing, livestock grazing, invasion of non-native species, accumulation of trash and pollutants in streambeds, farming in channels, and gravel mining. Groundwater pumping, upland development, water recharge basins, dams, and concrete structures to stabilize banks and channels change natural flow regimes which negatively impacts riparian systems. Increased runoff from urban development not only scours native vegetation but can also create permanent flow or pools in areas that were formerly ephemeral streams. Invasive species, such as bullfrogs and giant reed, displace native species in some permanent waters.

Urbanization and exotic plants threaten the Santa Cruz River, and major washes in the linkage design. Aggressive protection of these areas and will enhance the utility of this linkage design. Approximately twenty riparian restoration projects have been undertaken since the mid 90's along the Santa Cruz River, demonstrating growing interest in protecting the river (Fabre and Cayla 2009).

### *Recommendations and Guidelines for Mitigating Stream Impediments*

We endorse the following management recommendations for riparian connectivity and habitat conservation in riparian areas.

- 1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency, and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).
  - Urban development contributes to a “flashier” (more flood-prone) system. Check dams and settling basins should be required in urban areas within the watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000)].
  - Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
  - Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993).

However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kupferberg 1997, Kiesecker and Blaustein 1998, Maret et al. 2006).

- 2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops, and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).
- 3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of the river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite bosques should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).
- 4) **Maintain biotic interactions within evolved tolerance ranges.** Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas (Belsky et al. 1999, National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).
- 5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, with a few becoming significant problems like tamarisk and Russian olive. Removing stressors and reestablishing natural flow regimes can help bring riparian communities back into balance, however some exotics are persistent and physical eradication is necessary to restore degraded systems (Stromberg 2000, Savage 2004, but see D’Antonio and Meyerson 2002). Elimination of unnatural perennial surface pools can eradicate water-dependent invasives like bullfrogs, crayfish, and mosquitofish.
- 6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel.** Buffer strips can protect and improve water quality, provide habitat and connectivity for a disproportionate number of species (compared to upland areas), and provide numerous social benefits including improving quality of life for residents and increasing nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Continuous corridors provide important wildlife connectivity but recommended widths to sustain riparian plant and animal communities vary widely (from 30 to 500 m) (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Buffers of sufficient width protect edge sensitive species from negative impacts like predation and parasitism. We therefore recommend buffer strips on each side of the channel at least 200 m wide measured perpendicular to the channel starting from the annual high water mark.
- 7) **Enforce existing regulations.** We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the

buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).

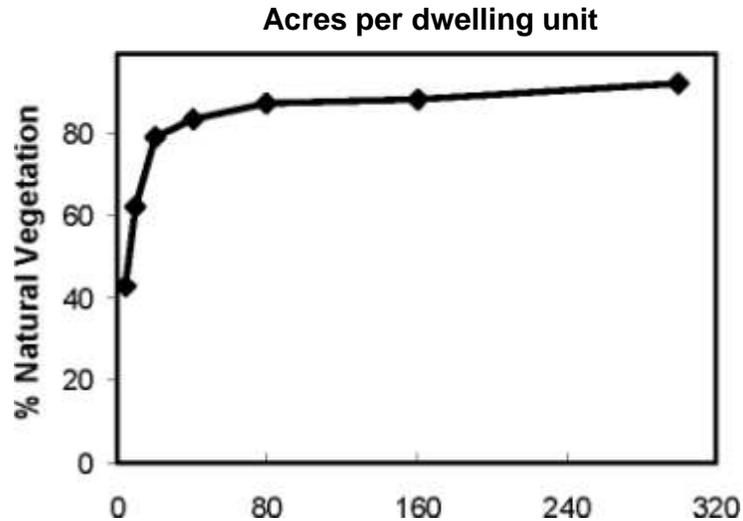


*Figure 40: Riparian vegetation along the Santa Cruz River*

## Urban Development as Barriers to Movement

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

- Development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which “hear” ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- Removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (see *Figure 41* below). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).



**Figure 41:** Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

- Decreased abundance and diversity of native species, and replacement by non-native species. In Arizona, these trends were evident for birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001), and loss of native species increased as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.
- Increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- Increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- Increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- Subsidized “suburban native predators” such as raccoons, foxes, and crows that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- Spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- Perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).
- Mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that

feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).

- Artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- Conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- Noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- Disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation, force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. Development currently accounts for approximately 2% of the land cover, and is expected to increase rapidly in parts of the Linkage Design.

### ***Urban Barriers in the Linkage Design***

The Ironwood – Tucson linkage is threatened by countless urban barriers. The following two areas within and near the linkage should be the focus of planning and urban barrier mitigation efforts:

- In the central portion of the linkage, various developments threaten to sever the main connection between the Ironwood wildland block and the Tucson wildland block through Avra Valley. There has been a significant amount of growth in areas southwest and west of Tucson Mountain Park and this growth is anticipated to continue and will include residential, commercial and other land used (Pima County 2008). Groups of light housing developments block connectivity between wildland blocks in this area. This is compounded further when houses block access to large buried sections of the CAP canal, which would otherwise allow connectivity for wildlife, as shown by the Google Earth image below (see *Figure 42* below). Species, such as the desert bighorn sheep, have already severed connectivity from previously used habitat in the Tucson Mountains, most likely due to human developments (Krausman 1997). Again, it is imperative that effective land use planning which considers wildlife and urban barrier mitigation take place within the linkage to allow wildlife connectivity between the Ironwood and Tucson wildland blocks.
- In and near the northern strand of the Ironwood – Tucson linkage, the town of Marana is continually expanding. The image from Google Earth below shows lands plotted for future development north of Twin Peaks Road (see *Figure 43* below). Census Bureau estimates indicate that Marana was the fourth fastest-growing city or town in Arizona from 1990 to 2000. Marana is growing by annexing existing communities such as Rillito (population 27,000) but even more importantly by annexing large areas of pristine land proposed as master-planned communities. Land use planning that addresses the needs of wildlife is needed in this area to protect

connectivity left between the Santa Cruz River and the northern Tucson Mountains. Much of the undeveloped land in this small area has been farmed or subject to past gravel mining and other industrial uses. Agriculture and other industry have been cited as potential cause for Tucson shovel-nosed snake decline (City of Tucson 2012). Effective land use planning, and urban barrier mitigation following the guidelines and recommendations outlined below is vital for this linkage and the Tucson – Tortolita – Santa Catalina Mountains Linkage Design which overlaps this linkage design.

### *Guidelines and Recommendations for Mitigation of Urban Barriers*

In addition to the preceding comments specific to both the Coyote – Ironwood Linkage and the Ironwood – Tucson Linkage, we offer the following recommendations to reduce the barrier effects of urban development throughout the Linkage Design:

- 1) **Integrate this Linkage Design into local land use plans.** Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design. 2) Discourage further residential development and subdivision of large parcels in the Linkage Design.
- 2) **Where development is permitted within the linkage design, encourage small building footprints** on large (> 40 acre) parcels with a minimal road network.
- 3) **Integrate this Linkage Design into county general plans,** and conservation plans of governments and nongovernmental organizations.
- 4) **Encourage conservation easements or acquisition of conservation land from willing land owners** in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
- 5) **Combine habitat conservation with compatible public goals** such as recreation and protection of water quality.
- 6) One reason we imposed a minimum width on each strand of the linkage design was to allow enough room for a **designated trail system** without having to compromise the permeability of the linkage for wildlife. Nonetheless, because of the high potential for human access, the trail system should be carefully planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and travel in groups in areas frequented by mountain lions or bears. Visitors should be discouraged from collecting reptiles and harassing wildlife.
- 7) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, **encourage landowners to be proud stewards of the linkage.** Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area. Developments within the linkage should have permeable perimeters, not walls. When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.

- 8) **Develop a public education campaign** to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.
- 9) **Discourage residents and visitors from feeding or providing water for wild mammals**, or otherwise allowing wildlife to lose their fear of people.
- 10) **Install wildlife-proof trash and recycling receptacles**, and encourage people to store their garbage securely.
- 11) **Do not install artificial night lighting** on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.
- 12) **Encourage the use of wildlife-friendly fencing** on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.
- 13) **Discourage the killing of ‘threat’ species** such as rattlesnakes.
- 14) **Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides**, and educate the public about the effects these chemicals have throughout the ecosystem.
- 15) **Pursue specific management protections for threatened, endangered, and sensitive species** and their habitats.
- 16) **Respect the property rights of the many people already living in these wildlife corridors**. Work with homeowners and residents to manage residential areas for wildlife permeability. Develop innovative programs that respect the rights of residents and enlist them as stewards of the linkage area.



**Figure 42:** Development in the central portion of the Ironwood – Tucson Linkage blocking access to a long CAP canal siphon just west of the Tucson wildland block near the Sandario/Mile Wide Road intersection



**Figure 43:** Development in the northern portion of the Ironwood – Tucson Linkage blocking access to and from the Santa Cruz River and the northern Tucson Mountains

## 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<sup>1</sup>. 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

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<sup>1</sup> 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. (A) Developing the model forces important assumptions into the open. (B) Using the model makes us explicitly deal with interactions (e.g., between species movement mobility and corridor length) that might otherwise be ignored. (C) The model is transparent, with every algorithm and model parameter available for anyone to inspect and challenge. (D) 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 44 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 *Acknowledgments*). 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<sup>2</sup>.

This scoring produced 4 scores (land cover, elevation, topographic position, distance from roads) for each pixel, each score being a number between 0 and 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<sup>3</sup> 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:

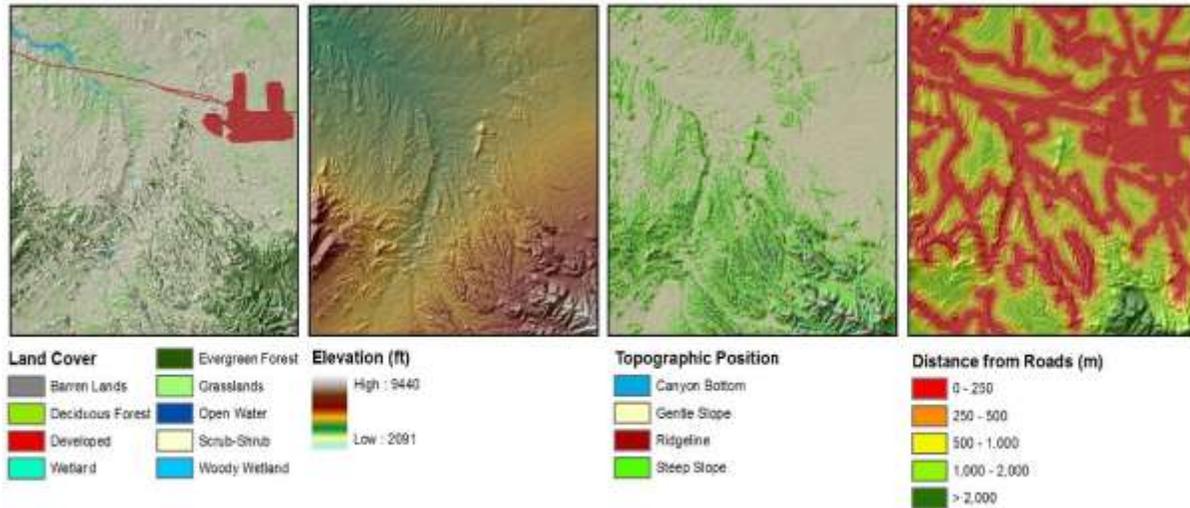
$$\text{HabitatSuitabilityScore} = \text{Veg}^{W1} * \text{Elev}^{W2} * \text{Topo}^{W3} * \text{Road}^{W4}$$

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

<sup>3</sup> 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 44:** 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<sup>2</sup>, 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species<sup>4</sup>. 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.

<sup>4</sup> 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*<sup>5</sup> (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<sup>6</sup>. 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<sup>7</sup>. 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 2<sup>nd</sup> 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 45* below). If a species had two or more distinct strands in its biologically best corridor, we eliminated any strand markedly worse than the best strand, but we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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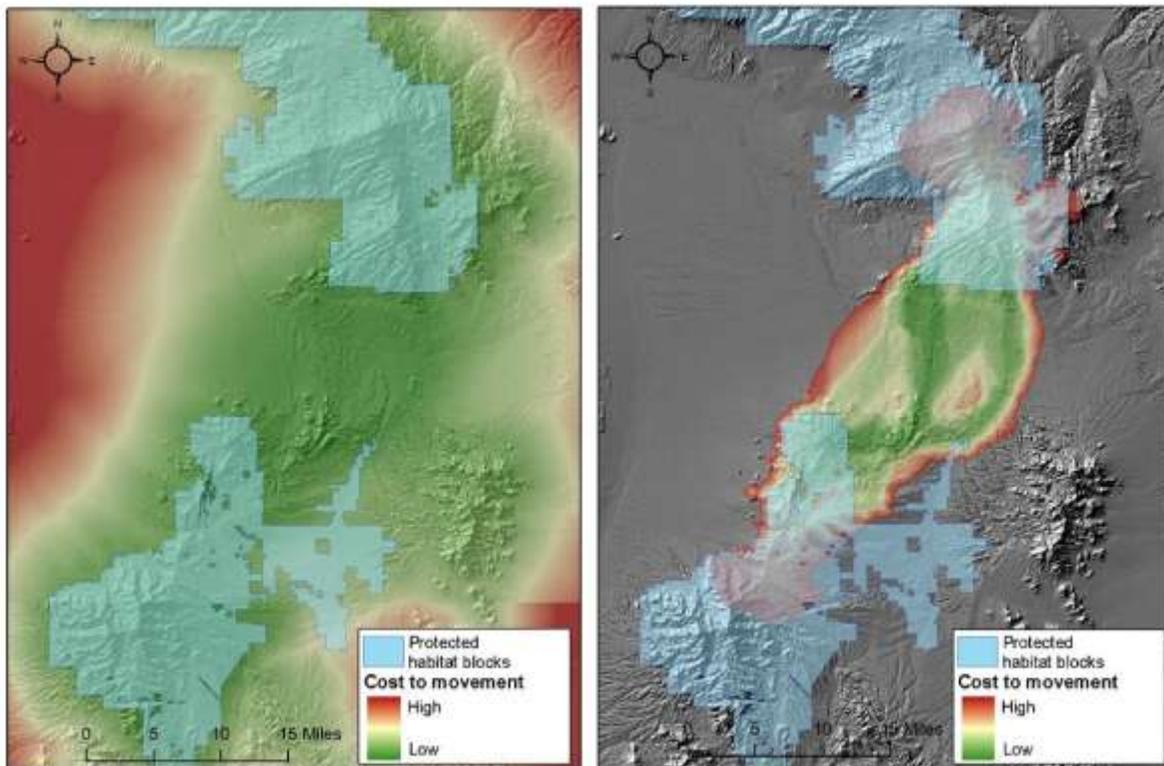
<sup>5</sup> Our approach has often been called Least Cost Corridor Analysis (Beier et al. 2006) because it identifies areas that require the least cost of travel (energetic cost, risk of mortality) to the animal. However, we avoid the words “least cost” because it is easily misunderstood as referring to the dollar cost of conserving land or building an underpass.

<sup>6</sup> 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. After developing a biologically best corridor for each species, we combined biologically best corridors to form a union of biologically best corridors (UBBC).

<sup>7</sup> 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 3<sup>rd</sup> 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<sup>8</sup> 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 45:** a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape

<sup>8</sup> 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. 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, and no widening was needed to encompass this diversity.

## 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 7:** 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	Gila Monster
<b>Factor Weights</b>					
<i>Land Cover</i>	65	70	0	30	10
<i>Elevation</i>	7	10	0	10	35
<i>Topography</i>	15	10	90	50	45
<i>Distance from Roads</i>	13	10	10	10	10
<b>Land Cover</b>					
<i>Conifer-Oak Forest and Woodland</i>	48	28		11	0
<i>Encinal</i>	48	50		11	56
<i>Mixed Conifer Forest and Woodland</i>	44	11		11	0
<i>Pine-Oak Forest and Woodland</i>	52	50		11	0
<i>Pinyon-Juniper Woodland</i>	67	67		11	44
<i>Ponderosa Pine Woodland</i>	52	44		11	0
<i>Spruce-Fir Forest and Woodland</i>	44	17		11	0
<i>Aspen Forest and Woodland</i>	41	22		11	0
<i>Juniper Savanna</i>	89	78		22	0
<i>Montane-Subalpine Grassland</i>	93	33		44	0
<i>Semi-Desert Grassland and Steppe</i>	100	72		56	56
<i>Big Sagebrush Shrubland</i>	78	89		33	0
<i>Blackbrush-Mormon-tea Shrubland</i>	74	67		44	0
<i>Chaparral</i>	52	50		11	44
<i>Creosotebush, Mixed Desert and Thorn Scrub</i>	89	94		44	78
<i>Creosotebush-White Bursage Desert Scrub</i>	89	94		44	33
<i>Desert Scrub (misc)</i>	74	100		89	78
<i>Gambel Oak-Mixed Montane Shrubland</i>	59	56		11	0
<i>Mat Saltbush Shrubland</i>	63	67		22	0
<i>Mesquite Upland Scrub</i>	74	72		33	67
<i>Mixed Low Sagebrush Shrubland</i>	74	89		44	0
<i>Paloverde-Mixed Cacti Desert Scrub</i>	63	100		78	100
<i>Pinyon-Juniper Shrubland</i>	70	78		22	44
<i>Sand Shrubland</i>	70	78		33	0
<i>Stabilized Coppice Dune and Sand Flat Scrub</i>	67	78		22	0
<i>Greasewood Flat</i>	41	61		33	0

	Badger	Black-tailed Jackrabbit	Black-tailed Rattlesnake	Desert Bighorn Sheep	Gila Monster
<i>Riparian Mesquite Bosque</i>	41	61		11	56
<i>Riparian Woodland and Shrubland</i>	41	67		11	56
<i>Arid West Emergent Marsh</i>	26	11		0	0
<i>Active and Stabilized Dune</i>	22	61		0	0
<i>Badland</i>	37	22		0	0
<i>Barren Lands, Non-specific</i>	33	28		22	0
<i>Bedrock Cliff and Outcrop</i>	15	28		89	89
<i>Cliff and Canyon</i>	11	28		100	89
<i>Mixed Bedrock Canyon and Tableland</i>	11	22		89	89
<i>Playa</i>	15	22		11	0
<i>Volcanic Rock Land and Cinder Land</i>	0	17		33	100
<i>Warm Desert Pavement</i>	11	17		11	44
<i>Wash</i>	22	56		11	78
<i>Invasive Grassland or Forbland</i>	63	61		44	0
<i>Invasive Riparian Woodland and Shrubland</i>	26	56		11	67
<i>Recently Mined or Quarried</i>	7	0		0	0
<i>Agriculture</i>	48	50		0	0
<i>Developed, Medium - High Intensity</i>	0	11		0	11
<i>Developed, Open Space - Low Intensity</i>	30	44		0	100
<i>Open Water</i>	7	11		0	0
<b>Elevation (ft)</b>					
	0 - 1676: 100	0 - 1829: 100		0 - 899: 89	0 - 518: 67
	1676 - 2438: 78	1829 - 2438: 67		899 - 1006: 100	518 - 1219: 100
	2438 - 4000: 44	2438 - 4000: 22		1006 - 2134: 78	1219 - 1463: 67
				2134 - 4000: 33	1463 - 1737: 33
					1737 - 4000: 0
<b>Topographic Position</b>					
<i>Canyon Bottom</i>	56	72	100	22	100
<i>Flat - Gentle Slopes</i>	100	94	11	33	56
<i>Steep Slope</i>	26	67	100	100	100
<i>Ridgetop</i>	37	67	100	56	100
<b>Distance from Roads</b>					
	0 - 250: 44	0 - 250: 11	0 - 35: 0	0 - 1000: 44	0 - 1000: 56
	250 - 15000: 100	250 - 500: 44	35 - 500: 56	1000 - 15000: 100	1000 - 3000: 78
		500 - 1000: 78	500 - 15000: 100		3000 - 15000: 100
		1000 - 15000: 100			

	Jaguar	Javelina	Kit Fox	Mountain Lion	Mule Deer
<b>Factor Weights</b>					
<i>Land Cover</i>	60	50	75	70	80
<i>Elevation</i>	5	30	0	0	0
<i>Topography</i>	15	20	15	10	15
<i>Distance from Roads</i>	20	0	10	20	5
<b>Land Cover</b>					
<i>Conifer-Oak Forest and Woodland</i>	89	33	22	100	67
<i>Encinal</i>	89	67	33	100	78
<i>Mixed Conifer Forest and Woodland</i>	78	44	17	78	78
<i>Pine-Oak Forest and Woodland</i>	78	33	17	100	78
<i>Pinyon-Juniper Woodland</i>	89	56	22	100	56
<i>Ponderosa Pine Woodland</i>	67	44	17	67	56
<i>Spruce-Fir Forest and Woodland</i>	67	22	0	67	22
<i>Aspen Forest and Woodland</i>	44	0	6	78	100
<i>Juniper Savanna</i>	78	33	78	67	67
<i>Montane-Subalpine Grassland</i>	67	22	22	44	67
<i>Semi-Desert Grassland and Steppe</i>	100	89	100	56	89
<i>Big Sagebrush Shrubland</i>	67	11	67	44	78
<i>Blackbrush-Mormon-tea Shrubland</i>	56	0	67	44	44
<i>Chaparral</i>	67	78	44	78	67
<i>Creosotebush, Mixed Desert and Thorn Scrub</i>	89	78	100	44	44
<i>Creosotebush-White Bursage Desert Scrub</i>	67	67	100	44	44
<i>Desert Scrub (misc)</i>	67	89	100	44	44
<i>Gambel Oak-Mixed Montane Shrubland</i>	78	22	56	78	67
<i>Mat Saltbush Shrubland</i>	56	0	72	44	22
<i>Mesquite Upland Scrub</i>	67	89	56	67	78
<i>Mixed Low Sagebrush Shrubland</i>	44	0	67	44	56
<i>Paloverde-Mixed Cacti Desert Scrub</i>	56	100	78	33	78
<i>Pinyon-Juniper Shrubland</i>	67	0	67	89	56
<i>Sand Shrubland</i>	44	0	89	56	33
<i>Stabilized Coppice Dune and Sand Flat Scrub</i>	44	33	100	56	44
<i>Greasewood Flat</i>	78	0	83	44	44
<i>Riparian Mesquite Bosque</i>	100	100	61	67	78
<i>Riparian Woodland and Shrubland</i>	100	89	50	89	78
<i>Arid West Emergent Marsh</i>	89	56	11	22	56
<i>Active and Stabilized Dune</i>	11	22	72	22	0
<i>Badland</i>	11	11	11	44	11

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

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

	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake	Tucson Shovel-nosed Snake
<i>Playa</i>	78	22	0	11
<i>Volcanic Rock Land and Cinder Land</i>	0	0	67	0
<i>Warm Desert Pavement</i>	56	44	0	33
<i>Wash</i>	78	78	67	78
<i>Invasive Grassland or Forbland</i>	78	11	22	22
<i>Invasive Riparian Woodland and Shrubland</i>	78	0	0	0
<i>Recently Mined or Quarried</i>	67	0	0	0
<i>Agriculture</i>	67	0	0	0
Developed, Medium - High Intensity	44	0	0	0
Developed, Open Space - Low Intensity	67	33	56	22
Open Water	67	0	0	0
<b><i>Elevation (ft)</i></b>				
	0 - 1402: 100	0 - 610: 78	0 - 427: 56	0 - 610: 100
	1402 - 1600: 67	610 - 914: 100	427 - 610: 78	610 - 732: 78
	1600 - 1768: 56	914 - 1524: 78	610 - 1707: 100	732 - 792: 44
	1768 - 4000: 22	1524 - 2134: 33	1707 - 2286: 56	792 - 914: 11
		2134 - 4000: 0	2286 - 4000: 0	914 - 4000: 0
<b><i>Topographic Position</i></b>				
Canyon Bottom	100	100	100	0
Flat - Gentle Slopes	100	100	33	100
Steep Slope	44	44	100	0
Ridgetop	44	44	100	0
<b><i>Distance from Roads</i></b>				
	0 - 200: 5	0 - 250: 56	0 - 500: 56	0 - 250: 56
	200 - 1000: 67	250 - 500: 67	500 - 1000: 67	250 - 1000: 67
	1000 - 3000: 89	500 - 1000: 78	1000 - 2000: 78	1000 - 2000: 89
	3000 - 15000: 100	1000 - 15000: 100	2000 - 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 (NMGF 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<sup>2</sup> (Long 1973). Goodrich and Buskirk (1998) found an average home range of 12.3 km<sup>2</sup> for males and 3.4 km<sup>2</sup> 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<sup>2</sup>. Messick and Hornocker (1981) found an average home range of 2.4 km<sup>2</sup> for adult males and 1.6 km<sup>2</sup> 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 7*.

*Patch size and configuration analysis* – We defined minimum potential habitat patch size as 2 km<sup>2</sup>, 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<sup>2</sup>, 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 within the potential linkage area. Within the BBC in the Coyote – Ironwood strand, habitat suitability scores ranged from 17.8 to 100.0, with an average suitability score of 82.3 (S.D: 11.9) (see *Figure 46* below). Almost the entire BBC in the Coyote – Ironwood strand (99.8%) is occupied by a potential population core, with the rest occupying non-suitable habitat (see *Figure 47* below). Most of the BBC (93.0%) was greater than its estimated needed minimum width (see *Figure 48* below). The BBC was measured at 26.5 km (16.5 mi) in length between wildland blocks used for analysis. Within the BBC in Ironwood – Tucson strand, habitat suitability scores ranged from 37.4 to 92.7, with an average of 78.3 (S.D:13.5) (see *Figure 49* below). Most of the BBC in the Ironwood – Tucson strand (99.7%) is occupied by a potential population core, with the rest occupying non-suitable habitat (see *Figure 50* below). Most of the BBC (98.4% ) was greater than its estimated needed minimum width (see *Figure 51* below). The BBC was measured at 18.0 km (11.2 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 in both the Coyote – Ironwood strand and the Ironwood – Tucson strand. 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 and Sandario Road, and habitat fragmentation.

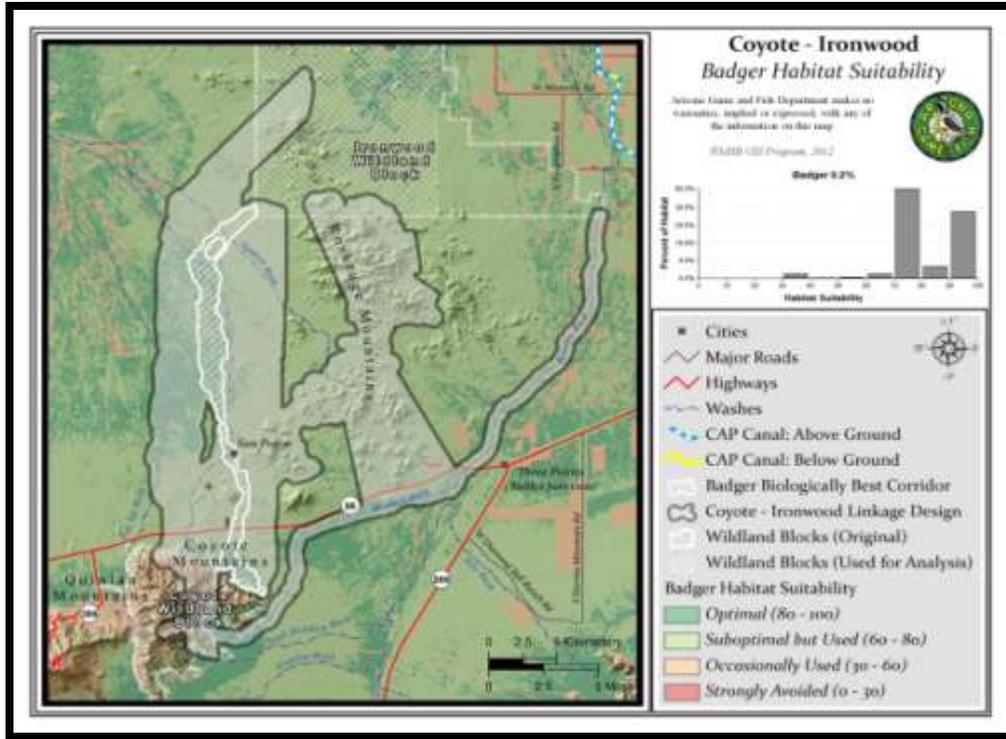


Figure 46: Map of Coyote – Ironwood modeled habitat suitability for badger

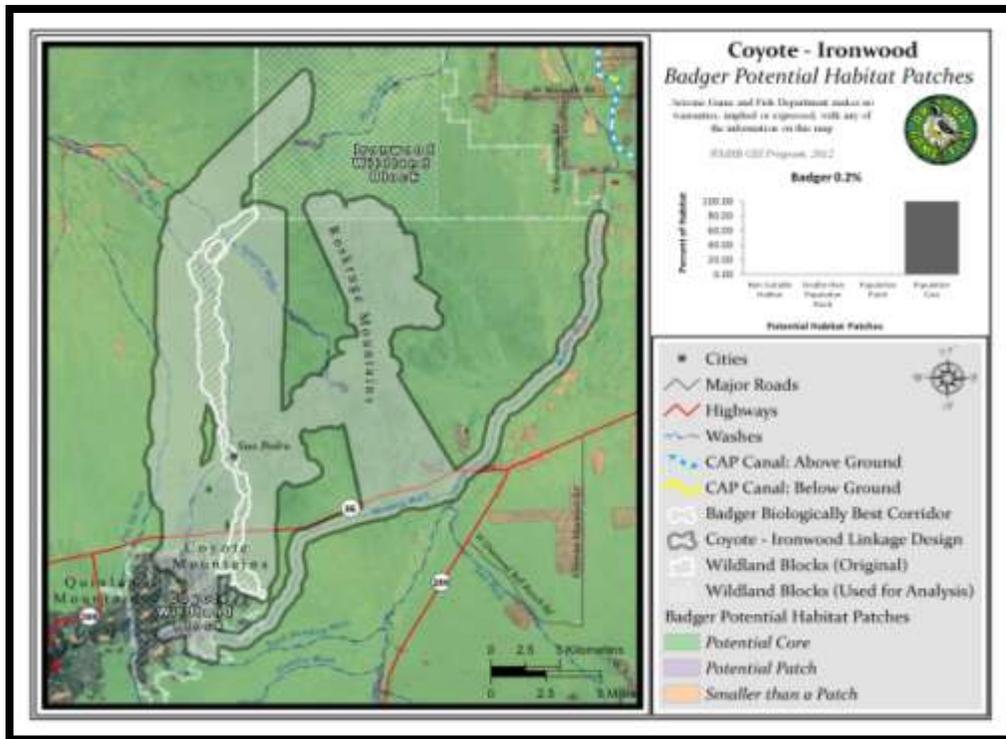


Figure 47: Map of Coyote – Ironwood potential habitat patches for badger

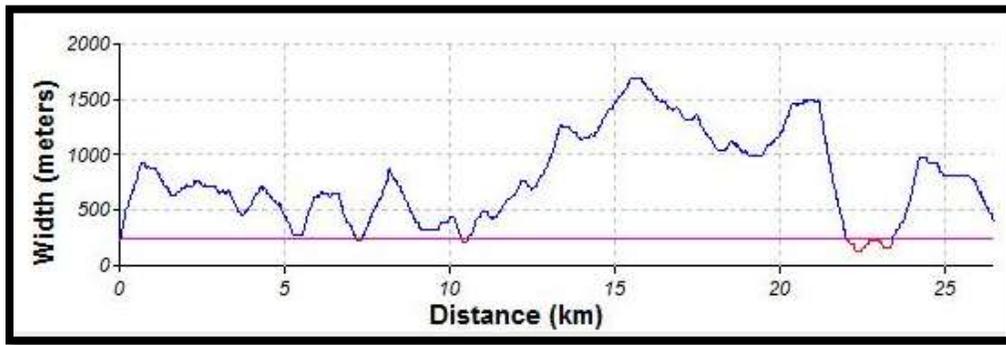


Figure 48: Width along the Coyote – Ironwood badger single species corridor

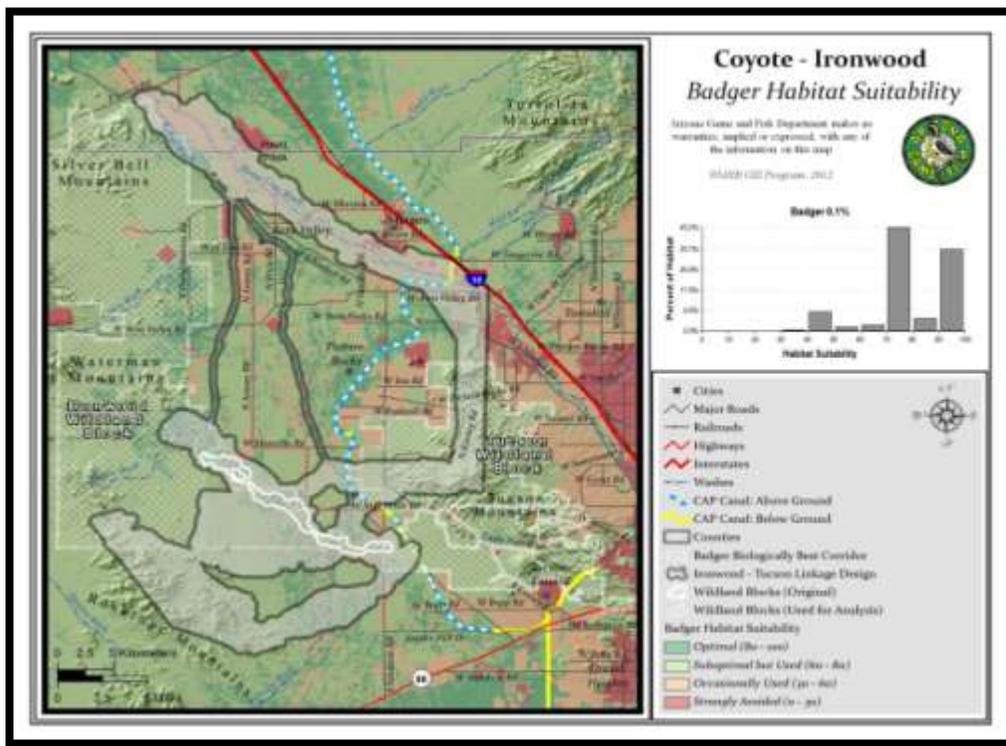


Figure 49: Map of Ironwood – Tucson modeled habitat suitability for badger

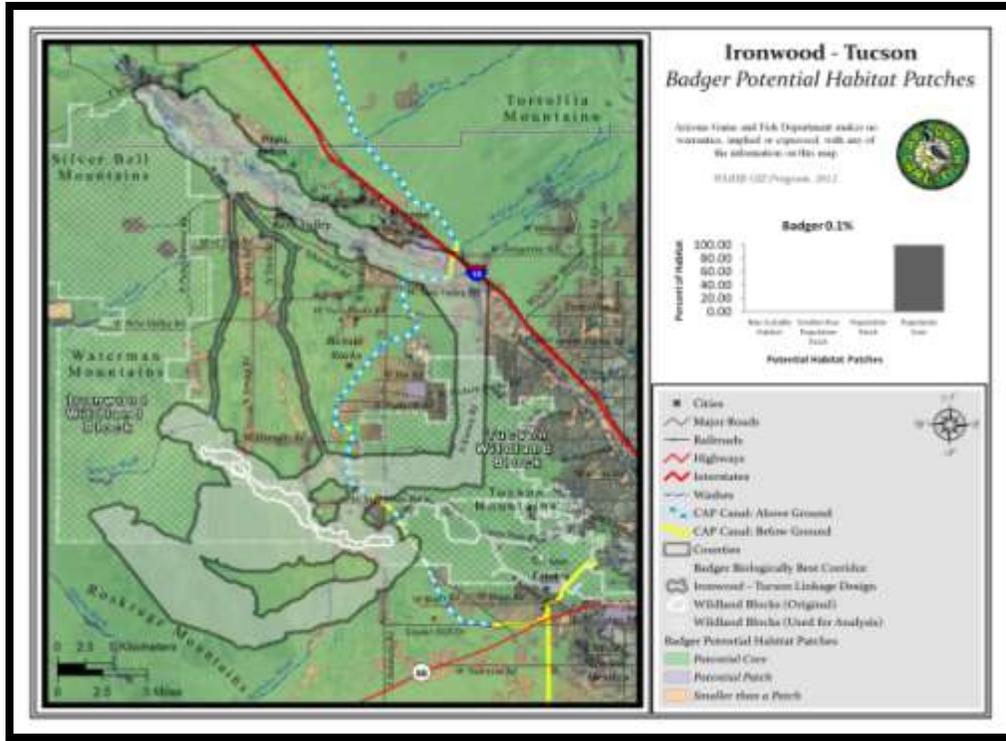


Figure 50: Map of Ironwood – Tucson potential habitat patches for badger

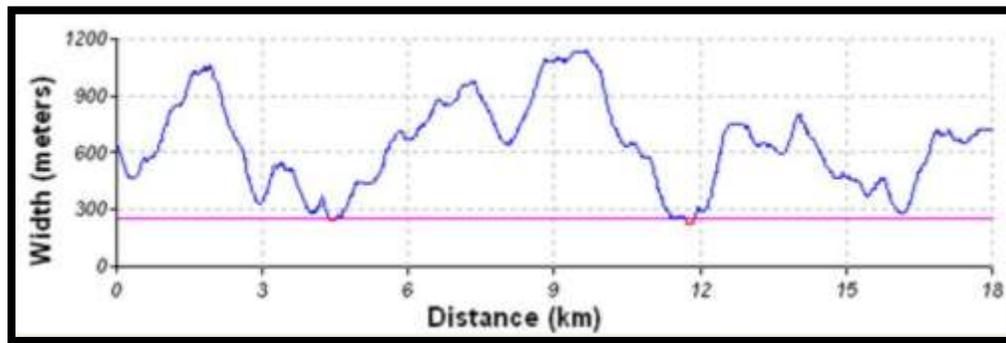


Figure 51: Width along the Ironwood – Tucson badger single species corridor

## Black-tailed Jackrabbit, *Lepus californius*

### *Justification for Selection*

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).



*Photo courtesy George Andrejko, AGFD*

### *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 7*.

*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.

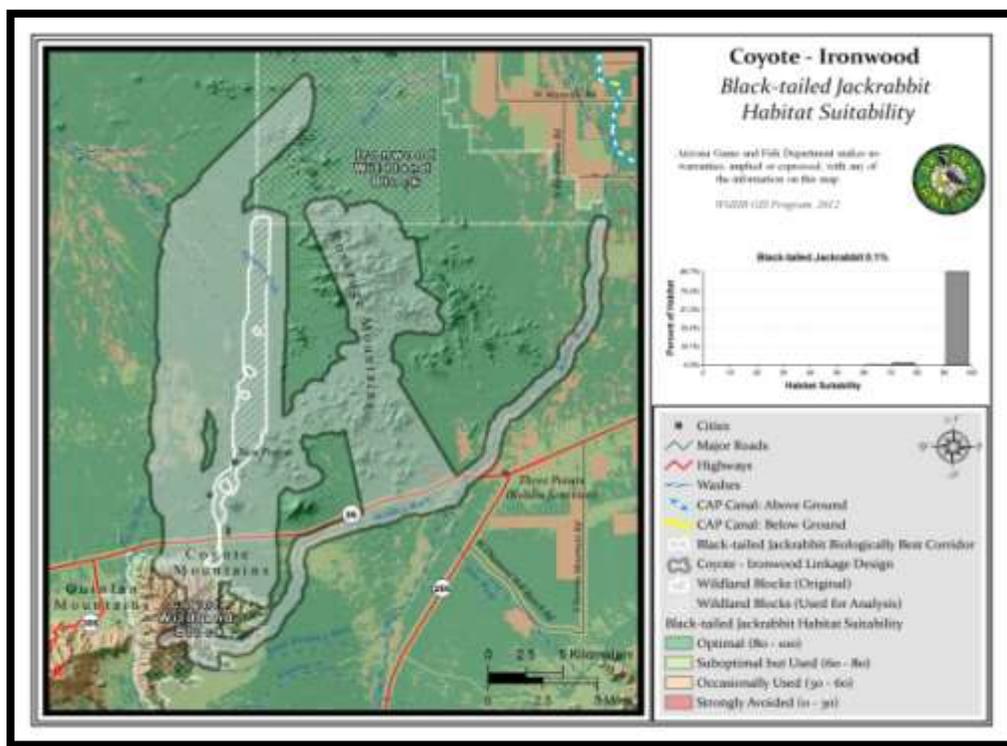
*Biologically best corridor analysis* – We used the methods described in Appendix A to identify the biologically best corridor for this species. Black-tailed jackrabbit were considered a passage species based

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 potential linkage area. Within the BBC in the Coyote – Ironwood strand, habitat suitability scores ranged from 66.2 to 99.4, with an average suitability of 98.4 (S.D: 4.64) (see *Figure 52* below). The entire BBC in the Coyote – Ironwood strand (100.0%) is occupied by a potential population core (see *Figure 53* below). Most of the BBC (93.4%) was greater than its estimated needed minimum width (see *Figure 54* below). The BBC was measured at 24.5 km (15.2 mi) in length between wildland blocks used for analysis. Within the BBC in Ironwood – Tucson strand, habitat suitability scores ranged from 21.2 to 99.4, with an average of 96.9 (S.D:10.91) (see *Figure 55* below). Most of the BBC in the Ironwood – Tucson strand (98.7%) is occupied by a potential population core, with the rest occupying non-suitable habitat (see *Figure 56* below). Most of the BBC (96.7%) was greater than its estimated needed minimum width (see *Figure 57* below). The BBC was measured at 15.1 km (9.4 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 badger in both the Coyote – Ironwood strand and the Ironwood – Tucson strand.



**Figure 52:** Map of Coyote – Ironwood modeled habitat suitability for black-tailed jackrabbit

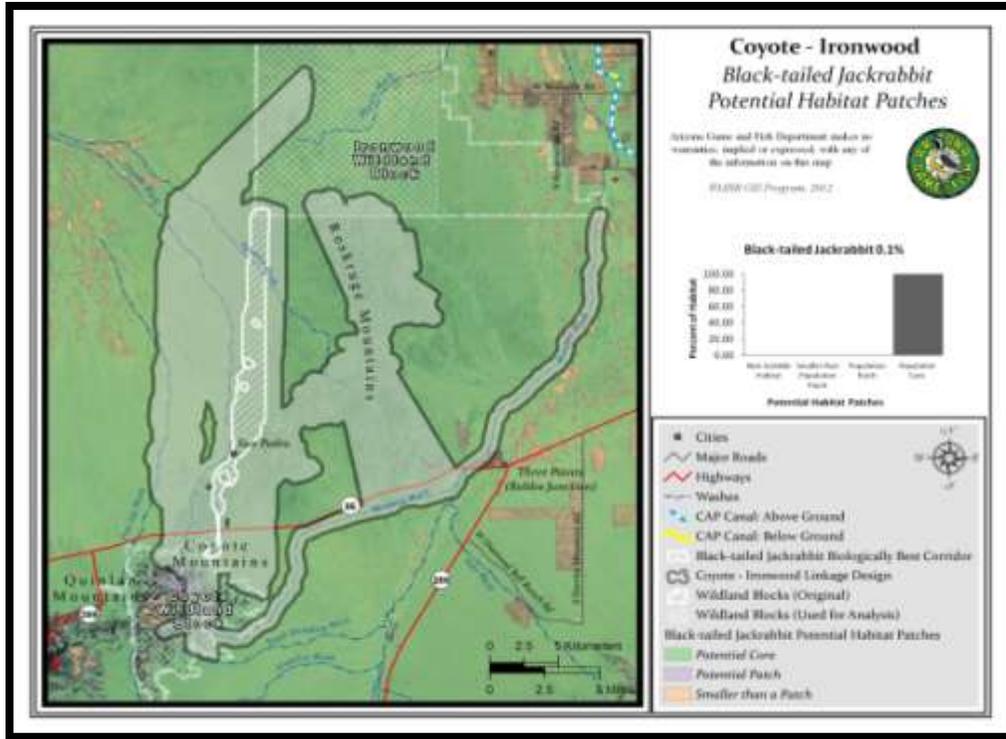


Figure 53: Map of Coyote – Ironwood potential habitat patches for black-tailed jackrabbit



Figure 54: Width along the Coyote – Ironwood black-tailed jackrabbit single species corridor

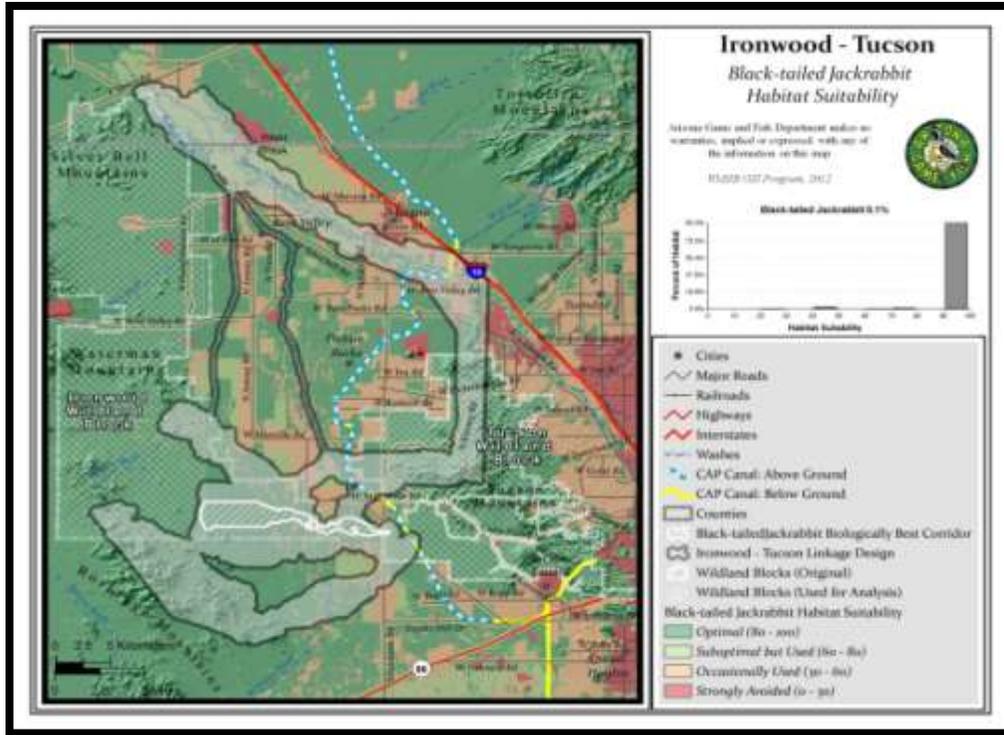


Figure 55: Map of Ironwood – Tucson modeled habitat suitability for black-tailed jackrabbit

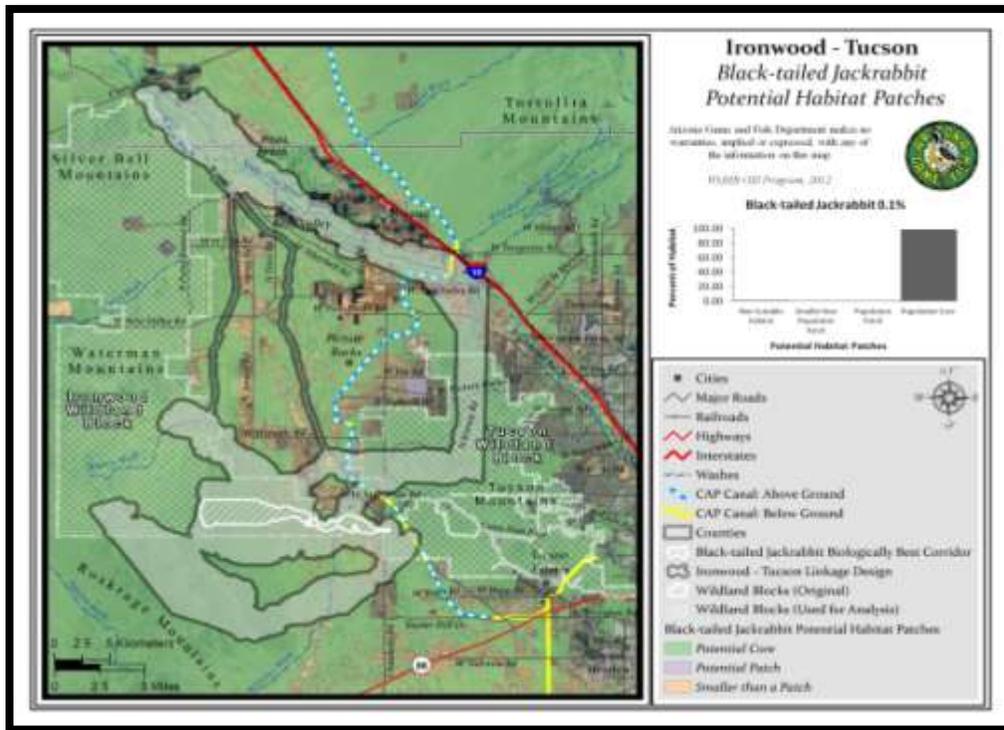
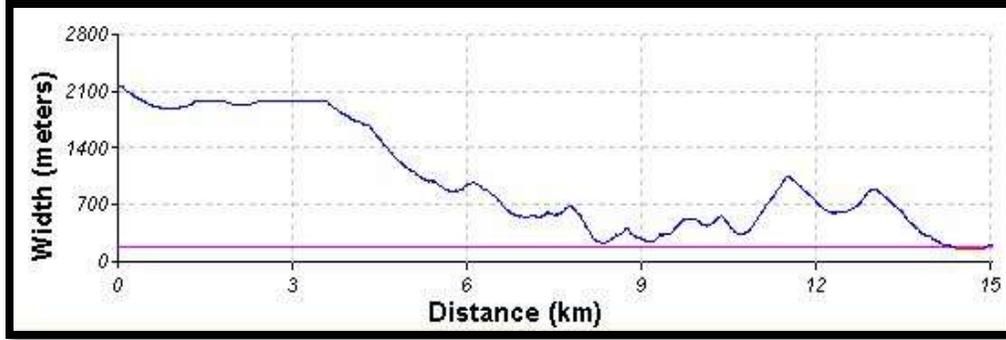


Figure 56: Map of Ironwood – Tucson potential habitat patches for black-tailed jackrabbit



*Figure 57: Width along the Ironwood – Tucson black-tailed jackrabbit single species 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.

### *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).



*Photo courtesy Randy Babb, AGFD*

### *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 7*.

*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 distance 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 Coyote – Ironwood strand. Habitat suitability scores ranged from 0 to 100, with an average suitability of 78.6 (S.D: 37.3) (see *Figure 58* below). Most of the trimmed BBC, 69.7%, is occupied by a potential population core, with 4.8% occupied by a potential habitat patch, 24.3% occupied by suitable habitat smaller than a patch, and the remainder by non-suitable habitat (see *Figure 59* below). Most of the trimmed BBC (95.2%) was greater than its estimated needed minimum width (see *Figure 60* below). The trimmed corridor was measured at 29.4 km (18.3 mi) in length between wildland blocks used for analysis. This corridor is of considerable distance for black-tailed rattlesnake to travel between wildland blocks. However, since this species was classified as a corridor dweller in this analysis, and its potential population cores and habitat patches are reasonably close together, this corridor should function to allow connectivity between wildland blocks. No single species BBC was modeled for black-tailed rattlesnake between the Ironwood and Tucson wildland blocks due to core/patch distance, amount of strongly avoided habitat between blocks, limited travel distance (Beck 1995), and limited dispersal of similar species (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team). However, habitat suitability and potential habitat patches were modeled as part of this analysis (see *Figure 61* and *Figure 62* below)

*Union of biologically best corridors* – The linkage design captures more suitable habitat in the southern and eastern portions of the Roskrige Mountains, and in the northern and western portions of the Tucson Mountains. However, the majority of the remaining linkage design consists of gentle slopes and is considered strongly avoided habitat for black-tailed rattlesnake.

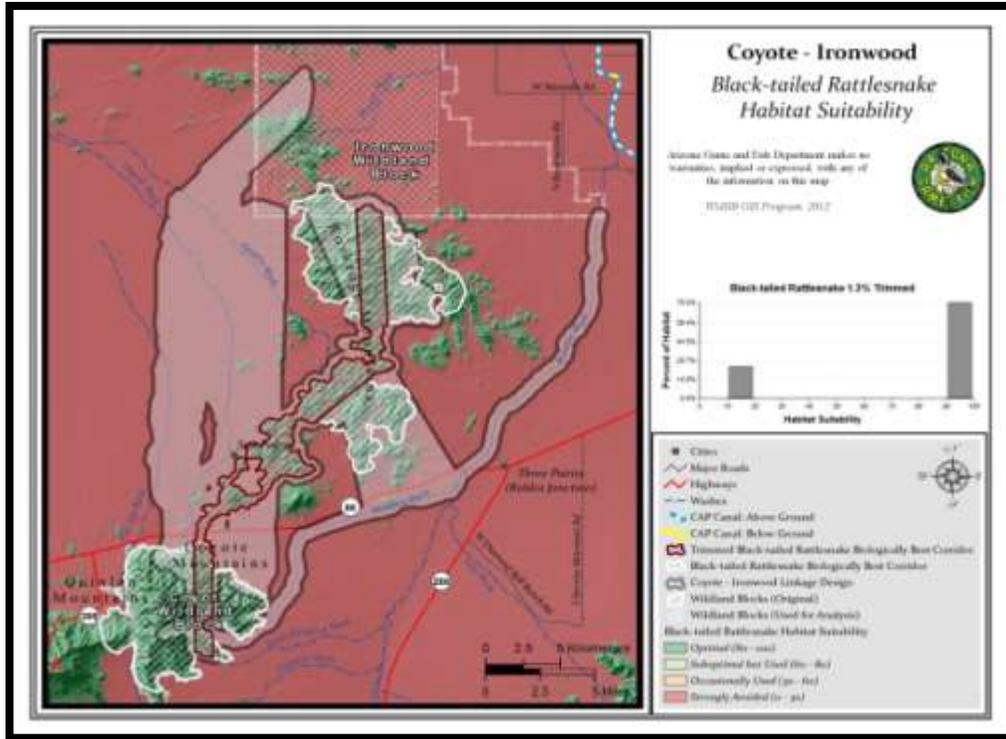


Figure 58: Map of Coyote – Ironwood modeled habitat suitability for black-tailed rattlesnake

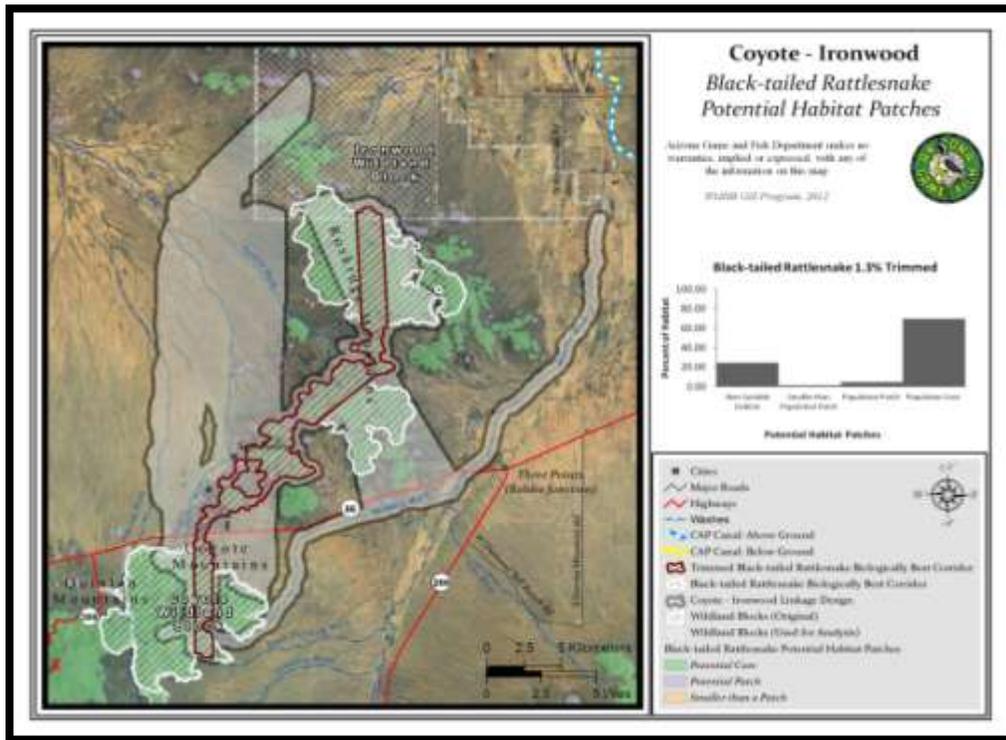


Figure 59: Map of Coyote – Ironwood potential habitat patches for black-tailed rattlesnake

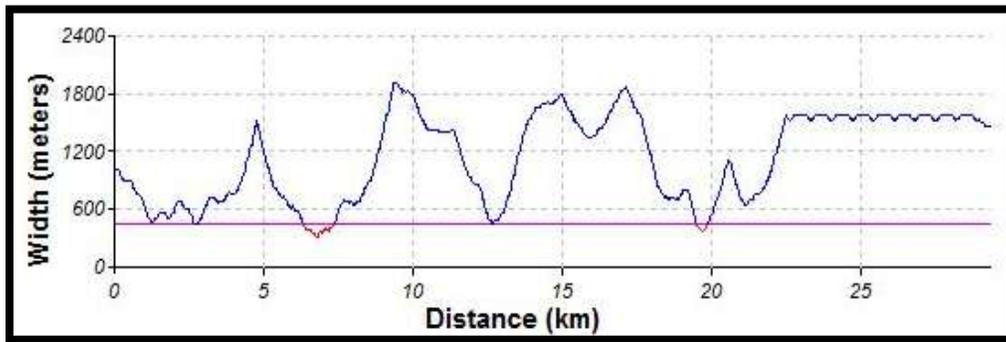


Figure 60: Width along the Coyote – Ironwood trimmed black-tailed rattlesnake single species corridor

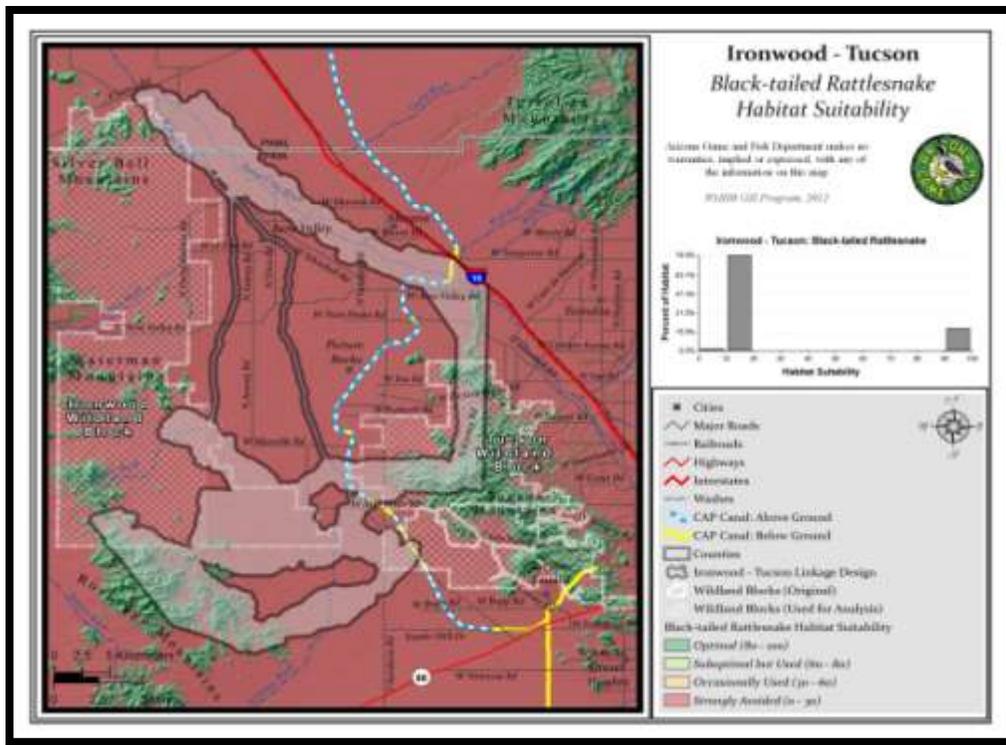


Figure 61: Map of Ironwood – Tucson modeled habitat suitability for black-tailed rattlesnake

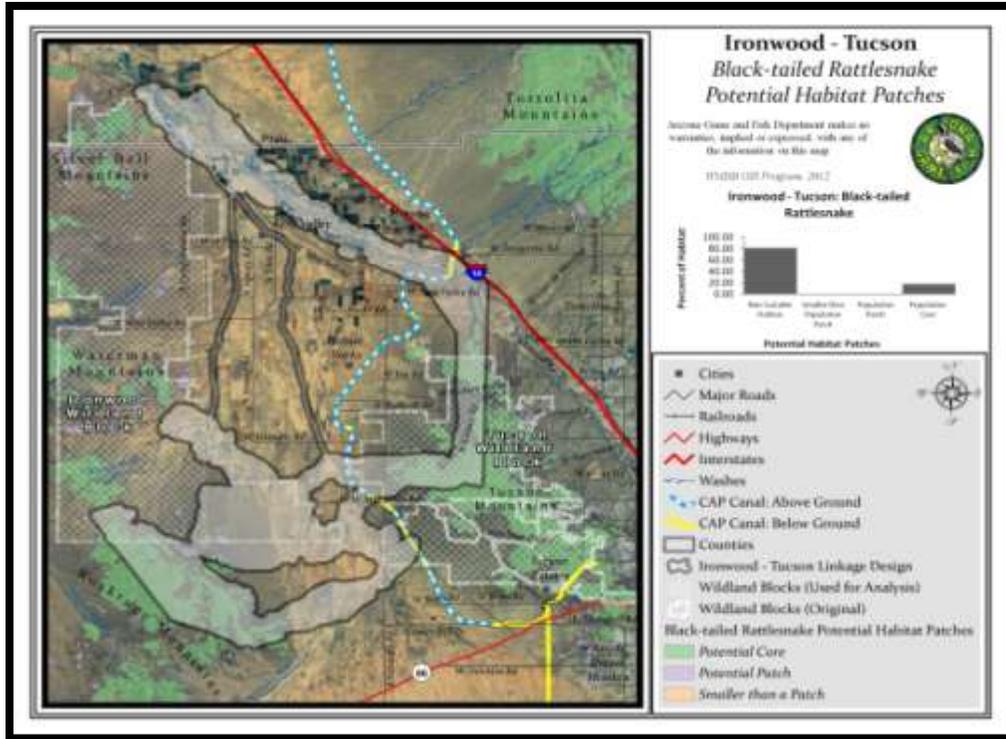


Figure 62: Ironwood – Tucson potential habitat patches and cores for black-tailed rattlesnake

## Desert Bighorn Sheep, *Ovis canadensis nelsoni*

### Justification for Selection

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



Photo courtesy George Andrejko, AGFD

### 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.

### 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).

Desert bighorn sheep used both the Coyote and Tucson wildland blocks as habitat historically, but do not have population distributions within these blocks as of 1960 (see *Figure 63* below; Brown 1993). However, the desert bighorn sheep population that exists primarily in the West Silver Bell and Silver Bell Mountains within the Ironwood wildland block today, represent one of the last viable desert bighorn sheep populations indigenous to the mountains surrounding Tucson (Bristow et al. 1996). Krausman (1997) stated that had human developments not occurred and habitats not been altered, the corridors connecting the mountain ranges surrounding Tucson might have ensured a higher population than exists today. Restoration of habitat and permeability within these corridors offer an opportunity for desert bighorn sheep populations in the Ironwood Wildland Block to achieve landscape connectivity with historical former habitats. However, connectivity in the Coyote – Ironwood strand seems more probable due to suitable habitat and potential patch/core distances, than does the Ironwood – Tucson strand.

### ***Spatial Patterns***

Home ranges for bighorn sheep vary depending upon population size, availability and connectivity of suitable habitat, and availability of water resources (Singer et al. 2001). Home ranges have been reported to range from 6.1 km<sup>2</sup> to 54.7 km<sup>2</sup> (Singer et al. 2001). One desert bighorn sheep study in Arizona reports an average home range of 16.9 ± 3.38 km<sup>2</sup> for ewes, and home ranges for males that increased with age from 11.7 km<sup>2</sup> for a one year old to 37.3 km<sup>2</sup> 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 7*.

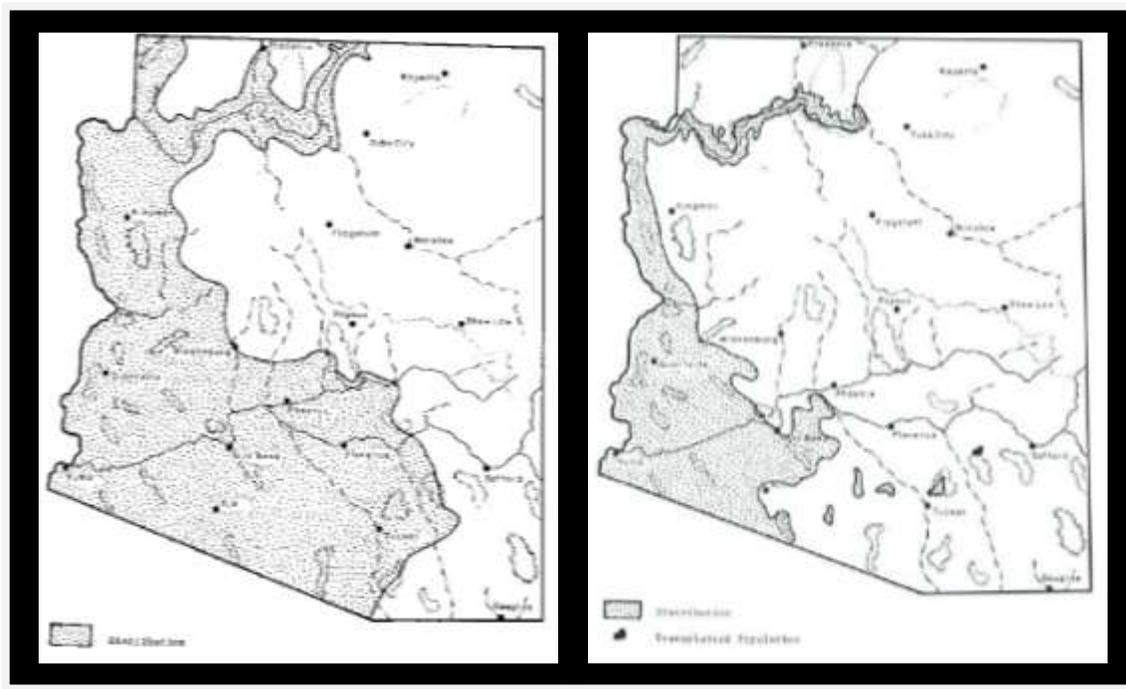
*Patch size and configuration analysis* – We defined minimum potential habitat patch size as 16.9 km<sup>2</sup> (Shackleton 1985), and minimum potential habitat core size was defined as 84.5 km<sup>2</sup>, or five times the minimum patch size. To determine potential habitat patches and cores, the habitat 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. 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 desert bighorn sheep within the trimmed BBC used in the Coyote – Ironwood strand. Habitat suitability scores ranged from 0 to 95.5, with an average suitability of 70.2 (S.D: 19.6) (see *Figure 64* below). Some, 34.5%, of the trimmed BBC is occupied by a potential population core, with 19.9% occupied by a potential habitat patch, 27.2% occupied by suitable habitat smaller than a patch, and the remainder by non-suitable habitat (see *Figure 65* below). Most of the trimmed BBC (94.3%) was greater than its estimated needed minimum width (see *Figure 66* below). The trimmed corridor was measured at 29.2 km (18.1 mi) in length between wildland blocks used for analysis. This corridor travels across numerous potential population cores, potential habitat patches and suitable habitat smaller than a patch. The close proximity of cores and patches, and the amount of suitable habitat in this corridor, make desert bighorn sheep connectivity between the Ironwood and Coyote wildland blocks and across State Route 86 probable. Within the trimmed BBC used in the Ironwood – Tucson strand, habitat suitability scores ranged from 0 to 95.5, with an average suitability of 57.3 (S.D: 18.4) (see *Figure 67* below). Some of the trimmed BBC, 28.3%, is occupied by a potential population core, with 6.9% occupied by a potential habitat patch, and the remainder by non-suitable habitat (see *Figure 68* below). Most of the trimmed BBC (93.8%) was greater than its estimated minimum width (see *Figure 69* below). The trimmed corridor was measured at 16.3 km (10.1 mi) in length between wildland blocks used for analysis. This corridor travels through mostly occasional use habitat, and a potential habitat core in the Tucson wildland block is approximately 13.7 km (8.5 mi) from suitable habitat smaller than a patch in the Roskrige Mountains within the original Ironwood wildland block.

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



**Figure 63:** Desert bighorn sheep known and suspected distribution in 1900 (left) and known distribution in 1960 (right) from (Brown 1993)

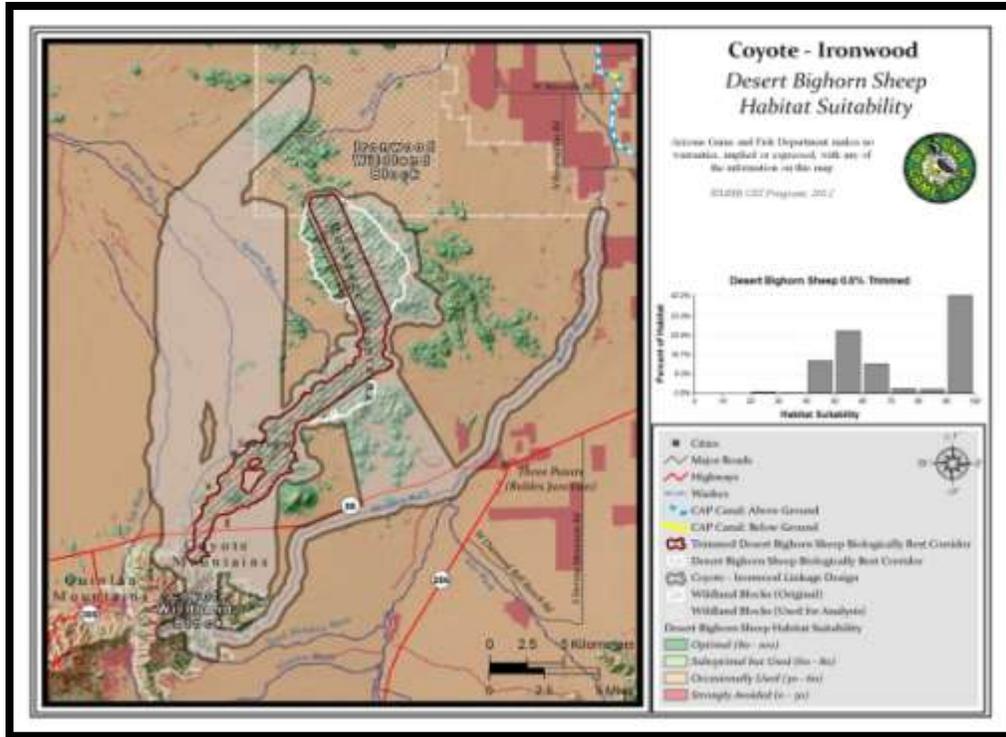


Figure 64: Map of Coyote – Ironwood modeled habitat suitability for desert bighorn sheep

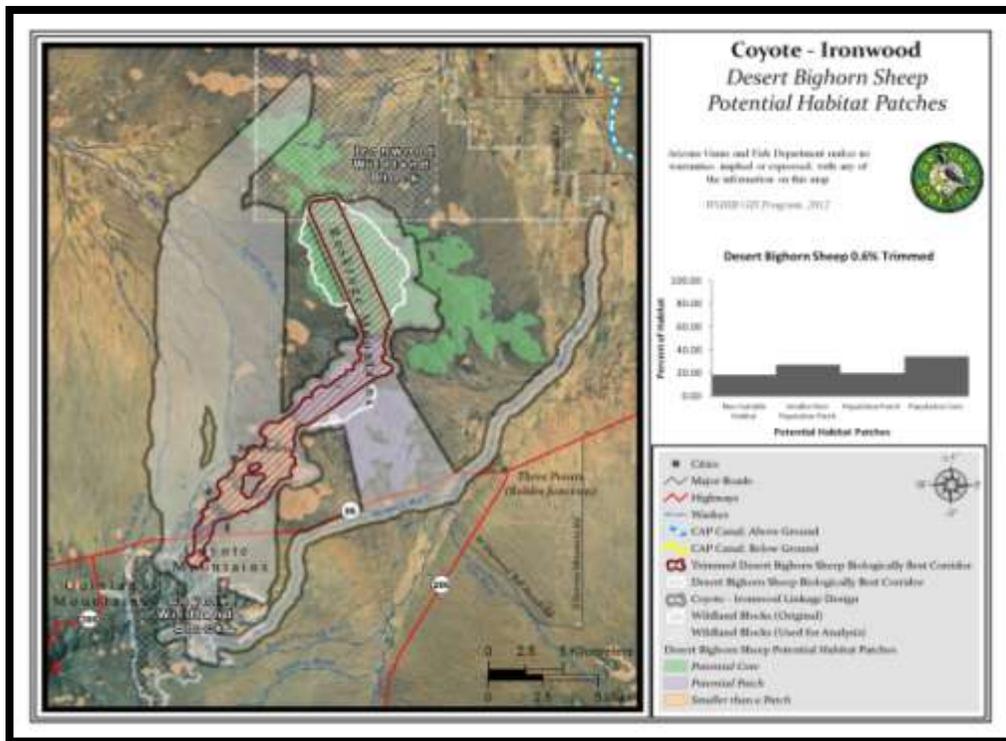


Figure 65: Map of Coyote – Ironwood potential habitat patches and cores for desert bighorn sheep

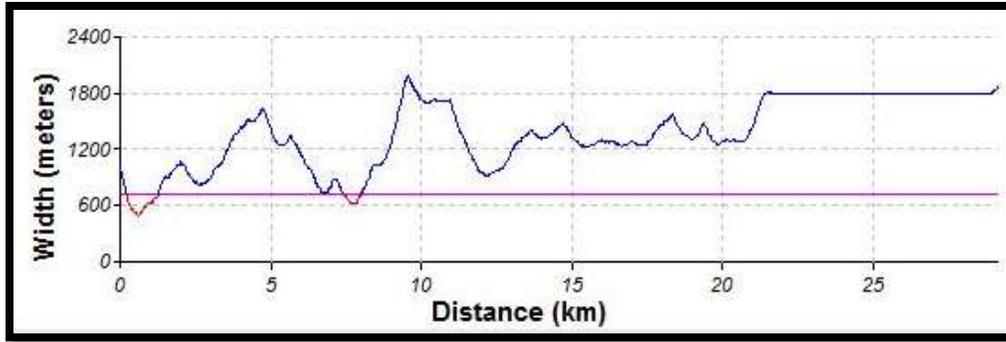


Figure 66: Width along the Coyote – Ironwood trimmed desert bighorn sheep single species corridor

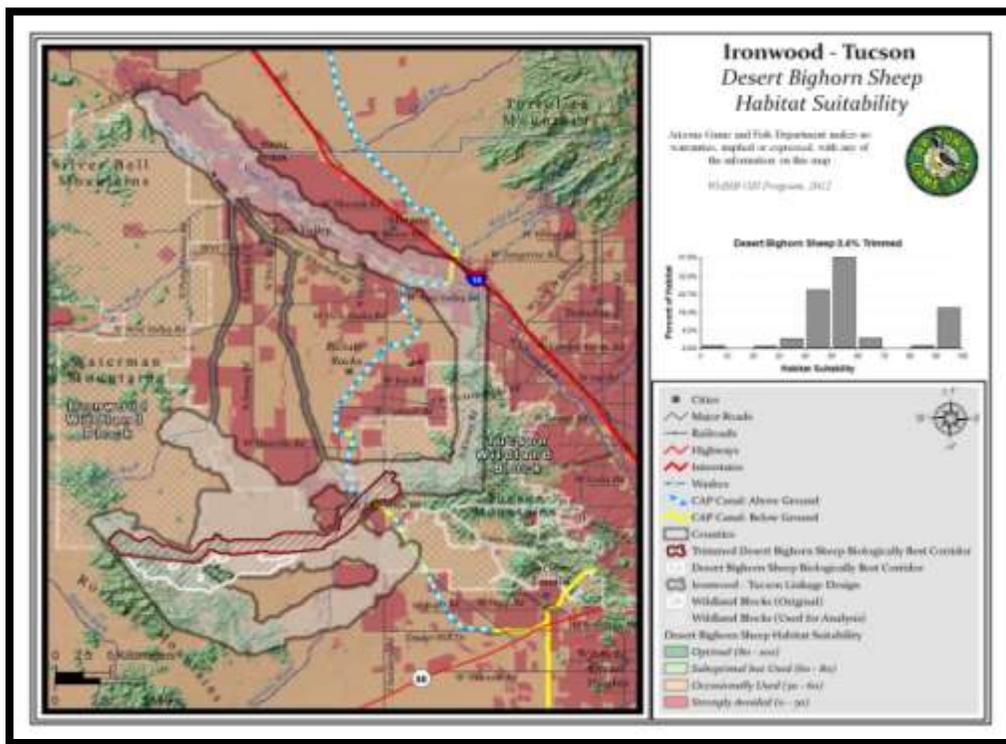


Figure 67: Map of Ironwood – Tucson modeled habitat suitability for desert bighorn sheep

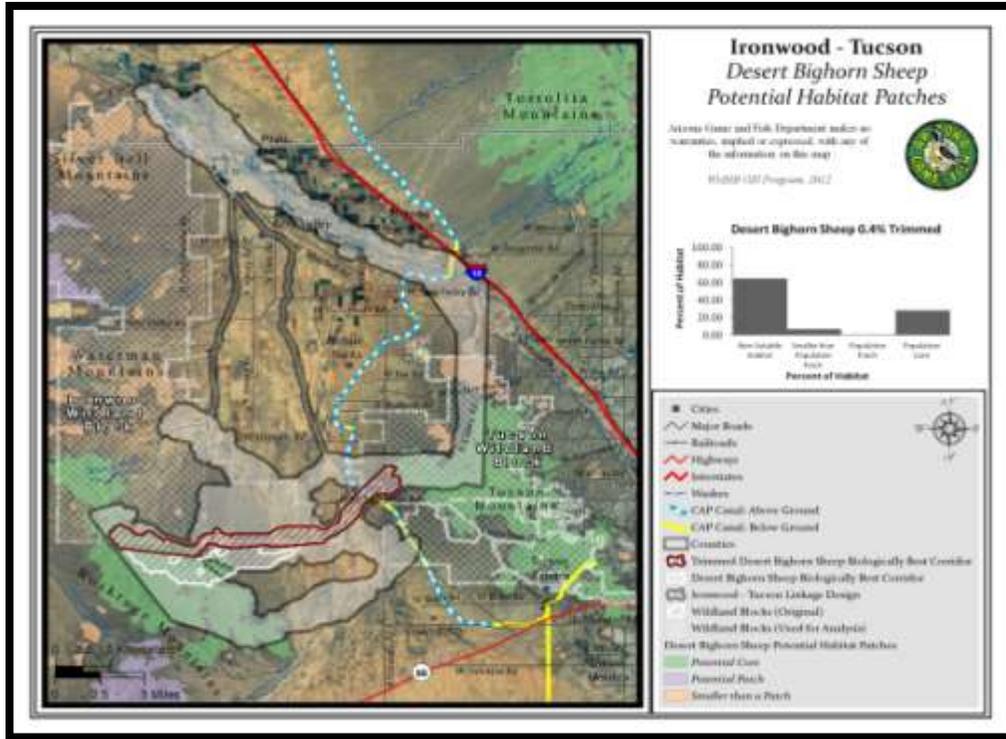


Figure 68: Map of Ironwood – Tucson potential habitat patches and cores for desert bighorn sheep

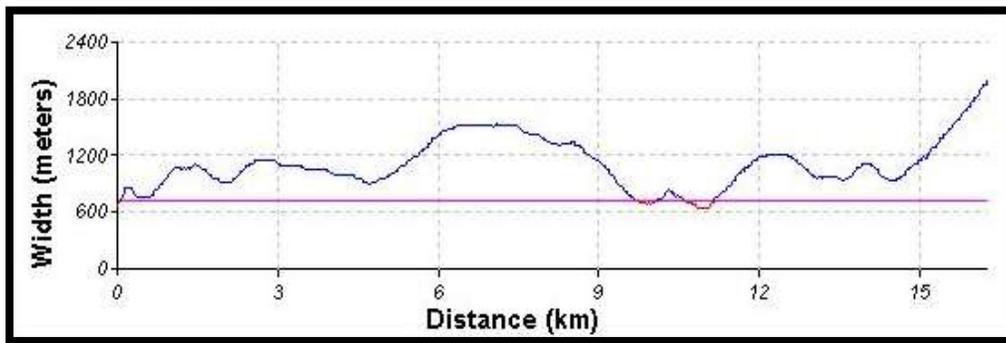


Figure 69: Width along the Ironwood – Tucson trimmed desert bighorn sheep single species corridor

## 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).

### *Distribution*

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



Photo courtesy Randy Babb, AGFD

### *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 7*.

*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.

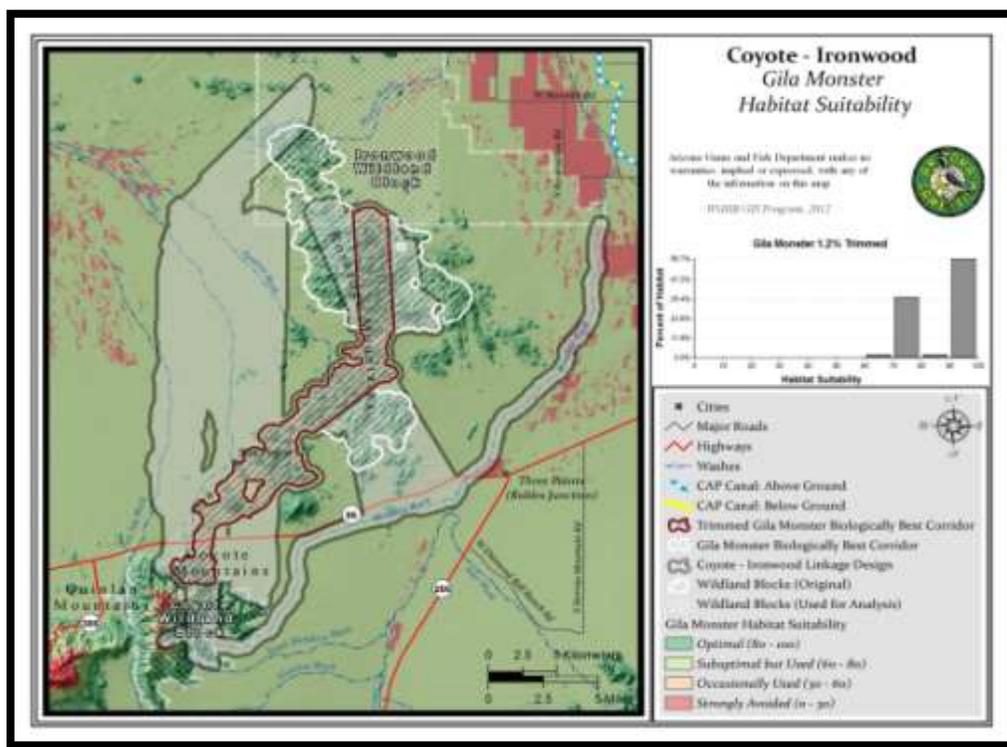
*Biologically best corridor analysis* – We used the methods described in Appendix A to identify the biologically best corridor for this species. Although Gila monsters are assumed to disperse up to 8 km or more (Rose and Goode, personal comm. with CorridorDesign Team), modeled single species corridor 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 Coyote – Ironwood strand. Habitat suitability scores ranged from 0 to 100, with an average suitability of 89.9 (S.D: 11.5) (see *Figure 70* below). Almost all of the trimmed BBC is occupied by a potential population core, with less than 1% occupied by non-suitable habitat (see *Figure 71* below). Most of the trimmed BBC (95.9%) was greater than its estimated needed minimum width (see *Figure 72* below). The trimmed corridor was measured at 28.5 km (17.7 mi) in length between wildland blocks used for analysis. Within the trimmed BBC used in the Ironwood – Tucson strand, habitat suitability scores also ranged from 0 to 100, with an average suitability of 85.8 (S.D: 18.9) (see *Figure 73* below). Most of the trimmed BBC (95.4%) is occupied by a potential population core, with the remainder mostly occupied by non-suitable habitat (see *Figure 74* below). Most of the trimmed BBC (90.0%) was greater than its estimated minimum width (see *Figure 75* below). The trimmed corridor was measured at 24.3 km (15.1 mi) in length between wildland blocks used for analysis.

*Union of biologically best corridors* – The linkage design captures more optimal and strongly avoided habitat. However, mostly suboptimal but usable habitat is captured by the linkage design.



**Figure 70:** Map of Coyote – Ironwood modeled habitat suitability for Gila monster

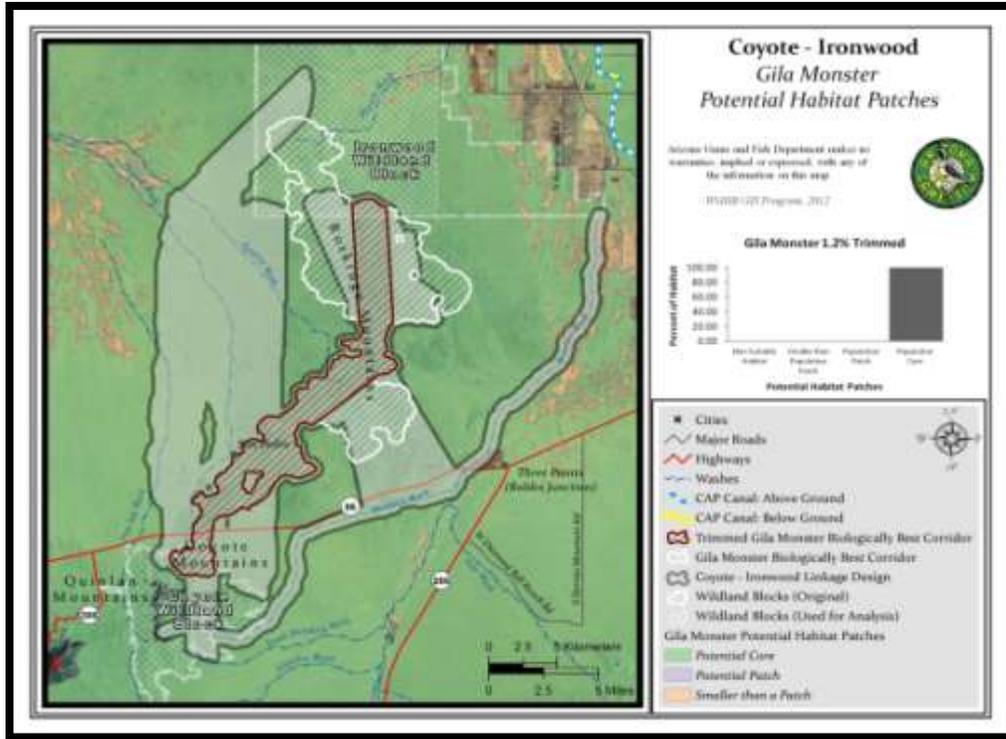


Figure 71: Map of Coyote – Ironwood potential habitat patches for Gila monster

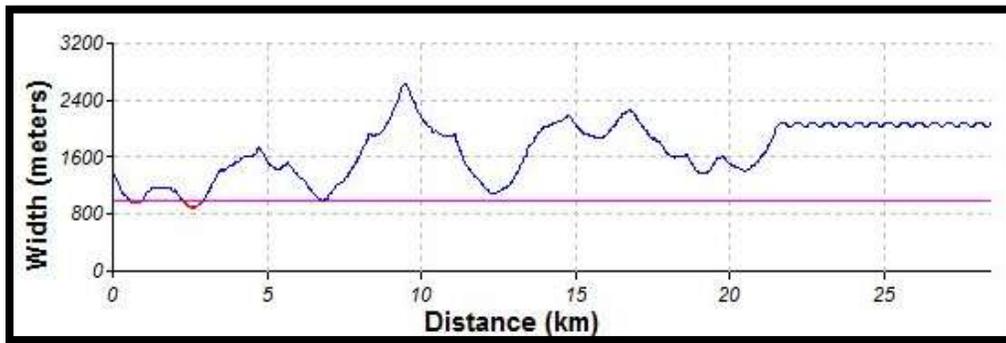


Figure 72: Width along the Coyote – Ironwood trimmed Gila monster single species corridor

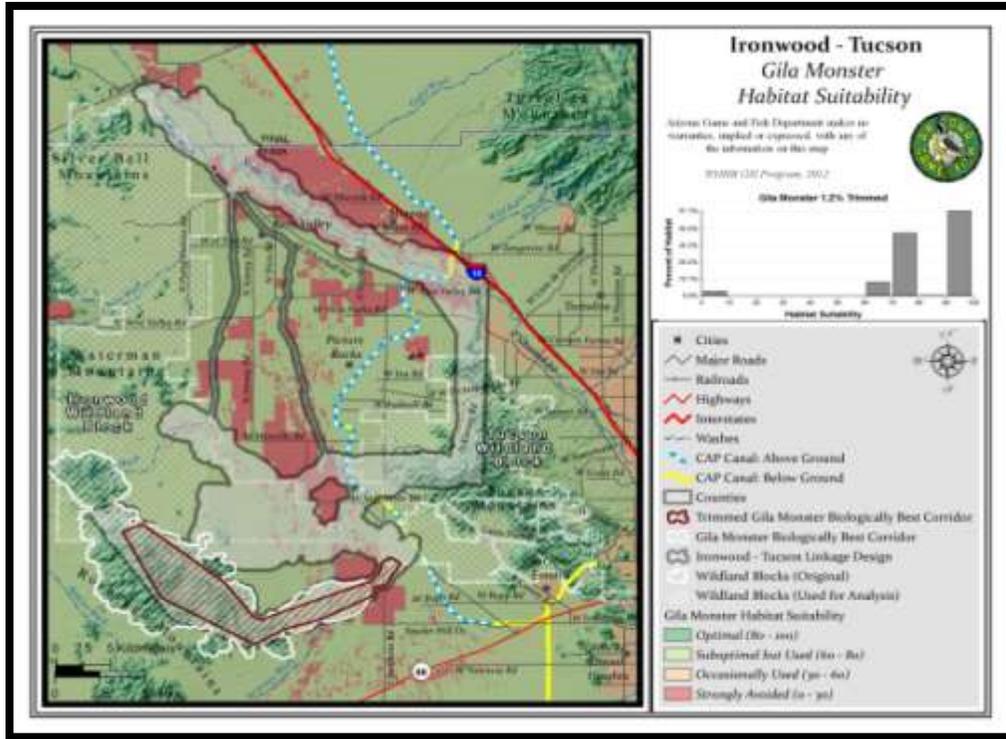


Figure 73: Map of Ironwood – Tucson modeled habitat suitability for Gila monster

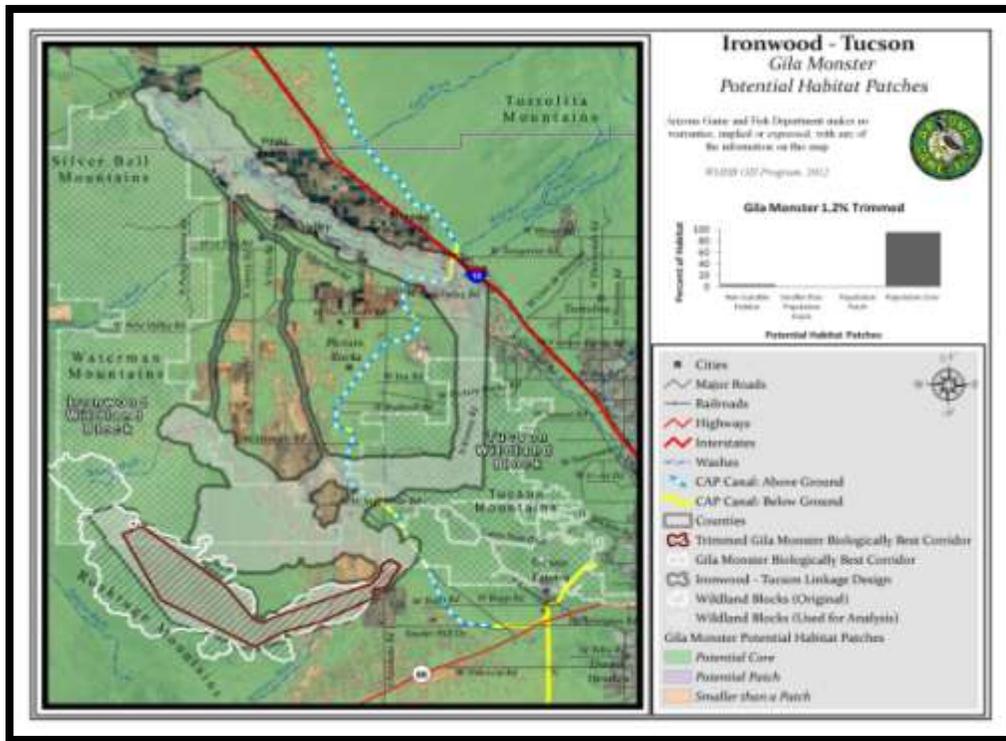
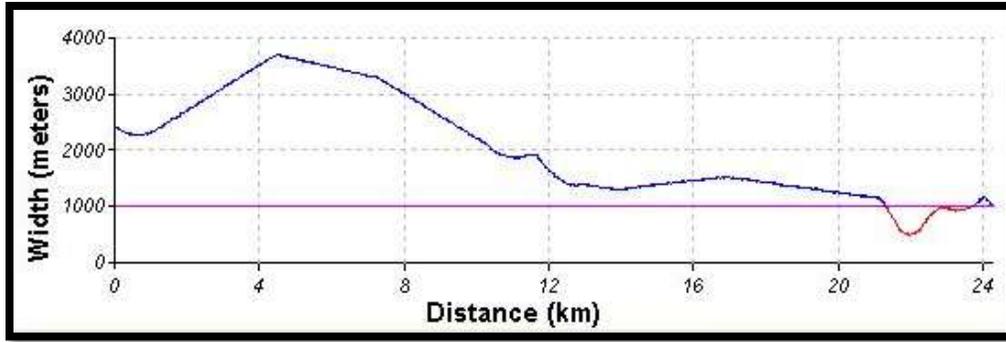


Figure 74: Map of Ironwood – Tucson potential habitat patches for Gila monster



*Figure 75: Width along the Ironwood – Tucson trimmed Gila monster single species corridor*

## Jaguar, *Panthera onca*

### *Justification for Selection*

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).



*Photo courtesy George Andrejko, AGFD*

### *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 km<sup>2</sup>, 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 km<sup>2</sup>, with one female ranging up to 38 km<sup>2</sup>, and one male ranging more than 90 km<sup>2</sup> (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 7*.

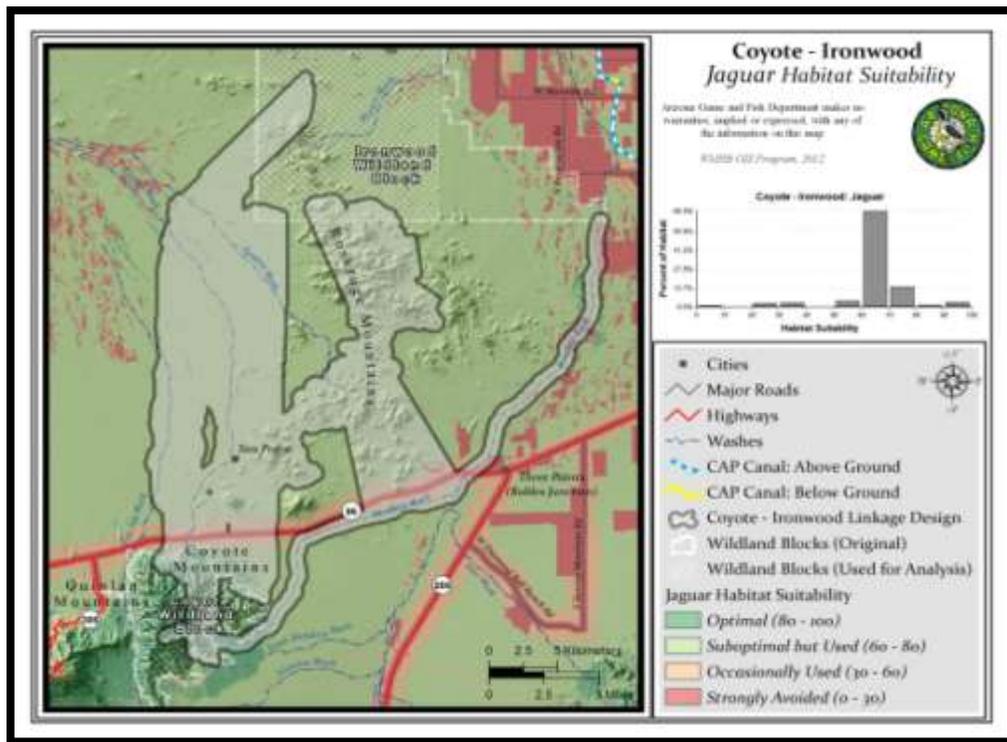
*Patch size and configuration analysis* – Minimum patch size for jaguar was defined as 41 km<sup>2</sup> and minimum core size as 205 km<sup>2</sup>. To determine potential habitat patches and cores, the habitat suitability

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 Ironwood and Tucson wildland blocks. Habitat suitability and potential habitat patches were modeled due to known occurrences of jaguar near the Coyote wildland block

## Results and Discussion

*Union of biologically best corridors* – The linkage design captures mostly suboptimal but usable habitat in the Coyote – Ironwood strand (see *Figure 76* below) and is almost entirely within a potential population core (see *Figure 77* below). The Ironwood – Tucson strand captures additional suboptimal but usable habitat for jaguar, however more strongly avoided habitat is also captured (see *Figure 78* below). The Ironwood – Tucson strand is partially within a potential population core for jaguar (see *Figure 79* below).



*Figure 76: Map of Coyote – Ironwood modeled habitat suitability for jaguar*

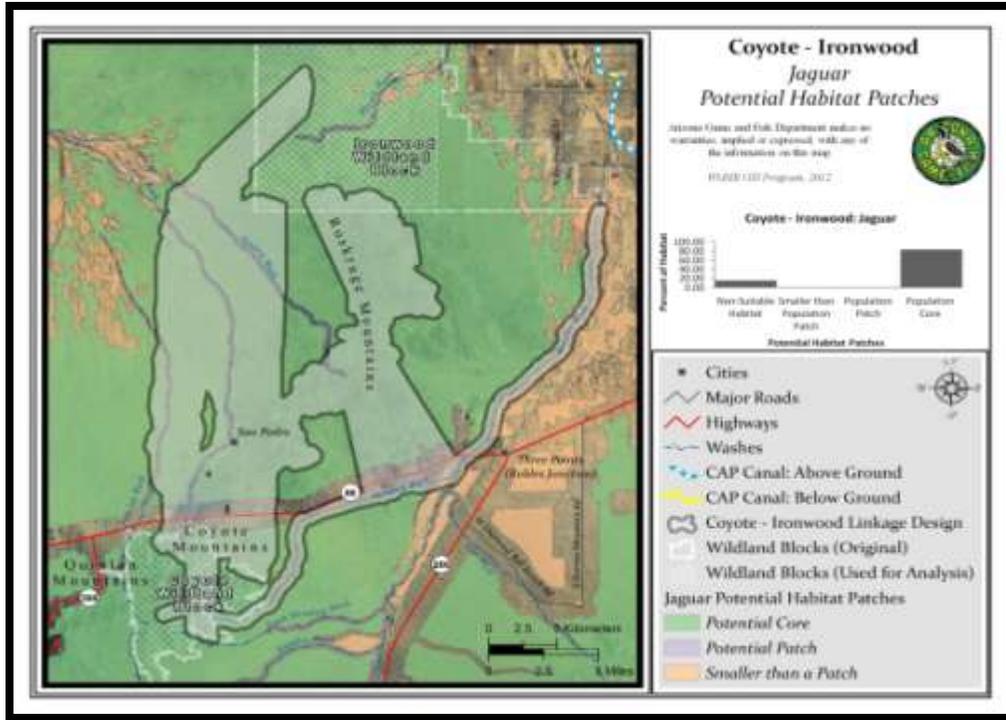


Figure 77: Map of Coyote – Ironwood potential habitat patches and cores for jaguar

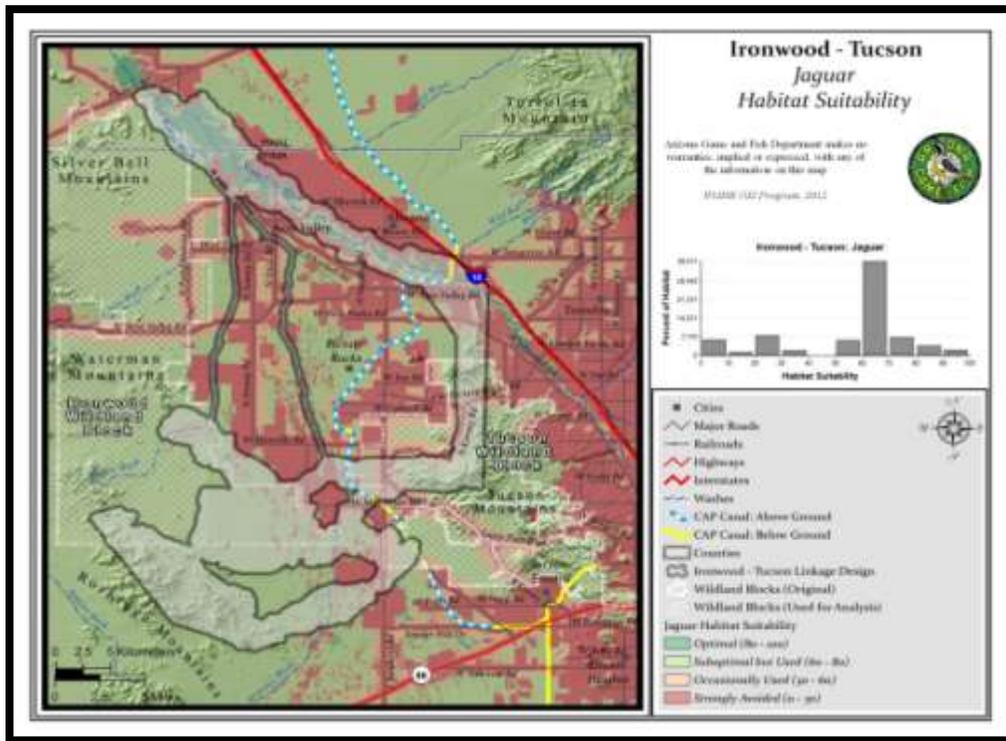


Figure 78: Map of Ironwood – Tucson modeled habitat suitability for jaguar

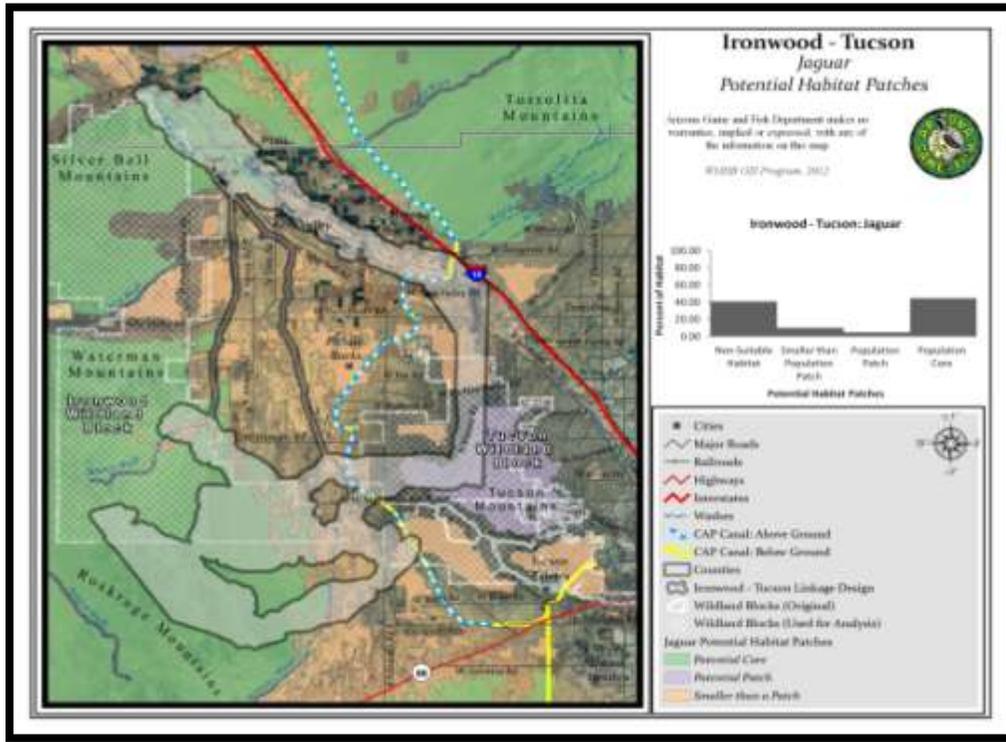


Figure 79: Map of Ironwood – Tucson potential habitat patches for jaguar

## 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 km<sup>2</sup> in the Tortolita Mountains (Bigler 1974), 4.93 km<sup>2</sup> 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 7*.

*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 Coyote – Ironwood BBC. Habitat suitability scores ranged from 75.6 to 100, with an average suitability of 99.4 (S.D: 3.3) (see *Figure 80* below). The entire BBC is occupied by a potential population core (see *Figure 81* below). Most of the BBC (99.6%) was greater than its estimated needed minimum width (see *Figure 82* below). The trimmed corridor was measured at 28.5 km (17.7 mi) in length between wildland blocks used for analysis. Within the trimmed BBC used in the Ironwood – Tucson strand, habitat suitability scores range from 0 to 100, with an average suitability of 85.8 (S.D: 18.9; see *Figure 83* below). Most of the trimmed BBC (95.4%) is occupied by a potential population core, with the remainder mostly occupied by non-suitable habitat (see *Figure 84* below). Most of the trimmed BBC (90.0%) was greater than its estimated minimum width (see *Figure 85* below). The trimmed corridor was measured at 24.3 km (15.1 mi) in length between modified wildland blocks.

*Union of biologically best corridors* – The linkage design captures more optimal and strongly avoided habitat. However, mostly suboptimal but usable habitat is captured by the linkage design.

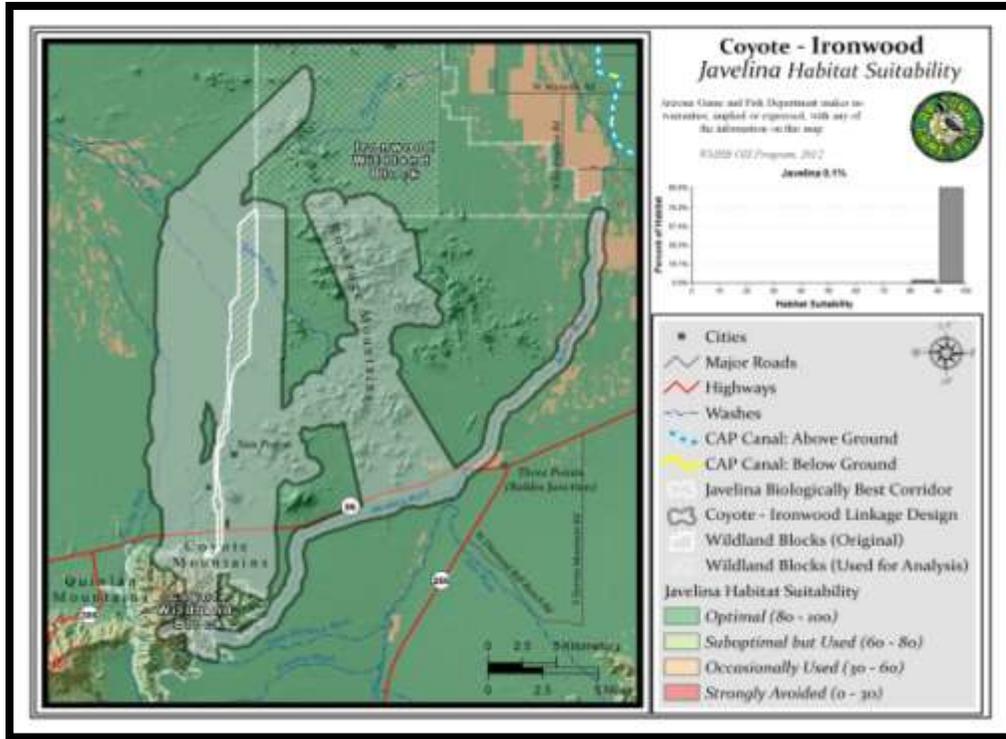


Figure 80: Map of Coyote – Ironwood modeled habitat suitability for javelina

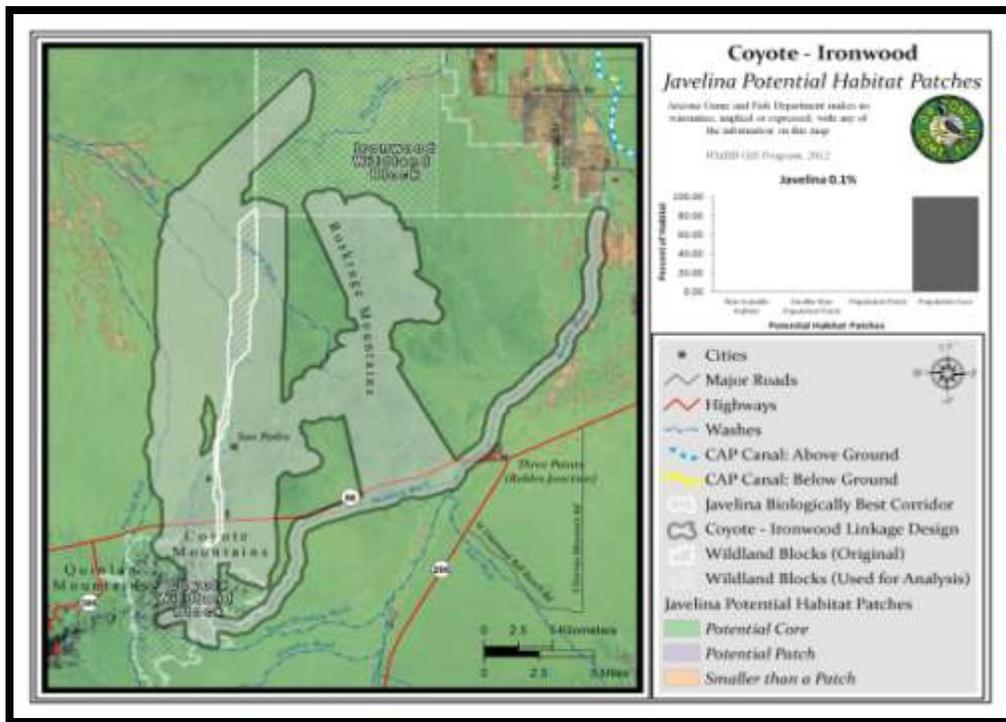


Figure 81: Map of Coyote – Ironwood potential habitat patches and cores for javelina

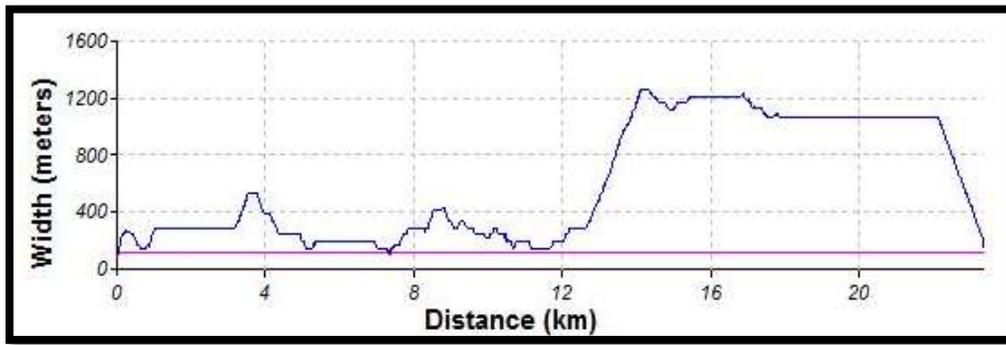


Figure 82: Length and corresponding widths of Coyote – Ironwood javelina single species corridor

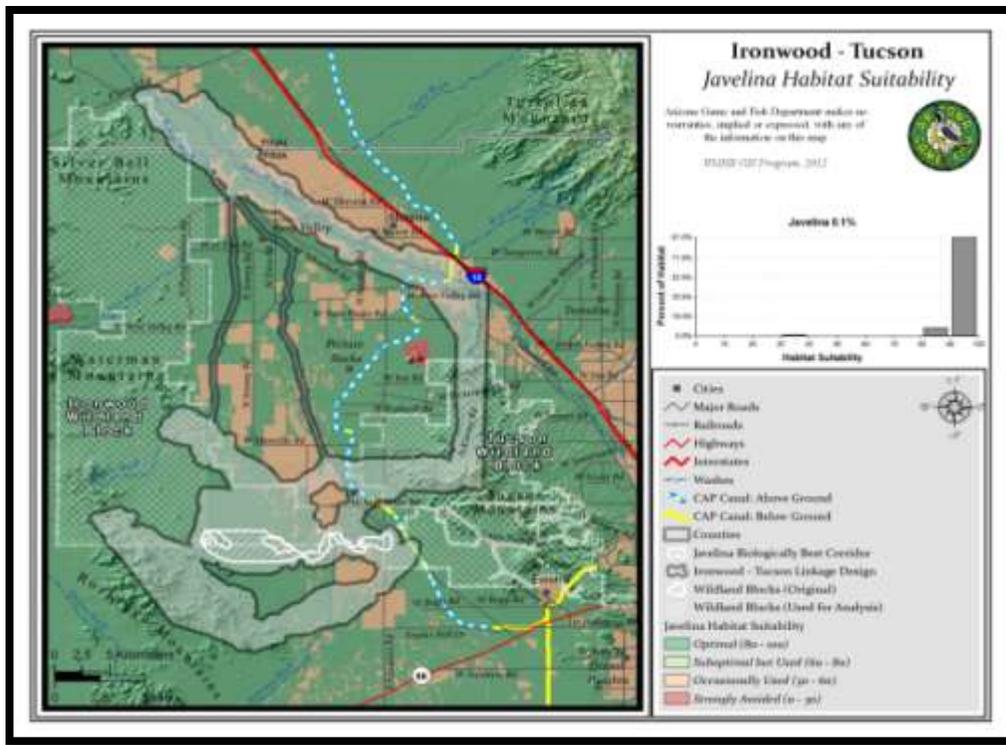


Figure 83: Map of Ironwood – Tucson modeled habitat suitability for javelina

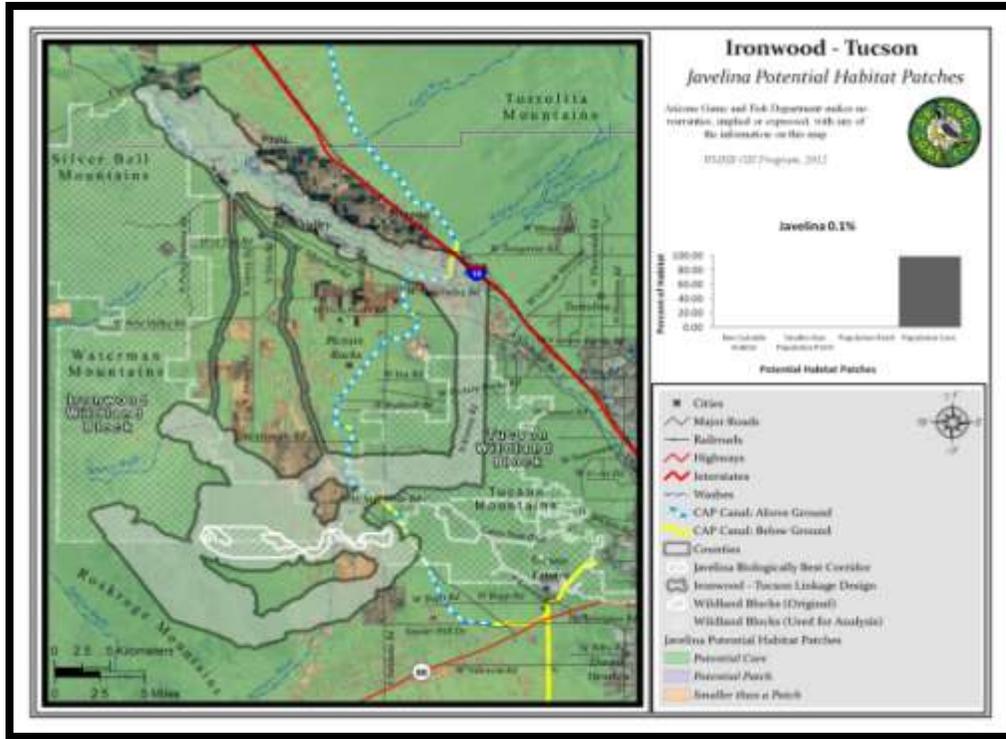


Figure 84: Map of Ironwood – Tucson potential habitat patches for javelina

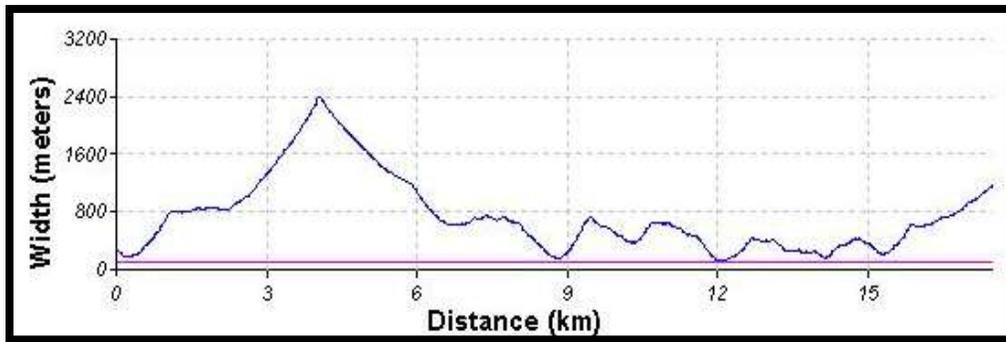


Figure 85: Length and corresponding widths of Ironwood – Tucson javelina single species corridor

## Kit Fox, *Vulpes macrotis*

### *Justification for Selection*

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

### *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, Chihuahuahua, 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.



*Photo courtesy George Andrejko, AGFD*

### *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 7*.

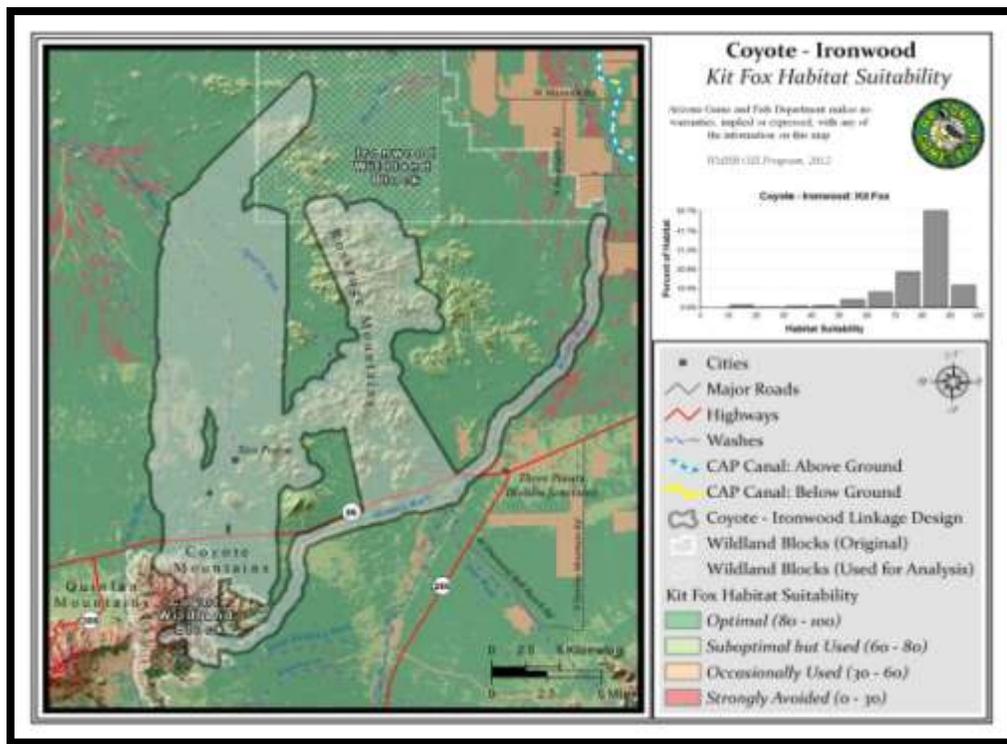
*Patch size and configuration analysis* – In our analyses, we defined minimum patch size for kit fox as 259 ha and minimum core size as 1,295 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis 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. Kit fox were classified as a passage species based on larger home range sizes recorded (Arjo et al. 2003), indicating mobility of the species, and the relatively short distance of approximately 3 km (1.9 mi) between the original wildland blocks that the modeled corridor passed through.

## Results and Discussion

*Initial biologically best corridor* – A BBC for kit fox was not included in the Coyote – Ironwood Linkage. This was due to the long distances the modeled BBC traveled, and the suitable habitat in other portions of the Coyote – Ironwood Linkage for kit fox. However, optimal, and suboptimal but used habitat (see *Figure 86* below), as well as potential population cores (see *Figure 87* below) are captured by the Coyote – Ironwood linkage. Within the BBC used in the Ironwood – Tucson strand, habitat suitability score range from 0 to 100, with an average suitability of 84.2 (S.D: 20.6) (see *Figure 88* below). Most of the BBC (97.4%) is occupied by a potential population core, with the remainder occupied by non-suitable habitat (see *Figure 89* below). Most of the BBC (98.1%) was greater than its estimated minimum width (see *Figure 90* below). The corridor was measured at 19.7 km (12.2 mi) in length between wildland blocks used for analysis.

*Union of biologically best corridors* – As mentioned above, the linkage design captures more suitable habitat and potential population core for kit fox in the Coyote – Ironwood linkage. Additional habitat is also captured in the Ironwood – Tucson linkage. The Ironwood – Tucson linkage also includes occasionally used habitat and strongly avoided areas where agriculture and urban development has been established.



**Figure 86:** Map of Coyote – Ironwood modeled habitat suitability for kit fox

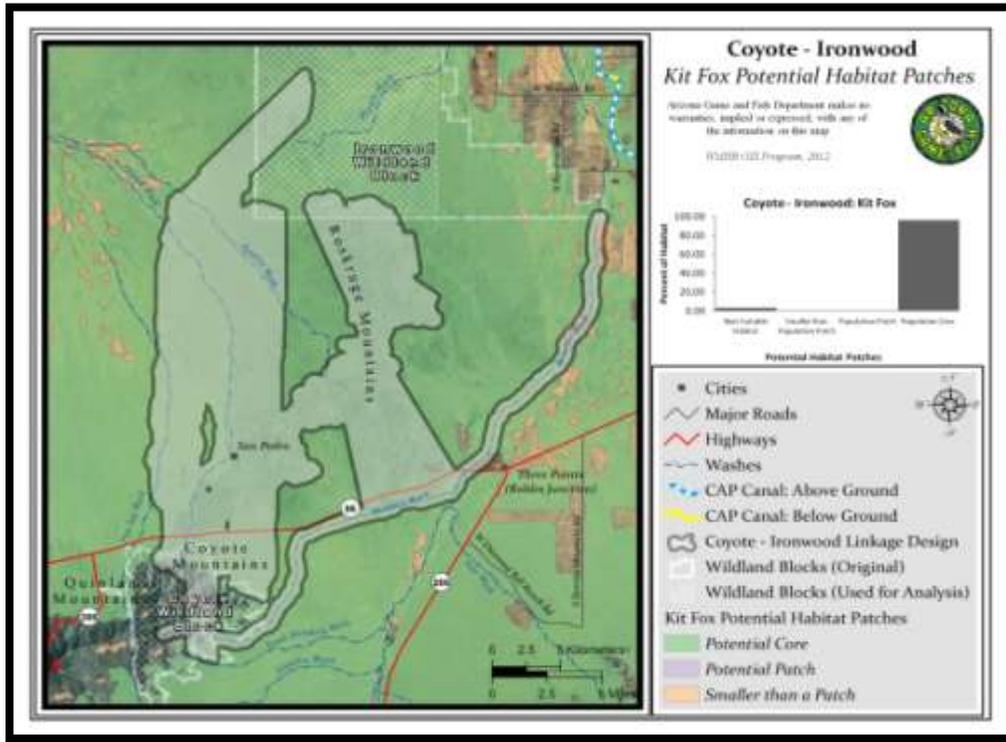


Figure 87: Map of Coyote – Ironwood potential habitat patches for kit fox

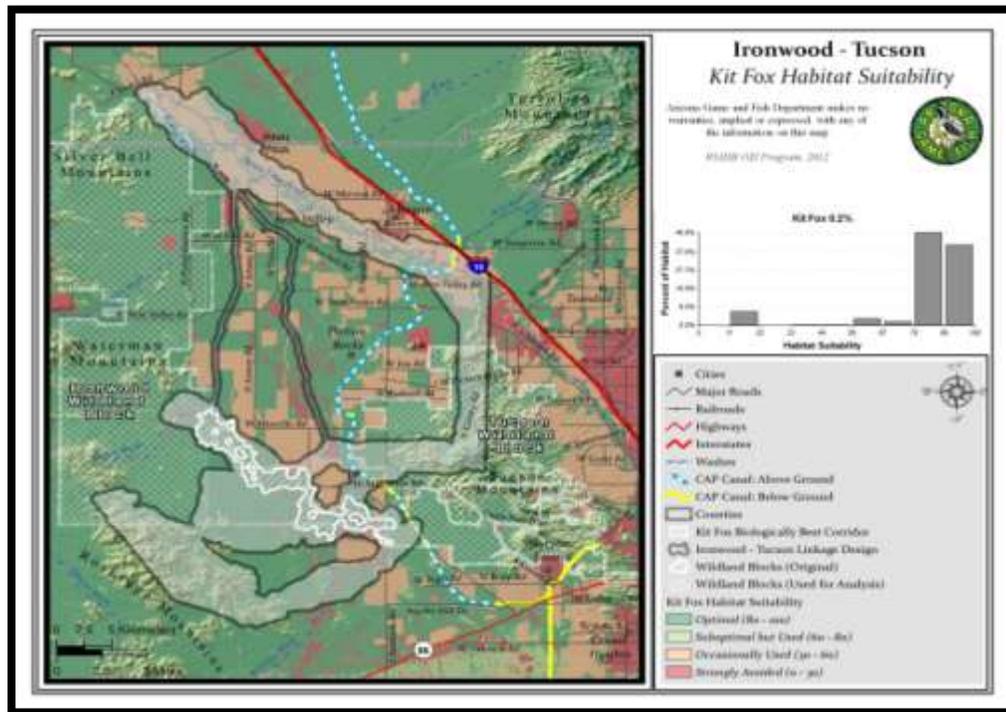


Figure 88: Map of Ironwood – Tucson modeled habitat suitability for kit fox

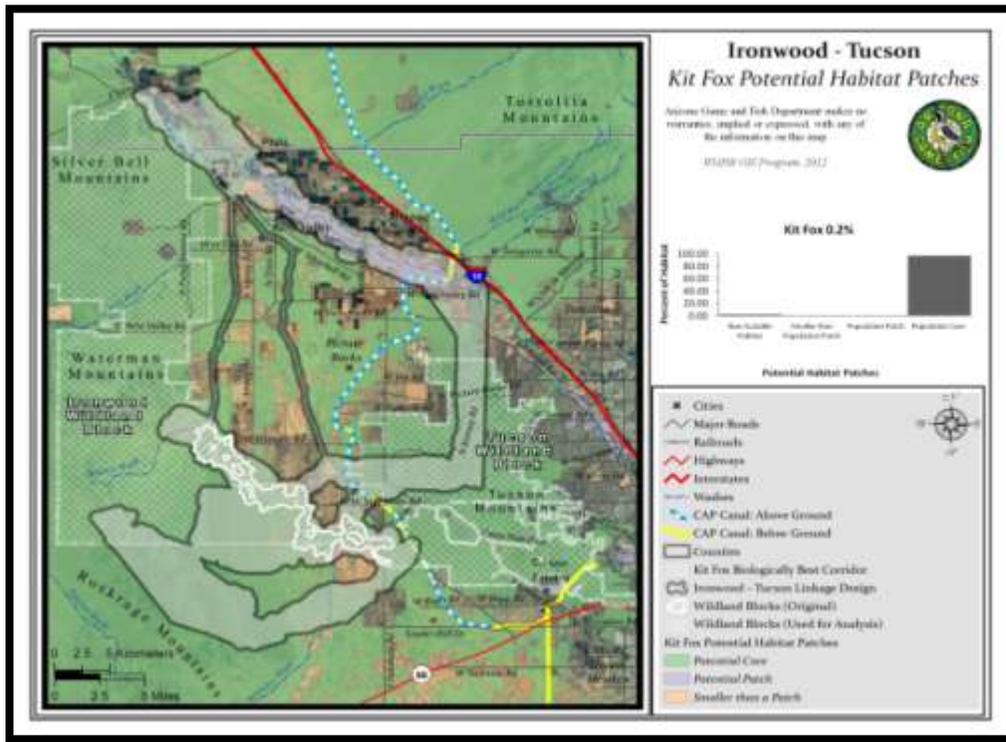


Figure 89: Map of Ironwood – Tucson potential habitat patches for kit fox

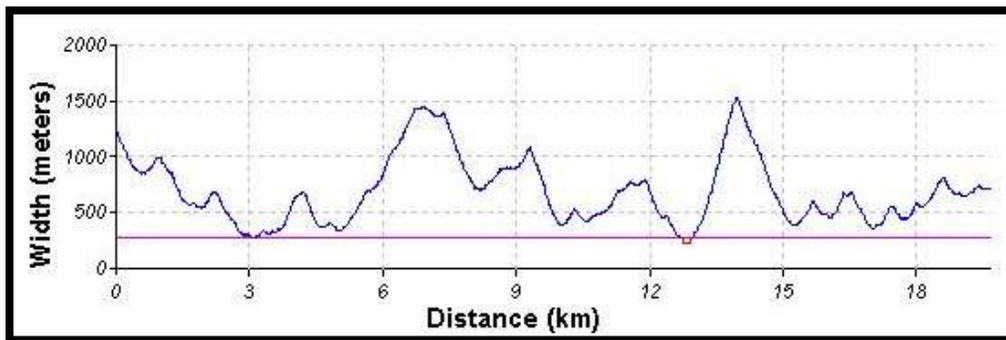


Figure 90: Width along the Ironwood – Tucson kit fox single species corridor

## 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 km<sup>2</sup> for males and 69.9 km<sup>2</sup> for females (Logan and Sweanor 2001). This study also reported daily movements averaging 4.1 km for males and 1.5 km for females (Logan and Sweanor 2001). Dispersal rates for juvenile mountain lions also vary between males and females. Logan and Sweanor's study found males dispersed an average of 102.6 km from their natal sites, and females dispersed an average of 34.6 km. A mountain lion population requires 1000 - 2200 km<sup>2</sup> 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 7*.

*Patch size and configuration analysis* – Minimum patch size for mountain lions was defined as 79 km<sup>2</sup>, 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 km<sup>2</sup>, 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).

## **Results and Discussion**

*Initial biologically best corridor* – Modeling results indicate mostly occasionally used habitat for mountain lion in the Coyote – Ironwood linkage, although suitability scores were near the suboptimal but used habitat (51.4). Habitat suitability scores ranged from 20.8 to 97.6, with an average suitability of 51.4 (S.D: 3.3; see *Figure 91* below). A small portion of the trimmed BBC, 1.7%, is within a potential population core, while 11.7% is occupied by suitable habitat smaller than a patch, and the rest occupied by less than suitable habitat (see *Figure 92* below). Most of the trimmed BBC (91.7%) was greater than its estimated needed minimum width (see *Figure 93* below). The trimmed corridor was measured at 29.7 km (18.5 mi) in length between wildland blocks used for analysis. Two strands emerged in the BBC for mountain lion within the Ironwood – Tucson linkage. One BBC follows the Santa Cruz River riparian vegetation from Ironwood Forest National Monument and meets the northern Tucson Mountains. Much of this corridor edges against, and partially includes, agricultural and developed areas within the boundaries of the Town of Marana, along the banks of the Santa Cruz River. The other strand runs from Ironwood Forest National Monument, north of the City of Tucson Central Avra Valley Storage and Recover Project (CAVSARP) property, through an available culvert underneath the CAP canal, and another culvert that exists on Sandario Road just south of Kinney Road. Within these trimmed BBC strands used in the Ironwood – Tucson linkage, habitat suitability scores range from 0 to 97.6, with an average suitability of 48.4 (S.D: 25.7; see *Figure 94* below). Some of the trimmed BBC, 22.8%, is occupied by suitable habitat smaller than a patch, with the remainder occupied by non-suitable habitat (see *Figure 95* below). Most of the trimmed BBC (98.5%) was greater than its estimated minimum width (see *Figure 96* below). The trimmed corridor was measured at 33.2 km (20.6 mi) in length between modified wildland blocks.

*Union of biologically best corridors* – The linkage design offers little more suitable habitat for mountain lion. Most additional habitat modeled for mountain lion within the linkage design shows only occasional use. However, since mountain lion are a mobile and far ranging species, its use of the majority of this linkage design is possible. Furthermore, mountain lion use of the Tucson Mountains has been well documented (Haynes et al. 2010). In relation to corridors, Haynes et al. (2010) concluded that the most likely movement of mountain lions occur to the west of the Tucson Mountains, stating “It is still likely that mountain lions can weave through the low density housing and the CAP Canal crossings to connect with the open desert of Avra Valley, the Tohono O’Odham Indian Reservation, and the Roskrige Mountains to the west. This area should be a high priority for conservation land use planning.” Although it was also concluded that it is unlikely there are pathways for mountain lions to the north of the Tucson Mountains, due to intensive agriculture and increasing development, the study also states that mountain lion use of the Santa Cruz River as a travel corridor is conceivable to the east (Haynes et al. 2010). Hopefully, this plan will help spur mitigation of urban barriers, and increased habitat restoration efforts to the north of the Tucson Mountains as well.

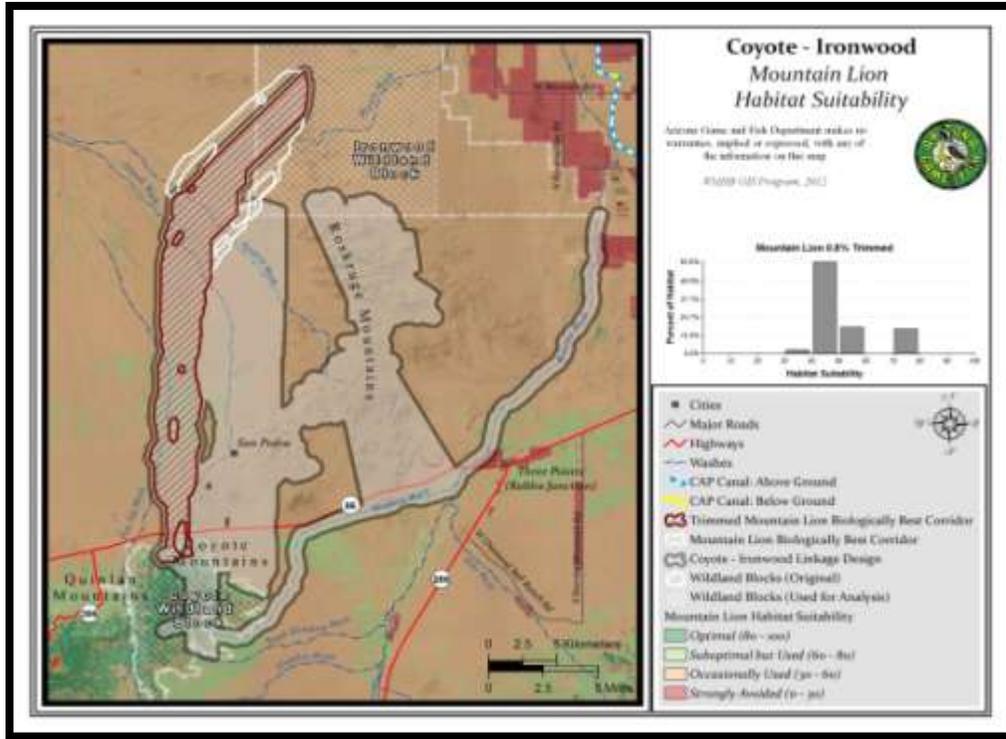


Figure 91: Map of Coyote – Ironwood modeled habitat suitability for mountain lion

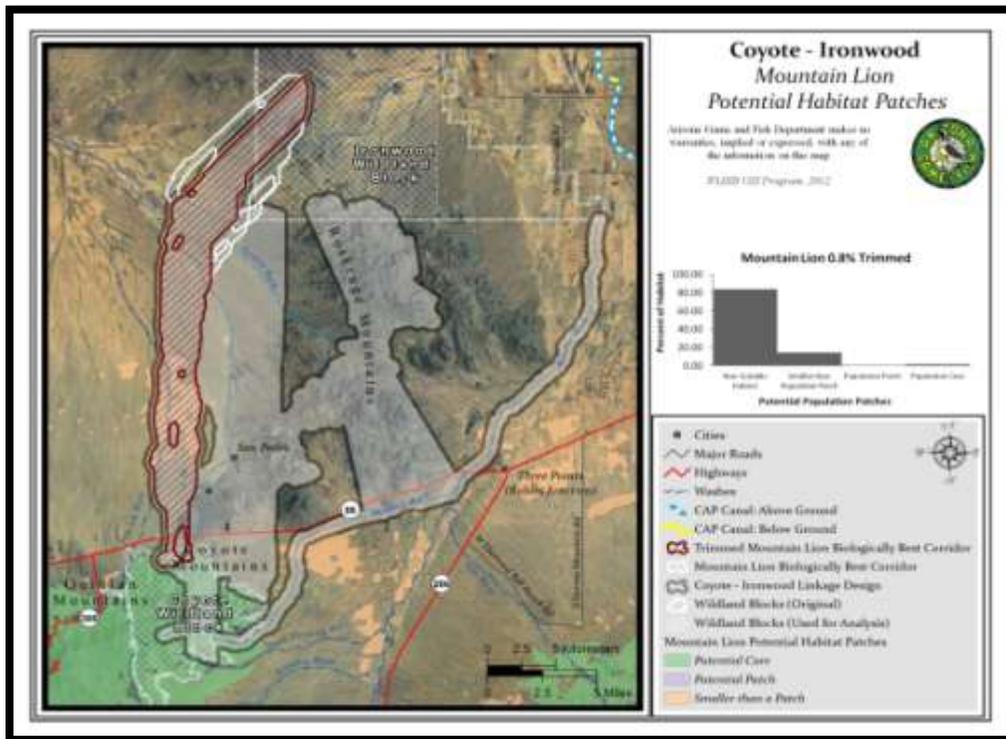


Figure 92: Map of Coyote – Ironwood potential habitat patches for mountain lion

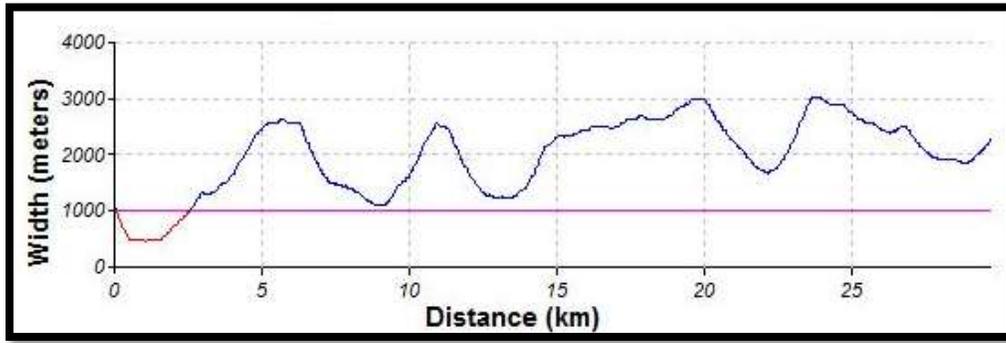


Figure 93: Width along the Coyote – Ironwood trimmed mountain lion single species corridor

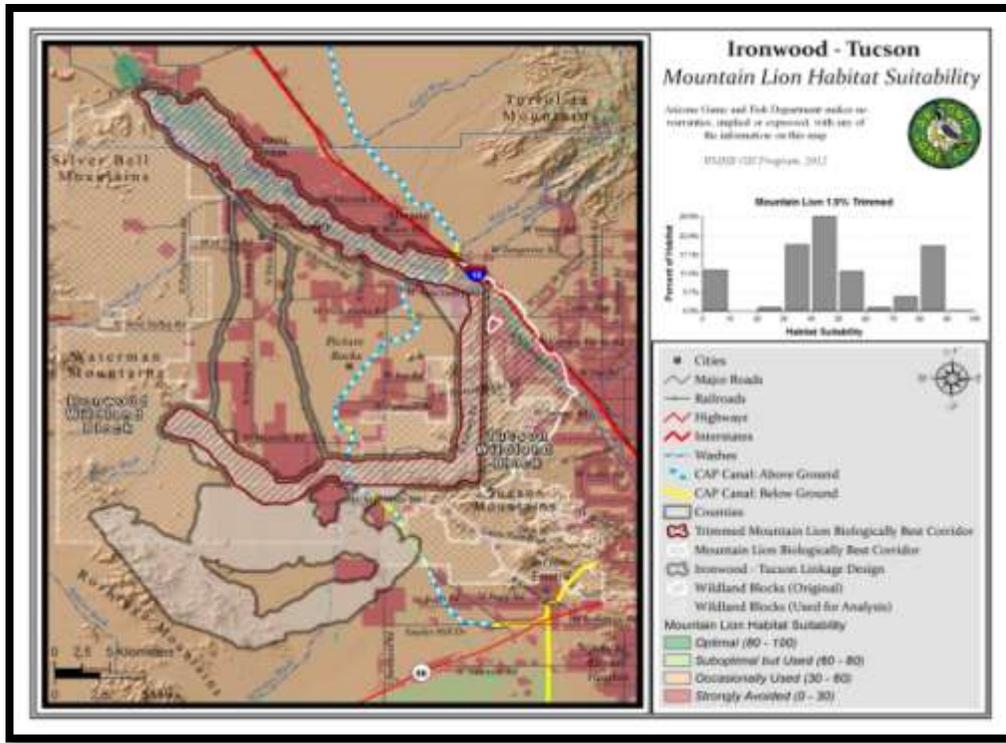


Figure 94: Map of Ironwood – Tucson modeled habitat suitability for mountain lion

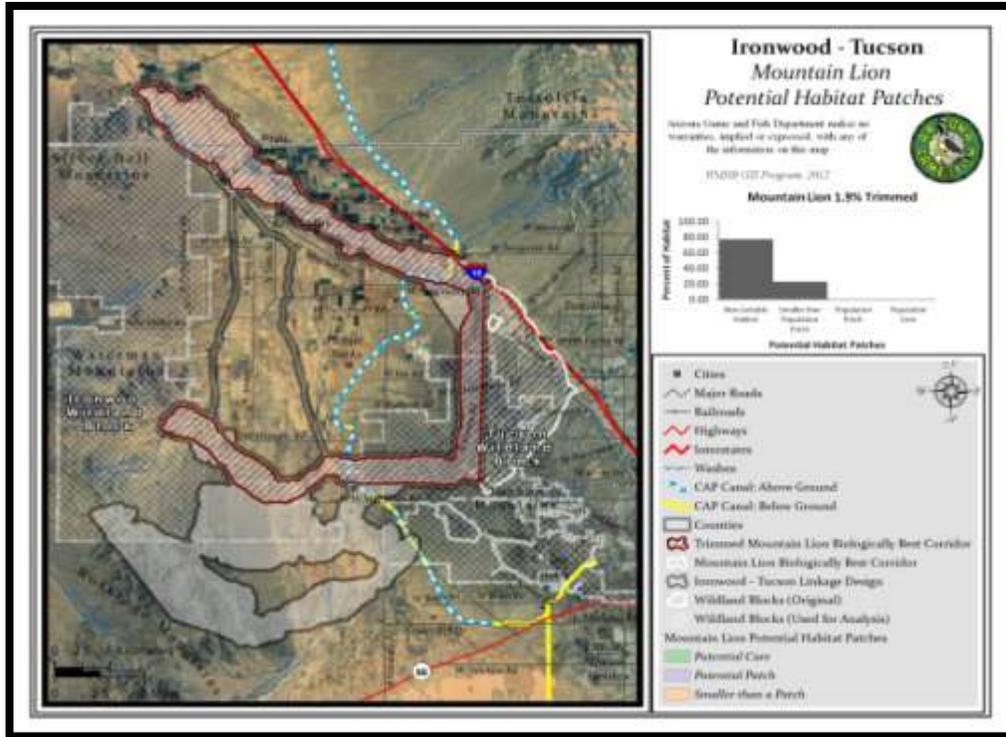


Figure 95: Map of Ironwood – Tucson potential habitat patches for mountain lion

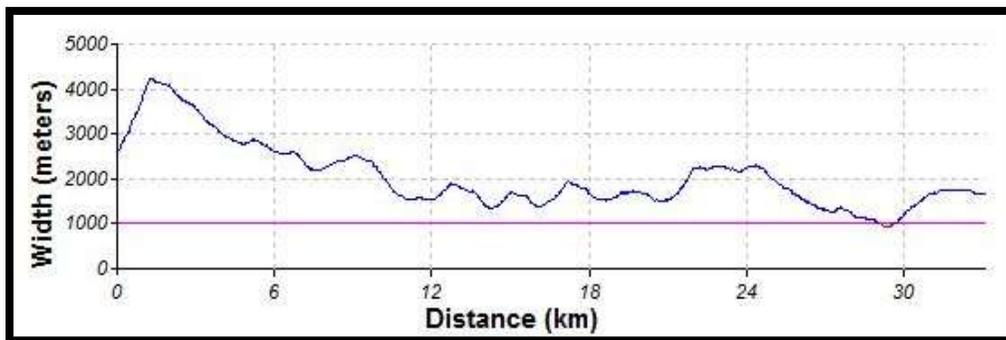


Figure 96: Width along the Ironwood - Tucson trimmed mountain lion single species corridor

## 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).

### *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).



*Photo courtesy George Andrejko, AGFD*

### *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<sup>2</sup>, with bucks' home ranges averaging 5.2 km<sup>2</sup> 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 (Scarborough 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 7*.

*Patch size and configuration analysis* – Minimum patch size for mule deer was defined as 9 km<sup>2</sup> and minimum core size as 45 km<sup>2</sup>. 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 habitat for mule deer within the trimmed BBC used in the Coyote – Ironwood Linkage. Habitat suitability scores ranged from 0 to 89.5, with an average suitability of 79.4 (S.D: 8.3; see *Figure 97* below). Almost the entire trimmed BBC is located within a potential population core (see *Figure 98* below). 91.7% of the trimmed BBC was greater than its estimated needed minimum width (see *Figure 99* below). The trimmed corridor was measured at 24.4 km (15.2 mi) in length between wildland blocks used for analysis. Within the original BBC used in the Ironwood – Tucson strand, habitat suitability scores range from 0 to 89.5, with an average suitability of 73.6 (S.D: 18.2; see *Figure 100* below). Most of the trimmed BBC (87.6% ) is occupied by a potential population core, with the remainder occupied by non-suitable habitat (see *Figure 101* below). Most of the BBC (94.8% ) was greater than its estimated minimum width (see *Figure 102* below). The BBC was measured at 15.2 km (9.4 mi) in length between modified wildland blocks.

*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.

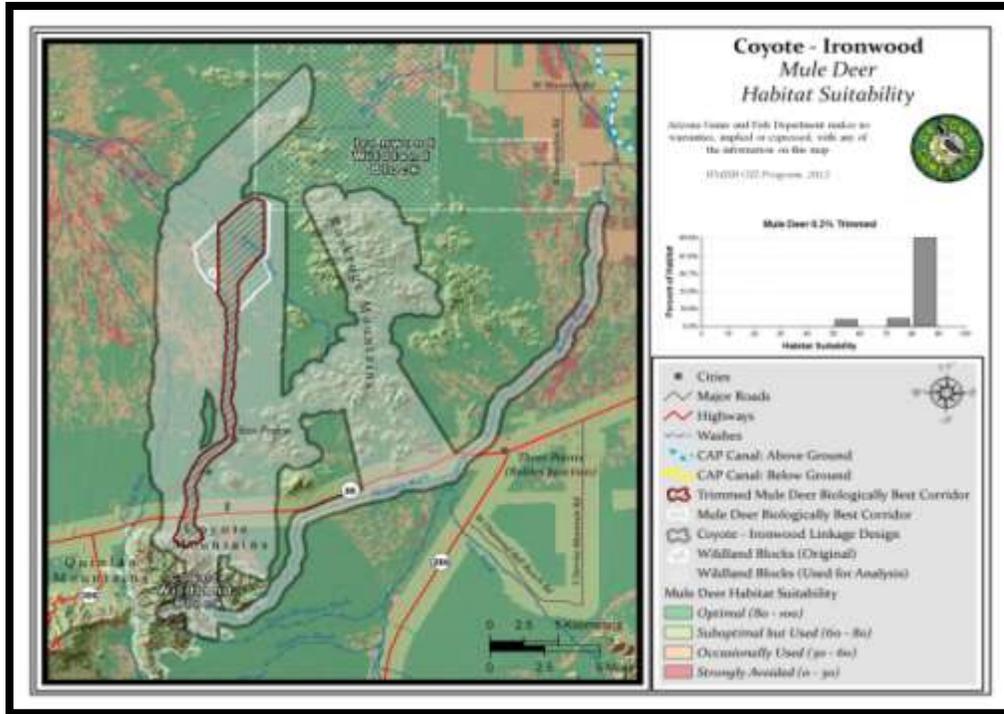


Figure 97: Map of Coyote – Ironwood modeled habitat suitability for mule deer

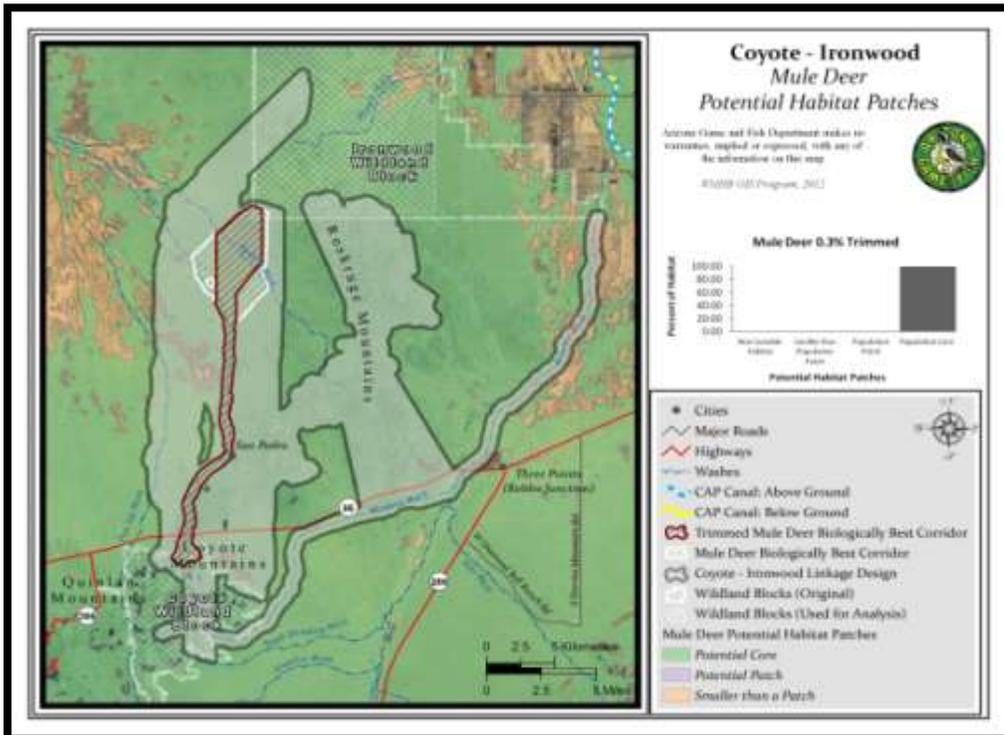


Figure 98: Map of Coyote – Ironwood potential habitat patches for mule deer

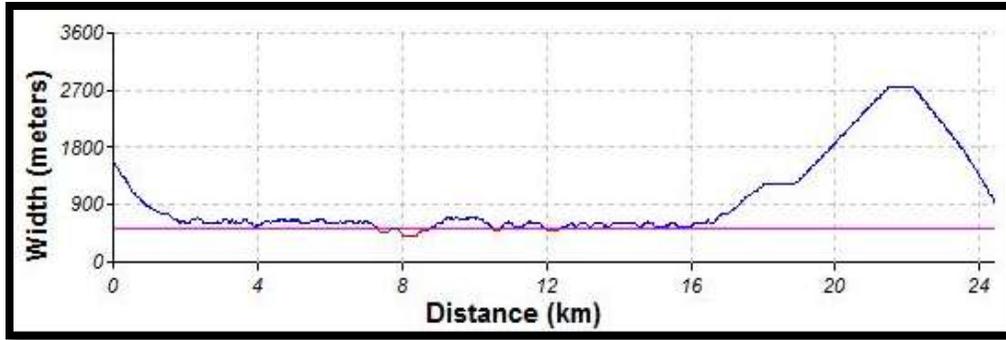


Figure 99: Width along the Coyote - Ironwood trimmed mule deer single species corridor

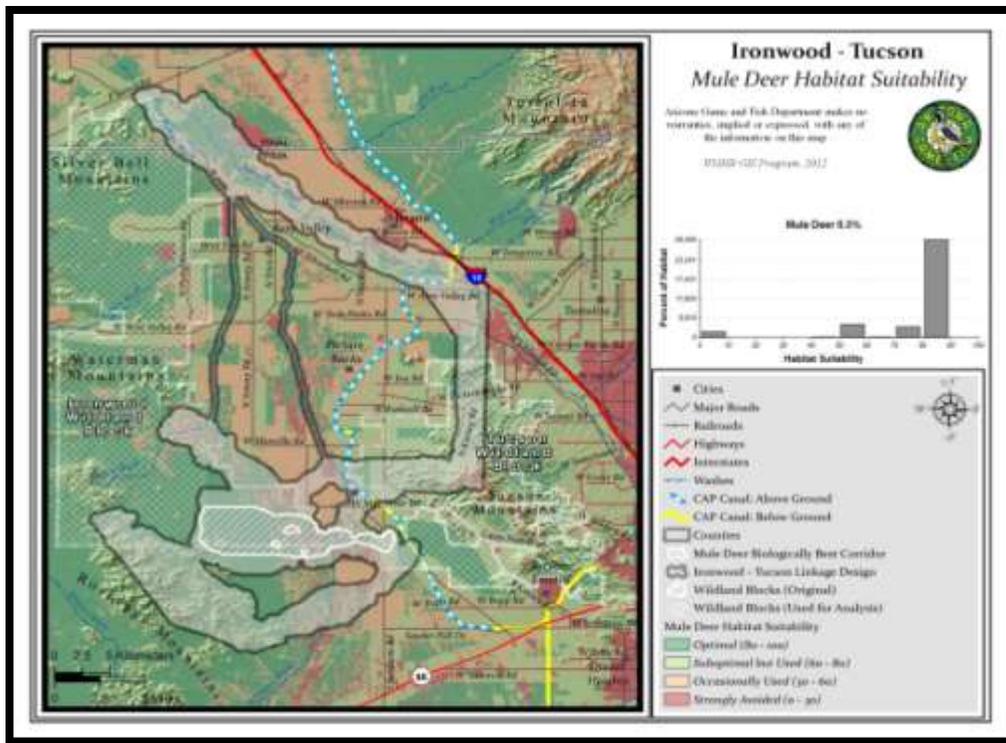


Figure 100: Map of Ironwood – Tucson modeled habitat suitability for mule deer

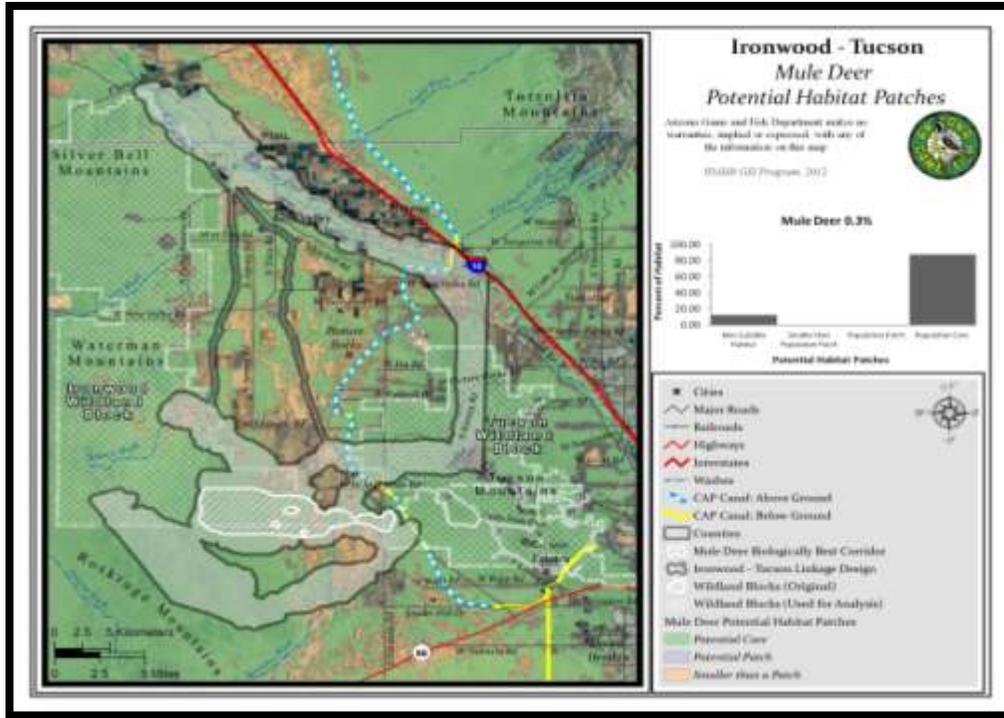


Figure 101: Map of Ironwood – Tucson potential habitat patches for mule deer

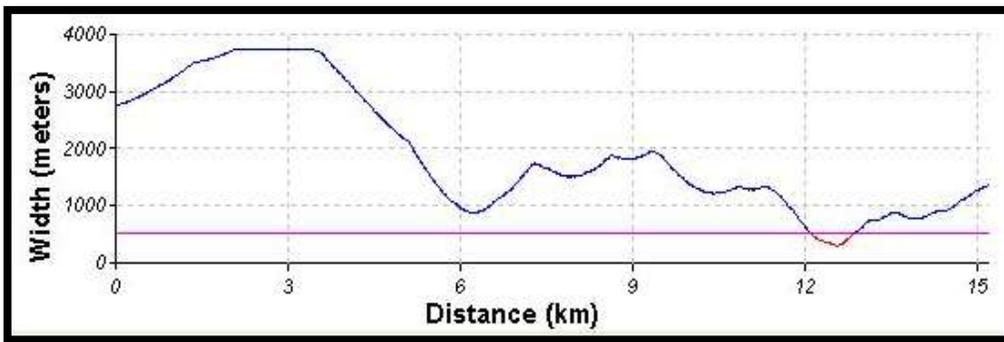


Figure 102: Width along the Ironwood – Tucson mule deer single species corridor

## 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 7*.

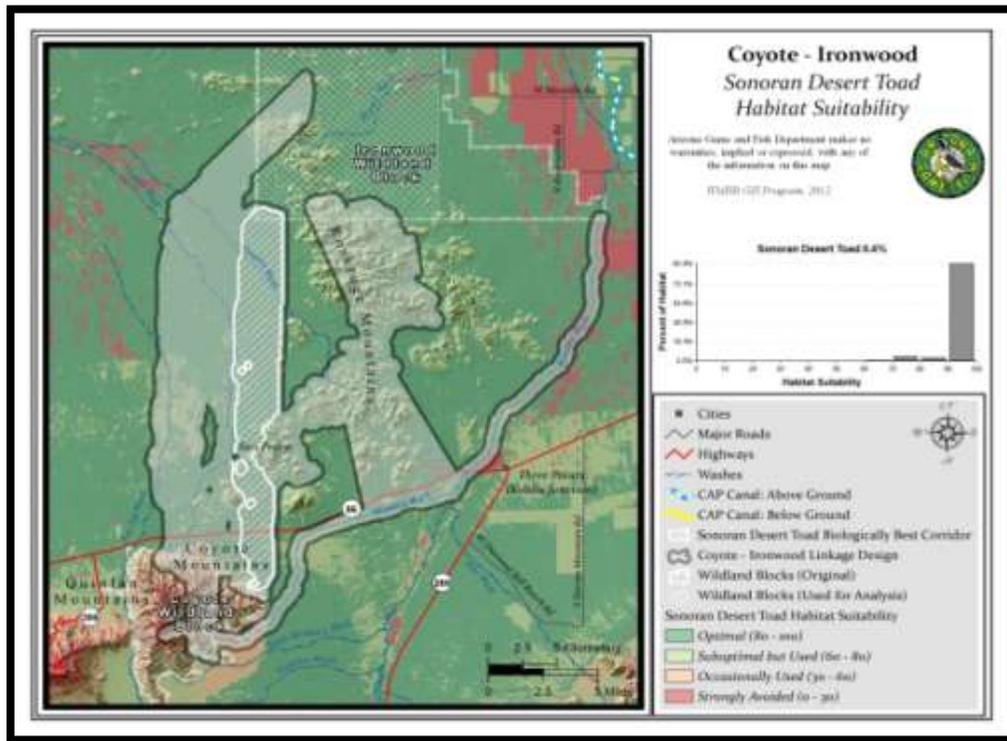
*Patch size and configuration analysis* – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha (Rosen and Mauz 2001; Phil Rosen, personal comm. with CorridorDesign Team). To determine potential habitat patches and cores, the habitat suitability 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.

### Results and Discussion

*Initial biologically best corridor* – Modeling results indicate mostly optimal habitat for Sonoran desert toad within the BBC used in the Coyote – Ironwood linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 98.1 (S.D: 6.6; see *Figure 103* below). Almost the entire BBC is located within a potential population core (see *Figure 104* below). Most of the BBC (91.0% ) was greater than its estimated needed minimum width (see *Figure 105* below). The corridor was measured at 26.5 km (15.2 mi) in length between wildland blocks used for analysis. Within the original BBC used in the Ironwood – Tucson strand, habitat suitability scores also ranged from 0 to 100, with an average suitability of 94.9 (S.D: 17.5; see *Figure 106* below). Most of the BBC (96.4%) is occupied by a potential population core, with much of the remainder occupied by non-suitable habitat (see *Figure 107* below). Most of the BBC (93.7% ) was greater than its estimated minimum width (see *Figure 108* below). The BBC was measured at 17.6 km (10.9 mi) in length between modified wildland blocks.

*Union of biologically best corridors* – The linkage design captures considerably more optimal and suboptimal but used habitat for Sonoran desert toad.



**Figure 103:** Map of Coyote – Ironwood modeled habitat suitability for Sonoran desert toad

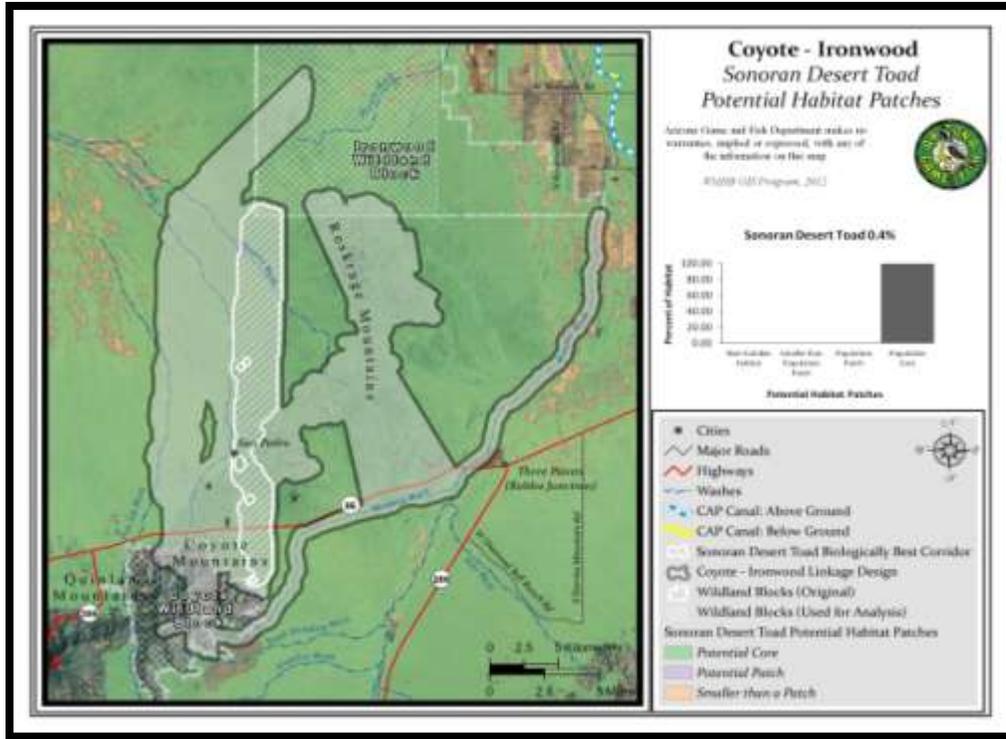


Figure 104: Map of Coyote – Ironwood potential habitat patches and cores for Sonoran desert toad

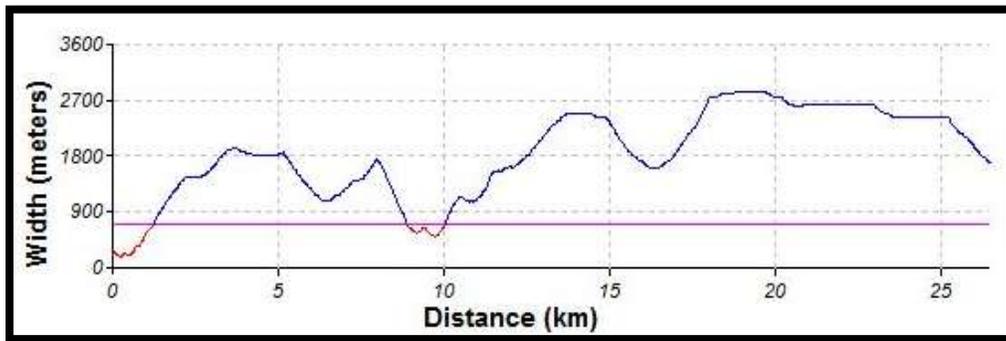


Figure 105: Width along the Coyote – Ironwood Sonoran desert toad single species corridor

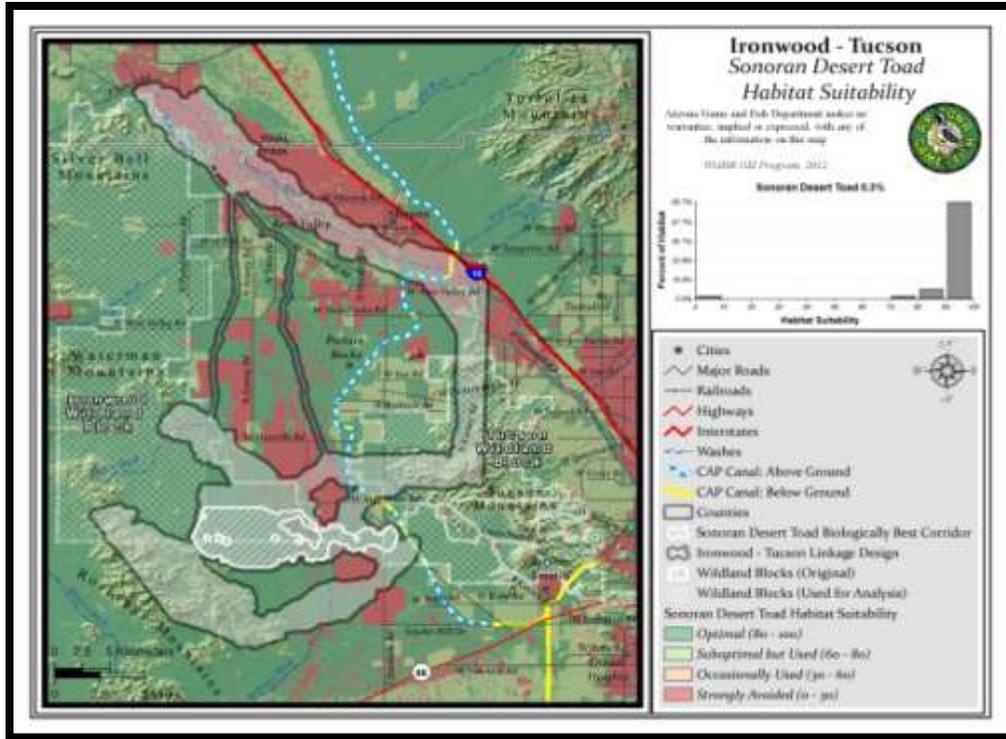


Figure 106: Map of Ironwood – Tucson modeled habitat suitability for Sonoran desert toad

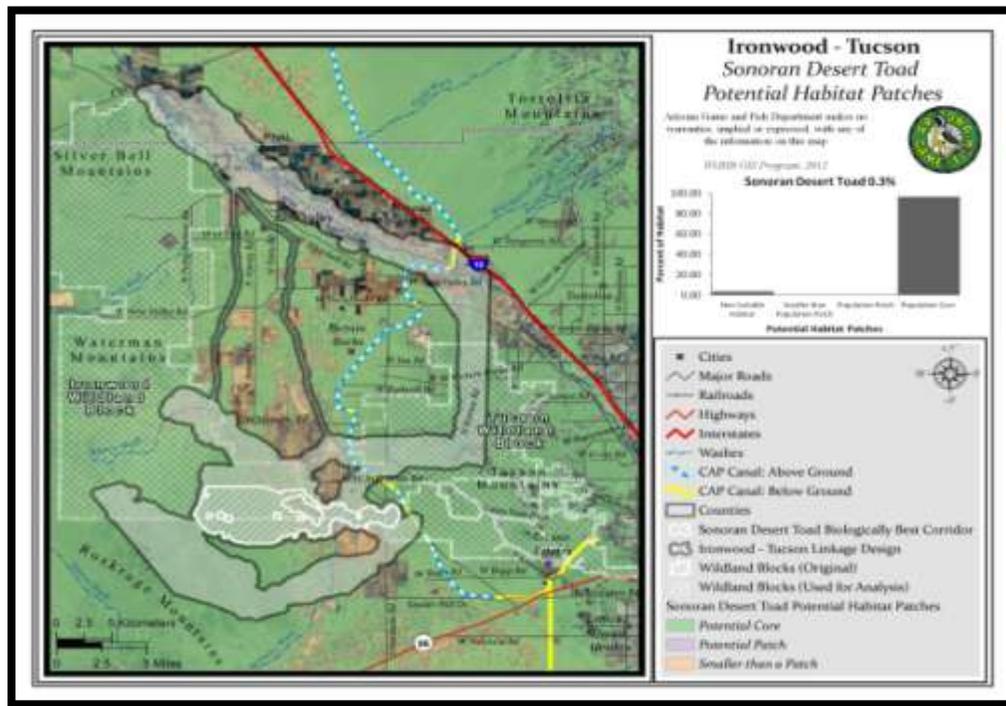
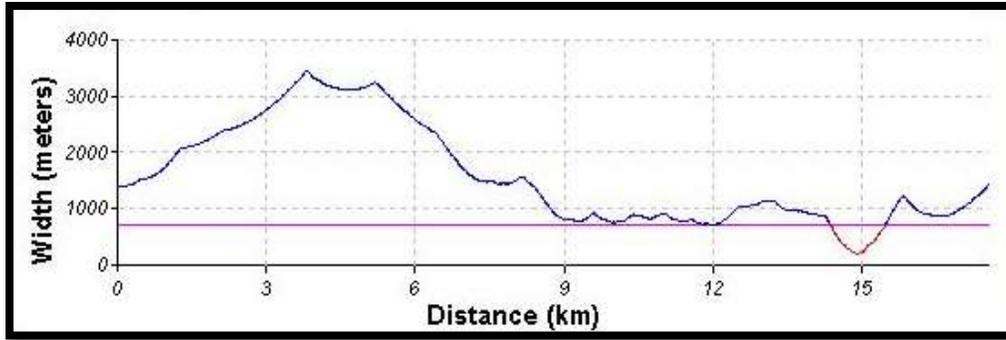


Figure 107: Map of Ironwood – Tucson potential habitat patches for Sonoran desert toad



*Figure 108: Width along the Ironwood - Tucson Sonoran desert toad single species 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).

### *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.



Photo courtesy Audrey Owens, AGFD

### *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 (Ofstedal 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 plant 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 Mojave 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 7*.

*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 optimal and suboptimal but used habitat for Sonoran desert tortoise within the trimmed BBC used in the Coyote – Ironwood linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 82.0 (S.D: 17.7; see *Figure 109* below). Most of the BBC (96.8%) is located within a potential population core, with the rest encompasses non-suitable habitat (see *Figure 110* below). Most of the trimmed BBC (93.4%) was greater than its estimated needed minimum width (see *Figure 111* below). The trimmed corridor was measured at 31.3 km (19.4 mi) in length between wildland blocks used for analysis. Within the trimmed BBC used in the Ironwood – Tucson strand, habitat suitability scores also ranged from 0 to 100, with an average suitability of 77.6 (S.D: 20.9; see *Figure 112* below). Most of the trimmed BBC (92.3%) is occupied by a potential population core, with most of the remainder occupied by non-suitable habitat (see *Figure 113* below). Most of the trimmed BBC (96.4%) was greater than its estimated minimum width (see *Figure 114* below). The trimmed BBC was measured at 25.3 km (15.7 mi) in length between modified wildland blocks.

*Union of biologically best corridors* – The linkage design captures considerably more optimal and suboptimal but used habitat for Sonoran desert tortoise. Although, urban barriers and roads, especially in the Ironwood – Tucson linkage threaten to sever connectivity for the species.

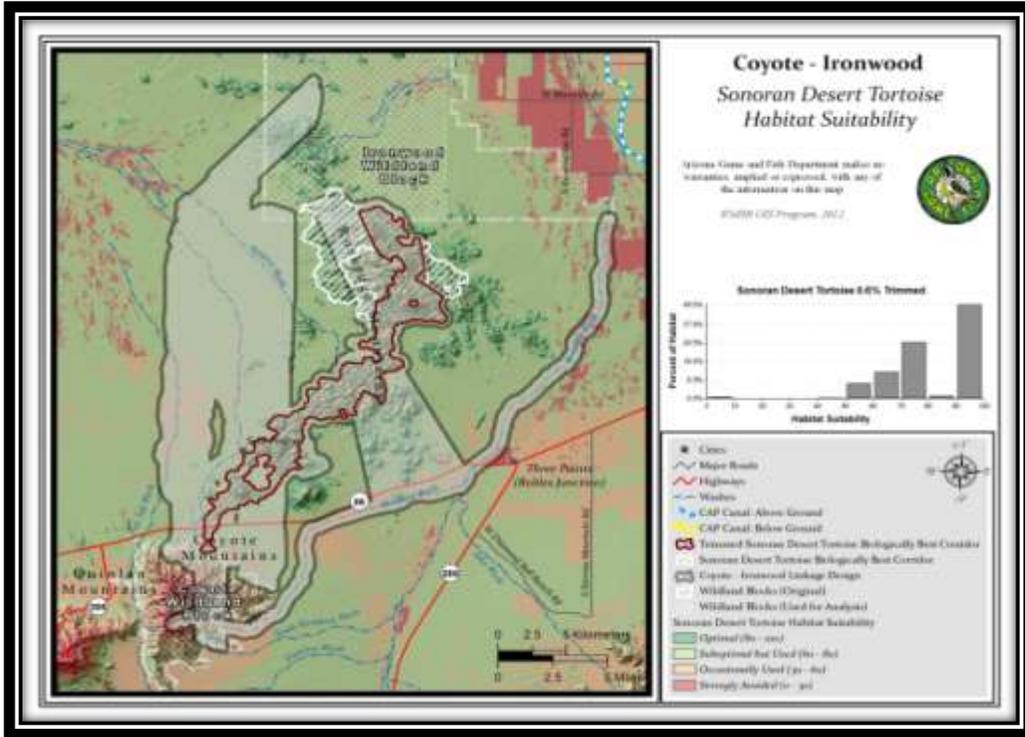


Figure 109: Map of Coyote – Ironwood modeled habitat suitability for Sonoran desert tortoise

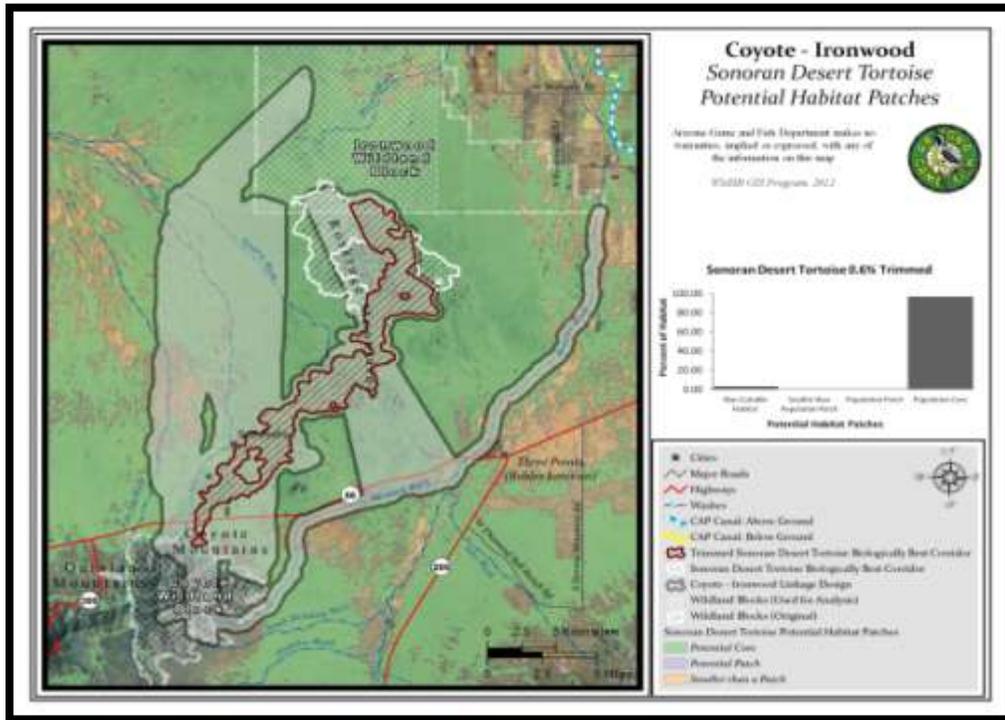


Figure 110: Map of Coyote – Ironwood potential habitat patches for Sonoran desert tortoise

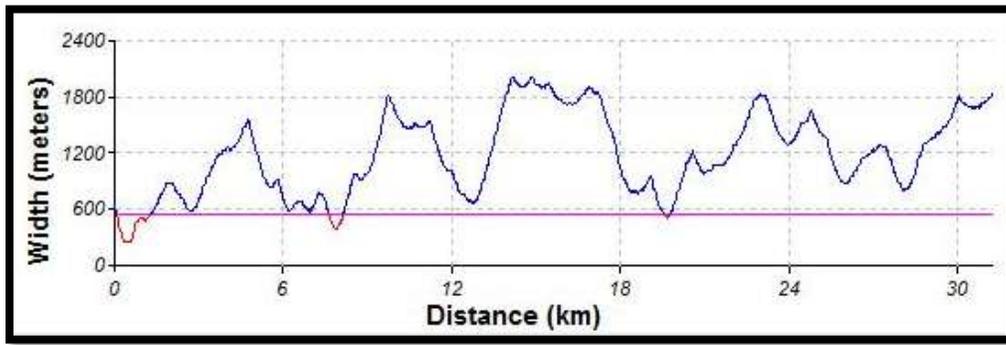


Figure 111: Width along the Coyote - Ironwood trimmed Sonoran desert tortoise single species corridor

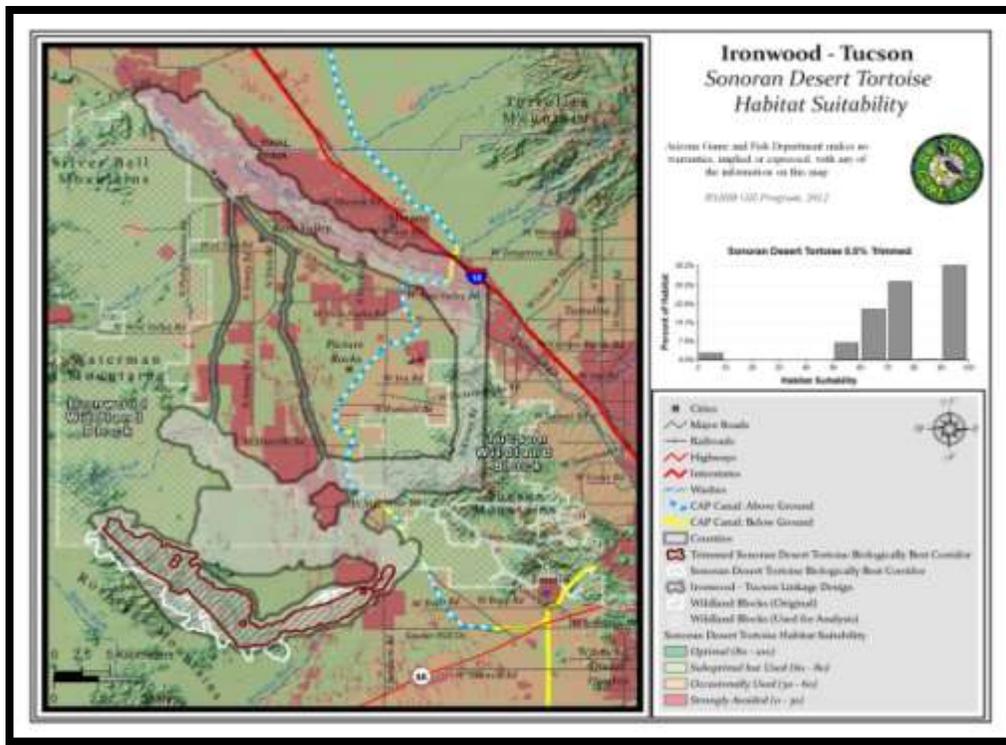


Figure 112: Map of Ironwood – Tucson modeled habitat suitability for Sonoran desert tortoise

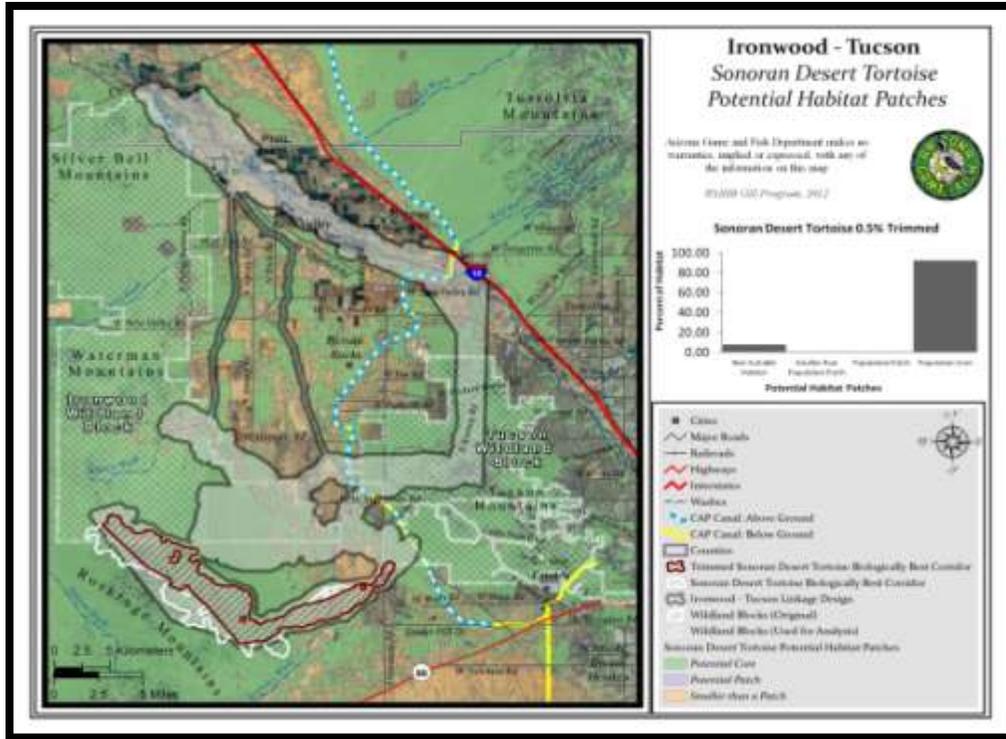


Figure 113: Map of Ironwood – Tucson potential habitat patches for Sonoran desert tortoise

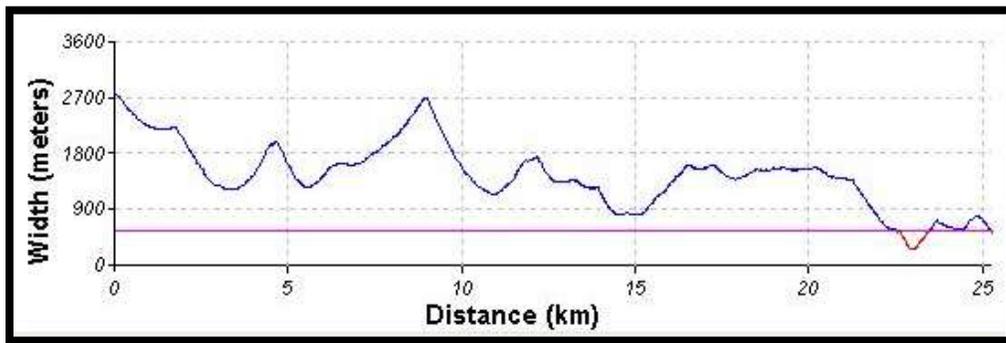


Figure 114: Width along the Ironwood - Tucson trimmed Sonoran desert tortoise single species corridor

## 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).

### *Distribution*

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



*Photo courtesy Randy Babb, AGFD*

### *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 7*.

*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.

### *Results and Discussion*

*Initial biologically best corridor* – Modeling results indicate a variety of habitats within the linkage design for Sonoran whipsnake. Mostly optimal and suboptimal but used habitat exists in the Coyote – Ironwood linkage for Sonoran whipsnake within the trimmed BBC used in the Coyote – Ironwood linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 84.7 (S.D: 19.2; see

Figure 115 below). Most of the BBC (90.8%) is located within a potential population core, with much of the rest encompassing non-suitable habitat (see Figure 116 below). Most of the trimmed BBC (92.3%) was greater than its estimated needed minimum width (see Figure 117 below). The trimmed corridor was measured at 28.5 km (17.7 mi) in length between wildland blocks used for analysis. Within the trimmed BBC used in the Ironwood – Tucson strand, habitat suitability scores also ranged from 0 to 100, with an average suitability of 76.9 (S.D: 25.3; see Figure 118 below). The majority of the trimmed BBC (70.7%) is occupied by a potential population core, with most of the remainder occupied by non-suitable habitat (see Figure 119 below). Most of the trimmed BBC (90.6%) was greater than its estimated minimum width (see Figure 120 below). The trimmed BBC was measured at 25.0 km (15.5 mi) in length between modified wildland blocks.

*Union of biologically best corridors* – The linkage design captures considerably more optimal and suboptimal but used habitat for Sonoran whipsnake. The Ironwood – Tucson linkage captures mostly additional occasionally used and strongly avoided habitat, although the Tucson Mountains offer more optimal habitat for the species.

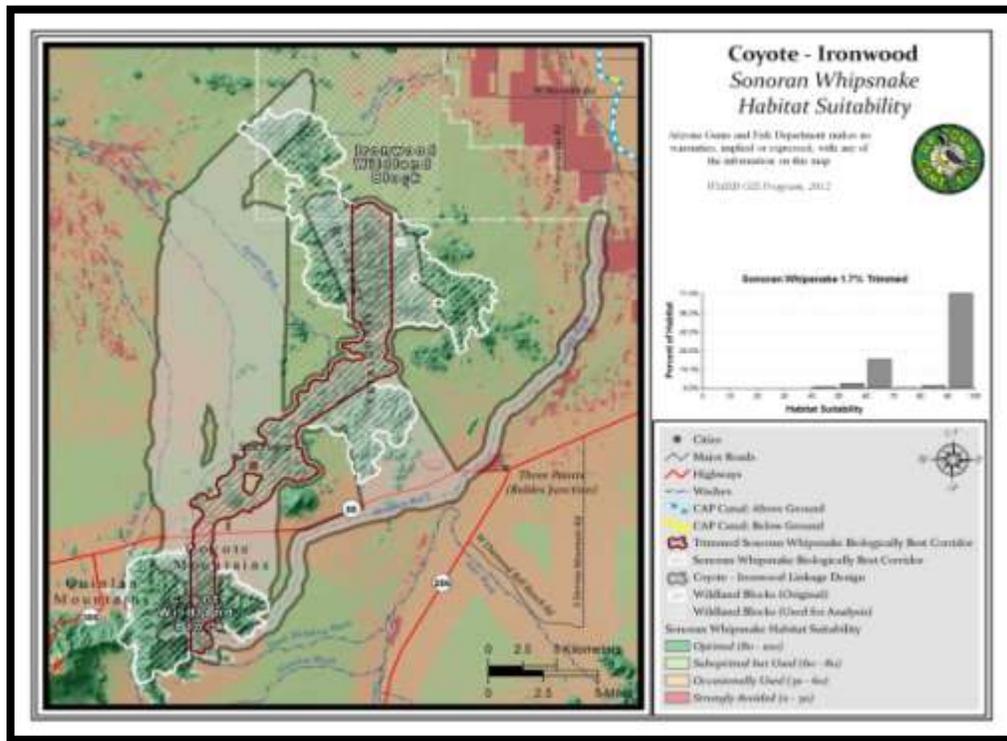


Figure 115: Map of Coyote – Ironwood modeled habitat suitability for Sonoran whipsnake

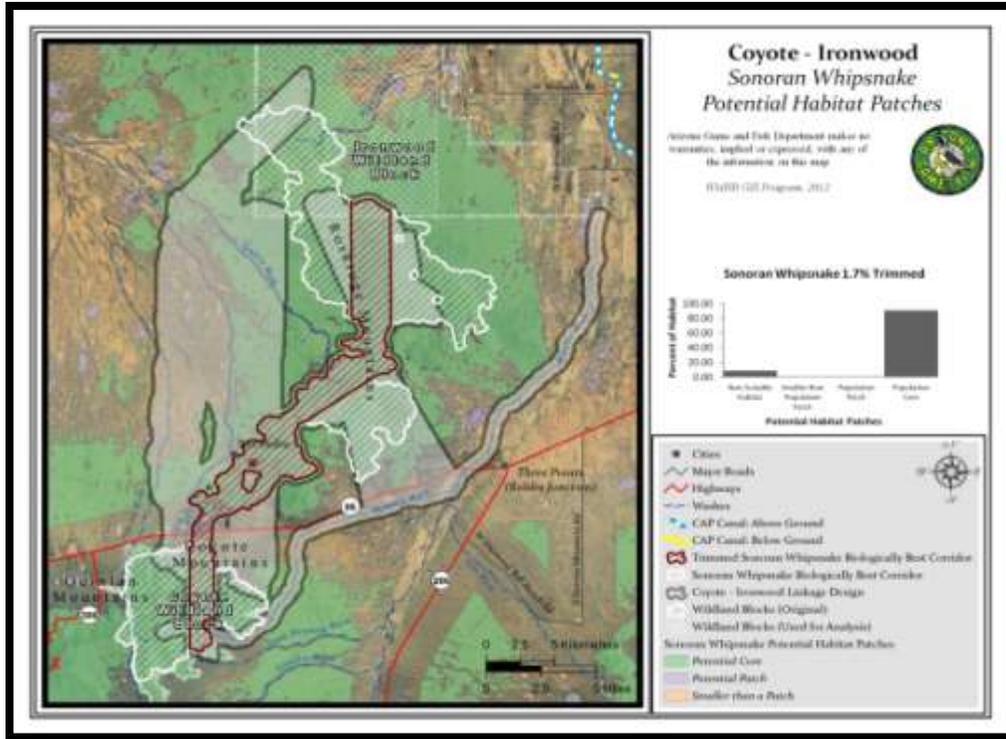


Figure 116: Map of Coyote – Ironwood potential habitat patches for Sonoran whipsnake

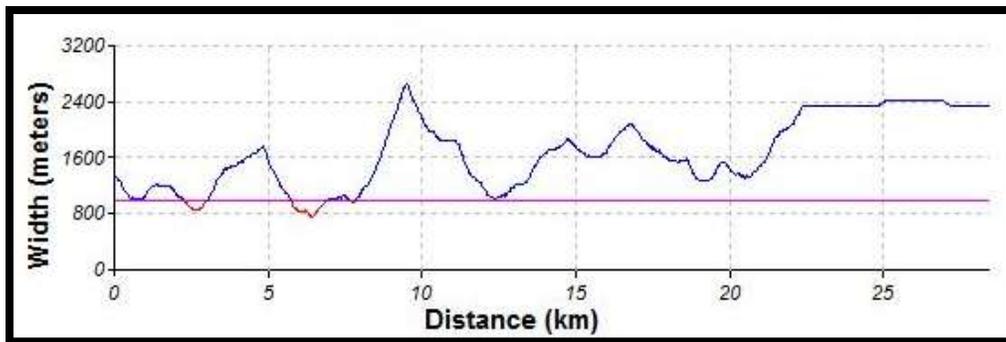


Figure 117: Width along the Coyote - Ironwood trimmed Sonoran whipsnake single species corridor

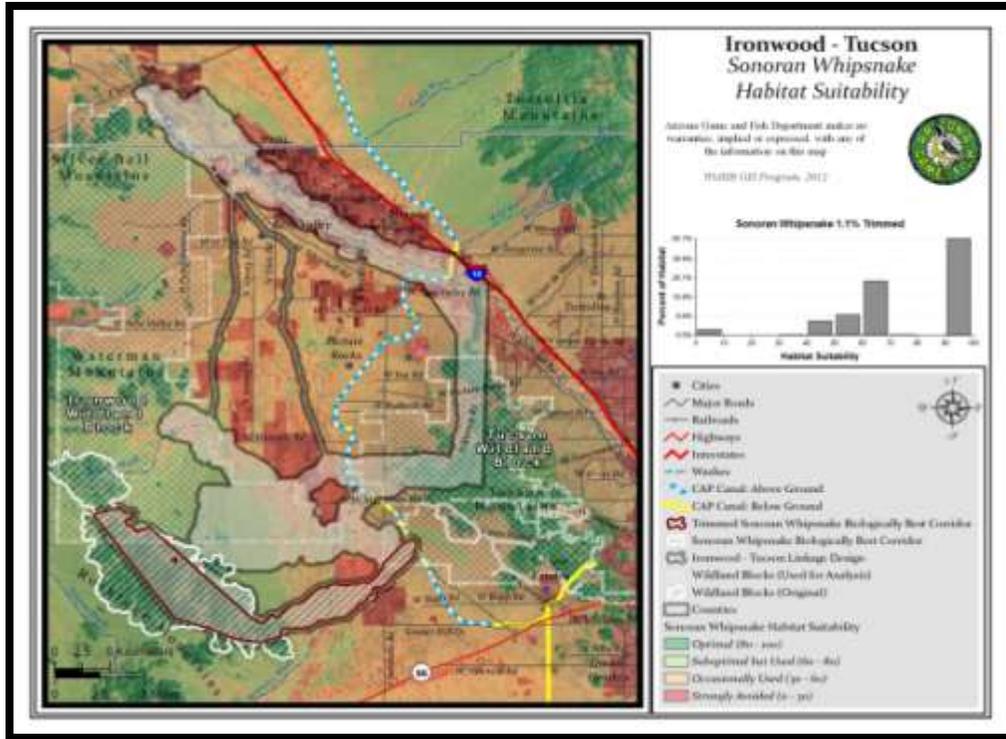


Figure 118: Map of Ironwood – Tucson modeled habitat suitability for Sonoran whipsnake

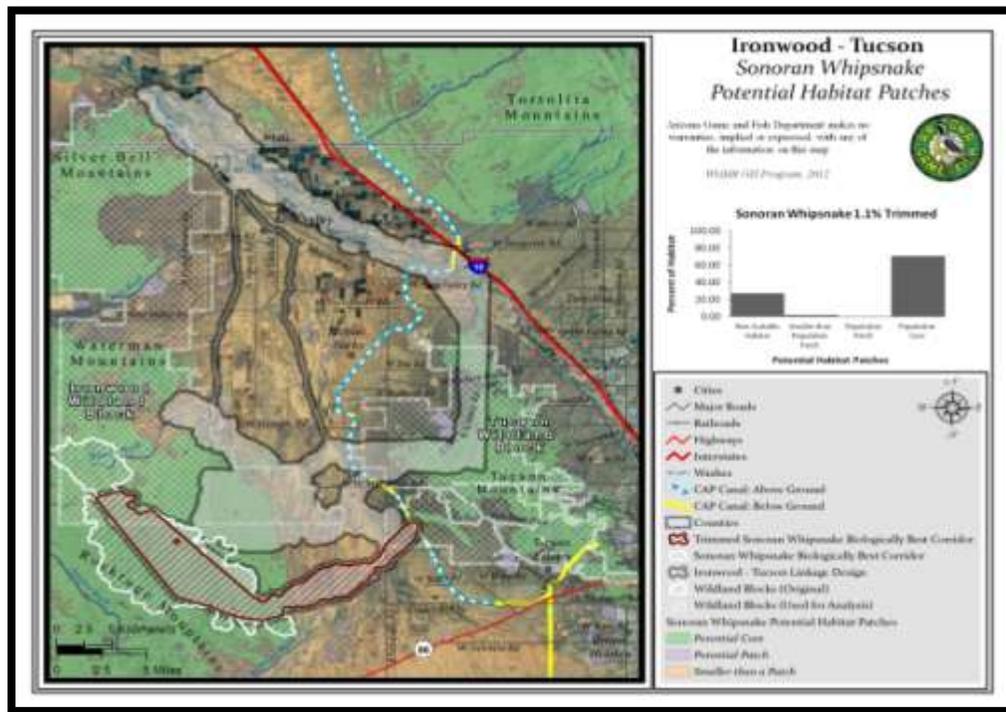
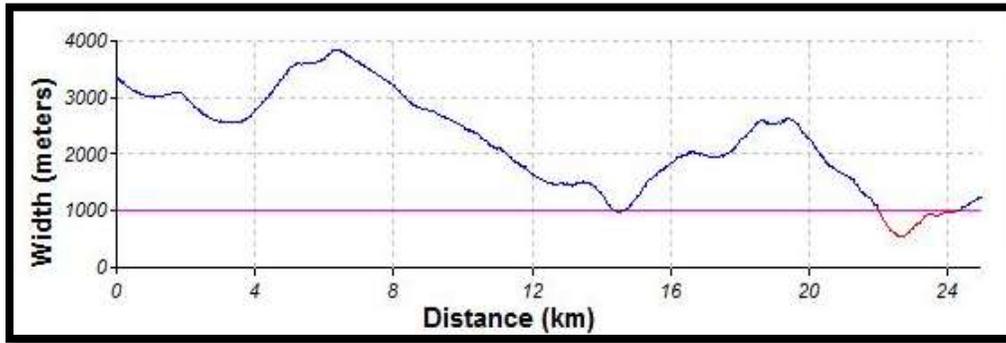


Figure 119: Map of Ironwood – Tucson potential habitat patches for Sonoran whipsnake



*Figure 120: Width along the Ironwood – Tucson trimmed Sonoran whipsnake single species corridor*

## Tucson Shovel-nosed Snake, *Chionactis occipitalis klauberi*

### *Justification for Selection*

Tucson shovel-nosed snakes have a very limited distribution, and are only known to exist in two counties of Arizona. They are susceptible to habitat loss, and are dependent on flat valley floors which are rapidly being converted to agriculture and residential development. A petition has recently been filed to protect the species under the Endangered Species Act.



Photo courtesy Randy Babb, AGFD

### *Distribution*

Tucson shovel-nosed snakes are a subspecies of the western shovel-nosed snake, which ranges from southern Arizona to southern California. This subspecies is found only within the deserts of Pima and Pinal counties within Arizona, and has apparently disappeared from a large part of its range in Avra Valley, possibly due to habitat fragmentation. Populations are known to exist near Picacho Peak State Park, and probably also within Ironwood Forest National Monument (Phil Rosen, personal comm. with CorridorDesign Team).

### *Habitat Associations*

This species is dependent on flat (< 1%), sandy valley floors, and may also use washes. They occur mainly in vegetation associations consisting of creosote bush and desert grasses.

### *Spatial Patterns*

Estimation of home range based on tracks in sandy places indicate this species may move less than many other snake species, needing only 25 ha to sustain a home range. While nothing is known about juvenile dispersal, most snakes are not known to have a dispersal phase. This species is likely to settle into a home range within 1-2 home ranges of their natal area, giving an estimated dispersal distance ranging from 0.25 – 2 km (P. Rosen, personal comm. with CorridorDesign Team).

### *Conceptual Basis for Model Development*

*Habitat suitability model* – Vegetation received an importance weight of 20%, while elevation, topography, and distance from roads received weights of 20%, 45%, and 15%, respectively. For specific scores of classes within each of these factors, see *Table 7*.

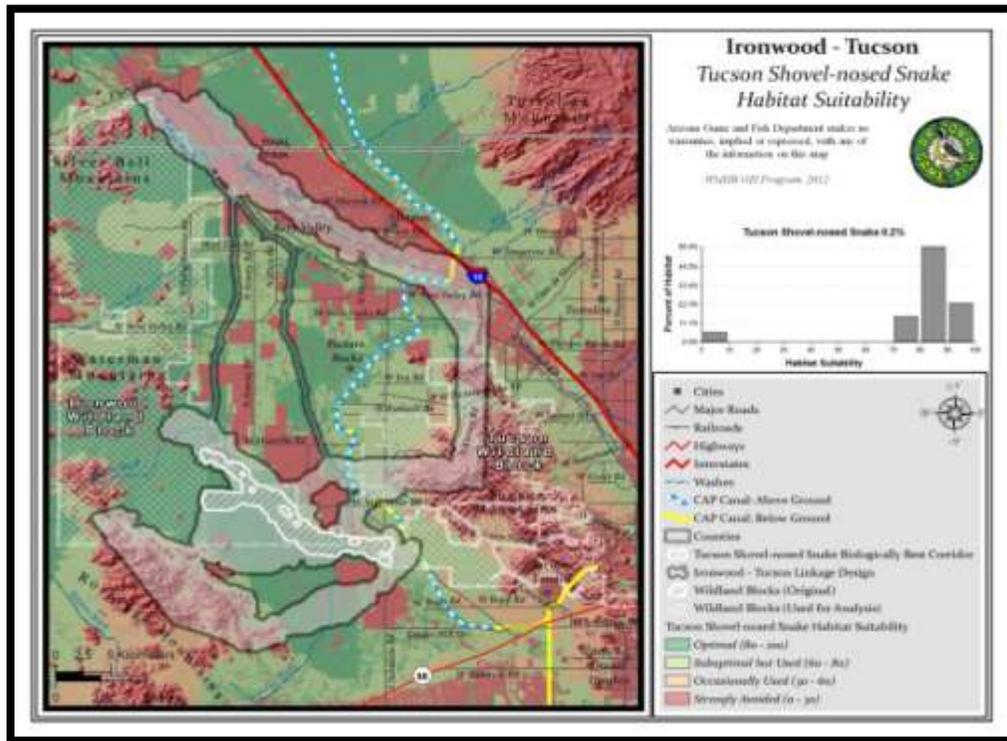
*Patch size and configuration analysis* – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 250 ha (Rosen and Mauz 2001; Phil Rosen, personal comm. with CorridorDesign Team). To determine potential habitat patches and cores, the habitat suitability 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. This species was classified as a corridor dweller due to its estimated limited dispersal (P. Rosen, personal comm. with CorridorDesign Team).

### *Results and Discussion*

*Initial biologically best corridor* – Modeling results indicate a variety of habitats within the linkage design for the Tucson shovel-nosed snake. A corridor was not modeled between the Coyote and Ironwood wildland blocks, as this species has not historically been distributed in this area. Mostly optimal and suboptimal but used habitat exists in the BBC within the Ironwood – Tucson linkage for Tucson shovel-nosed snake. Habitat suitability scores ranged from 0 to 93.0, with an average suitability of 78.9 (S.D: 19.9; see *Figure 121* below). Most of the BBC (91.8%) is located within a potential population core, with the rest encompassing non-suitable habitat (see *Figure 122* below). Most of the BBC (95.1%) was greater than its estimated needed minimum width (see *Figure 123* below). The corridor was measured at 16.5 km (10.3 mi) in length between wildland blocks used for analysis.

*Union of biologically best corridors* – The linkage design captures some additional suitable habitat for Tucson shovel-nosed snake. However, much of the historically suitable habitat for this species in Avra Valley has been converted to active agriculture or urban developments. In the mid-1970s, Tucson shovel-nosed snakes were once observed numerous times per night in Avra Valley (Rosen 2003 as reported in City of Tucson 2012). However, the last known record of the Tucson shovel-nosed snake in Avra Valley occurred in 1979 (Rosen 2003 as reported in City of Tucson 2012), despite surveillance efforts near Marana by Rosen near the Town of Marana in 2003 and 2007 (City of Tucson 2012). The likely cause of this subspecies’ decline is the loss of habitat to active agriculture and urban development (U.S. Fish and Wildlife Service 2010b). In 2007, three Tucson shovel-nosed snakes were detected in Pinal County near the Santa Cruz Flats (Rosen 2008 as reported in City of Tucson 2012). These records may provide evidence the snake still inhabits nearby Avra Valley (Rosen 2008 as reported in City of Tucson 2012). The linkage design may offer an opportunity to conserve remaining habitat for Tucson shovel-nosed snake in Avra Valley.



**Figure 121:** Map of Ironwood – Tucson modeled habitat suitability for Tucson shovel-nosed snake

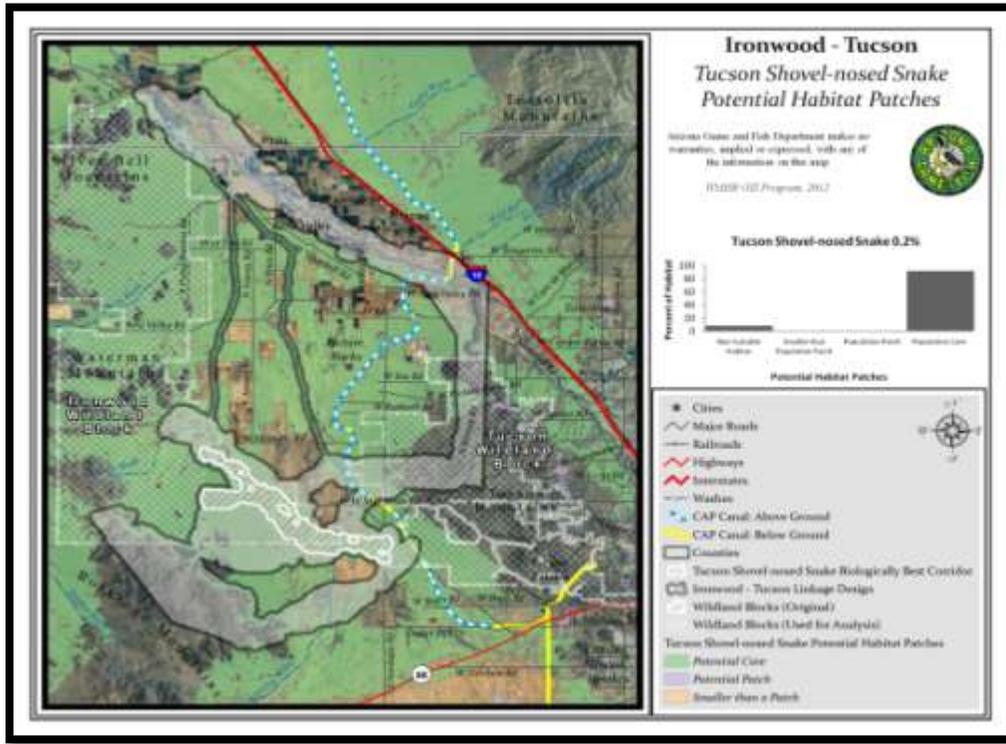


Figure 122: Map of Ironwood – Tucson potential habitat patches for Tucson shovel-nosed snake

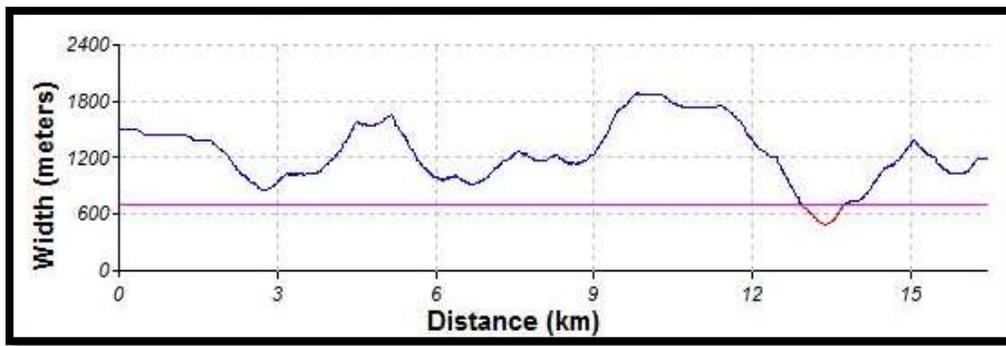


Figure 123: Width along the Ironwood – Tucson Tucson shovel-nosed snake single species corridor

## 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 8: HDMS Species Occurrence in the Linkage Design**

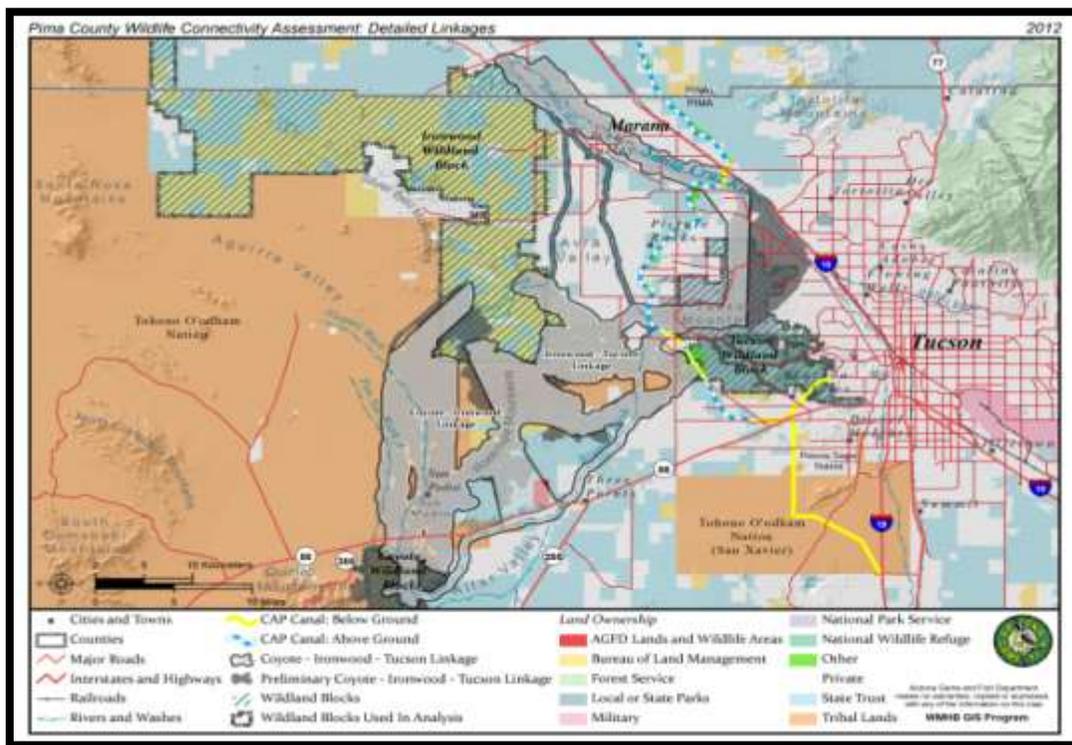
Taxonomic Group	Common Name	Scientific Name	FWS	USFS	BLM	STATE	Corridor Design	SDCP
Amphibian	Chiricahua Leopard Frog	<i>Lithobates (Rana) chiricahuensis</i>	LT			WSC	Yes	Yes
Amphibian	Western Narrow-mouthed Toad	<i>Gastrophryne olivacea</i>		S	S	WSC	No	No
Bird	Bullock's Oriole	<i>Icterus bullockii</i>					No	No
Bird	Cactus Ferruginous Pygmy-owl	<i>Glaucidium brasilianum cactorum</i>	SC	S	S	WSC	No	Yes
Bird	Harris's Hawk	<i>Parabuteo unicinctus</i>					No	No
Bird	Rufous-winged Sparrow	<i>Peucaea carpalis</i>					No	Yes
Bird	Swainson's Hawk	<i>Buteo swainsoni</i>		S			No	Yes
Bird	Tropical Kingbird	<i>Tyrannus melancholicus</i>				WSC	No	No
Bird	Western Burrowing Owl	<i>Athene cucularia hypugaea</i>	SC	S	S		No	Yes
Bird	Yellow-billed Cuckoo (Western U.S. DPS)	<i>Coccyzus americanus</i>	PS:C	S		WSC	No	Yes
Mammal	Bat Colony							
Mammal	Bat Foraging Area	High Netting Concentration						
Mammal	California Leaf-nosed Bat	<i>Macrotus californicus</i>	SC	S	S	WSC	No	Yes
Mammal	Cave Myotis	<i>Myotis velifer</i>	SC		S		No	No
Mammal	High Netting Concentration	Bat Foraging Area					No	No
Mammal	Jaguar	<i>Panthera onca</i>	LE			WSC	Yes	Yes
Mammal	Pocketed Free-tailed Bat	<i>Nyctinomops femorosaccus</i>		S			No	No
Mammal	Silver-haired Bat	<i>Lasionycteris noctivagans</i>					No	No
Plant	Arid Throne Fleabane	<i>Erigeron arisolius</i>		S			No	No
Plant	Balloon Vine	<i>Cardiospermum corindum</i>					No	No
Plant	California Sage	<i>Salvia columbariae</i>					No	No
Plant	Chiricahua Rock Cress	<i>Arabis tricornuta</i>		S			No	No
Plant	Kelvin Cholla	<i>Cylindropuntia x kelvinensis</i>				SR	No	No
Plant	Lotebush	<i>Ziziphus obtusifolia</i>					No	No

Taxonomic Group	Common Name	Scientific Name	FWS	USFS	BLM	STATE	Corridor Design	SDCP
Plant	Pima Indian Mallow	<i>Abutilon parishii</i>	SC	S	S	SR	No	No
Plant	Pima Pineapple Cactus	<i>Coryphantha scheeri</i> var. <i>robustispina</i>	LE			HS	No	Yes
Plant	Pringle Lip Fern	<i>Cheilanthes pringlei</i>					No	No
Plant	Rincon Milkweed Vine	<i>Gonolobus arizonicus</i>					No	No
Plant	Small-flower Unicorn-plant	<i>Proboscidea parviflora</i>					No	No
Plant	Sparseleaf Hermannia	<i>Hermannia pauciflora</i>					No	No
Plant	Thornber Fishhook Cactus	<i>Mammillaria thornberi</i>				SR	No	No
Plant	Tumamoc Globeberry	<i>Tumamoca macdougalii</i>		S	S	SR	No	Yes
Reptile	Northern Green Ratsnake	<i>Senticolis triaspis intermedia</i>		S			No	No
Reptile	Redback Whiptail	<i>Aspidoscelis xanthonota</i>	SC				No	Yes
Reptile	Reticulate Gila Monster	<i>Heloderma suspectum suspectum</i>		S			Yes	No
Reptile	Sonoran Desert Tortoise	<i>Gopherus agassizii</i> (Sonoran Population)	C	S		WSC	Yes	No
Reptile	Tucson Shovel-nosed Snake	<i>Chionactis occipitalis klauberi</i>	C				Yes	Yes

## 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 124* below):

- We trimmed biologically best corridors with “bubble areas” created from widening the strands to meet width requirements over 90% of the corridor. This 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 added an arm in the Coyote – Ironwood linkage, following topography in the Roskruge Mountains with high habitat suitability for multiple species, to accommodate species detections along State Route 86 and recommended mitigation from Lowery et al. (2010). This also functionally connects Pima County’s Northern Altar Valley Reserve to the linkage design.
- We widened the northern strand in the Ironwood – Tucson Linkage to accommodate species detections along Twin Peaks Road and recommended mitigation from Lowery et al. (2007).
- We added a riparian strand 1 km wide along Mendoza Wash and Brawley Wash to accommodate movement of terrestrial species based on species detections from Lowery et al. (2010).
- We buffered Blanco Wash and Robles/Brawley Wash 200m to capture riparian corridors through the linkage design based on recommendations from Majka et al (2007).



*Figure 124: Progression of the 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.

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 toumeyii*, 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.

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. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

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*, *Dasyllirion*, 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 dominates 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*, *Dasyllirion 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 neovermicosia*, *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 (3 CLASSES)** – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulation of earthen material. Generally, vegetation accounts for less than 15% of total cover.

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

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 below 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

## ALTERED OR DISTURBED (1 CLASS) –

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

## DEVELOPED AND AGRICULTURE (3 CLASSES) –

### Agriculture

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

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

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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](mailto: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.