August 2012

Pima County Wildlife Connectivity Assessment: Detailed Linkages

Mexico – Tumacacori – Baboquivari Linkage Design

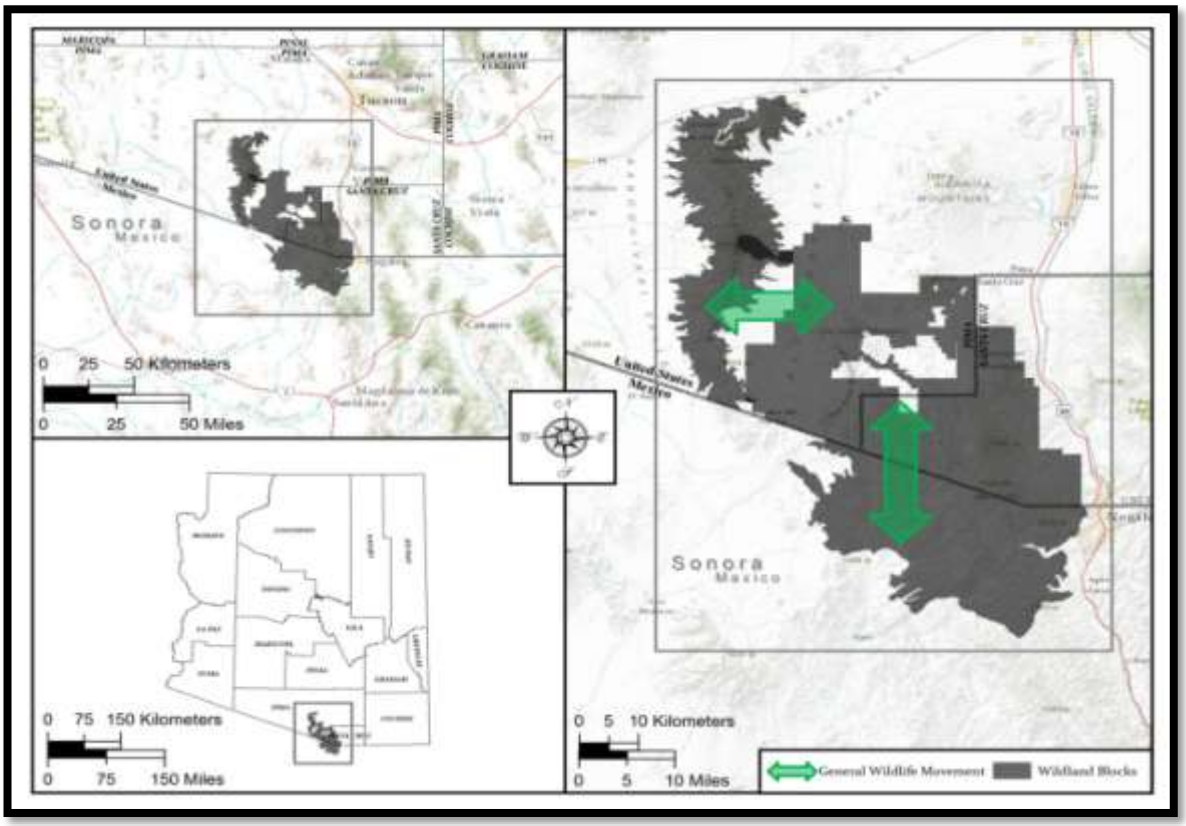

Looking into Mexico at the end of the Pedestrian Border Fence

Arizona Game and Fish Department

Regional Transportation Authority of Pima County

Mexico – Tumacacori – Baboquivari

Linkage Design



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

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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, 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 wildland blocks near the Arizona section of the United States and Mexico international border, near Sasabe, Arizona: the Emerald Mountains in Mexico (Mexico), the Tumacacori Highlands and Buenos Aires National Wildlife Refuge (Tumacacori), and the Baboquivari Mountains (Baboquivari). The linkage design is composed of two linkages for movement and reproduction of wildlife – one linkage between Mexico's Emerald Mountains and the Tumacacori Highlands/Buenos Aires National Wildlife Refuge (Mexico – Tumacacori), and another linkage between the Tumacacori Highlands/Buenos Aires National Wildlife Refuge and the Baboquivari Mountains (Tumacacori – Baboquivari; see *Figure 1* below).

This linkage design is based on a focal species approach. We identified 19 focal species to model, which are known to inhabit or which historically inhabited the previously mentioned wildland blocks, based on the recommendations of workshop participants, and other agency and academic scientists. Species of Greatest Conservation Need potential species distributions, as identified and modeled in Arizona's State Wildlife Action Plan, were also used to confirm possible focal species presence, through Habimap Arizona$_{TM}$. Focal species, in which habitat and/or corridors were modeled as part of this report, include eleven mammals, six reptiles, and two amphibians (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 and pronghorn 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 19 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 Mexico, Tumacacori, and Baboquivari wildland blocks. We also analyzed the size and configuration of suitable habitat patches to verify that the final linkage design provides live-in or move-through habitat for each focal species. We visited focus areas in the field to identify and evaluate barriers to wildlife movement, and we provide detailed mitigations for those barriers in the section titled Linkage Design and Recommendations.

Both the Mexico – Tumacacori and Tumacacori – Baboquivari linkage strands contain many obstacles to wildlife movement. An animal moving north from the Emerald Mountains in Mexico to the Tumacacori Highlands/Buenos Aires National Wildlife Refuge in the United States, may encounter border infrastructure, such as Normandy-style vehicle barriers, or stretches of bollard pedestrian fence, approximately five meters in height, along with an array of border-related activities. Meanwhile, an animal moving west terrestrially from the Tumacacori Highlands/Buenos Aires National Wildlife refuge to the Baboquivari Mountains must cross State Route 286.

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. U.S. – Mexico border policies, and border security that incorporate the needs of wildlife, is also important to allow wildlife connectivity across international lines.

This report contains recommendations to maintain and increase permeability for wildlife throughout the linkage design, ultimately allowing the movement of wildlife populations, and associated flow of genes, between the Emerald Mountains in Mexico, Tumacacori Highlands/Buenos Aires National Wildlife Refuge, and Baboquivari Mountains to improve. This linkage design presents a vision that would maintain large-scale ecosystem processes that are essential to the continued integrity of existing conservation investments. Without accommodating wildlife needs through thoughtful land-use, border policy, and project planning, the connectivity in this area will continue to suffer.

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 help motivate and inform watershed planning, habitat restoration, conservation easements, zoning, and land acquisition. This plan can also be incorporated into the movement needs of wildlife, while still addressing international border security. 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), in the event future transportation projects are planned in this area by providing planners with the following:

- Recommendations for the retrofitting of existing road structures, such as 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 crossing structures 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-kill 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 Mexico – Tumacacori – Baboquivari linkage design*

MAMMALS	Amphibians	REPTILES
*American Pronghorn	*Chiricahua Leopard Frog[HDMS/SDCP]	*Black-tailed Rattlesnake
*Badger	*Sonoran Desert Toad	*Desert Box Turtle[HDMS/SDCP]
*Black Bear		*Giant Spotted Whiptail[HDMS/SDCP]
*Black-tailed Jackrabbit		*Gila Monster [HDMS]
*Coues' White-tailed Deer		*Sonoran Desert Tortoise[HDMS]
*Jaguar [HDMS]		*Sonoran Whipsnake
*Javelina		
*Kit Fox		
*Mountain Lion		
*Mule Deer		
*White-nosed Coati		

: 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.

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 (also see *Appendix D* at the end of this report).

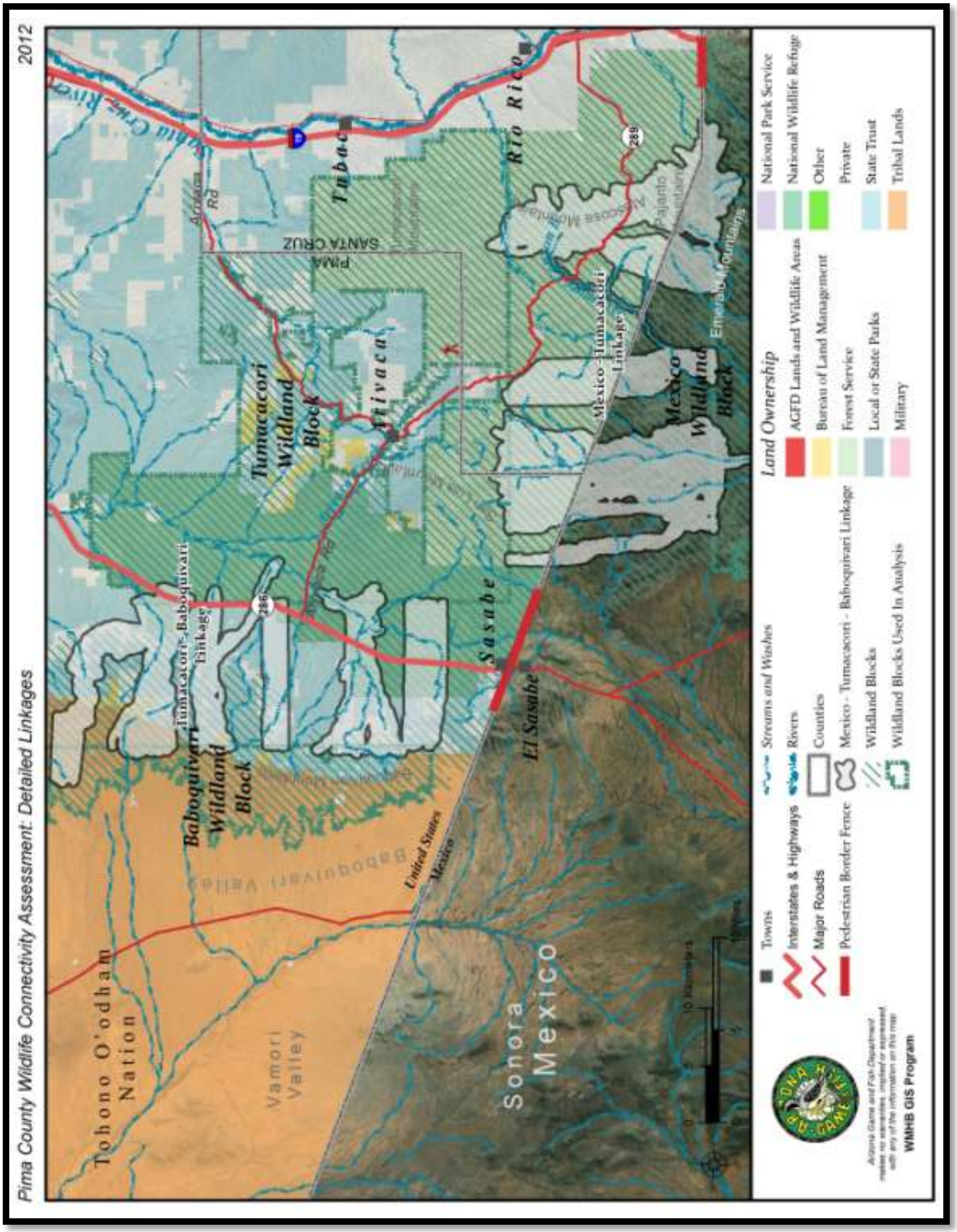


Figure 1: *The linkage design between the Mexico, Tumacacori, and Baboquivari wildland blocks includes a Mexico – Tumacacori linkage and a Tumacacori – Baboquivari linkage*

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).

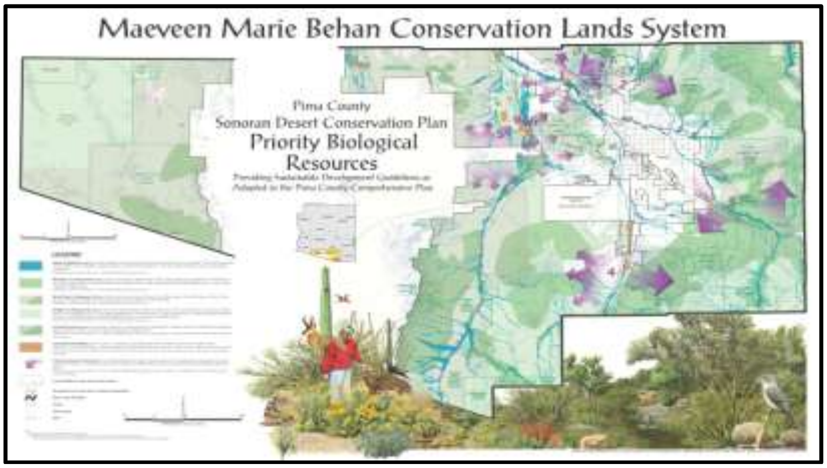


Figure 2: *The Maeveen Marie Behan Conservation Lands System shows the biologically preferred reserve design and works to provide sustainable guidelines for future development. Critical Landscape Connections, or broadly-defined areas where wildlife connectivity is significantly compromised, but can still 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.

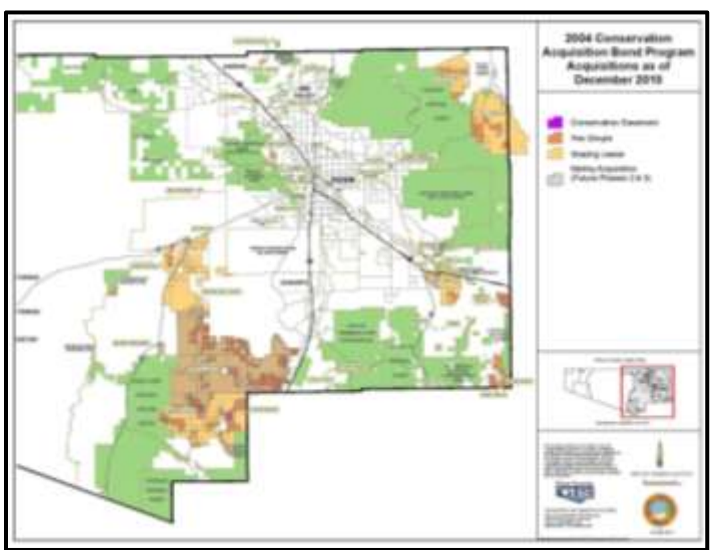


Figure 3: *The 2004 Conservation Acquisition Bond Program was approved to help implement the Sonoran Desert Conservation Plan (Pima County 2011). Multi-use lands are important for habitat and wildlife conservation in the region.*

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 ear-marked $45 million to be used to incorporate wildlife linkage conservation into transportation projects. Over the 20-year timeframe of the RTA, these funds will mitigate barriers to wildlife movement and reduce wildlife-vehicle collisions.

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

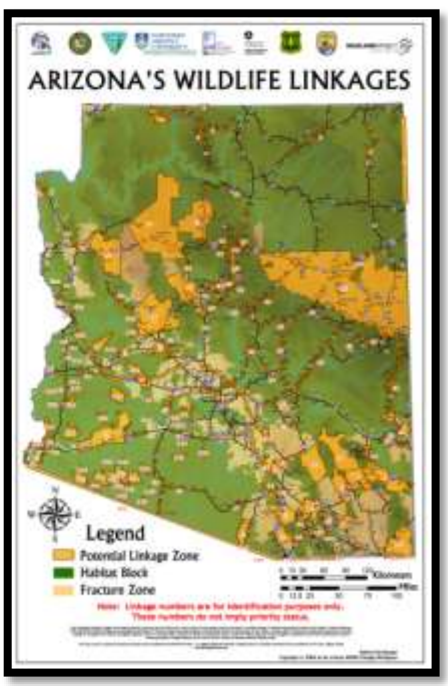
Habitat connectivity can be represented at various spatial scales. In Arizona, we have found it valuable to identify statewide, county-wide, and fine-scale habitat blocks and wildlife linkages to serve different conservation and planning objectives. The linkage planning tools created at each scale have 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, US Bureau of Land Management, US Fish and Wildlife Service, US 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 www.corridordesign.org) which provided the template for this report.

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

Overview of the Pima County Wildlife Connectivity Assessment

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



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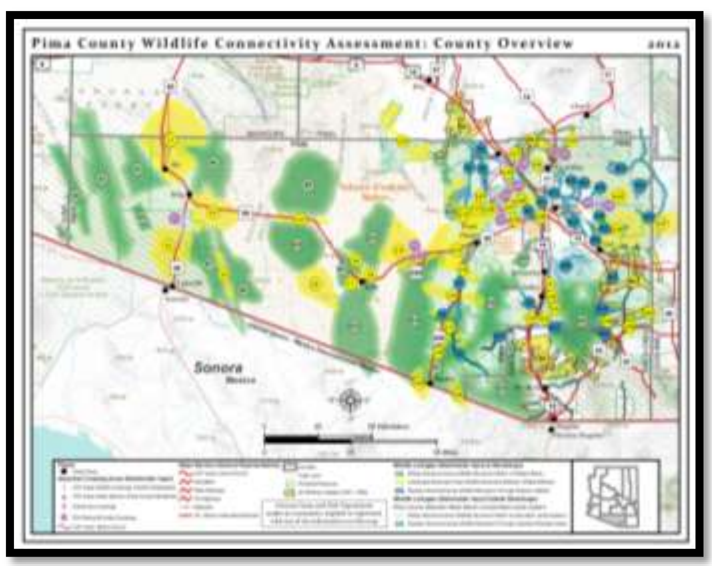

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Figure 4 and Figure 5: *Statewide map of wildlife linkages and barriers created by the Arizona Wildlife Linkages Workgroup (2006). County-wide map of wildlife linkage created for the Pima County Wildlife Connectivity Assessment: Report on Stakeholder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

Ecological Significance and Existing Conservation Investments of the Mexico – Tumacacori – Baboquivari 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 Mexico – Tumacacori – Baboquivari Linkage Planning Area

The Mexico – Tumacacori – Baboquivari linkage planning area lies at the crossroads of two major ecoregions; the Apache Highlands, which create the mountainous sky islands, and the Sonoran Desert, which extends west and south into Mexico. The Sonoran Desert is the most tropical of North America's warm deserts (Marshall et al. 2000). Bajadas sloping down from the mountains support forests of ancient saguaro cacti, 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; The Nature Conservancy 2006). More than 500 species of birds migrate through, breed, or permanently reside in the ecoregion, which are nearly two-thirds of all species that occur from northern Mexico to Canada (Marshall et al. 2000). The Sonoran Desert Ecoregion's rich biological diversity prompted Olson and Dinerstein (1998) to designate it as one of 233 of the earth's most biologically valuable ecoregions, whose conservation is critical for maintaining the earth's biodiversity.

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.

Three wildland blocks exist here: Mexico's Emerald Mountains (Mexico), the Tumacacori Highlands/Buenos Aires National Wildlife Refuge (Tumacacori), and Baboquivari Mountains (Baboquivari). These wildland blocks are separated by various topographic features, including the flat lands of Altar Valley between the Tumacacori and Baboquivari wildland blocks, and the steep topography of the Atascosa and Pajarito Mountains, between the Mexico and Tumacacori wildland blocks. Man-made features separating the blocks include: the U.S. – Mexico International Border pedestrian fencing and vehicle barriers, and State Route 286.

Maintaining connectivity between these wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in these ecoregions, and allow the expansion of ranges to historically used habitats. Providing connectivity is paramount in sustaining this unique area's diverse natural heritage. Current and future human activities could sever natural connections and alter the functional integrity of this natural system. Conserving linkages will ensure that wildlife will thrive in the wildland blocks and the potential linkage area.

Below is a description of the ecological significance of each wildland block (see *Figure 6* below for a map of land cover categories; see *Appendix F* at the end of this report for a description of biantional landcover classifications):

Mexico Wildland Block

The Mexico wildland block encompasses over 221,718 acres of the Emerald Mountains, completely within the country of Mexico. These mountains are dominated by grass/pasture, and forests, which comprise the largest percentages of its binational landcover classification. Elevation here ranges from 2,923 feet to 5,902 feet.

Tumacacori Wildland Block
The Tumacacori wildland block includes over 381,240 acres of land encompassing the numerous mountain ranges that comprise the Tumacacori Highlands including, the Atascosa, Los Guijas, Pajarito, Tumacacori, and San Luis Mountains. The wildland block is dominated by shrub, wash, and forest. Elevation in the block ranges from 2,992 feet to 7,106 feet.

Baboquivari Wildland Block
The Baboquivari wildland block includes over 163,555 acres of land encompassing the Baboquivari Mountains, and closer to the U.S.-Mexico International Border, the Pozo Verde Mountains. The wildland block is dominated by shrub and forest. Elevation in this block ranges from 2,762 feet to 7,719 feet.

Conservation Investments in the Mexico – Tumacacori – Baboquivari Linkage Planning Area

The Mexico, Tumacacori, and Baboquivari wildland blocks represent large areas of land with varying conservation protection of habitat for different wildlife species in the linkage planning area. Connectivity between these wildland blocks would help to provide the contiguous habitat necessary to sustain viable populations of sensitive and far ranging species in the Apache Highlands and Sonoran Desert, and provide the chance for important focal species to expand their range to historically used habitats. Increasing wildlife connectivity here is paramount in sustaining this unique area's diverse natural heritage. Current and future human activities could sever natural connections and alter the functional integrity of this natural system. Conserving and restoring linkages will ensure that wildlife will thrive in the wildland blocks and the potential linkage area:

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

Mexico Wildland Block
The Mexico wildland block, encompassing the Emerald Mountains, is not currently protected by conservation lands. This lack of conservation protection, provided a unique challenge to delineating the block's boundaries for use in this analysis. The Pima County Hillside Development Overlay Zone Ordinance, which requires a permit for grading land with slope ≥ 15% (Pima County 2012), may offer some conservation protection for lands within Pima County, Arizona, and has been used to delineate the boundaries of wildland blocks within the County for use in many of the Pima County Wildlife Connectivity Assessment: Detailed Linkages. While this ordinance does not apply to lands within Mexico, the steep topography that innately exists by using this method to define the block is resistant to many types of development, and offers a topographical protection of the block. The Mexican Nation maintains the right to develop lands within a wildland block.

Tumacacori Wildland Block
The entire Tumacacori wildland block is protected by conservation investments. The block includes the Buenos Aires National Wildlife Refuge, over 126,162 acres of land, administered by the U.S. Fish and Wildlife Service. The block also includes over 203,854 acres of Coronado National Forest, managed by

the U.S. Forest Service. Additionally, portions of Ranch Seco and Sopori Ranch, managed by Pima County for conservation, are included in the block at over 38,792 acres.

Baboquivari Wildland Block

The Baboquivari wildland block includes the Coyote Mountains Wilderness which is over 5,000 acres managed by the U.S. Bureau of Land Management (BLM). Further south, The Baboquivari Peak Wilderness, over 2,000 acres in size, is also located within the wildland block. The Baboquivari Peak Wilderness is also administered by the BLM. Much of the wildland block is located within the Tohono O'odham Nation. Since the majority of this wildland block is not conventionally protected by conservation areas, it was useful in this analysis to define its boundaries by also referencing the Pima County Hillside Development Overlay Zone Ordinance, and digitizing lands that meet ordinance criteria. While this ordinance does not apply to lands within the Tohono O'odham Nation, the steep topography that innately exists by using this method to define the block is resistant to many types of development, and offers a topographical protection of the block. Tribal sovereignty includes the right to develop tribal lands within a wildland block.

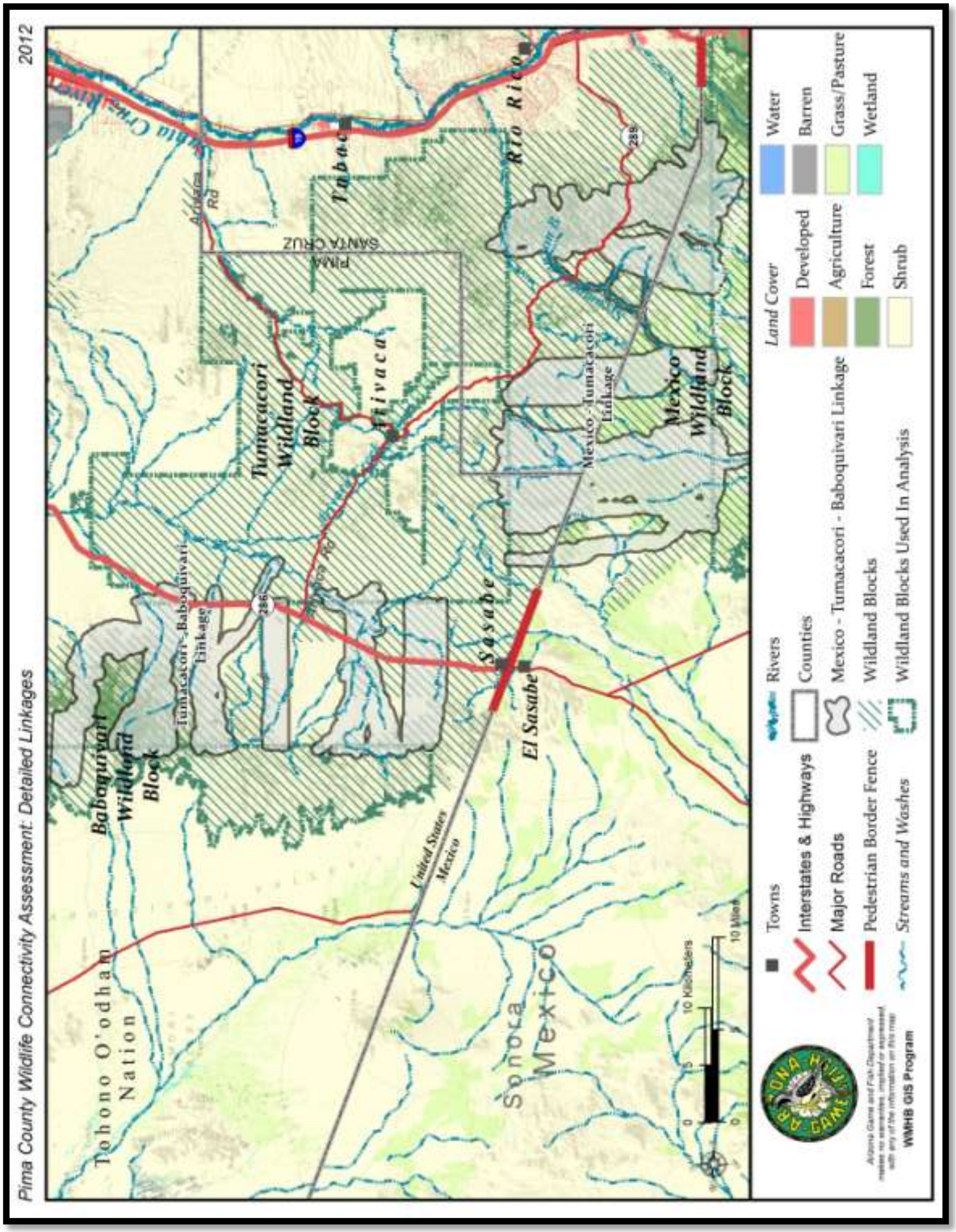

Figure 6: *Land cover in the Mexico – Tumacacori – Baboquivari linkage design*

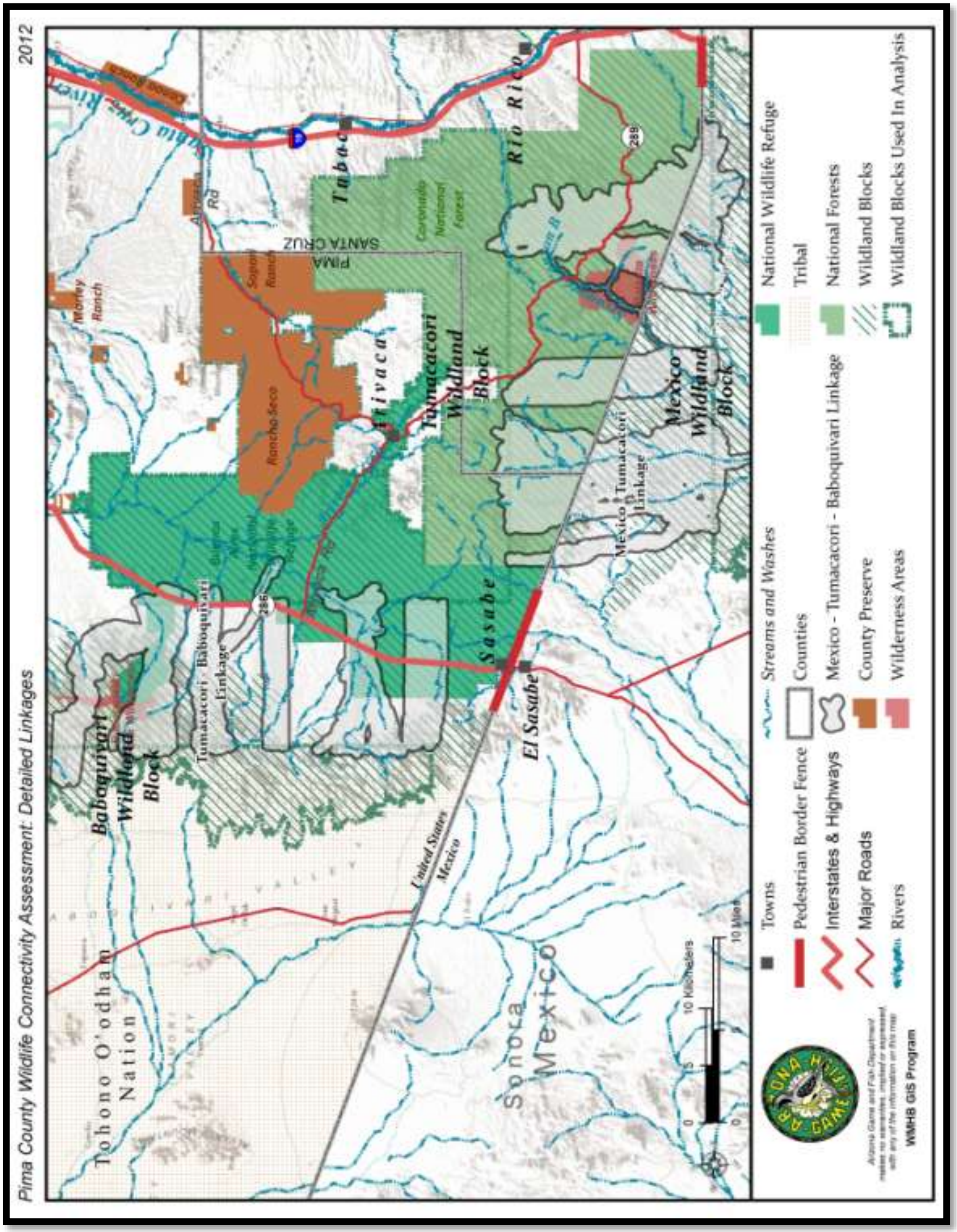

Figure 7: *Existing conservation investments in the Mexico – Tumacacori – Baboquivari linkage design*

The Mexico – Tumacacori – Baboquivari Linkage Design

The linkage design (see *Figure 1* for a map of the linkage design at the beginning of this report) includes a Mexico – Tumacacori linkage strand, and a Tumacacori – Baboquivari 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 Mexico – Tumacacori Linkage

The Mexico – Tumacacori linkage runs between the Mexico wildland block and the Tumacacori wildland block, acoss the U.S.-Mexico International Border. It spans about 17.8 km (11.1 mi) in a straight-line between each wildland block used in this analysis. The linkage encompasses 104,695 acres (42,369 ha) of land, of which approximately 50% is located within the Coronado National Forest, and 50% is located in south of the U.S.-Mexico International Border within Mexico. It is primarily composed of shrub (56.3%), grass/pasture (27.9%), forest (11.4%), and wash (4.1%). This linkage has an average slope of 25.5% (Range: 0 – 263.9%, SD: 19.2). Most of the land (47.9%) is steeply sloped, and flatly-gently sloped (21.2%), with the rest a mix of canyon bottom and ridgetop.

LINKAGE DESIGN GOALS

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

This linkage between the Mexico and Tumacacori wildland blocks has become increasingly threatened by barriers to wildlife connectivity:

U.S.-Mexico International Border

Border security measures and infrastructure along the U.S.-Mexico International Border have increased dramatically in recent years (Roberts et al. 2010). Stretches of bollard-style pedestrian border fence, approximately five meters in height, extend for seven kilometers east of Sasabe, Arizona, representing a major barrier to wildlife. Continuing from the pedestrian fence, almost the entire remainder of the border is barricaded by Normandy-style vehicle barriers, although these barriers may be more permeable to wildlife. While the pedestrian fence does not enter the linkage, vehicle barriers line the international border throughout.

The Tumacacori - Baboquivari Linkage

The Tumacacori – Baboquivari linkage runs through Altar Valley from the Tumacacori Highlands and Buenos Aires National Wildlife Refuge to the Baboquivari Mountains. The linkage spans approximately 12.3 km (7.6 mi) in a straight-line between each wildland block used in this analysis. The linkage encompasses 72,761 acres (29,445 ha) of land, of which 39.9% is State Trust land, 29.1% is national wildlife refuge, 15.0% is private land, 13.9% is tribal land, and the rest is administered by the U.S. Bureau of Land Management. The linkage is primarily composed of shrub (85.1%), forest (8.2%), and wash (6.3%). This strand has an average slope of 18.1% (Range: 0-369.5%, SD: 23.9). The majority of land in this strand is classified as having flat-gentle slopes (59.3%), with steep slopes occupying the second largest topographic classification (23.7%).

State Route 286
State Route 286 may represent a major barrier to wildlife movement from the Tumacacori wildland block to the Baboquivari wildland block, especially with increasing traffic from boarder law enforcement. This road likely represents the largest transportation related barrier to wildlife in the linkage design.

Characteristics of the Entire Linkage Design

The linkage design encompasses 177,457 acres (71,814 ha) of land, of which 29.7% is within Coronado National Forest, 29.0% is within Mexico, 16.4% is State Trust land, 12.0% is national wildlife refuge, 5% is tribal land, and the rest is owned or administered by miscellaneous entities (see *Figure 1* for a map of the linkage design and land ownership at the beginning of this report). Shrub accounts for 68.1% of the land cover. Grass/pasture accounts for 16.5%, 10.1% is forest, and 5.0% is wash (see *Table 2* below).

A range of topographic diversity exists within the linkage design, providing for the ecological needs of the focal species, as well as creating a buffer against a potential shift in ecological communities due to climate change (see *Figure 8* below). The majority of slope in the linkage design is less than 10%, with many other categories well represented. About 37% of the land is classified as gentle slopes, 40% as steep slopes, and the remaining 23% as canyon bottom or ridgetop. There is a variety of land aspects represented, most of which west aspects.

Table 2: *Approximate binational landcover found within the Mexico – Tumacacori – Baboquivari linkage design*

Modified Binational Land Cover Class	% of Linkage Design
Developed	0.2%
Agriculture	0.0%
Forest	10.1%
Shrub	68.1%
Water	0.0%
Barren	0.0%
Grass/Pasture	16.5%
Wetland	0.0%
Wash	5.0%

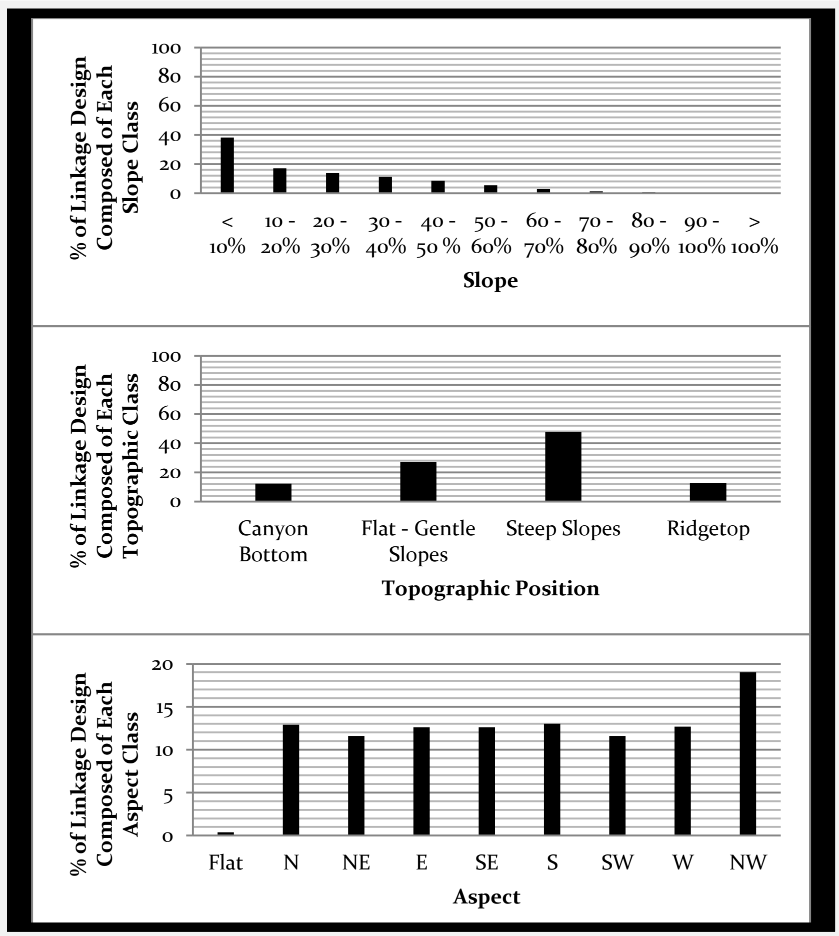

Figure 8: *Topographic diversity encompassed by Mexico – Tumacacori – Baboquivari linkage design: a) Topographic position, b) Slope, c) Aspect*

Removing and Mitigating Barriers to Movement

Although roads and utility infrastructure may 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 maintain connectivity between the Mexico, Tumacacori, and Baboquivari wildland blocks, 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 9* and *Figure 10* below):

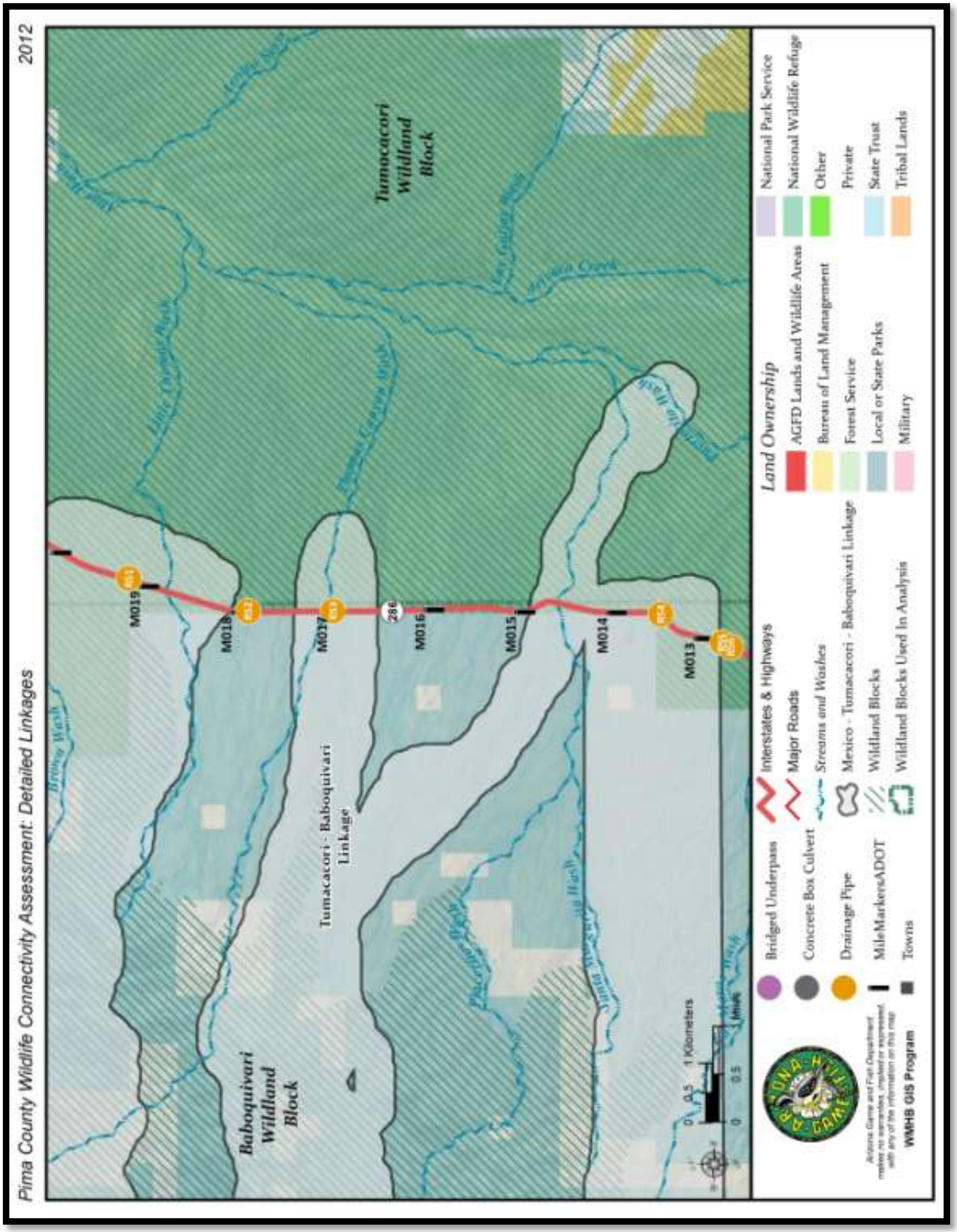

Figure 9: *Road structures within the northern portion of the Tumacacori – Baboquivari linkage*

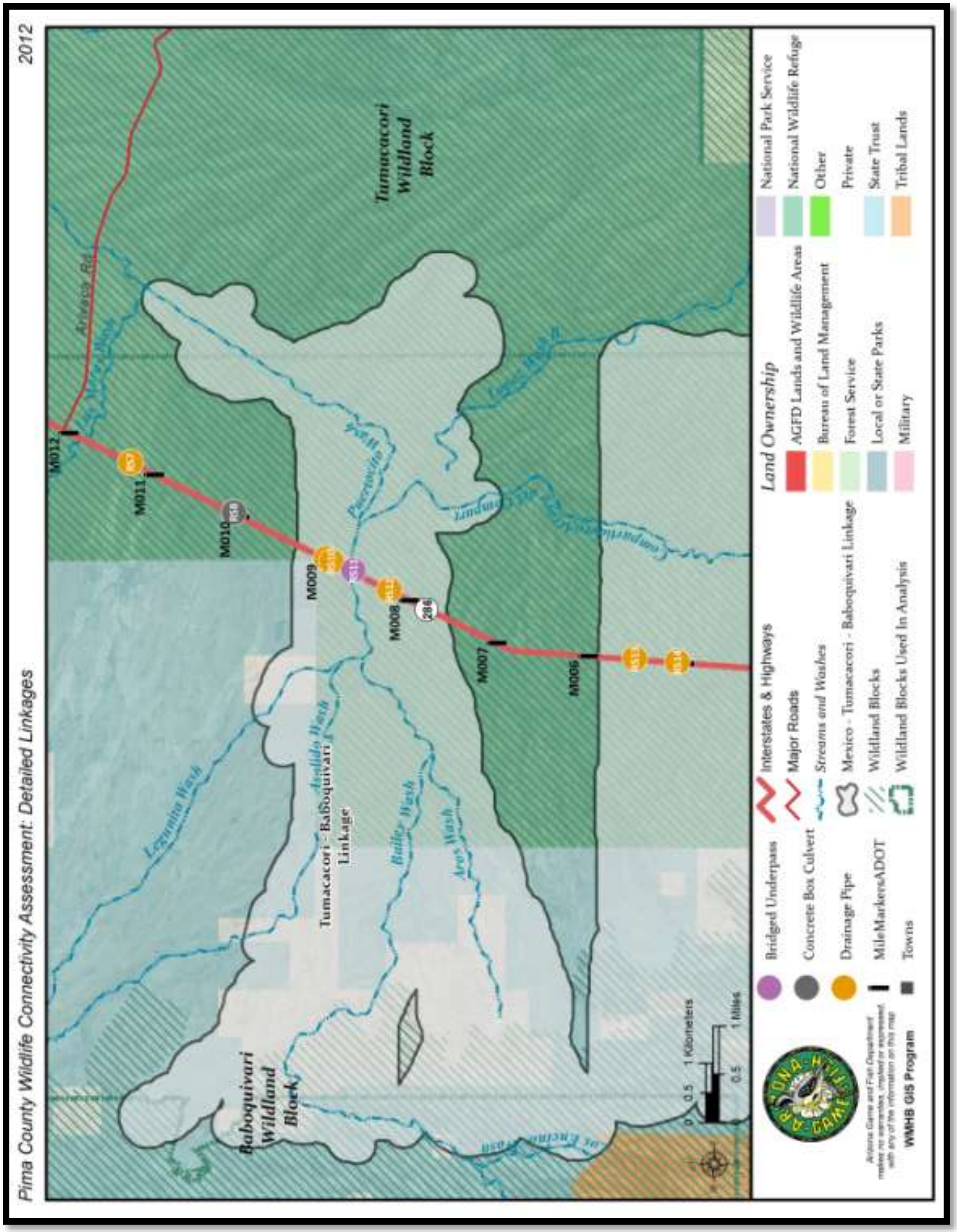

Figure 10: *Road structures within the southern portion of the Tumacacori – Baboquivari linkage*

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

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

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

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

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses, bridges, culverts, and pipes (see *Figure 11* below). While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald and St Clair 2004).

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. Forman et al. (2003) documented approximately 50 overpasses that have been built in the world, with only 6 of these occurring in North America. Recently, three overpasses were constructed over U.S. Highway 93 in northwestern Arizona to improve permeability of the highway for desert bighorn sheep and prevent negative wildlife-vehicle interactions based on McKinney and Smith's (2007) desert bighorn movement study. Overpasses are typically 30 to 50 m wide, but can be as large as 200 m wide. In Banff National Park, Alberta, grizzly bears, wolves, and all ungulates (including bighorn sheep, deer, elk, and moose) prefer overpasses to underpasses, while species such as mountain lions prefer underpasses (Clevenger and Waltho 2005).

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

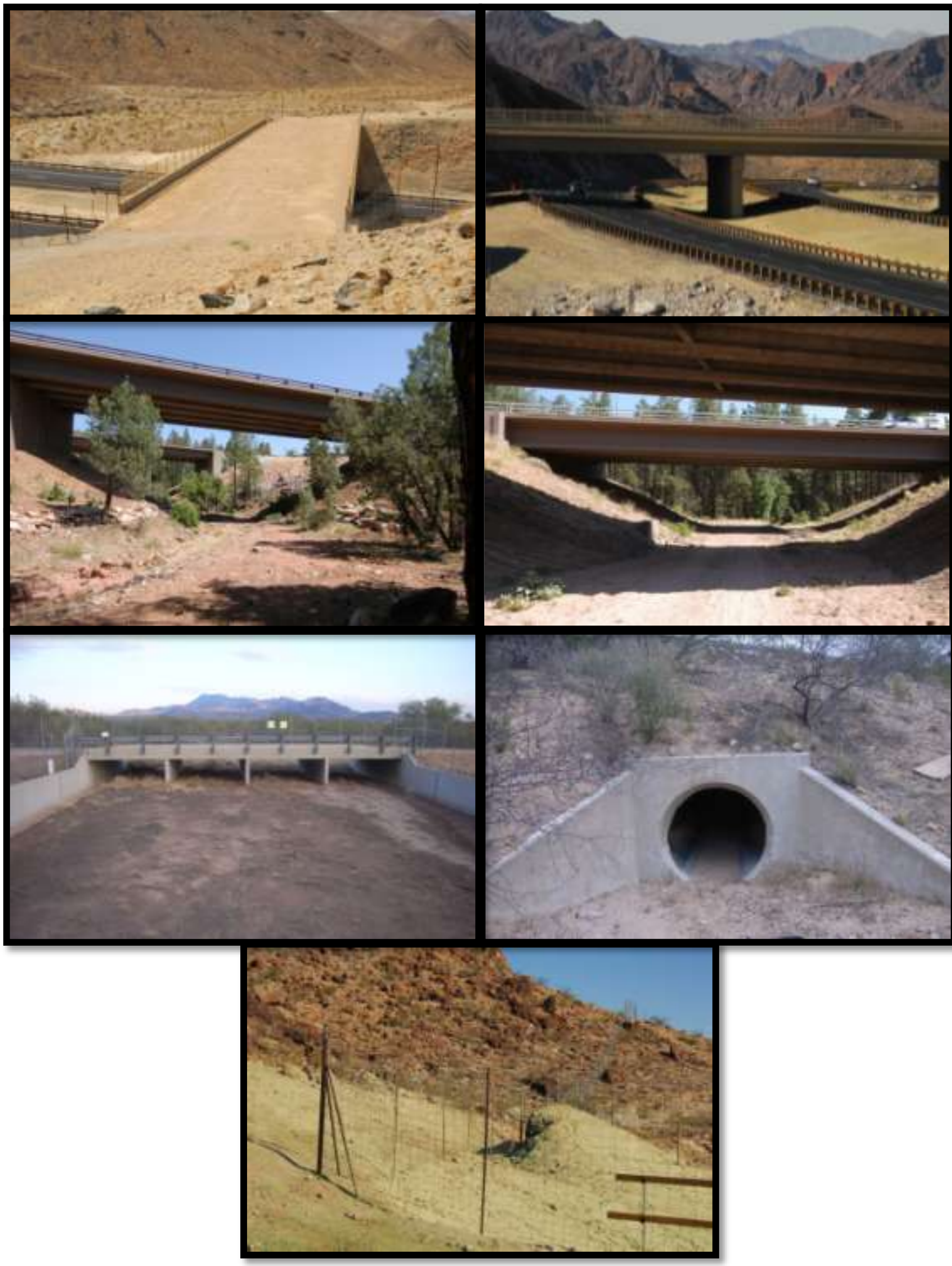

Figure 11: *Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (bottom) should be used to guide animals into crossing structures (Photographs courtesy George Andrejko and Dean Pokrajac, AGFD).*

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

General Standards and Guidelines for Wildlife Crossing Structures

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

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

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

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

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

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

6) **Fencing should never block entrances to crossing structures, and instead should direct animals towards crossing structures** (Yanes et al. 1995). In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in road kill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Along Arizona State Route 260, a combination of wildlife underpasses and ungulate-proof fencing reduce elk-vehicle collisions by 80% (Dodd et al. 2007). Fences, guard rails, and embankments at least 2 m high discourage animals from crossing roads (Barnum 2003, Cain et al. 2003, Malo et al. 2004). One-way ramps on roadside fencing can allow an animal to escape if it is trapped on a road (Forman et al. 2003).

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

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

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

Specifications for Wildlife Crossing Structures

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

These specifications 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 24.2 km (15.1 mi) of roads and highways in the linkage design (See *Table 4* below). We focused our field investigations on State Route 286, as it is may be the largest barrier to wildlife due to transportation in the linkage design.

Table 4: *Roads greater than 1 kilometer in length in the Mexico – Tumacacori – Baboquivari linkage design*

Road Name	Kilometers	Miles
Ruby Rd	9.2	5.7
State Route 286	15.0	9.3

Recommendations for Crossing Structures in the Tumacacori – Baboquivari Linkage

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. State Route 286 (SR 286) was the focus of field observations, as this may be the largest barrier to wildlife due to transportation in the linkage design. These recommendations will improve wildlife connectivity across SR 286, and refer to waypoints on the maps at the beginning of this section (see *Figure 9* and *Figure 10* above):

State Route 286

- Road structure RS1, near SR 286 mile post 19, consists of a drainage pipe under SR 286, approximately 1.2 m (4 ft) in diameter (see *Figure 12* below). This structure should be retrofitted to accommodate movements of large-sized mammals and herpetofauna, based on its location within and near biologically best corridors for Gila monster, and jaguar. This should be done to the specifications of culverts and associated fencing/barriers for herpetofauna and large-sized mammals referenced above.
- Road structure RS2, near SR 286 mile post 18, consists of a drainage pipe under SR 286, approximately 1.8 m (6 ft) in diameter (see *Figure 13* below). This structure should be retrofitted to accommodate movements of large-sized mammals, based on its location near the biologically best corridor for jaguar. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.
- Road structure RS3, near SR 286 mile post 17, consists of a drainage pipe under SR 286, near Thomas Canyon Wash, approximately 1.2 m (4 ft) in diameter (see *Figure 14* below). This structure should be retrofitted to accommodate movements of herpetofauna, based on its location within the biologically best corridor for Sonoran desert tortoise. This should be done to the specifications of culverts and associated barriers for herpetofauna referenced above.
- Road structure RS4, between SR 286 mile posts 13 – 14, consists of a set of three drainage pipes under SR 286, approximately 1.2 m (4 ft) in diameter (see *Figure 15* below). This structure should be retrofitted to accommodate movements of small and medium-sized mammals, and herpetofauna (including amphibians), based on its location within and near the biologically best corridors for badger, black-tailed jackrabbit, desert box turtle, kit fox, and Sonoran desert toad.

This should be done to the specifications of culverts and associated barriers/fencing for medium-sized mammals and herpetofauna referenced above.

- Road structure RS5, near SR 286 mile post 13, consists of a drainage pipe under SR 286, approximately 0.9 m (3 ft) in diameter (see *Figure 16* below). This structure should be retrofitted to accommodate movements of small and medium-sized mammals, and herpetofauna (including amphibians), based on its location near the biologically best corridors for badger, black-tailed jackrabbit, desert box turtle, kit fox, and Sonoran desert toad. This should be done to the specifications of culverts and associated barriers/fencing for medium-sized mammals and herpetofauna referenced above.
- Road structure RS6, near SR 286 mile post 13, consists of a set of three drainage pipes under SR 286, approximately 1.1 m (3.5 ft) in diameter (see *Figure 17* below). This structure should be retrofitted to accommodate movements of small and medium-sized mammals, and herpetofauna (including amphibians), based on its location near the biologically best corridors for badger, black-tailed jackrabbit, desert box turtle, kit fox, and Sonoran desert toad. This should be done to the specifications of culverts and associated barriers/fencing for medium-sized mammals and herpetofauna referenced above.
- Road structure RS7, between SR 286 mile posts 11 – 12, consists of a set of two drainage pipes under SR 286, approximately 0.8 m (2.5 ft) in diameter (see *Figure 18* below). This structure should not be considered a priority to retrofit, as it is outside of the linkage design.
- Road structure RS8, near SR 286 mile posts 10, consists of a set of a three-celled concrete box culvert under SR 286, approximately 3 m (10 ft) in height and 3 m (10 ft) in width (see *Figure 19* below). While this structure is located outside of the linkage design, its relatively large height and width may allow passage of most species of wildlife, including large-sized mammals. Thus, this culvert should be retrofitted with fencing to accommodate movements of large-sized mammals, based on its current construction.
- Road structure RS9, near SR 286 mile post 9, consists of a drainage pipe under SR 286, approximately 0.8 m (2.5 ft) in diameter (see *Figure 20* below). This structure should be retrofitted to accommodate movements of large-sized mammals, based on its location within the biologically best corridors for Coues' white-tailed deer and mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.
- Road structure RS10, near SR 286 mile post 9, consists of a drainage pipe under SR 286, approximately 1.1 m (3.5 ft) in diameter (see *Figure 21* below). This structure should be retrofitted to accommodate movements of large-sized mammals, based on its location within the biologically best corridors for Coues' white-tailed deer and mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.
- Road structure RS11, between SR 286 mile posts 8 – 9, consists of a bridged underpass spanning Bailey Wash (see *Figure 22* below). This structure should be retrofitted to accommodate movements of medium and large-sized mammals, based on its location within the biologically best corridors for Coues' white-tailed deer, javelina, and mountain lion. This should be done to the specifications of culverts and associated fencing for medium and large-sized mammals referenced above.
- Road structure RS12, between SR 286 mile posts 8 – 9, consists of a drainage pipe under SR 286, approximately 0.6 m (2 ft) in diameter (see *Figure 23* below). This structure should be retrofitted to accommodate movements of medium and large-sized mammals, based on its location near the biologically best corridors for javelina, mountain lion, and mule deer. This should be done to the specifications of culverts and associated fencing for medium and large-sized mammals referenced above.
- Road structure RS13, between SR 286 mile posts 5 – 6, consists of a set of two drainage pipes under SR 286, approximately 0.9 m (3 ft) in diameter (see *Figure 24* below). This structure

should be retrofitted to accommodate movements of large-sized mammals, based on its location within the biologically best corridors for Coues' White-tailed deer, and mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.

- Road structure RS14, near SR 286 mile post 5, consists of a set of two drainage pipes under SR 286, approximately 0.9 m (3 ft) in diameter (see *Figure 24* below). This structure should be retrofitted to accommodate movements of large-sized mammals, based on its location within the biologically best corridors for Coues' White-tailed deer, and mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.

Figure 12: *Drainage pipe under SR 286 (RS1)*

Figure 13: *Drainage pipe under SR 286 (RS2)*

Figure 14: *Drainage pipe under SR 286 (RS3)*

Figure 15: *A set of three drainage pipes under SR 286 (RS4)*

Figure 16: *Drainage pipe under SR 286 (RS5)*

Figure 17: *A set of three drainage pipes under SR 286 (RS6)*

Figure 18: *A set of two drainage pipes under SR 286 (RS7)*

Figure 19: *Concrete box culvert under SR 286 (RS8)*

Figure 20: *Drainage pipe under SR 286 (RS9)*

Figure 21: *Drainage pipe under SR 286 (RS10)*

Figure 22: *Bailey Wash Bridge along SR 286 (RS11)*

Figure 23: *Drainage pipe under SR 286 (RS12)*

Figure 24: *A set of two drainage pipes under SR 286 (RS13)*

Figure 25: *Drainage pipe under SR 286 (RS16)*

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 ≥ 4 m tall, have vertical gaps 5-10 cm wide and are associated with vegetation clearing and roads ≥ 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 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 are evident within the linkage design. As mentioned at the beginning of the Mexico – Tumacacori – Baboquivari Linkage Design Section, the Mexico – Tumacacori linkage lies just east of a stretch of bollard-style pedestrian border fence, approximately five meters in height, and extending seven kilometers east of Sasabe, Arizona (see *Figure 26* below). However, continuing on from the pedestrian fence, Normandy-style vehicle barriers, bisect the linkage along the U.S.-Mexico International Border (see *Figure 27* below).

Guidelines and Recommendations for Mitigation of Artificial Lighting

We offer the below guidelines to mitigate artificial lighting related to border infrastructure. These guidelines follow the Arizona Game and Fish Department's Wildlife Friendly Guidelines (2009b) for mitigation of artificial lighting:

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

Figure 26: *Bollard-style pedestrian fence along the U.S.-Mexico International Border east of Sasabe, AZ*

Figure 27: *Normandy-style vehicle barriers extending from the pedestrian fence along the U.S.-Mexico International Border east of Sasabe, AZ*

Appendix A: Linkage Design Methods

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

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

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

Focal Species Selection

To represent the needs of the ecological community within the potential linkage area, we used a focal species approach (Lambeck 1997). Focal species were originally chosen by the CorridorDesign Team at Northern Arizona University and Regional biologists familiar with species across the State that had one or more of the following characteristics:

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

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

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

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

Habitat Suitability Models

We created habitat suitability models (see *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 28 below*):

- *Vegetation and land cover.* The CorridorDesign Team originally used the Southwest ReGAP (SWREGAP) land cover dataset in this analysis. We used the USGS U.S.-Mexico Border Environmental Health (BEHI) Initiative Binational Land Cover Dataset 2001 to model cross-border habitat suitability. The dataset was modified to include binational stream/wash data from BEHI (See *Appendix F* at the end of the report).
- *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 nine 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). The Corridor Design Team at Northern Arizona University recruited biologists wherever possible to assign habitat suitability scores. When a species expert could not be used, the CorridorDesign Team assigned species scores, and then average results. Regardless of whether the scores were generated by a species expert or CorridorDesign Team biologists, the scorer first reviewed the literature on habitat selection by the focal species[2]. Binational land cover was analyzed using zonal statistics to determine which SWREGAP categories each binational land cover encompassed. Then, original species scores for land cover categories encompassed by BEHI binational land cover categories were averaged for each species.

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

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

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

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

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

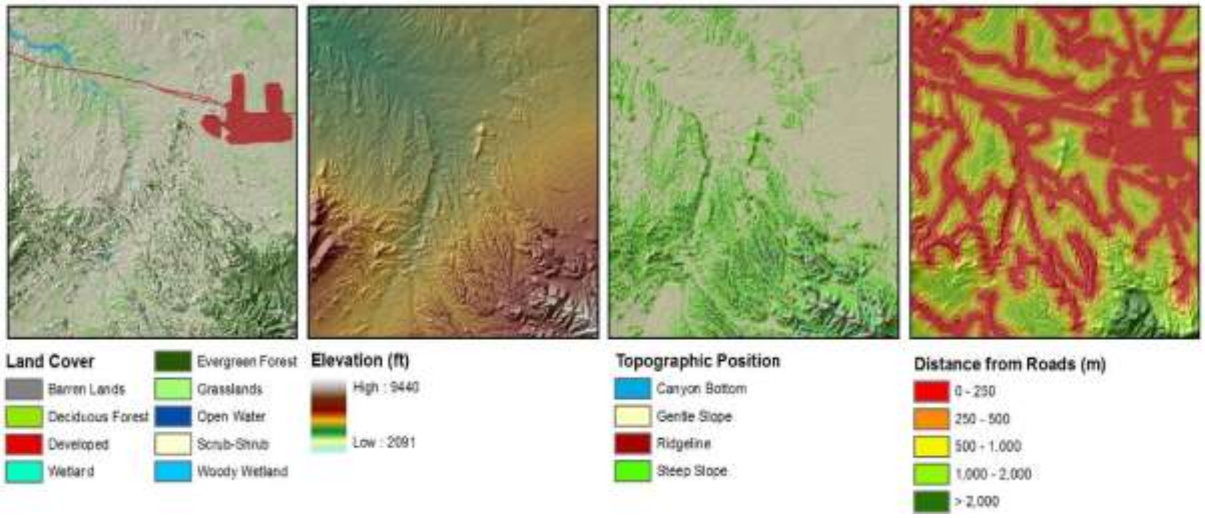

Figure 28*: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window*

Identifying Potential Breeding Patches and Potential Population Cores

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

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

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

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

Identifying Biologically Best Corridors

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

We developed BBCs only for some focal species, namely species that (a) exist in both wildland blocks, or have historically existed in both and could be restored to them, (b) can move between wildland blocks in less time than disturbances such as fire or climate change will make the current vegetation map obsolete, and (c) move near the ground through the vegetation layer (rather than flying, swimming, or being carried by the wind), and (d) have habitat preferences that can reasonably be represented using GIS variables.

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

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

To create each biologically best corridor, we used the habitat suitability score as an estimate of the cost of movement through the pixel[7]. For each pixel, we calculated the lowest cumulative cost to that pixel from a starting point in one wildland block. We similarly calculated the lowest cumulative travel cost from the 2nd wildland block, and added these 2 travel costs to calculate the *total travel cost* for each pixel. The total travel cost thus reflects the lowest possible cost associated with a path between wildland blocks that passes through the pixel. Finally, we defined the biologically best corridor as the swath of pixels with the lowest total travel cost and a minimum width of 1000m (See *Figure 29* below). After developing a biologically best corridor for each species, we combined biologically best corridors to form a union of biologically best corridors (UBBC). If a species had two or more distinct we retained multiple strands if they had roughly equal travel cost and spacing among habitat patches.

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

[6] The GIS algorithm will almost always select a corridor 100 m long (width of a freeway) over a corridor 5 miles long, even if the habitat is much better in the longer corridor.

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

Patch Configuration Analysis

Although the UBBC identifies an optimum corridor between the wildland blocks, this optimum might be poor for a species with little suitable habitat in the potential linkage area. Furthermore, corridor analyses were not conducted for some focal species (see 3rd paragraph of previous section). To address these issues, we examined the maps of potential population cores and potential habitat patches for each focal species (including species for which a BBC was estimated) in relation to the UBBC. For each species, we examined whether the UBBC encompasses adequate potential habitat patches and potential habitat cores, and we compared the distance between neighboring habitat patches to the dispersal[8] distance of the species. For those species (*corridor-dwellers*, above) that require multiple generations to move between wildland blocks, a patch of habitat beyond dispersal distance will not promote movement. For such species, we looked for potential habitat patches within the potential linkage area but outside of the UBBC. When such patches were within the species' dispersal distance from patches within the UBBC or a wildland block, we added these polygons to the UBBC to create a *preliminary linkage design*.

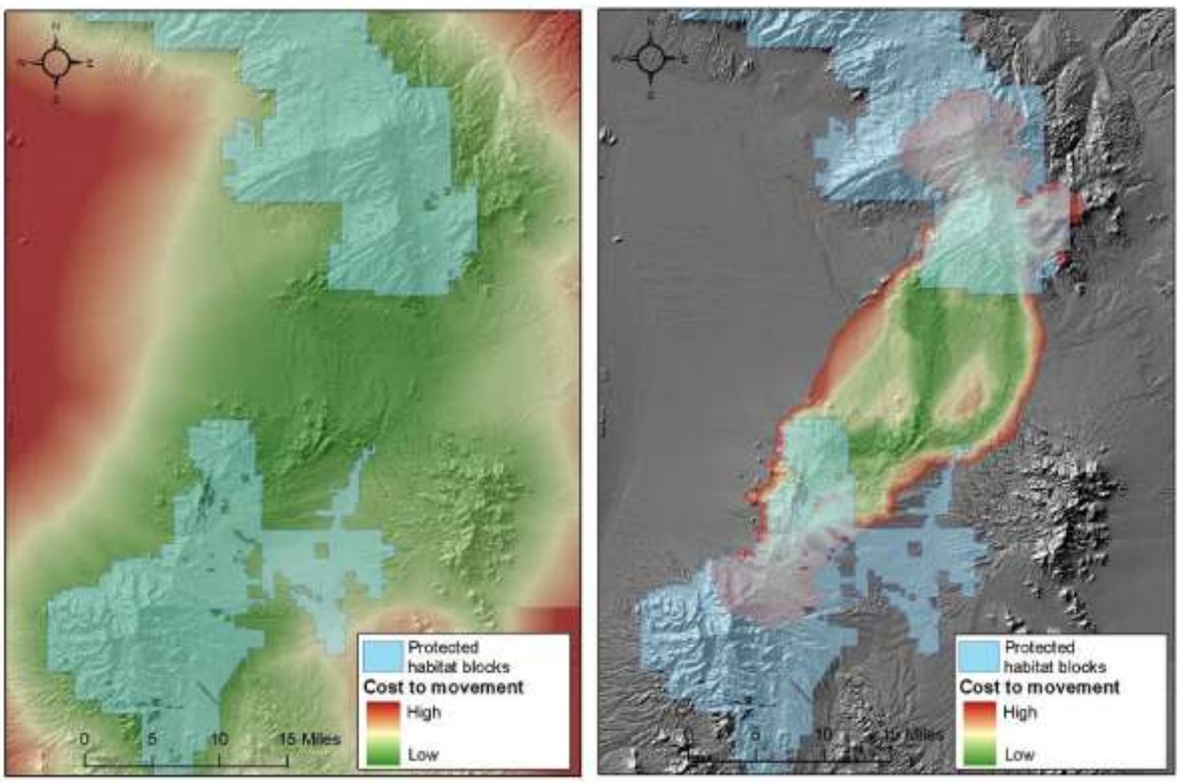

Figure 29*: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape*

[8] Dispersal distance is how far an animal moves from its birthplace to its adult home range. We used dispersal distances reported by the species expert, or in published literature. In some cases, we used dispersal distance for a closely-related species.

Minimum Linkage Width

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

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

Minimum widths for individual species corridors were estimated based on home range values used to calculate potential habitat patch sizes, and whether or not the species was classified as a *corridor dweller* or *passage species* (see definition for focal species). Based on recommendations from Beier et al. (2008), individual models for corridor dwellers were more than 2 times the width of their home range over 90% of the length of the model, while passage species model widths were less than the width of their home range. Minimum widths for passage species were also maintained over 90% of the corridor model where possible. Home range widths were estimated from home range area assuming a 2:1 rectangle. It is especially important that the linkage will be useful in the face of climate change. Climate change scientists unanimously agree that average temperatures will rise 2 to 6.4 C over pre-industrial levels by 2100, and that extreme climate events (droughts and storms) will become more common (Millennium Ecosystem Assessment 2005). Although it is less clear whether rainfall will increase or decrease in any location, there can be no doubt that the vegetation map in 2050 and 2100 will be significantly different than the map of current vegetation used in our analyses. Implementing a corridor design narrowly conforming to current distribution of vegetation types would be risky. Therefore, in widening terrestrial linkage strands, we attempted to maximize local diversity of aspect, slope, and elevation to provide a better chance that the linkage will have most vegetation types well-distributed along its length during the coming decades of climate change. Because of the diversity of focal species used to develop the UBBC, our preliminary linkage design had a lot of topographic diversity. Some widening of the UBBC was needed to increase the width of a few merged biologically best corridor strands.

Field Investigations

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

Appendix B: Individual Species Modeling Parameters

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

	American Pronghorn	Badger	Black Bear	Black-tailed Jackrabbit	Black-tailed Rattlesnake
Factor Weights					
Land Cover	45	65	75	70	0
Elevation	0	7	10	10	0
Topography	37	15	10	10	90
Distance from Roads	18	13	5	10	10
Binational Land Cover					
Developed	11	15	0	28	
Agriculture	28	48	44	50	
Forest	33	48	86	49	
Shrub	68	74	48	85	
Water	39	7	0	11	
Barren	15	18	0	19	
Grass/Pasture	86	95	45	75	
Wetland	28	41	56	64	
Wash	78	22	22	56	
Elevation (ft)					
		0 - 1676: 100	0 - 762: 22	0 - 1829: 100	
		1676 - 2438: 78	762 - 1219: 44	1829 - 2438: 67	
		2438 - 4000: 44	1219 - 1981: 100	2438 - 4000: 22	
			1981 - 2591: 89		
			2591 - 4000: 67		
Topographic Position					
Canyon Bottom	100	56	78	72	100
Flat - Gentle Slopes	100	100	44	94	11
Steep Slope	22	26	78	67	100
Ridgetop	44	37	67	67	100
Distance from Roads					
	0 - 100: 11	0 - 250: 44	0 - 100: 11	0 - 250: 11	0 - 35: 0
	100 – 250: 44	250 - 15000: 100	100 - 500: 67	250 - 500: 44	35 - 500: 56
	250 – 1000: 78		500 - 1500: 100	500 - 1000: 78	500 - 15000: 100
	1000 – 1500: 100			1000 - 15000: 100	100

	Chiricahua Leopard Frog	Coues' White-tailed Deer	Desert Box Turtle	Giant Spotted Whiptail
Factor Weights				
Land Cover	55	65	40	70
Elevation	25	5	15	30
Topography	10	15	20	
Distance from Roads	10	15	25	
Binational Land Cover				
Developed	39	9	28	73
Agriculture	44	33	56	67
Forest	33	92	11	11
Shrub	15	52	56	28
Water	89	33	56	89
Barren	0	11	11	0
Grass/Pasture	44	64	61	17
Wetland	44	84	100	84
Wash	44	22	33	56
Elevation (ft)				
	0 - 1006: 0	0 - 610: 33	0 - 610: 0	0 - 579: 0
	1006 - 1829 : 100	610 - 914: 44	610 - 701: 56	579 - 792: 67
	1829 - 2743: 89	914 - 1219: 89	701 - 1219: 100	792 - 1676: 100
	2743 - 4000: 78	1219 – 1829: 100	1219 - 1402: 67	1676 - 1981: 56
		1829 – 2438: 78	1402 - 1524: 11	1981 - 4000: 11
		2438 – 4000: 33	1524 - 4000: 0	
Topographic Position				
Canyon Bottom	100	100	78	78
Flat - Gentle Slopes	100	100	100	100
Steep Slope	44	44	67	67
Ridgetop	33	33	67	67
Distance from Roads				
	0 - 100: 22	0 - 100: 22		0 - 500: 56
	100 - 500: 56	100 - 500: 56		500 - 1500: 78
	500 - 1000: 78	500 - 1000: 78		500 - 15000: 100
	1000 - 15000: 100	1000 - 15000: 100		
	0 - 1006: 0	100		
	1006 - 1829 : 100	100		

	Gila Monster	Javelina	Kit Fox	Mountain Lion
Factor Weights				
Land Cover	10	50	75	70
Elevation	35	30	0	0
Topography	45	20	15	10
Distance from Roads	10	0	10	20
Binational Land Cover				
Developed	56	50	22	11
Agriculture	0	33	33	0
Forest	25	47	24	100
Shrub	67	84	80	52
Water	0	0	0	11
Barren	30	11	7	29
Grass/Pasture	28	61	89	62
Wetland	56	95	56	78
Wash	78	100	44	33
Elevation (ft)	0 - 518: 67	0 - 1524: 100		
	518 - 1219: 100	1424 - 2134: 78		
	1219 - 1463: 67	2134 - 4000: 0		
	1463 - 1737: 33			
	1737 - 4000: 0			
Topographic Position				
Canyon Bottom	100	100	33	100
Flat - Gentle Slopes	56	100	100	78
Steep Slope	100	33	56	78
Ridgetop	100	67	67	67
Distance from Roads				
	0 - 1000 : 56		0 - 50 : 33	0 - 200: 22
	1000 - 3000: 78		50 - 250: 78	200 - 500: 44
	3000 - 15000: 89		250 - 500: 89	500 - 1000: 56
			500 - 15000: 100	1000 - 1500: 89
				1500 - 15000: 100

	Mule Deer	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake	White-nosed Coati
Factor Weights					
Land Cover	80	5	30	30	95
Elevation	0	50	25	10	0
Topography	15	25	40	45	0
Distance from Roads	5	20	5	15	5
Binational Land Cover					
Developed	34	56	17	28	22
Agriculture	44	67	0	0	56
Forest	70	8	8	75	92
Shrub	59	85	50	82	48
Water	0	67	0	0	0
Barren	22	52	0	26	18
Grass/Pasture	78	78	11	84	45
Wetland	78	95	28	89	95
Wash	89	78	78	67	56
Elevation (ft)					
		0 - 1402: 100	0 - 610: 78	0 - 427: 56	
		1402 - 1600: 67	610 - 914: 100	427 - 610: 78	
		1600 - 1768: 56	914 - 1524: 78	610 - 1707: 100	
		1768 - 4000: 22	1524 - 2134: 33	1707 - 2286: 56	
			2134 - 4000: 0	2286 - 4000: 0	
Topographic Position					
Canyon Bottom	89	100	100	100	
Flat - Gentle Slopes	89	100	100	33	
Steep Slope	67	44	44	100	
Ridgetop	44	44	44	100	
Distance from Roads					
	0 - 250: 33	0 - 200: 5	O - 250: 56	0 - 500: 56	0 - 500: 22
	250 - 1000: 78	200 - 1000: 67	250 - 500: 67	500 - 1000: 67	500 - 1000: 78
	1000 - 15000: 100	1000 - 3000: 89	500 - 1000: 78	1000 - 2000: 78	1000 - 15000: 100
		3000 - 15000: 100	1000 - 15000: 100	2000 - 15000: 100	89

Appendix C: Individual Species Analysis

American Pronghorn, *Antilocapra americana*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

In northern populations, home range has been estimated to range from 0.2 to 5.2 km2, depending on season, terrain, and available resources (O'Gara 1978). However, large variation in sizes of home and seasonal ranges due to habitat quality and weather conditions make it difficult to apply data from other studies (O'Gara 1978). Other studies report home ranges that average 88 km2 (Ockenfels et al. 1994) and 170 km2 in central Arizona (Bright & Van Riper III 2000), and in the 75 – 125 km2 range (n=37) in northern Arizona (Ockenfels et al. 1997). One key element in pronghorn movement is distance to water. One study found that 84% of locations were less than 6 km from water sources (Bright & Van Riper III 2000), and another reports collared pronghorn locations from 1.5-6.5 km of a water source (Yoakum et al. 1996). Habitats within 1 km of water appear to be key fawn bedsite areas for neonate fawns (Ockenfels et al. 1992).

Conceptual Basis for Model Development

Habitat Suitability Model – Vegetation received an importance weight of 45%, while topography and distance from roads received weights of 37% and 13%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum patch size for pronghorn was defined as 50 km2 and minimum core size as 250 km2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. However, a biologically best corridor was not included in the linkage design, due to marginal habitat suitability west of State Route 286 and south of the U.S.-Mexico International Border (Jim Heffelfinger, personal comm. with Dean Pokrajac).

Results and Discussion

Union of biologically best corridors – The majority of the Mexico – Tumacacori linkage captures optimal, suboptimal but used, and occasionally used habitat for American pronghorn (see *Figure 30* below). Almost the entire linkage design captures encompasses a potential population core (see *Figure 31* below). However, habitat suitability and potential habitat patches are likely greatly overestimated in models represented below, due to the generalized binational landcover used in the analysis, and shrub encroachment into grassland areas. Almost the entire Tumacacori – Baboquivari linkage captures optimal habitat for American pronghorn (see *Figure 32* below). Much of the Tumacacori – Baboquivari linkage is also located in a potential population core (see *Figure 33* below). Similar to the Mexico – Tumacacori linkage, the Tumacacori – Baboquivari linkage likely overestimates habitat suitability and potential habitat patches for American pronghorn, again due to the generalized binational landcover used in the analysis, and shrub encroachment into grassland areas.

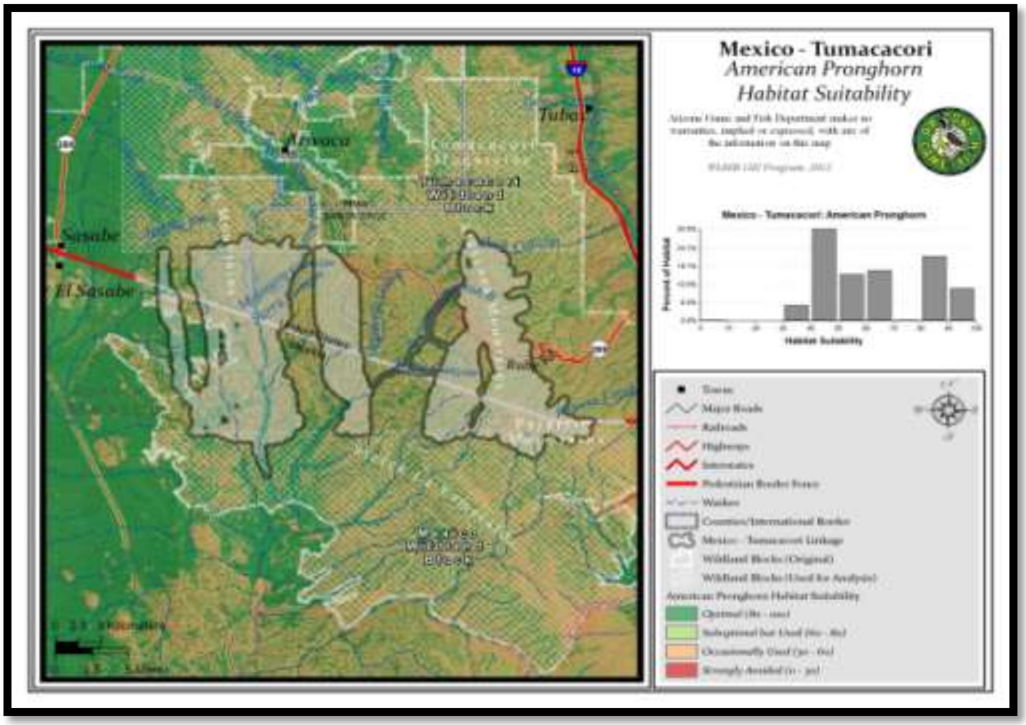

__Figure 30:__ Map of habitat suitability for American pronghorn within the Mexico – Tumacacori linkage

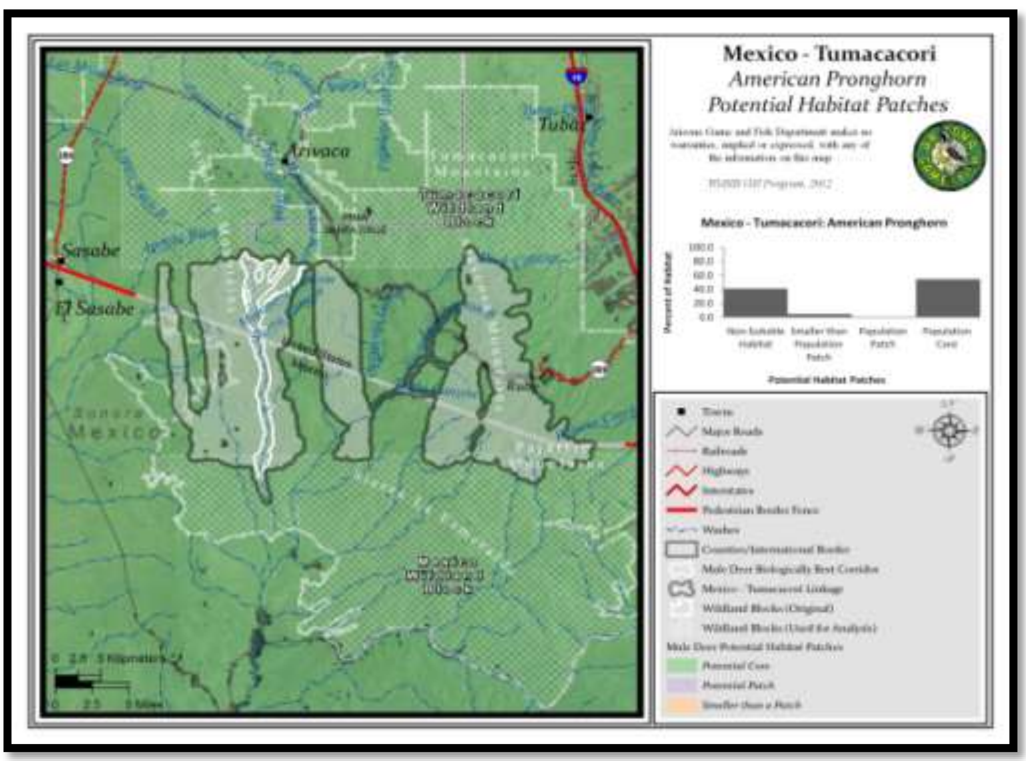

__Figure 31:__ Map of potential habitat patches for American pronghorn within the Mexico – Tumacacori linkage

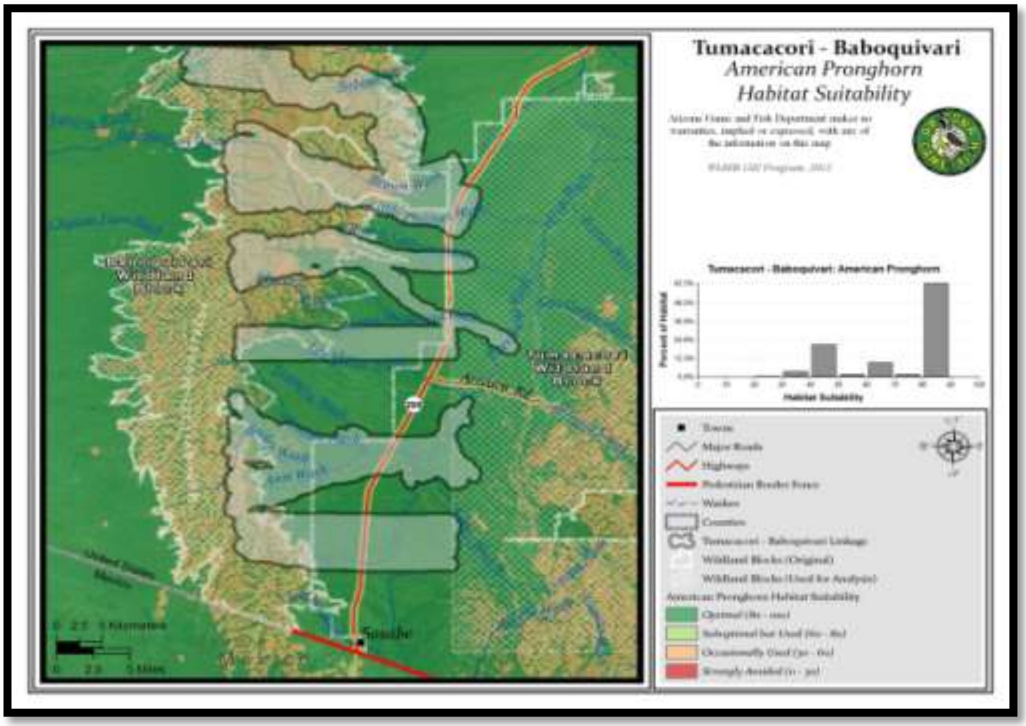

Figure 32: *Map of habitat suitability for American pronghorn within the Tumacacori – Baboquivari linkage*

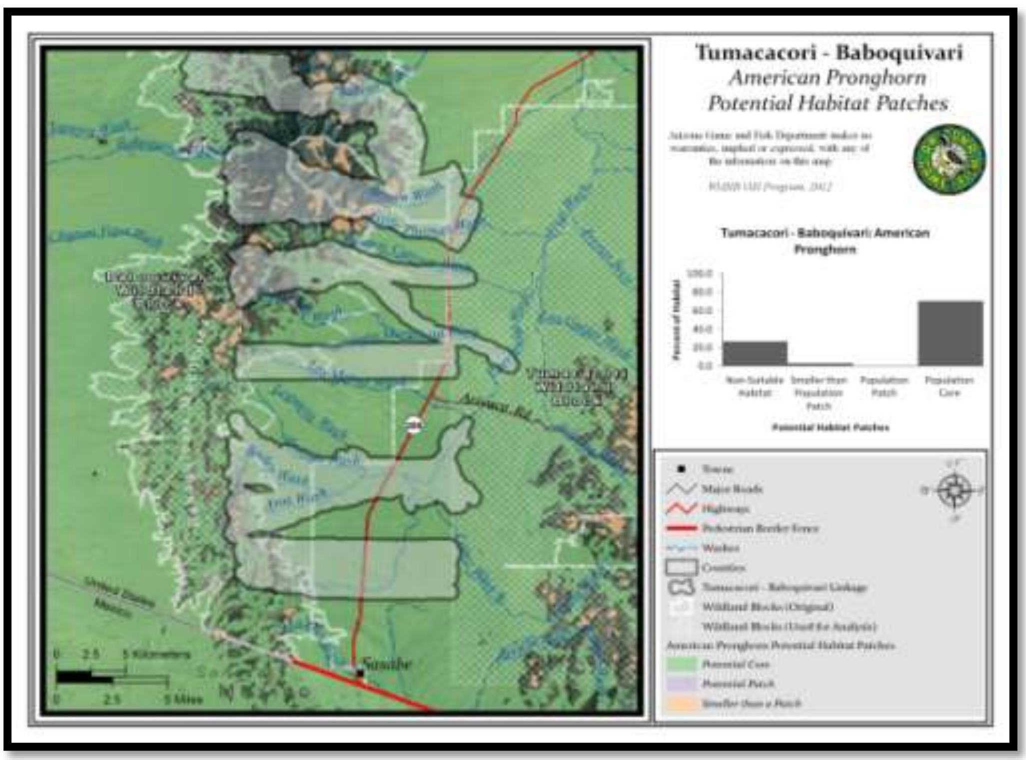

Figure 33: *Map of potential habitat patches for American pronghorn within the Tumacacori – Baboquivari linkage*

Badger, *Taxidea taxus*

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. However, a biologically best corridor for badger was not included in the Mexico – Tumacacori linkage, as it traversed a section of the pedestrian fence along the U.S.-Mexico International Border, and there is optimal habitat and potential population cores elsewhere in the linkage (see *Figure 34 and Figure 35* below). Badger was considered a passage species in the Tumacacori – Baboquivari linkage due to long dispersal distances recorded by Messick and Hornocker (1981), and distance between wildland blocks used in this analysis. The original biologically best corridor for this species in the Tumacacori – Baboquivari linkage was trimmed to eliminate additional strands which do not provide suitable habitat for other focal species, in order to decrease the width of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for badger in the trimmed BBC used within the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 26.2 to 86.2, with an average suitability of 80.3 (S.D: 7.8; see *Figure 36* below). The entire trimmed BBC (100.0%) is occupied by a potential population core (see *Figure 37* below). Most of the trimmed BBC (96.6%) was greater than its estimated needed minimum width (see *Figure 38* below). The trimmed BBC was measured at 12.9 km (8.0 mi) in length between wildland blocks used in the analysis.

Union of biologically best corridors – The majority of the linkage design captures additional optimal and suboptimal but used habitat, along with potential population cores for badger.

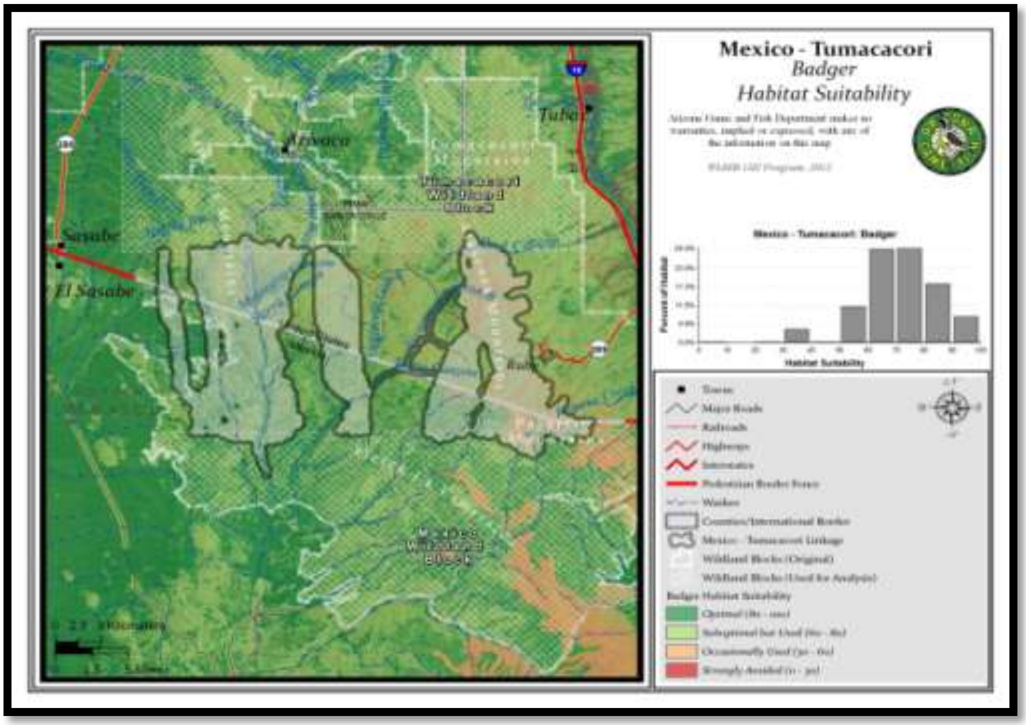

Figure 34: *Map of habitat suitability for badger within the Mexico – Tumacacori linkage*

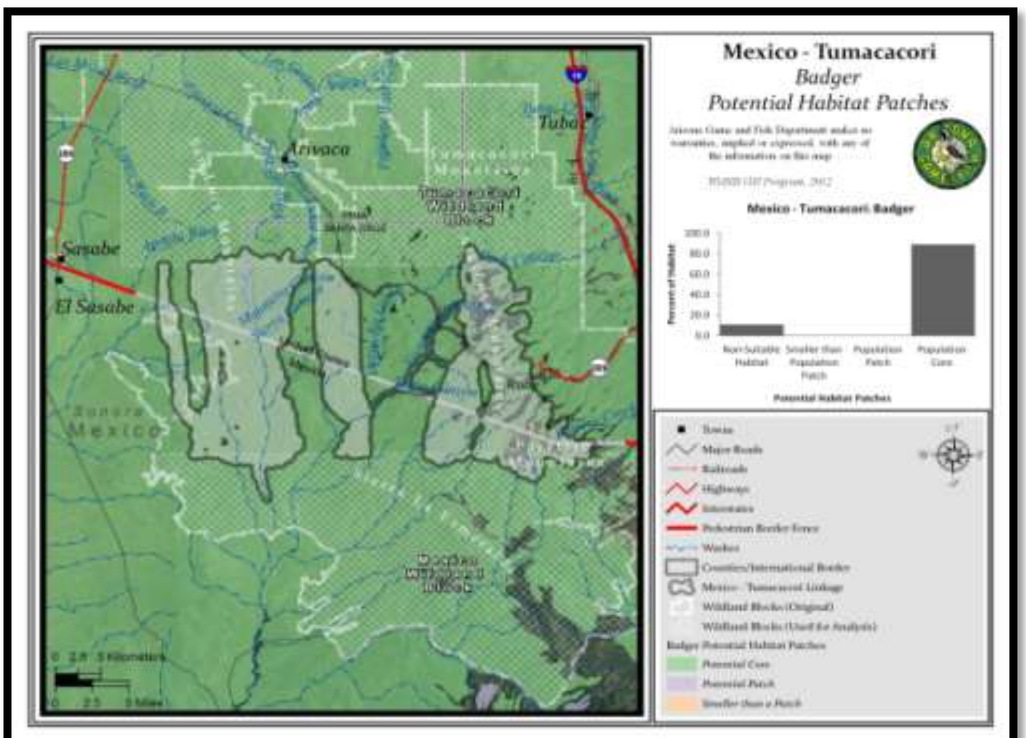

Figure 35: *Map of potential habitat patches for badger within the Mexico – Tumacacori linkage*

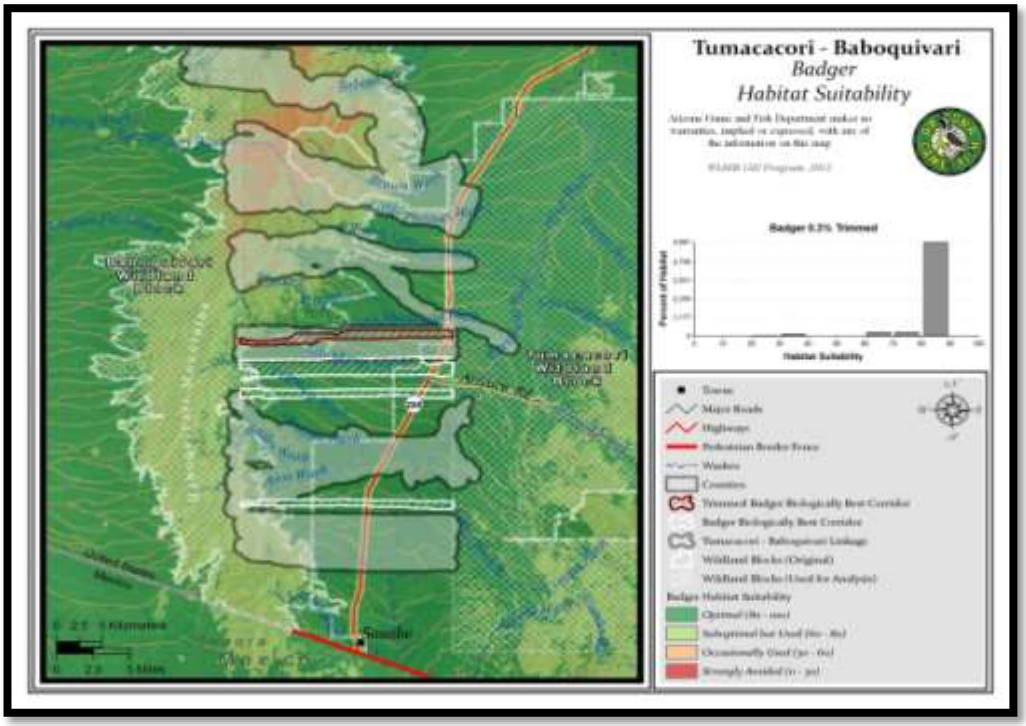

Figure 36: *Map of Tumacacori – Baboquivari habitat suitability for badger*

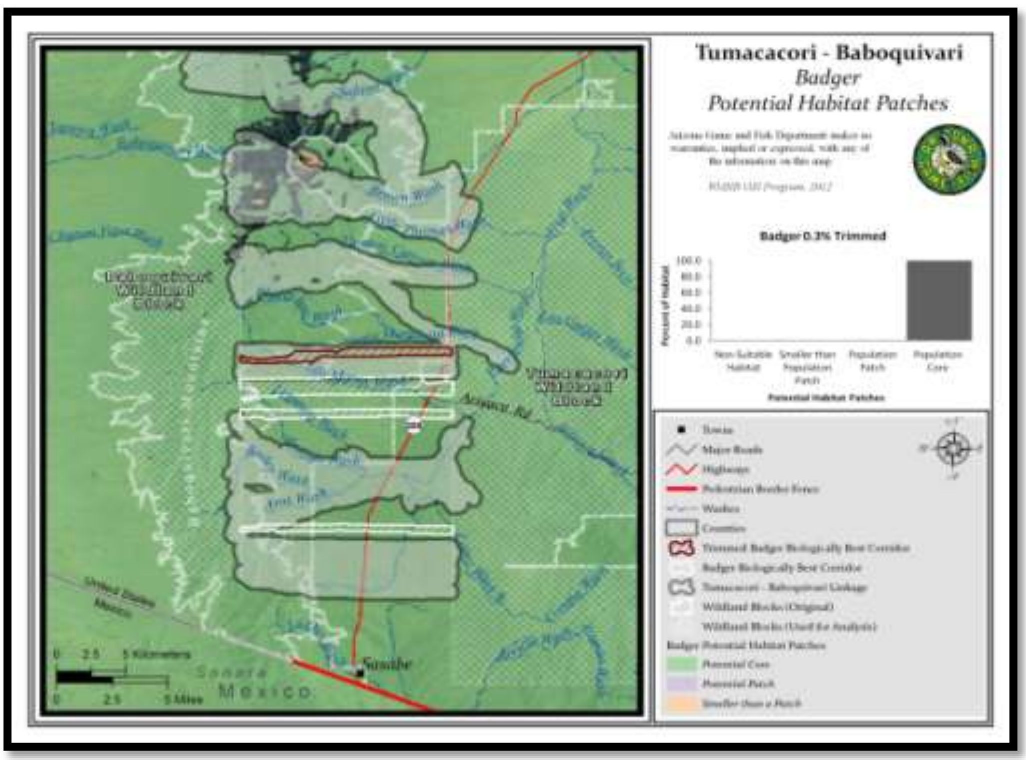

Figure 37: *Map of Tumacacori – Baboquivari potential habitat patches for badger*

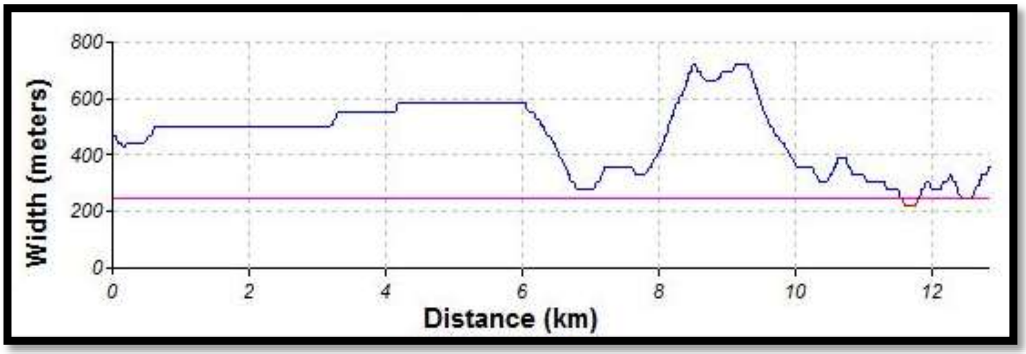

Figure 38: *Width along the Tumacacori – Baboquivari badger trimmed biologically best corridor*

Black Bear, *Ursus americanus*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

Individual black bears do not have territorial interactions, and home ranges of both sexes commonly overlap. Home ranges are generally larger in locations or years of low food abundance, and smaller when food is plentiful and have been observed to range from 2 - 170 km2 (Larivière 2001). Daily foraging movements are also dependent on food supply, and have been observed to range from 1.4 – 7 km (Larivière 2001). Males have larger dispersal distances than females, as females stay close to their natal range, and males must migrate to avoid larger males as their mother comes back into estrus (Schwartz & Franzmann 1992). Depending on vegetation, females may disperse up to 20 km, while males often move 20-150 km (S. Cunningham, personal comm. with CorridorDesign Team).

Conceptual Basis for Model Development

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

Patch size and configuration analysis – We defined minimum potential habitat patch size as 10 km2, since this is the minimum amount of optimum habitat necessary to support a female and cub (Bunnell & Tait 1981; S. Cunningham, pers. comm.). Minimum potential habitat core size was defined as 50km2, 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. Black bear was classified as a passage species in the Mexico – Tumacacori linkage due to dispersal distance (S. Cunningham, personal comm. with CorridorDesign Team) and distance between the Mexico and Tumacacori wildland blocks. A biologically best corridor for black bear was not included in the Tumacacori – Baboquivari linkage due to limited occurrence of black bear in the Baboquivari Mountains (Jim Heffelfinger, personal comm. with Dean Pokrajac).

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for black bear in the BBC used within the Mexico – Tumacacori linkage. Habitat suitability scores range from 0 to 87.1, with an average suitability of 71.5 (S.D: 17.9; see *Figure 39* below). Some of the BBC (38.0%) is occupied by a potential population core, with a portion occupied by potential patches (38.2%) and suitable habitat smaller than a patch (see *Figure 40* below). Most of the BBC (94.1%) was greater than its estimated needed minimum width (see *Figure 41* below). The BBC was measured at 22.7 km (14.1 mi) in length between wildland blocks used in the analysis.

Union of biologically best corridors – Although the linkage design captures mostly occasional use habitat for black bear, some optimal habitat also exists. Similarly, much of the linkage design is not within potential habitat patches for black bear, but some additional population cores are captured. In the Tumacacori – Baboquivari linkage, which did not include a biologically best corridor for black bear, optimal habitat and a potential population core exist in the northern portion (see *Figure 42* and *Figure 43* below).

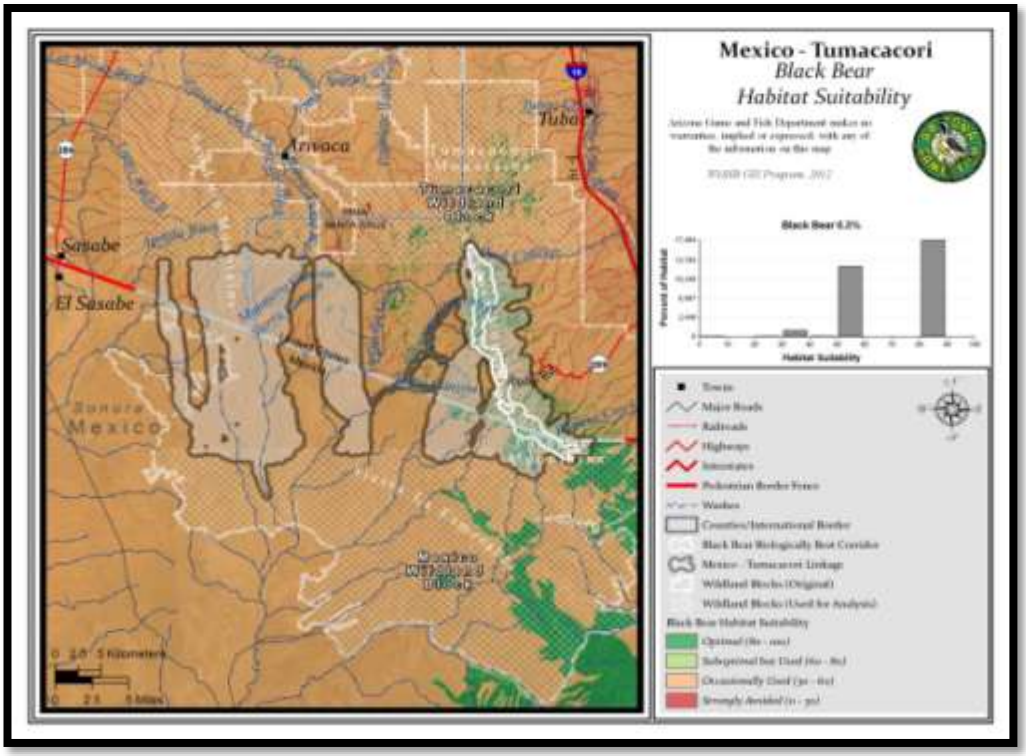

Figure 39: *Map of Mexico – Tumacacori habitat suitability for black bear*

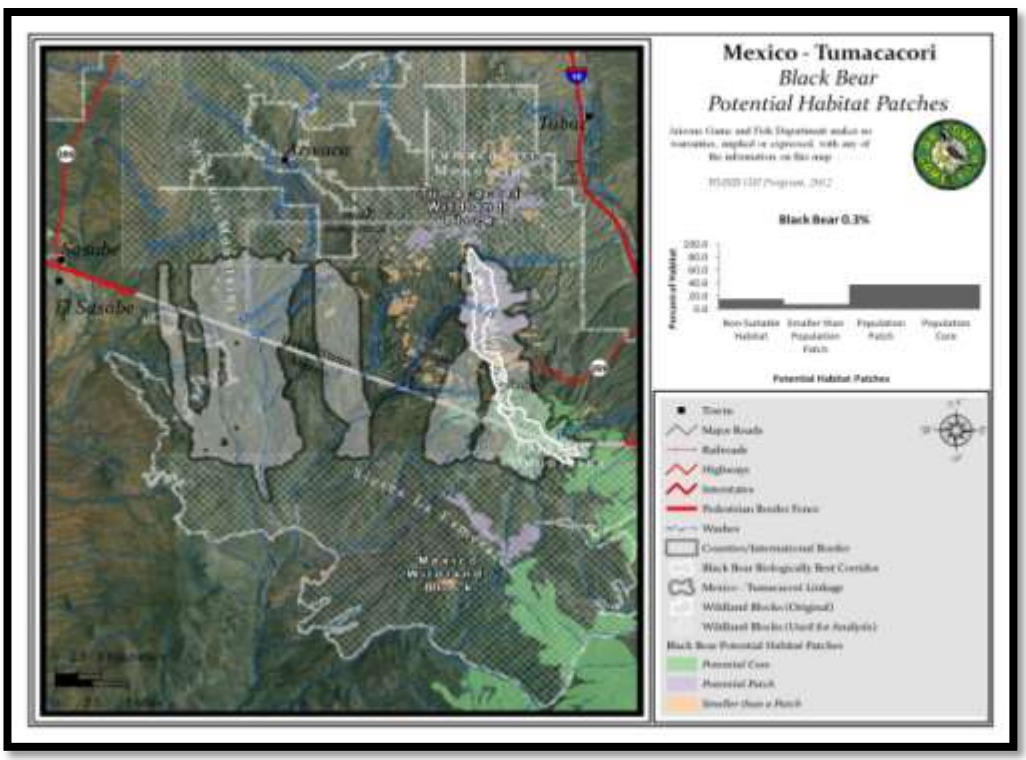

Figure 40: *Map of Mexico – Tumacacori potential habitat patches for black bear*

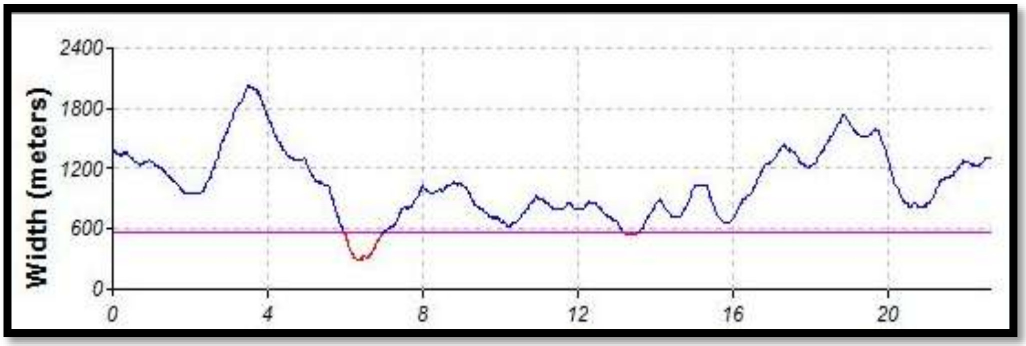

Figure 41: *Width along the Mexico – Tumacacori black bear biologically best corridor*

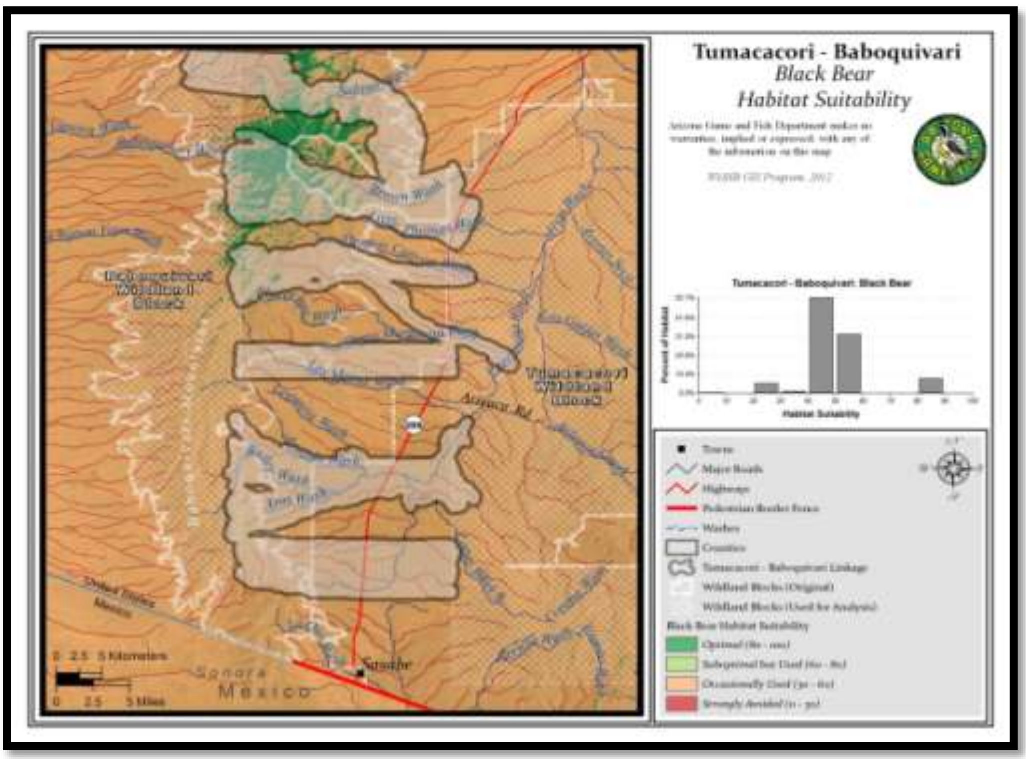

Figure 42: *Map of habitat suitability for black bear within the Tumacacori – Baboquivari linkage*

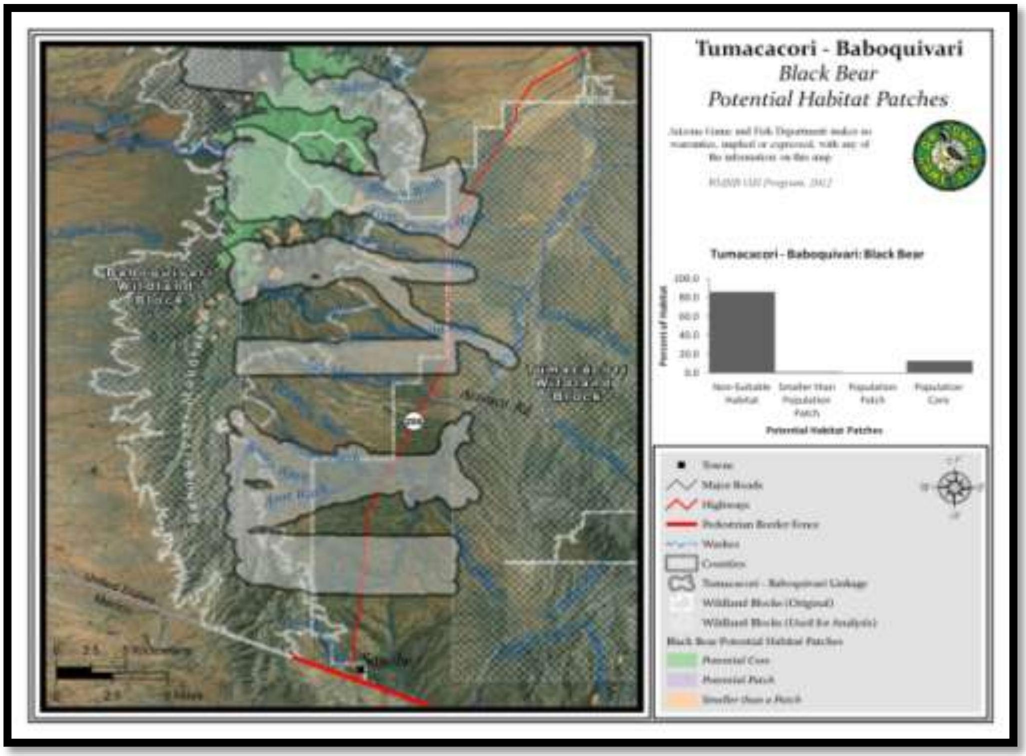

Figure 43: *Map of potential habitat patches for black bear within the Tumacacori – Baboquivari linkage*

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).

Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Black-tailed jackrabbit was classified as a passage species for this analysis, due to daily movements (Hoffmeister 1986). The original biologically best corridor for this species was trimmed to eliminate additional strands in the Mexico – Tumacacori linkage which do not provide suitable habitat for other focal species, in order to decrease the width of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for black-tailed jackrabbit in the trimmed BBC used within the Mexico – Tumacacori linkage. Habitat suitability scores range from 0 to 88.7, with an average suitability of 85.2 (S.D: 7.0; see *Figure 44* below). Almost the entire trimmed BBC (99.9%) occupies potential population cores (see *Figure 45* below). The entire trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 46* below). It was measured at 18.7 km (11.6 mi) in length between wildland blocks used in the analysis. Ample suitable habitat also exists for black-tailed jackrabbit in the BBC used within the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 32.7 to 88.7, with an average suitability of 86.8 (S.D: 6.1; see *Figure 47* below). Almost the entire BBC along contains potential population cores (99.1%; see *Figure 48* below). The entire BBC (100%) was greater than its estimated needed minimum width, and measures 12.7 km (7.9 mi; (see *Figure 49* below).

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

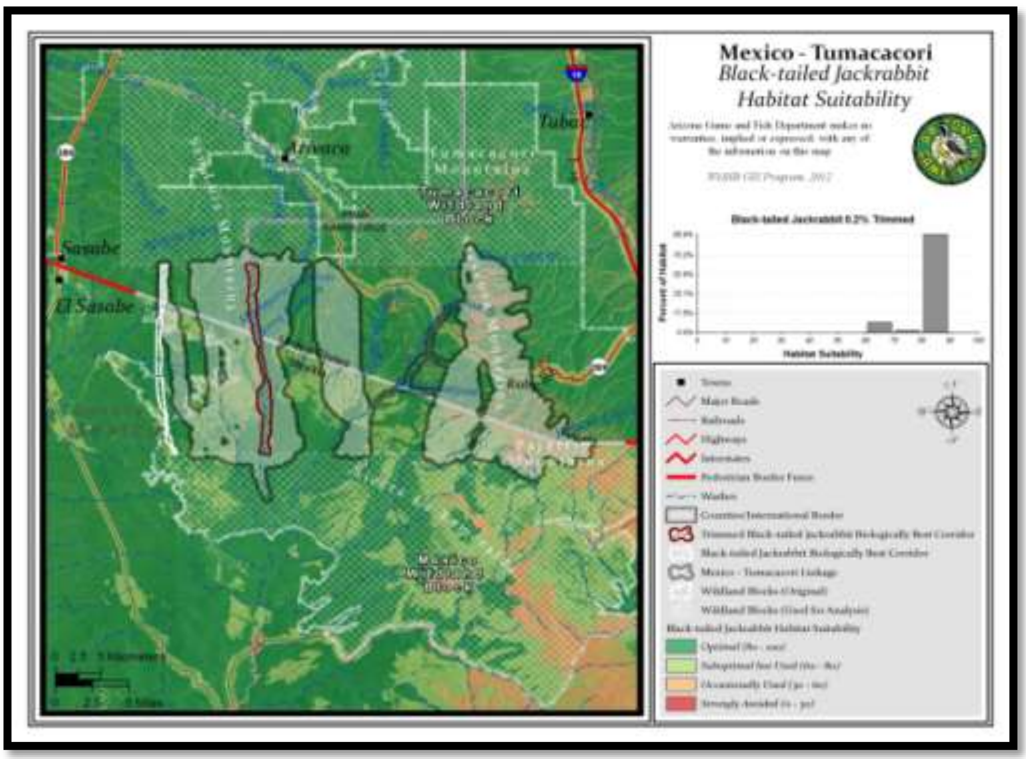

Figure 44: *Map of Mexico – Tumacacori habitat suitability for black-tailed jackrabbit*

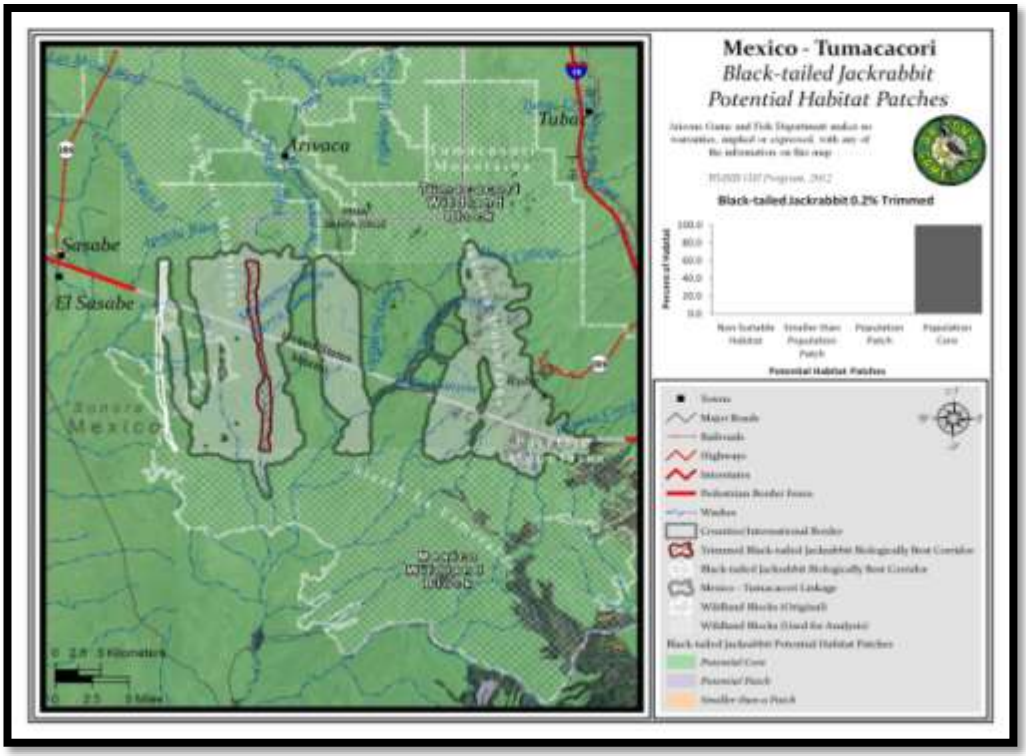

Figure 45: *Map of Mexico – Tumacacori potential habitat patches for black-tailed jackrabbit*

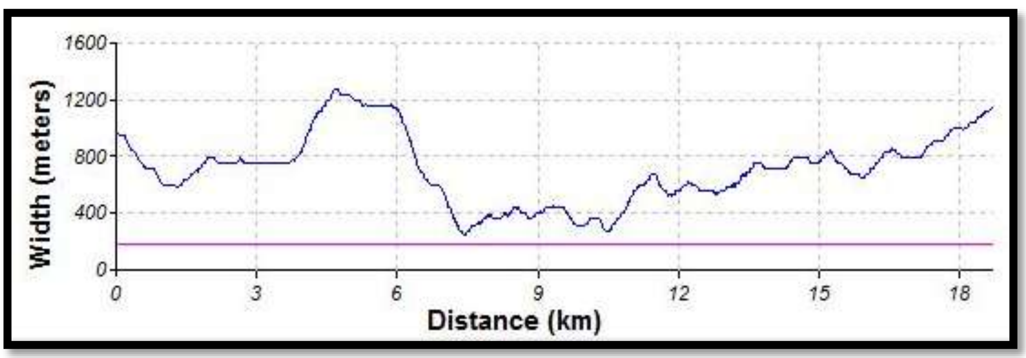

Figure 46: *Width along the Mexico – Tumacacori black-tailed jackrabbit trimmed biologically best corridor*

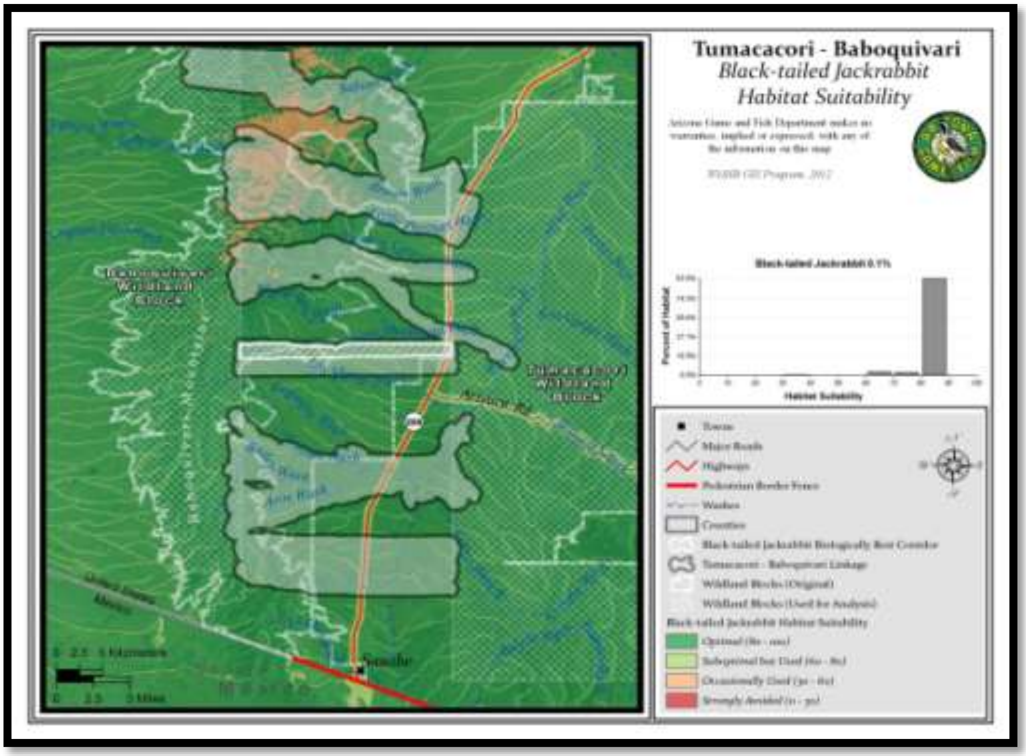

Figure 47: *Map of Tumacacori – Baboquivari habitat suitability for black-tailed jackrabbit*

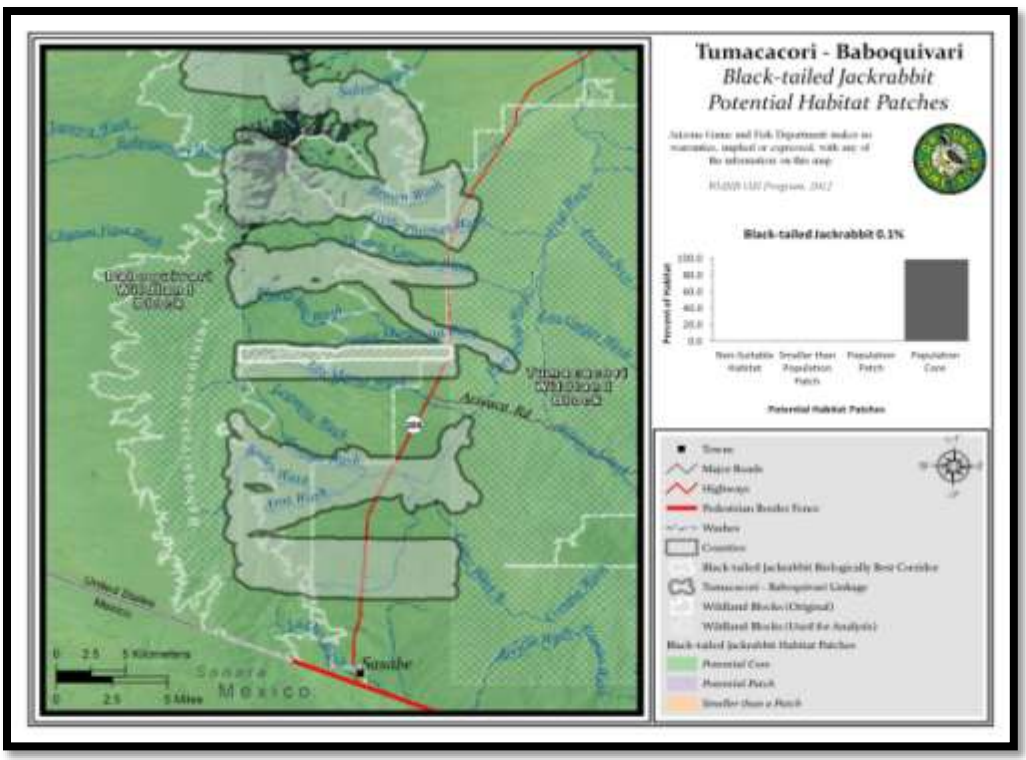

Figure 48: *Map of Tumacacori – Baboquivari potential habitat patches for black-tailed jackrabbit*

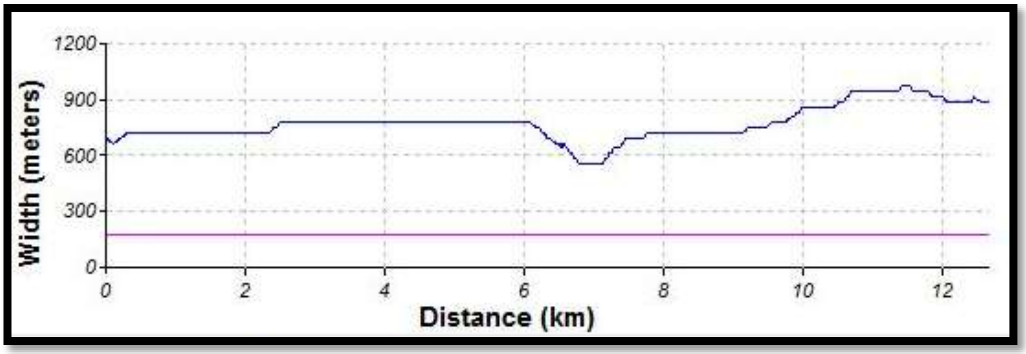

Figure 49: *Width along the Tumacacori – Baboquivari black-tailed jackrabbit biologically best corridor*

Black-tailed Rattlesnake, *Crotalus molossus*

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Beck (1995) found home ranges from 3-4 ha in size; however, it is thought that home ranges for most black-tailed rattlesnakes are slightly larger (Phil Rosen, personal comm. to CorridorDesign Team) so minimum patch size was defined as 10 ha. Minimum core size was defined as 100 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Black-tailed rattlesnake were classified as a corridor dweller in this analysis due to limited dispersal distances of similar species (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team), and distance between the Mexico – Tumacacori wildland blocks. A biologically best corridor for black-tailed rattlesnake was not included in the Tumacacori – Baboquivari linkage due to the distance required to travel between mapped habitat patches.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for black-tailed rattlesnake in the BBC used within the Mexico – Tumacacori linkage. Habitat suitability scores range from 12.9 to 100.0, with an average suitability of 90.8 (S.D: 26.6; see *Figure 50* below). Most of the BBC (92.6%) is occupied by a potential population core (see *Figure 51* below). The entire BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 52* below). The BBC was measured at 20.1 km (12.5 mi) in length between wildland blocks used in the analysis.

Union of biologically best corridors – The linkage design captures additional optimal habitat and potential population cores for black-tailed rattlesnake. The Tumacacori – Baboquivari linkage, in which a biologically best corridor for black-tailed rattlesnake was not included, captures additional optimal and strongly avoided habitat, as well as potential population cores in the Baboquivari Mountains (see *Figure 53* and *Figure 54* below).

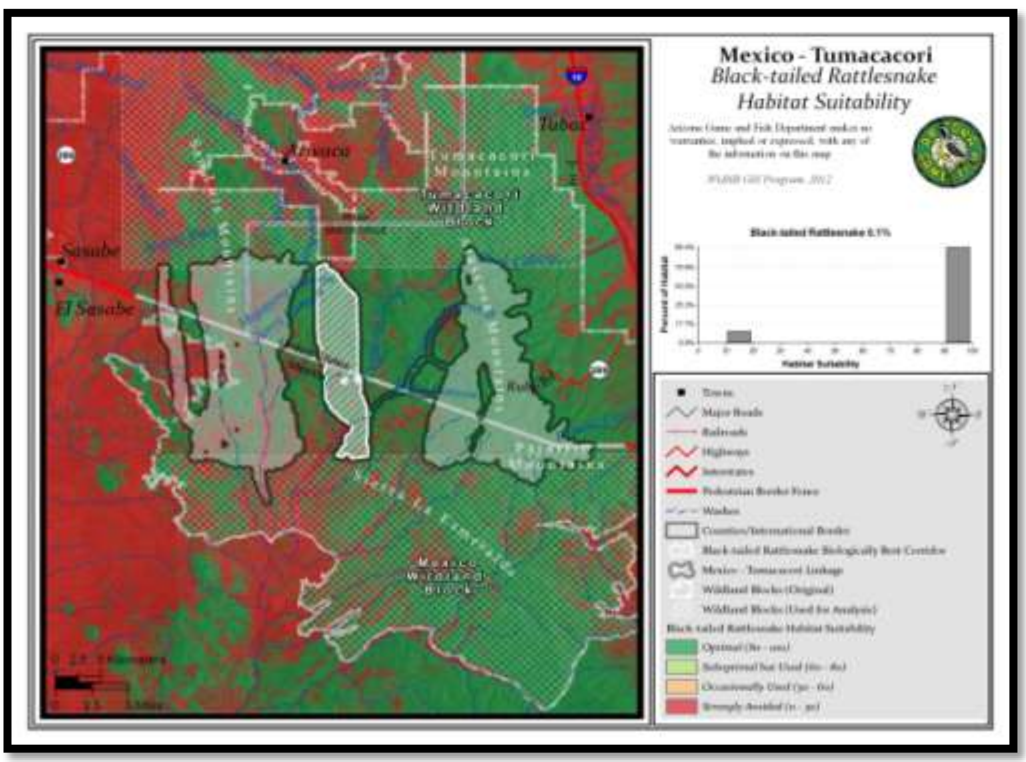

Figure 50: *Map of Mexico – Tumacacori habitat suitability for black-tailed rattlesnake*

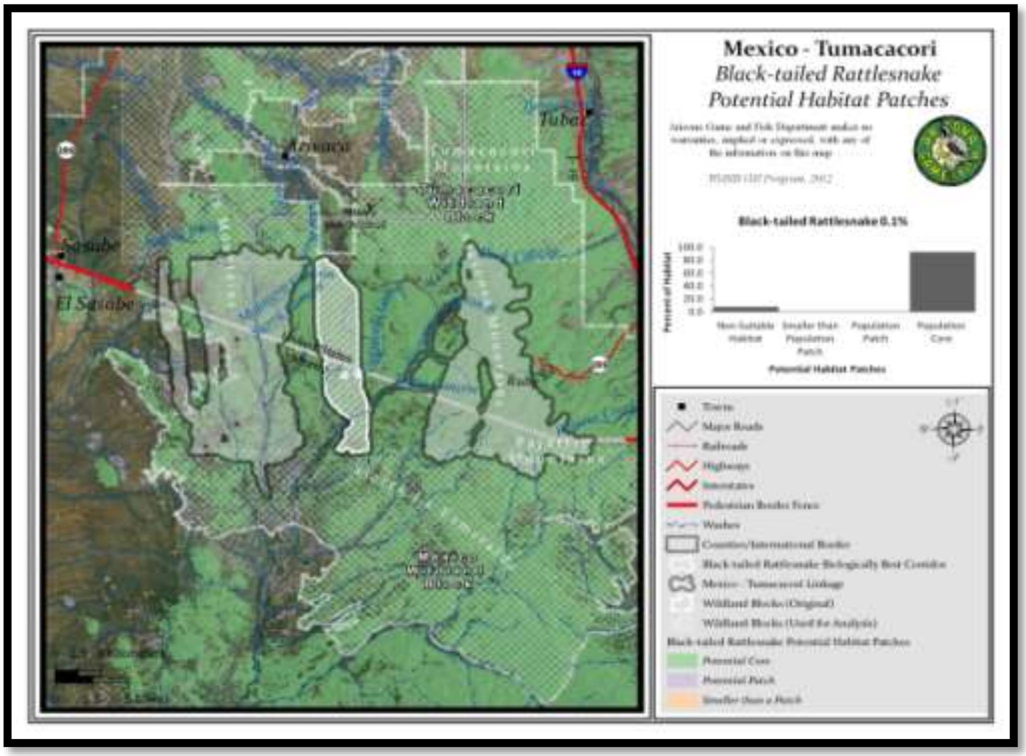

Figure 51: *Map of Mexico – Tumacacori potential habitat patches for black-tailed rattlesnake*

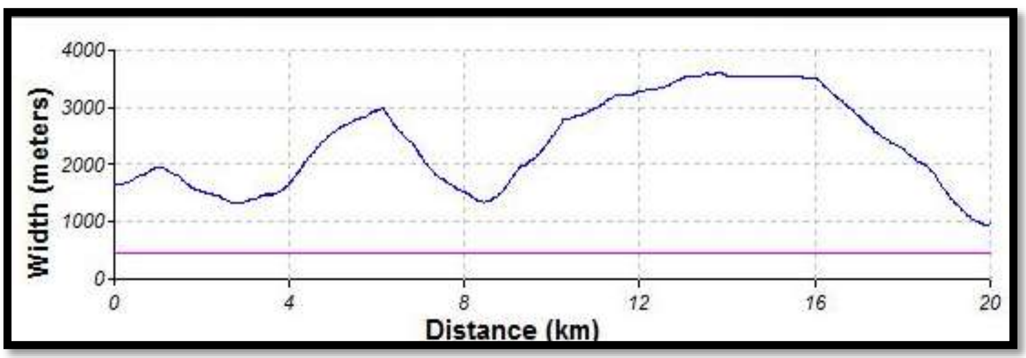

Figure 52: *Width along the Mexico – Tumacacori black-tailed rattlesnake biologically best corridor*

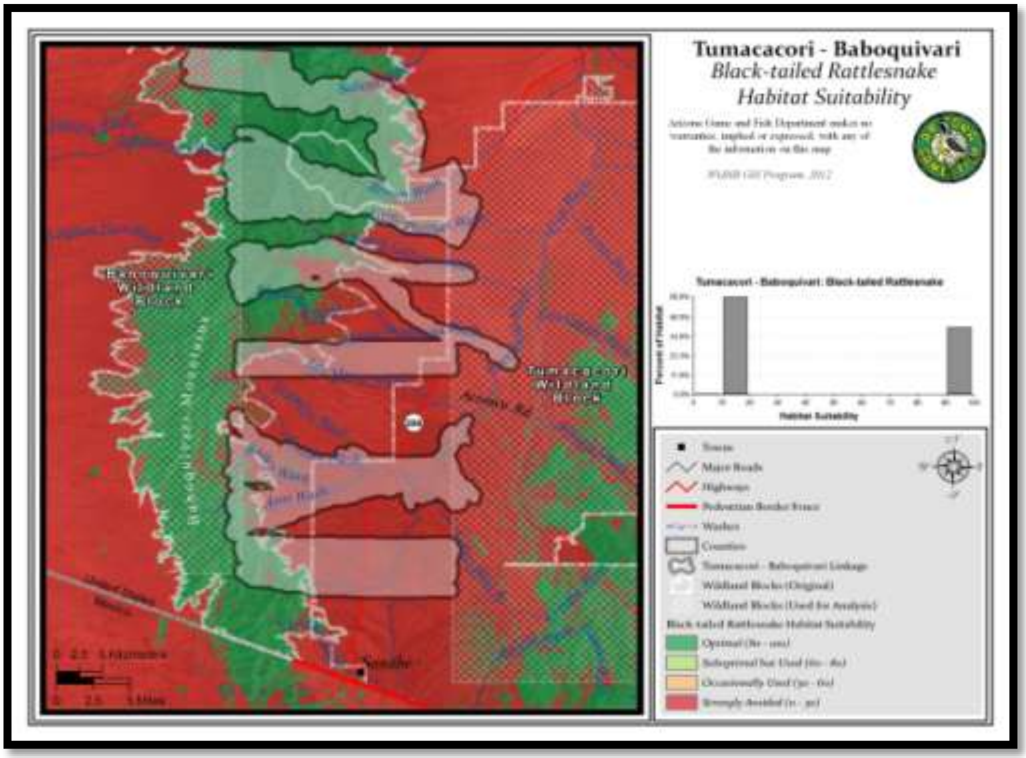

Figure 53: *Map of Tumacacori – Babquivari habitat suitability for black-tailed rattlesnake*

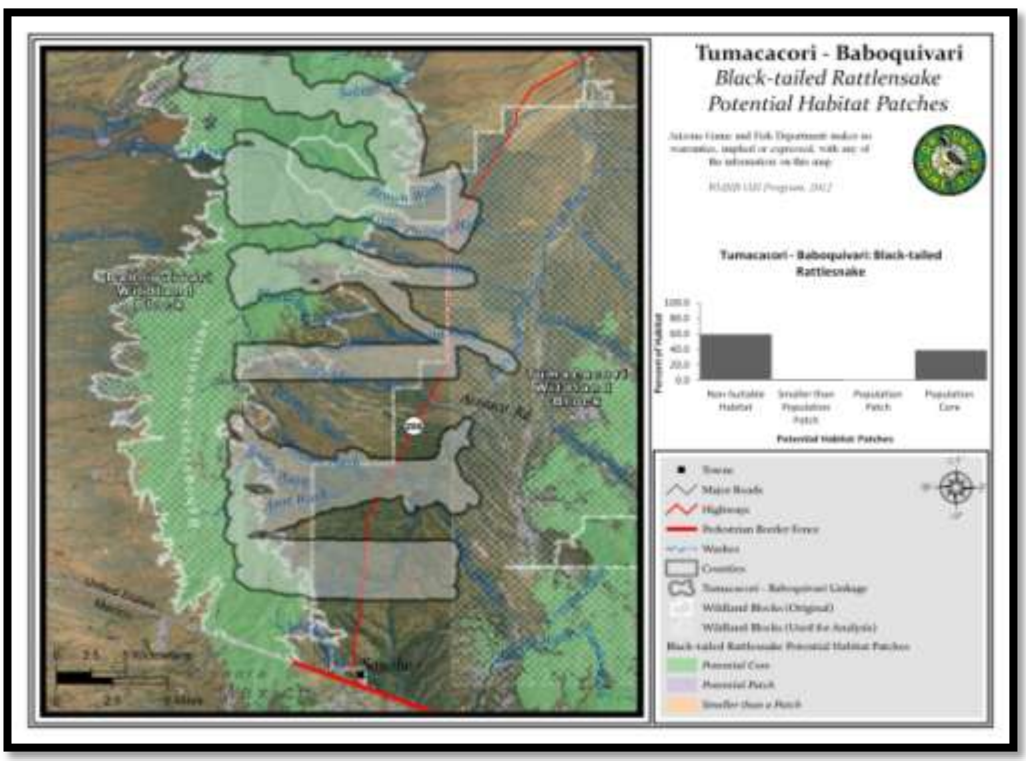

Figure 54: *Map of Tumacacori – Baboquivari potential habitat patches for black-tailed rattlesnake*

Chiricahua Leopard Frog, *Lithobates chiricahuensis* (Formerly *Rana chiricahuensis*)

Justification for Selection

Photo courtesy Christina Akins, AGFD

The Chiricahua leopard frog's population is declining in Arizona, and has been extirpated from about 75 percent of its historic range in Arizona and New Mexico (U.S. Fish and Wildlife Service 2002). Reasons for decline include habitat fragmentation, major water manipulations, water pollution, and heavy grazing (Arizona Game and Fish Department 2001). The Chiricahua leopard frog has been listed as A threatened species by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2002), and is also Forest Service Sensitive and a Species of Special Concern in Arizona (Arizona Game and Fish Department 2001). This frog has a metapopulation structure and requires dispersal corridors to include a buffer and riparian and stream corridors (Pima Co., Arizona 2001). Human activities have eliminated natural dispersal corridors in Arizona (Pima Co., Arizona 2001).

Distribution

The range of the Chiricahua leopard frog includes the montane regions of central and southern Arizona, southwestern New Mexico south into the Sierra Madre Occidental to western Jalisco, Mexico (Pima Co., Arizona 2001). Within Arizona, this species' range is divided into two portions: one extending from montane central Arizona east and south along the Mogollon Rim to montane parts of southwestern New Mexico; the other extends through the southeastern montane sector of Arizona and into Sonora, Mexico (Degenhardt 1996; Arizona Game and Fish Department 2001).

Habitat Associations

The Chiricahua leopard frog's primary habitat is oak, mixed oak, and pine woodlands, but also is found in areas of chaparral, grassland, and even desert (Arizona Game and Fish Department 2001). Within these habitats, this frog is an aquatic species that uses a variety of water sources including thermal springs and seeps, stock tanks, wells, intermittent rocky creeks, and main-stream river reaches (Degenhardt 1996). Other aquatic systems include deep rock-bound pools and beaver ponds (Arizona Game and Fish Department 2001). The elevation range for this species is 1,000 – 2,600m (New Mexico Department of Game and Fish 2004).

Spatial Patterns

Home range requirements of Chiricahua leopard frogs are not known. Available information on movements of Chiricahua leopard frogs indicates that most individuals stay within a few kilometers of their breeding sites, though occasionally individuals will move distances of several kilometers (NatureServe 2005). Chiricahua leopard frogs have been observed dispersing up to 1.5 miles from their home ponds (Pima Co., Arizona 2001).

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 55%, while elevation, topography, and distance from roads received weights of 25%, 10%, and 10%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Patch size & configuration analysis – Minimum patch size was defined as 0.05 ha, while minimum core size was defined as 0.1 ha (Phil Rosen, personal comm. with CorridorDesign Team).

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Chiricahua leopard frog was classified as a corridor dweller due to observed dispersal distances (Pima Co., Arizona 2001), and distance between wildland blocks used in this analysis. The original biologically best corridor for this species was trimmed to eliminate additional strands in the Tumacacori – Baboquivari linkage which do not provide suitable habitat for other focal species, in order to decrease the width of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate some suitable habitat for Chiricahua leopard frog in the BBC used within the Mexico – Tumacacori linkage. Habitat suitability scores range from 0 to 63.7, with an average suitability of 51.3 (S.D: 11.6; see *Figure 55* below). Some of the BBC (17.6%) occupies potential population cores, with a small portion occupying potential patches (0.5%), and the rest containing non-suitable habitat (see *Figure 56* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 57* below). The BBC was measured at 20.1 km (12.5 mi) in length between wildland blocks used for analysis. Some suitable habitat also exists for Chiricahua leopard frog in the trimmed BBC used within the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 30.3 to 63.7, with an average suitability of 39.7 (S.D: 10.7; see *Figure 58* below). A small portion of the trimmed BBC occupies potential habitat cores (0.2%), and potential habitat patches (0.2%), while the rest occupies non-suitable habitat (see *Figure 59* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 60* below). The trimmed BBC was measured at 15.0 km (9.3 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional occasionally used habitat for Chiricahua leopard frog, although some additional suboptimal but used habitat is also captured. Also, some additional potential population cores for Chiricahua leopard frog also occur in the linkage design.

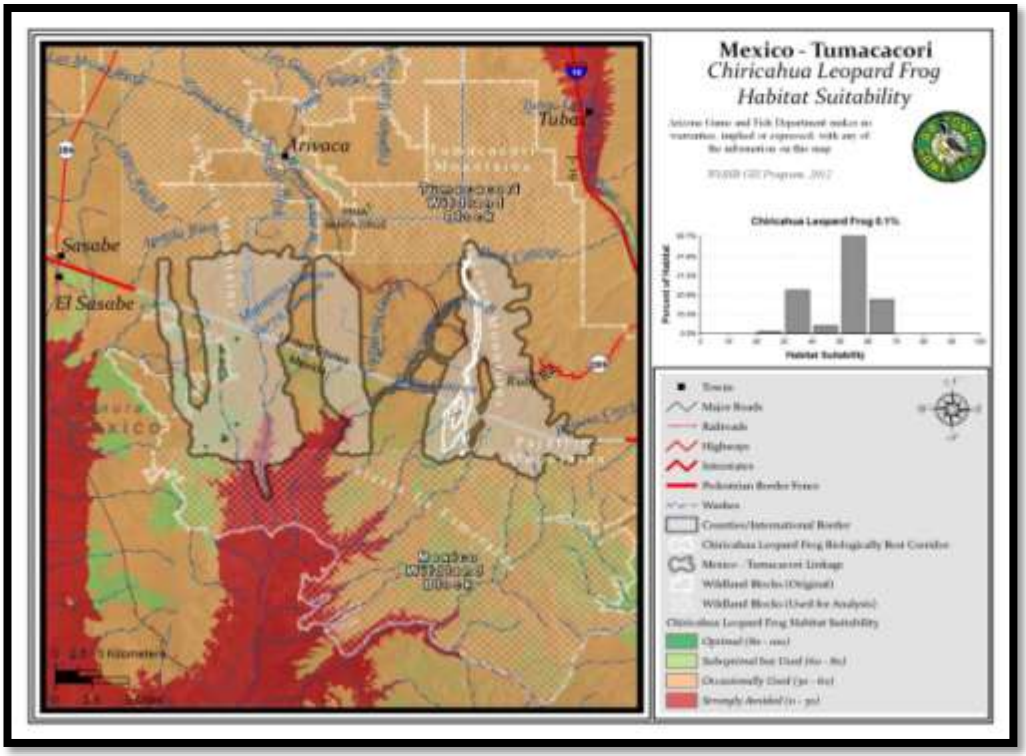

Figure 55: *Map of Mexico – Tumacacori habitat suitability for Chiricahua leopard frog*

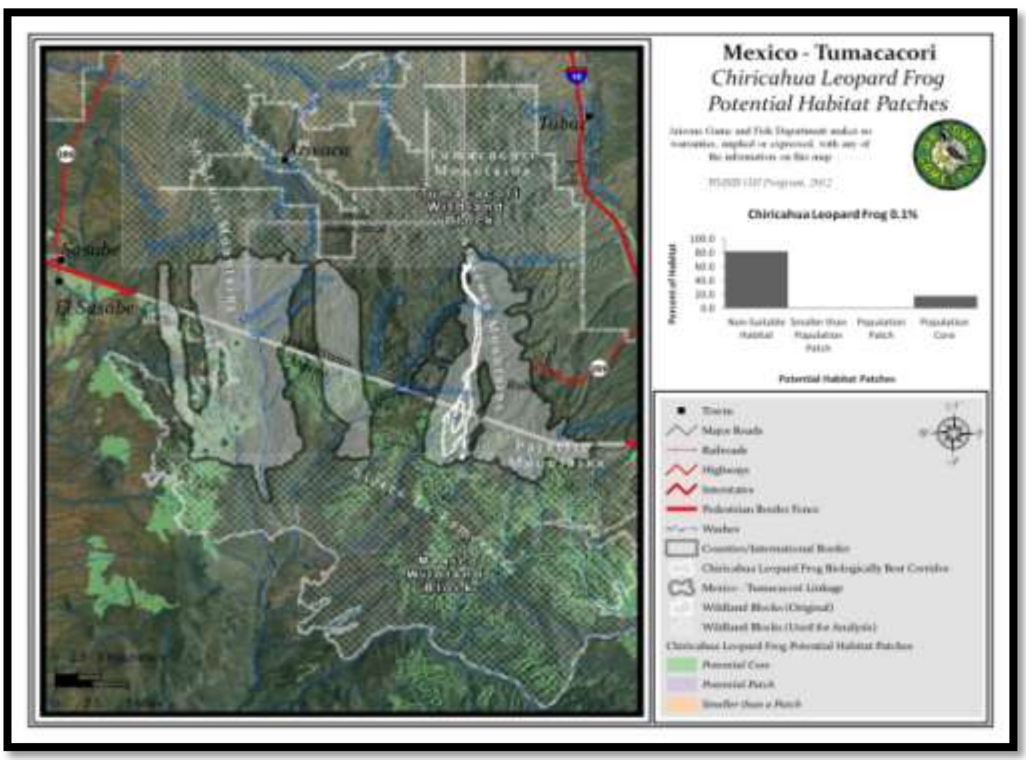

Figure 56: *Map of Mexico – Tumacacori potential habitat patches for Chiricahua leopard frog*

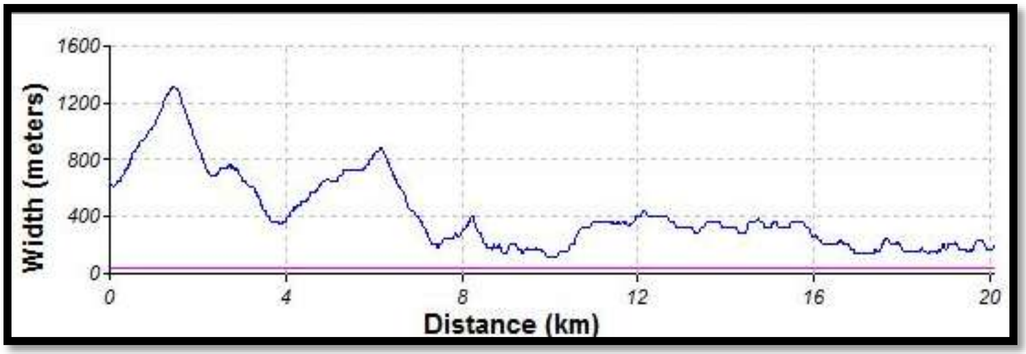

Figure 57: *Width along the Mexico – Tumacacori Chiricahua leopard frog biologically best corridor*

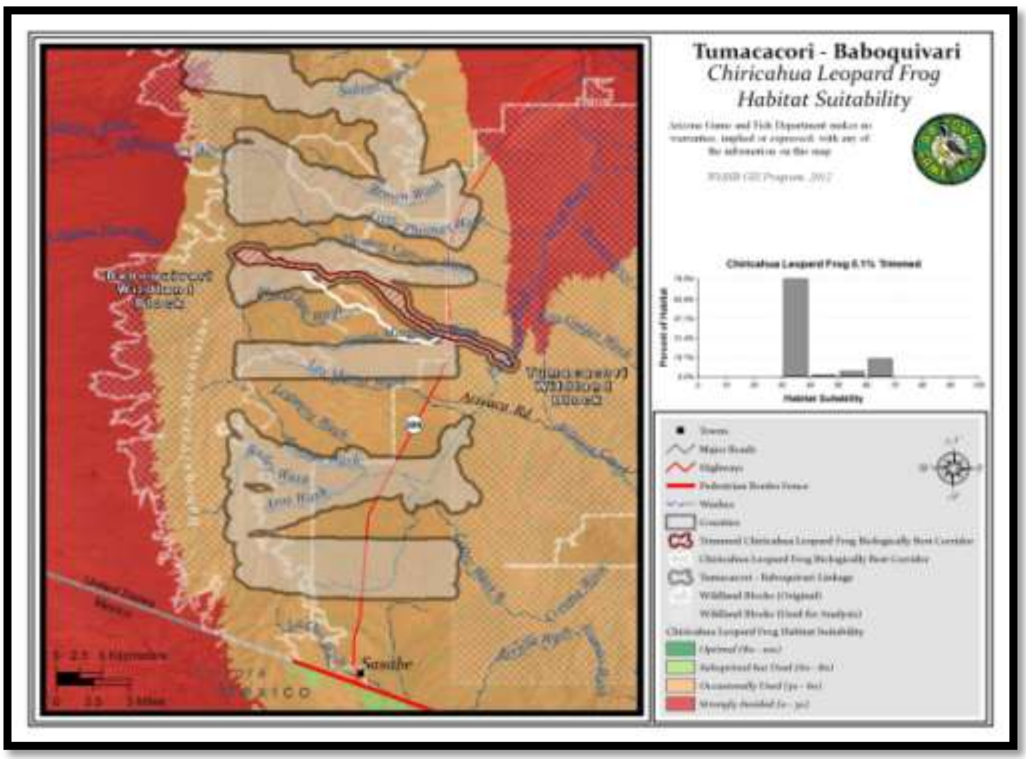

Figure 58: *Map of Tumacacori – Baboquivari habitat suitability for Chiricahua leopard frog*

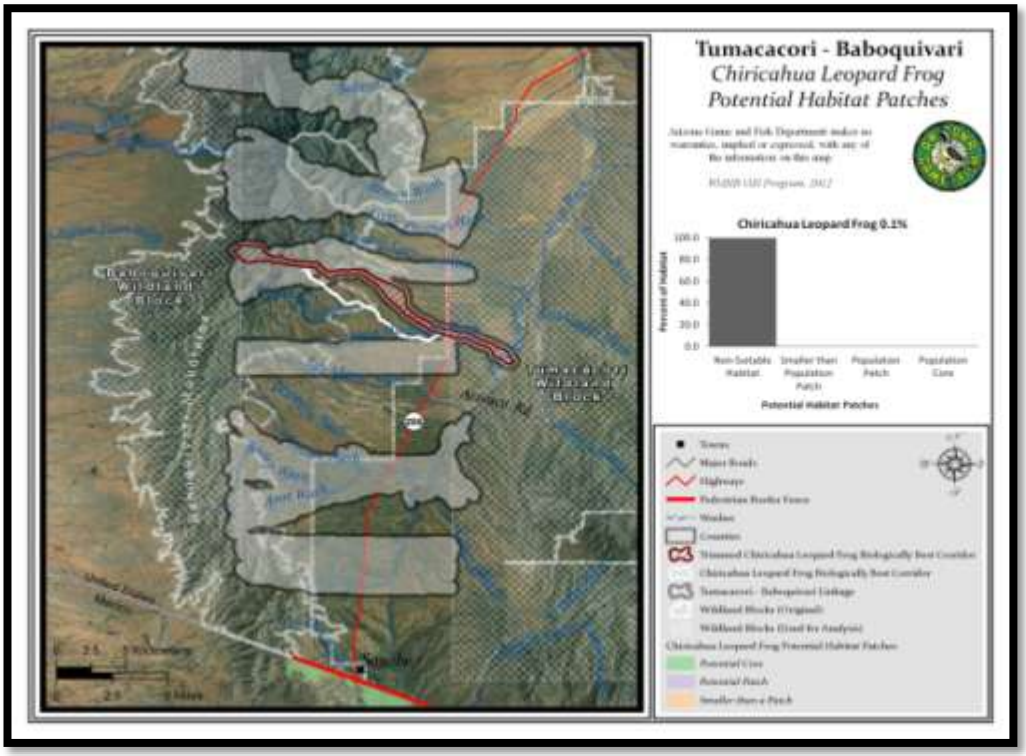

Figure 59: *Map of Tumacacori – Baboquivari potential habitat patches for Chiricahua leopard frog*

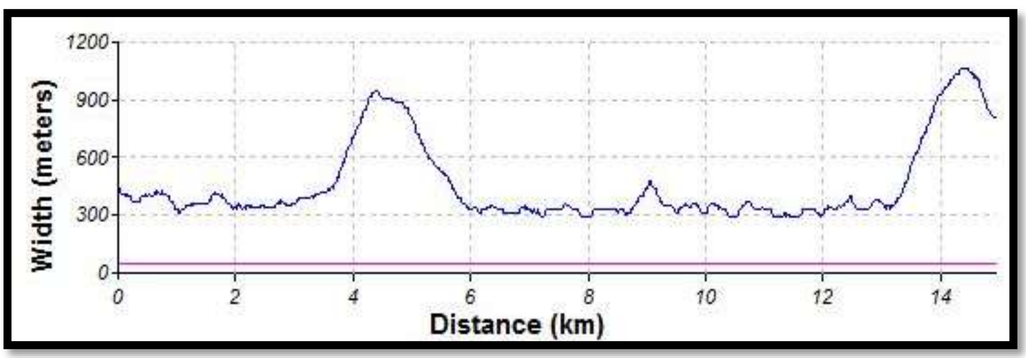

Figure 60: *Width along the Tumacacori – Baboquivari Chiricahua leopard frog trimmed biologically best corridor*

Coues' White-tailed Deer, *Odocoileus virginianus couesi*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

White-tailed deer are not territorial, and may have large overlap of home ranges (Smith 1991). Female home ranges in the Santa Rita Mountains were found to average 5.18 km2, while male home ranges averaged 10.57 km2 (Ockenfels et al. 1991). Knipe (1977) speculated that Coues' white-tailed deer have a home range from 5-16 km2. Galindo-Leal (1992) estimated the density of Coues' white-tailed deer to range from 0.82-14.21 deer/km2 in the Michilia Biosphere Reserve of Mexico, while Leopold (1959) estimated a density of 12-15 deer/km2 in an undisturbed area of the Sierra Madre Occidental mountain area of Mexico. While this species does not migrate, it does shift habitat use seasonally, eating fruits (nuts, beans, berries) in summer, forbs and browse in fall, and evergreen browse in winter (McCulloch 1973; Welch 1960). Dispersal distance for young males at two areas in southern Texas established new areas of use 4.4±1.0 km and 8.2±4.3 km, respectively, from the center of their autumn home range (McCoy et al. 2005).

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Coues' white-tailed deer was considered a passage species based on large home ranges (Ockenfels et al. 1991) and dispersal distances (McCoy et al. 2005), and the distance between wildland blocks used in analysis.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for Coues' white-tailed deer in the BBC used within the Mexico – Tumacacori linkage. Habitat suitability scores range from 17.8 to 94.7, with an average suitability of 77.0 within the BBC (S.D: 17.8; see *Figure 61* below). Most of the BBC (93.0%) is occupied by a potential population core, with the rest non-suitable habitat (see *Figure 62* below). Most of the BBC (93.6%) was greater than its estimated needed minimum width (see *Figure 63* below). The BBC was measured at 21.4 km (13.3 mi) in length between wildland blocks used for analysis. Suitable habitat for Coues' white-tailed deer also exists in the BBC used within the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 15.4 to 82.4, with an average suitability of 58.8 within the BBC (S.D: 7.3; see *Figure 64* below). Some of the BBC (51.9%) is occupied by a potential population core, with a small portion occupied by suitable habitat smaller than a patch (5.7%), and the rest non-suitable habitat (see *Figure 65* below). Most of the BBC (93.5%) was greater than its estimated needed minimum width (see *Figure 66* below). The BBC was measured at 13.2 km (8.2 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional suboptimal but used and potential population cores for Coues' white-tailed deer.

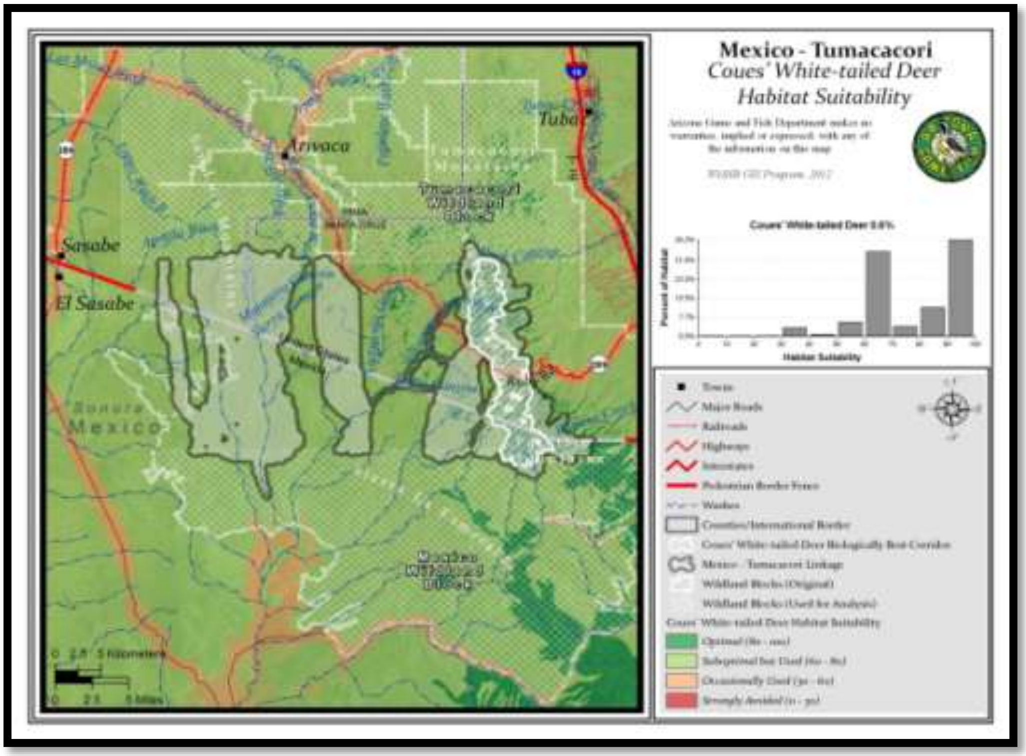

Figure 61: *Map of Mexico – Tumacacori habitat suitability for Coues' white-tailed deer*

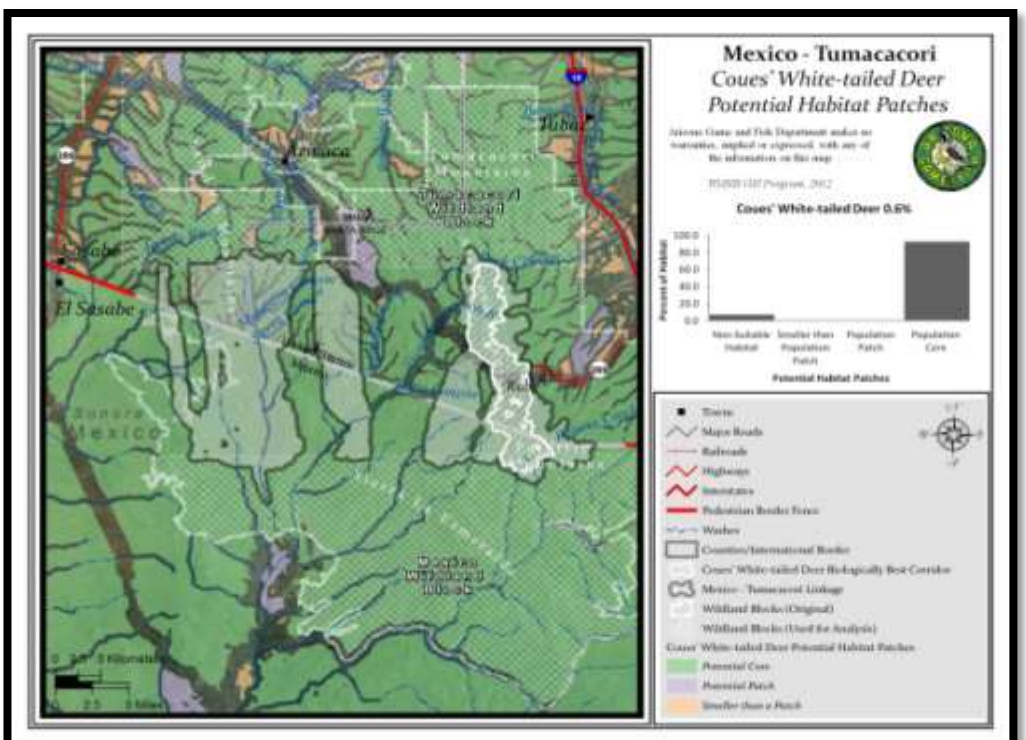

Figure 62: *Map of Mexico – Tumacacori potential habitat patches for Coues' white-tailed deer*

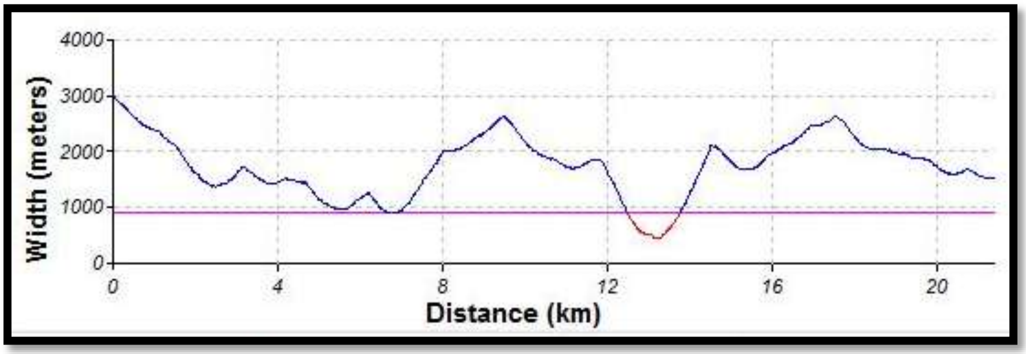

Figure 63: *Width along the Mexico – Tumacacori Coues' white-tailed deer trimmed biologically best corridor*

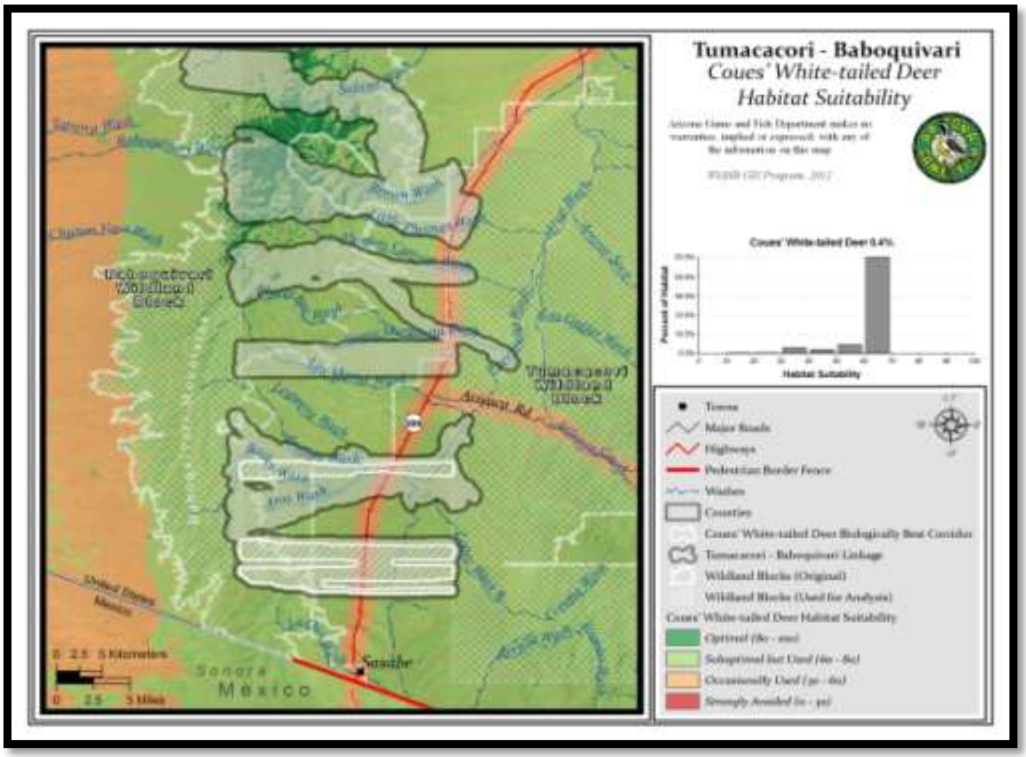

Figure 64: *Map of Tumacacori – Baboquivari habitat suitability for Coues' white-tailed deer*

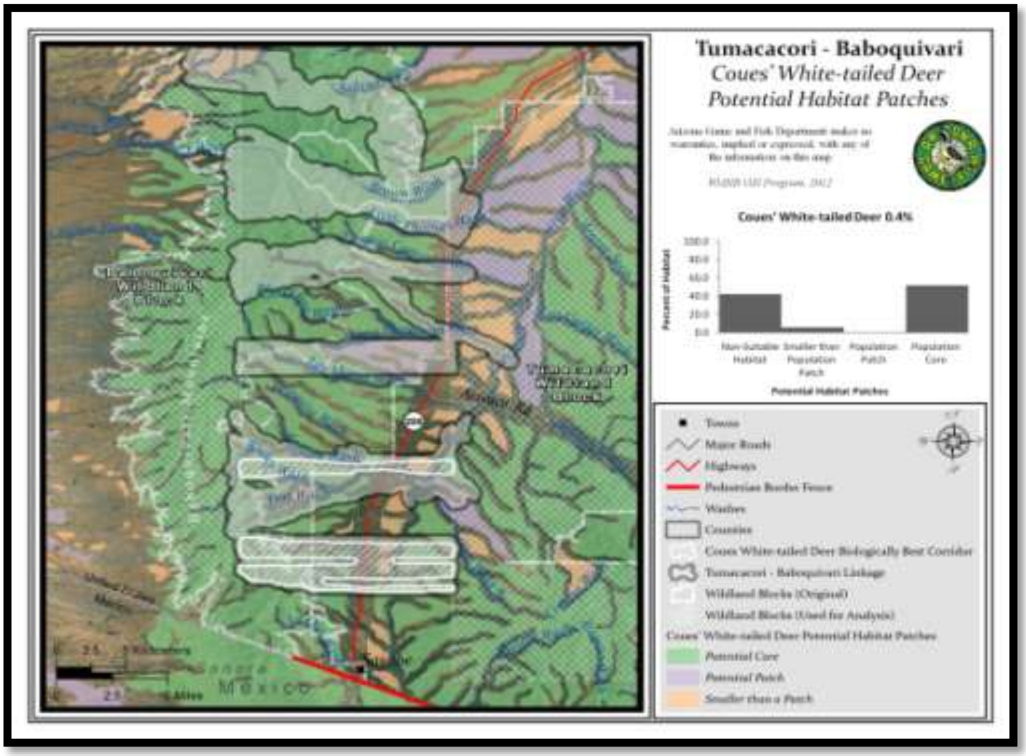

Figure 65: *Map of Tumacacori – Baboquivari potential habitat patches for Coues' white-tailed deer*

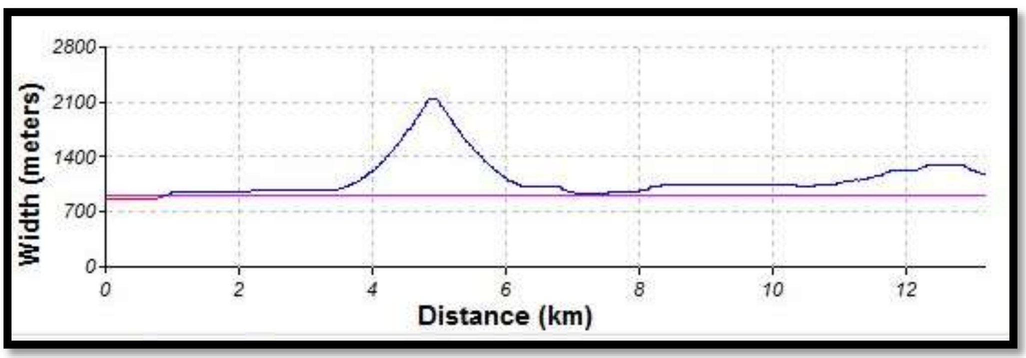

Figure 66: *Width along the Tumacacori – Baboquivari Coues' white-tailed deer trimmed biologically best corridor*

Desert Box Turtle, *Terrapene ornate luteola*

Justification for Selection

The desert box turtle is uncommon in Arizona, and its habitat continues to be limited by recent residential developments (Pima Co., Arizona 2001). Habitat alterations from agriculture also may be eliminating populations in some areas of its range (New Mexico Department of Game and Fish 2004). This turtle is sensitive to highway traffic, and automobiles are considered a significant cause of mortality (Pima Co., Arizona 2001).

Photo courtesy George Andrejko, AGFD

Distribution

The desert box turtle's range encompasses south-central New Mexico south to central Chihuahua and Sonora, Mexico, and from west Texas across southern New Mexico to the eastern base of the Baboquivari Mountains (Pima Co., Arizona 2001). In Arizona, the desert box turtle occurs in Pima and Santa Cruz counties (New Mexico Department of Game and Fish 2004). This species has historically occurred in the Santa Cruz Valley, but may have been extirpated (Phil Rosen, personal comm. with CorridorDesign Team).

Habitat Associations

This species is associated with arid and semiarid regions, and is found in grasslands, plains, and pastures (New Mexico Department of Game and Fish 2004). It prefers open prairies with herbaceous vegetation and sandy soil (New Mexico Department of Game and Fish 2004). This turtle also occurs in rolling grass and shrub land, as well as open woodlands with herbaceous understory (Pima Co., Arizona 2001). Specifically, it is common to mesquite-dominated bajada and abundant in bajada grasslands, grassland flats, and mesquite-dominated flats, but uncommon in rocky slopes and bajada desertscrub (New Mexico Department of Game and Fish 2004). This turtle has been observed taking refuge in subterranean mammal burrows, especially those of the kangaroo rat (Plummer 2004). Elevation range for this species is 0 to 2000 meters, but elevations of 1,200 to 1,600 meters are most suitable (Pima Co., Arizona 2001). In arid regions such as the linkage planning area, this species is dependent on inhabitable sections of riparian bottoms (Phil Rosen, personal comm. with CorridorDesign Team).

Spatial Patterns

Due to extended periods of unfavorable weather conditions within its range, the desert box turtle is active only a few weeks out of the year (Plummer 2004). During activity, it requires up to 12 ha for its home range, including land with moist soil that is not compacted (Pima Co., Arizona 2001). One study in Cochise County, Arizona reported average home ranges of 1.1 ha in a dry year and 2.5 ha in a wet year (Pima Co., Arizona 2001). Another study at Fort Huachuca found home ranges that varied from 1.6 ha to 12.4 ha, with an average of 8.5 ha (Pima Co., Arizona 2001). Daily movements include early morning and late afternoon excursions to flat water sites, including cattle tanks (New Mexico Department of Game and Fish 2004; Plummer 2004).

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 40%, while elevation, topography, and distance from roads received weights of 15%, 20%, and 25%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 5 ha, and minimum potential core size was defined as 50 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. Desert box turtle was considered a corridor dweller due to its small home range size and limited movements (Pima Co., Arizona 2001). The original biologically best corridor for this species was trimmed to eliminate additional strands in the Mexico – Tumacacori linkage which do not provide suitable habitat for other focal species, in order to decrease the width of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for desert box turtle within the trimmed BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0 to 82.1, with an average suitability of 77.1 (S.D: 4.9; see *Figure 67* below). Almost all of the trimmed BBC (99.9%) is occupied by potential population cores (see *Figure 68* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 69* below). The trimmed corridor was measured at 18.7 km (11.6 mi) in length between wildland blocks used for analysis. Suitable habitat for desert box turtle also exists within the BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 52 to 79.3, with an average suitability of 77.1 (S.D: 4.4; see *Figure 70* below). Almost all of the BBC (99.9%) is occupied by potential population cores (see *Figure 71* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 72* below). The corridor was measured at 12.6 km (7.8 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional suboptimal but used habitats and potential population cores for desert box turtle.

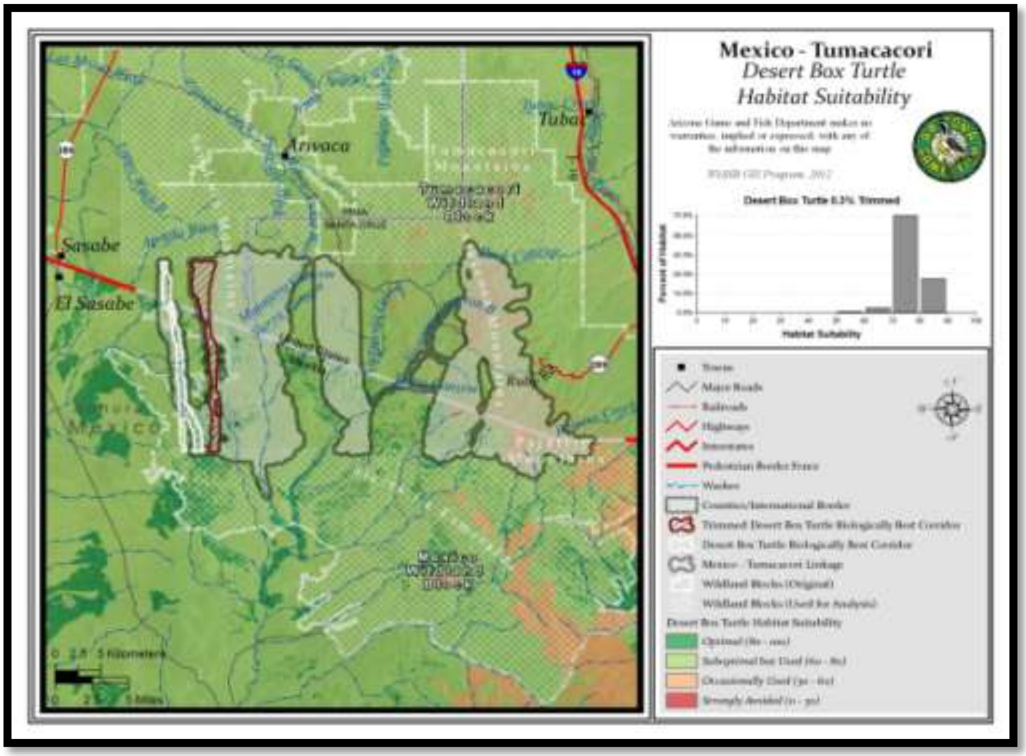

Figure 67: *Map of Mexico – Tumacacori habitat suitability for desert box turtle*

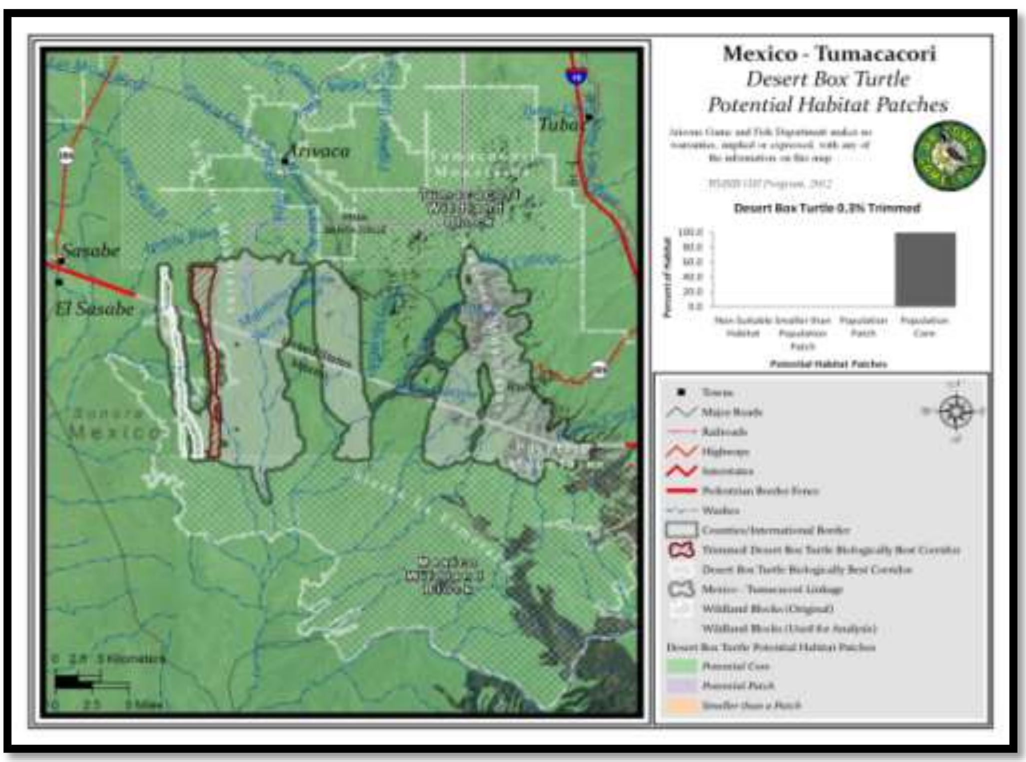

Figure 68: *Map of Mexico – Tumacacori potential habitat patches for desert box turtle*

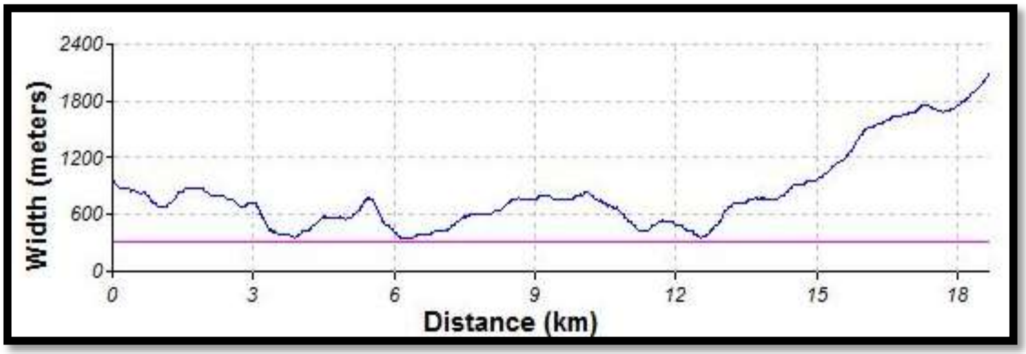

Figure 69: *Width along the Mexico – Tumacacori desert box turtle trimmed biologically best corridor*

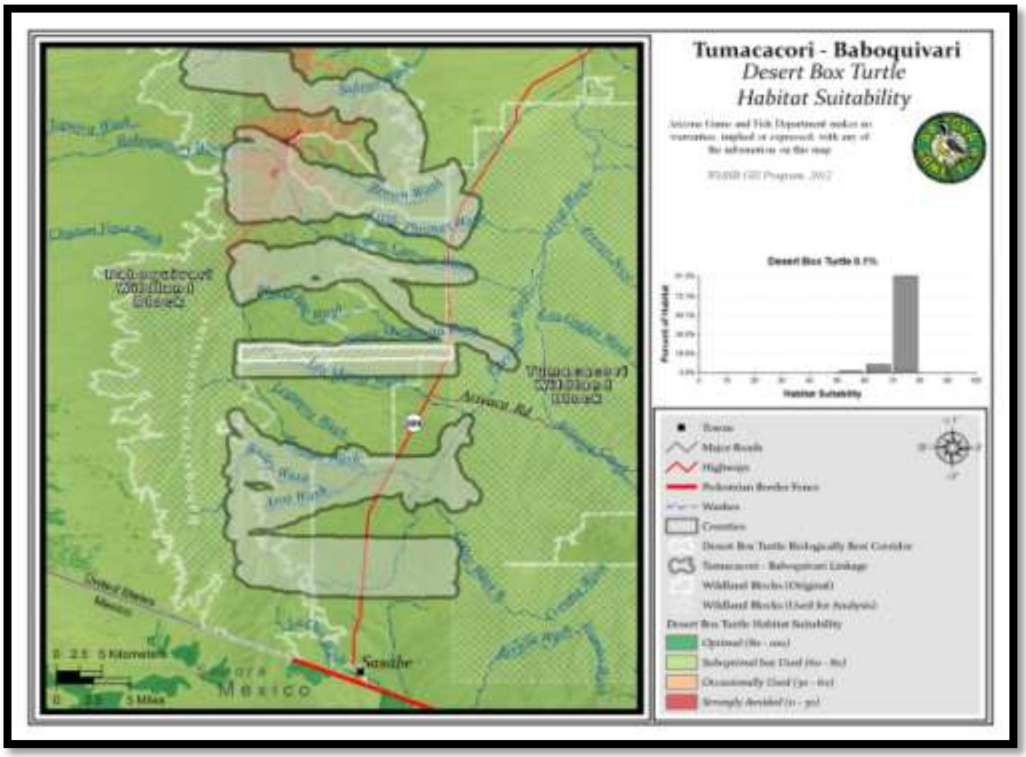

Figure 70: *Map of Tumacacori – Baboquivari habitat suitability for desert box turtle*

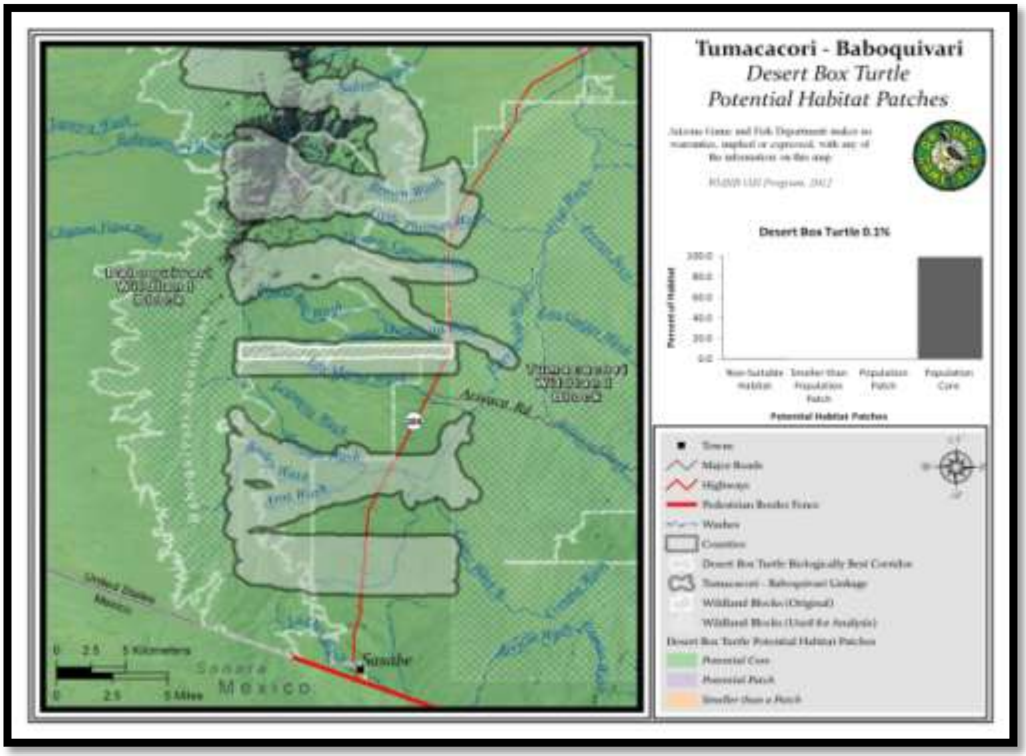

Figure 71: *Map of Tumacacori – Baboquivari potential habitat patches for desert box turtle*

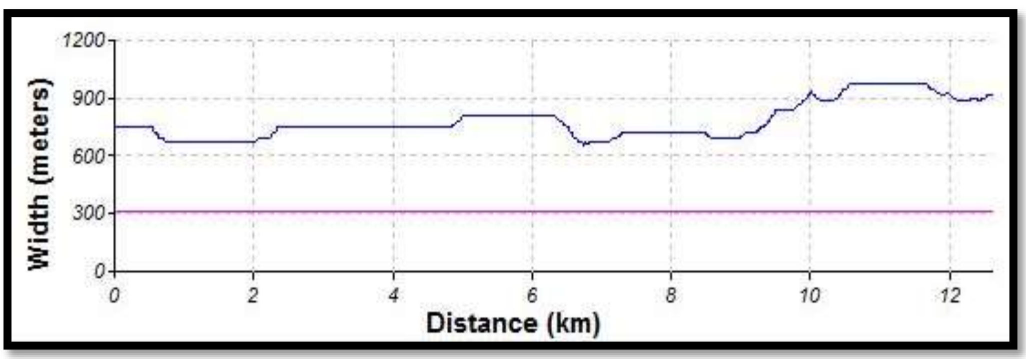

Figure 72: *Width along the Tumacacori – Baboquivari desert box turtle biologically best corridor*

Giant Spotted Whiptail, *Aspidoscelis burti stictogrammus*

Justification for Selection

Photo courtesy Randy Babb, AGFD

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

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 70%, while elevation received a weight of 30%. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum patch size was defined as 4 ha, while minimum core size was defined as 25 ha. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Giant spotted whiptail was classified as a corridor dweller in this analysis due to their small home range size (Rosen et al. 2002), and distance between wildland blocks. The original biologically best corridor for this species was trimmed to eliminate additional strands in the Tumacacori – Baboquivari linkage which do not provide suitable habitat for other focal species, in order to decrease the width of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for giant spotted whiptail within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 84.0, with an average suitability of 74.3 (S.D: 7.9; see *Figure 73* below). Most of the BBC (96.2%) is occupied by potential population cores (see *Figure 74* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 75* below). The corridor was measured at 19.1 km (11.9 mi) in length between wildland blocks used for analysis. Suitable habitat for giant spotted whiptail also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 66.6 to 84.0, with an average suitability of 76.8 (S.D: 3.0; see *Figure 76* below). The entire trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 77* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 78* below). The trimmed corridor was measured at 13.5 km (8.4 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional suboptimal but used and occasionally used habitat for giant spotted whiptail, as well as potential population cores.

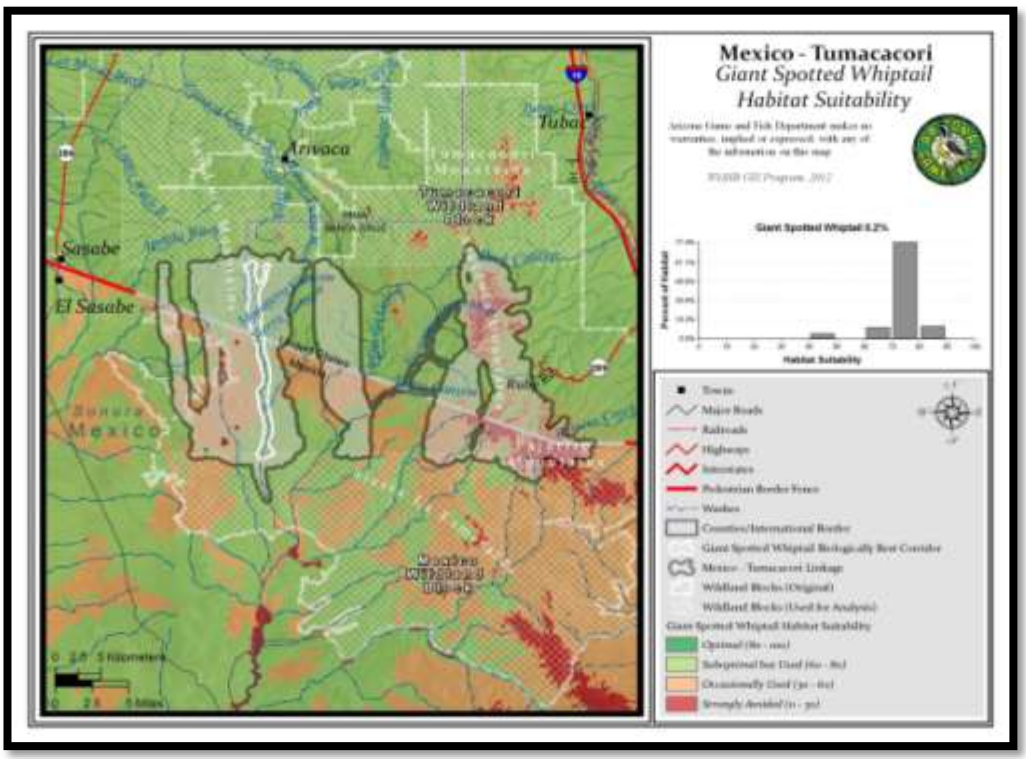

Figure 73: *Map of Mexico – Tumacacori habitat suitability for giant spotted whiptail*

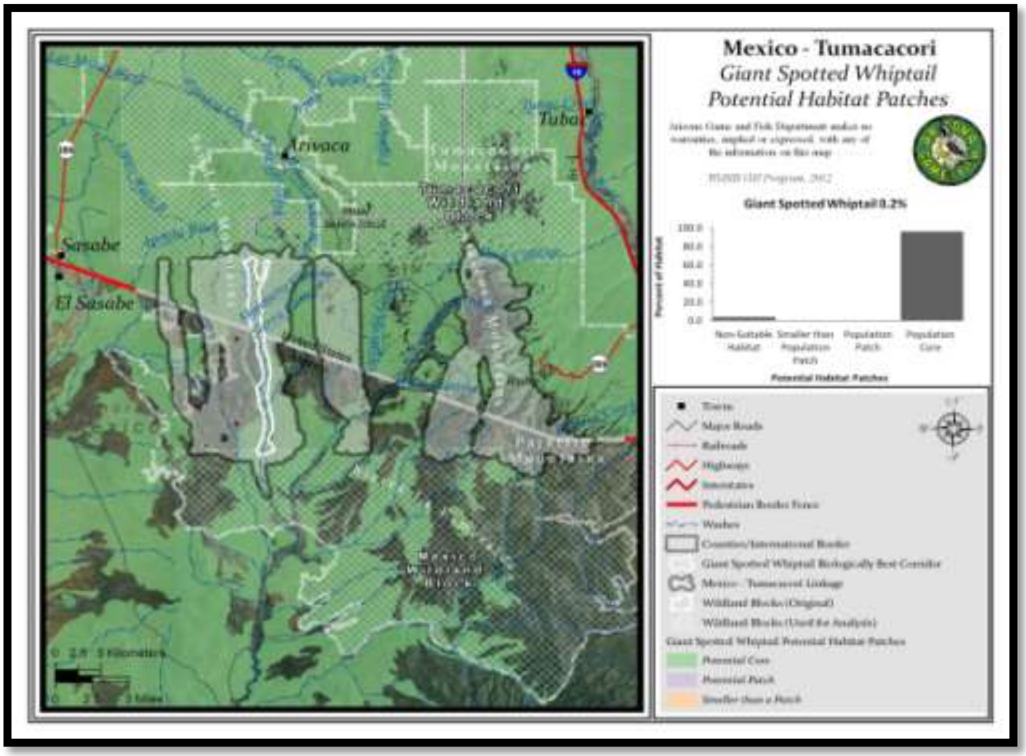

__Figure 74:__ Map of Mexico – Tumacacori potential habitat patches for giant spotted whiptail

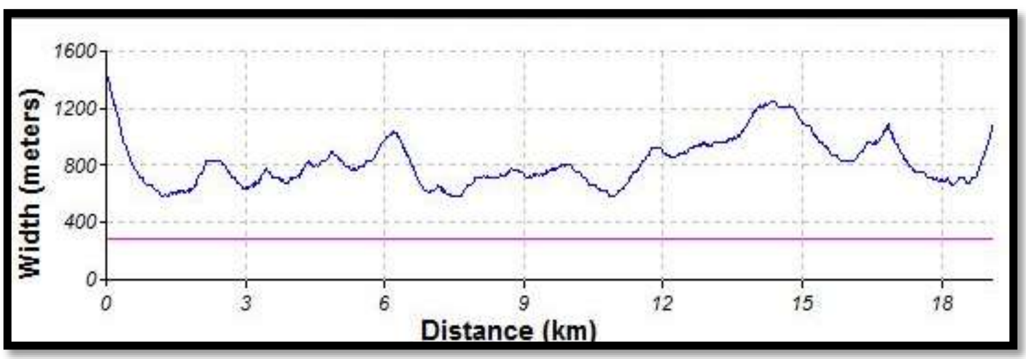

__Figure 75:__ Width along the Mexico – Tumacacori giant spotted whiptail biologically best corridor

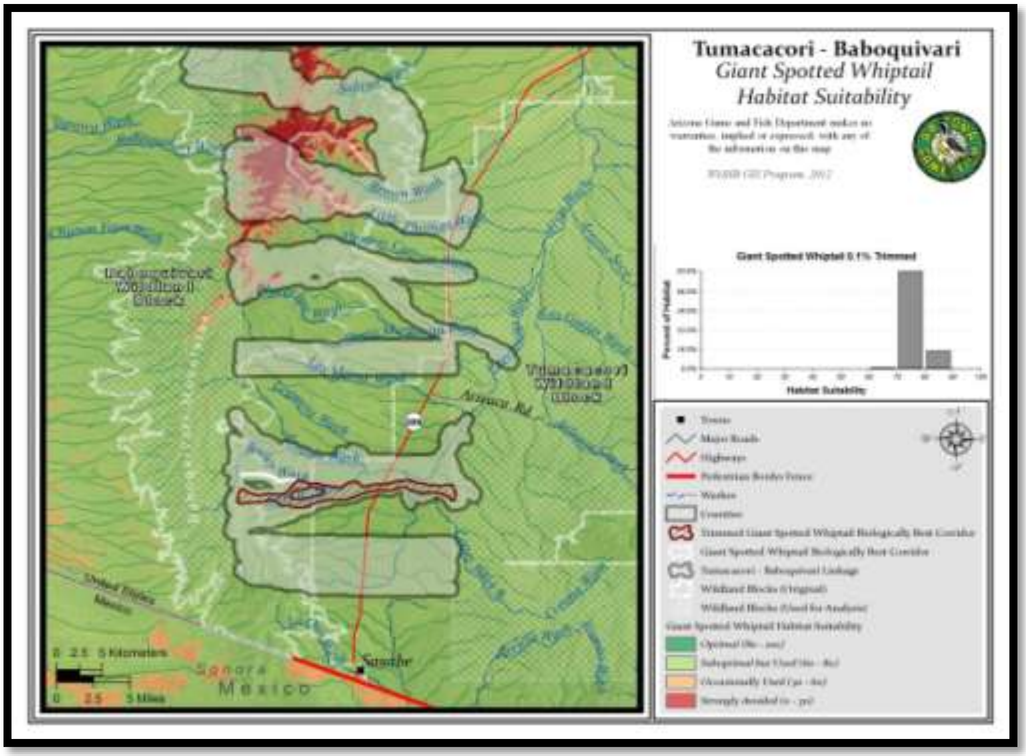

Figure 76: *Map of Tumacacori – Baboquivari habitat suitability for giant spotted whiptail*

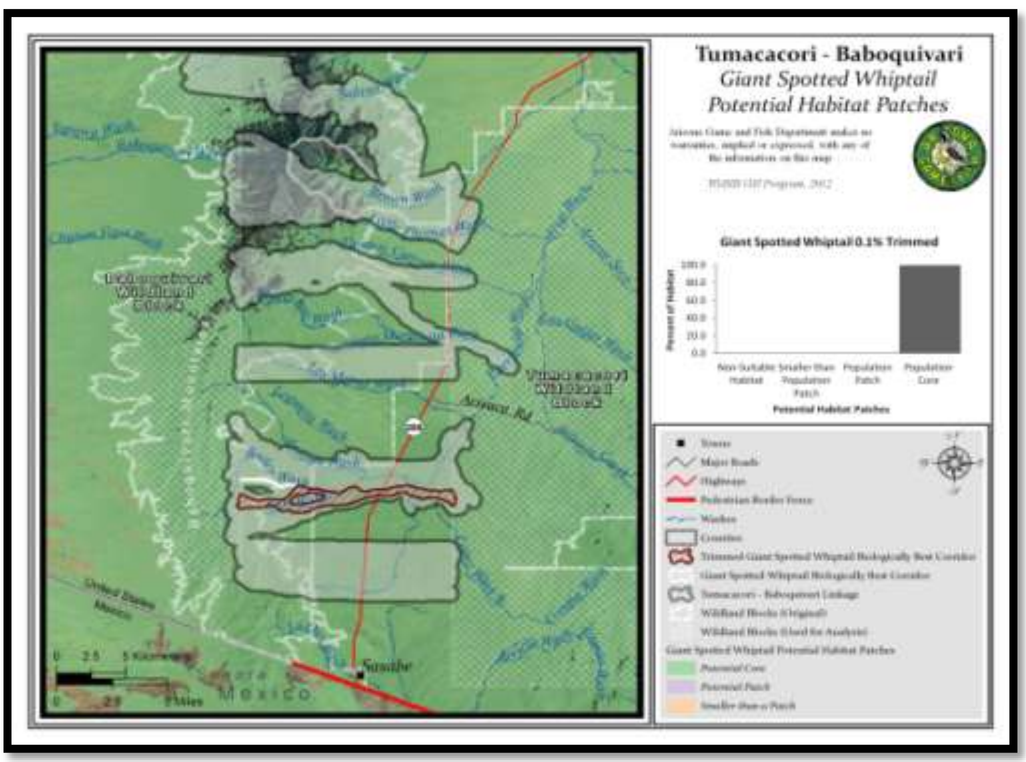

Figure 77: *Map of Tumacacori – Baboquivari potential habitat patches for giant spotted whiptail*

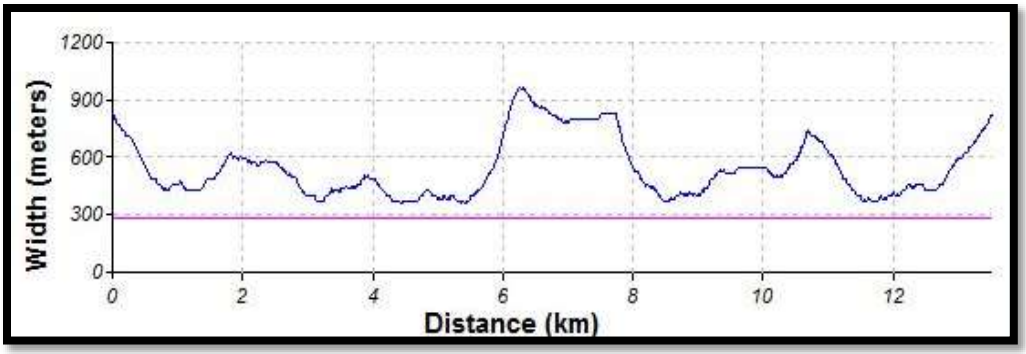

Figure 78: *Width along the Tumacacori – Baboquivari trimmed giant spotted whiptail biologically best corridor*

Gila Monster, *Heloderma suspectum*

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. While Gila monster may be capable of dispersal of up to 8 km or more, the species was classified as a corridor dweller in this analysis due to distance between wildland blocks. The original biologically best corridor for this species was trimmed to eliminate “balloon” areas that were created to maintain its estimated minimum width over 90% of its length.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for Gila monster within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to

97.5, with an average suitability of 87.8 (S.D: 10.6; see *Figure 79* below). Most of the BBC (99.9%) is occupied by potential population cores (see *Figure 80* below). Most of the BBC (94.0%) was greater than its estimated needed minimum width (see *Figure 81* below). The corridor was measured at 20.0 km (12.4 mi) in length between wildland blocks used for analysis. Suitable habitat for Gila monster also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 0 to 97.5, with an average suitability of 85.0 (S.D: 10.1; see *Figure 82* below). The entire trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 83* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 84* below). The trimmed corridor was measured at 18.9 km (11.7 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for Gila monster, as well as potential population cores.

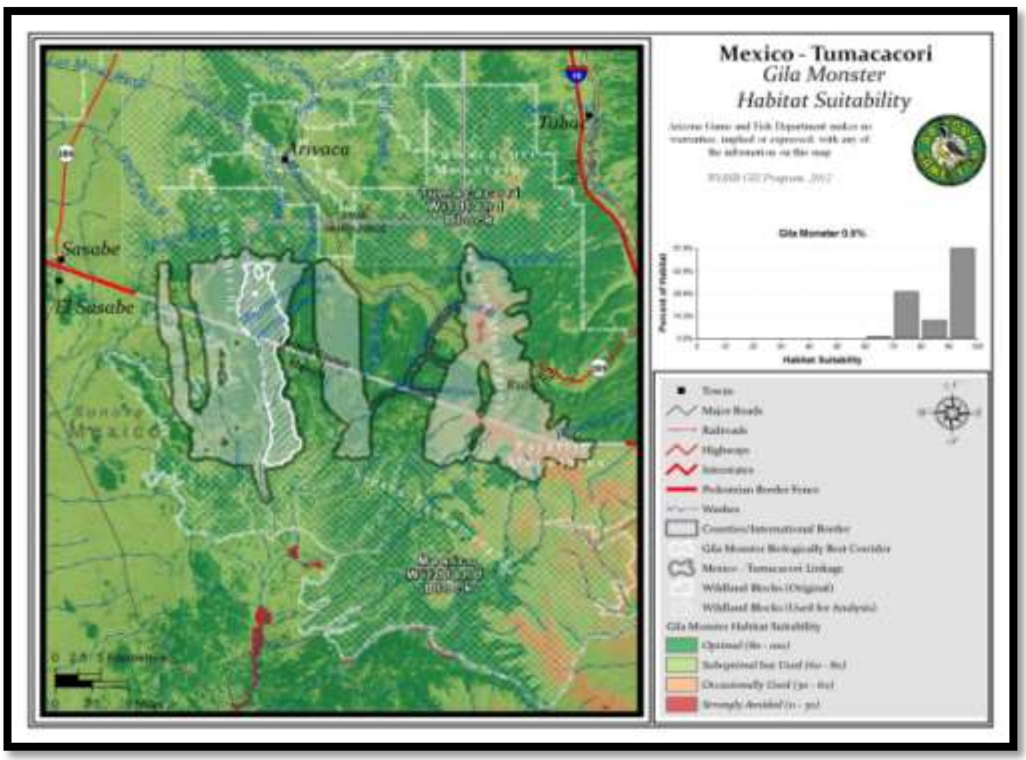

Figure 79: *Map of Mexico – Tumacacori habitat suitability for Gila monster*

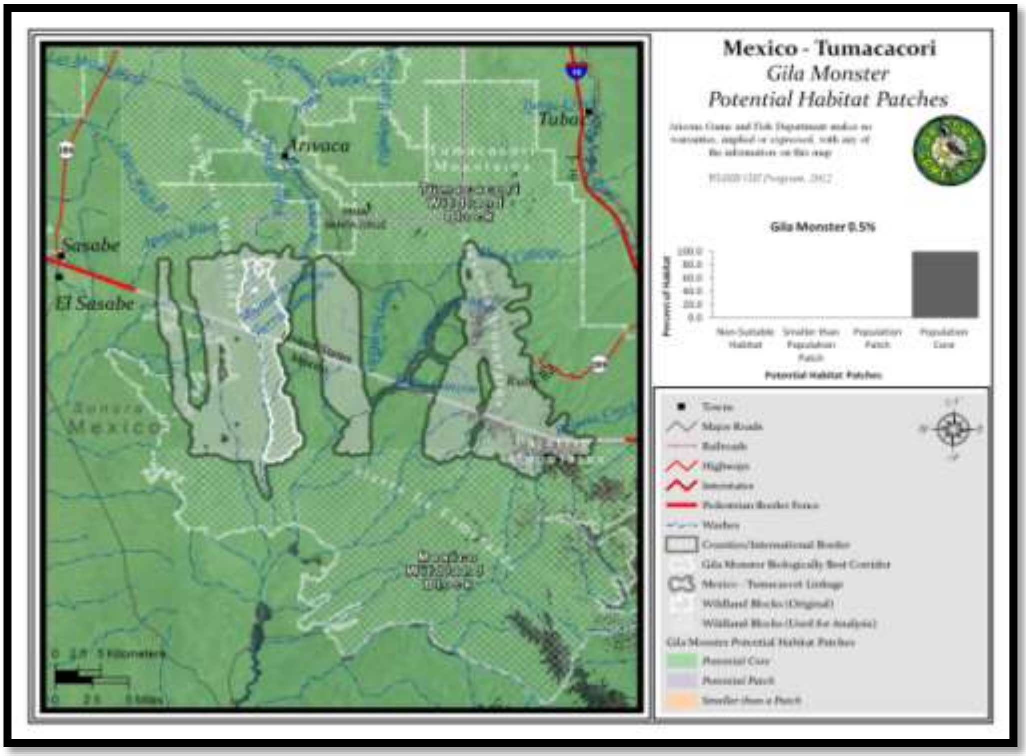

Figure 80: *Map of Mexico – Tumacacori potential habitat patches for Gila monster*

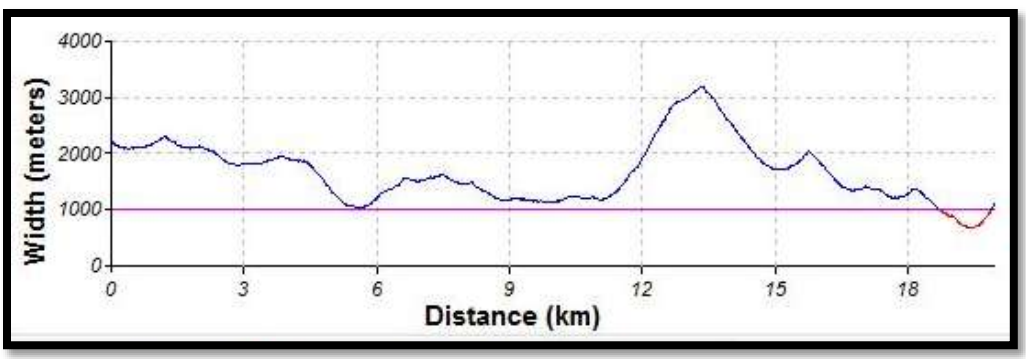

Figure 81: *Width along the Mexico – Tumacacori Gila monster biologically best corridor*

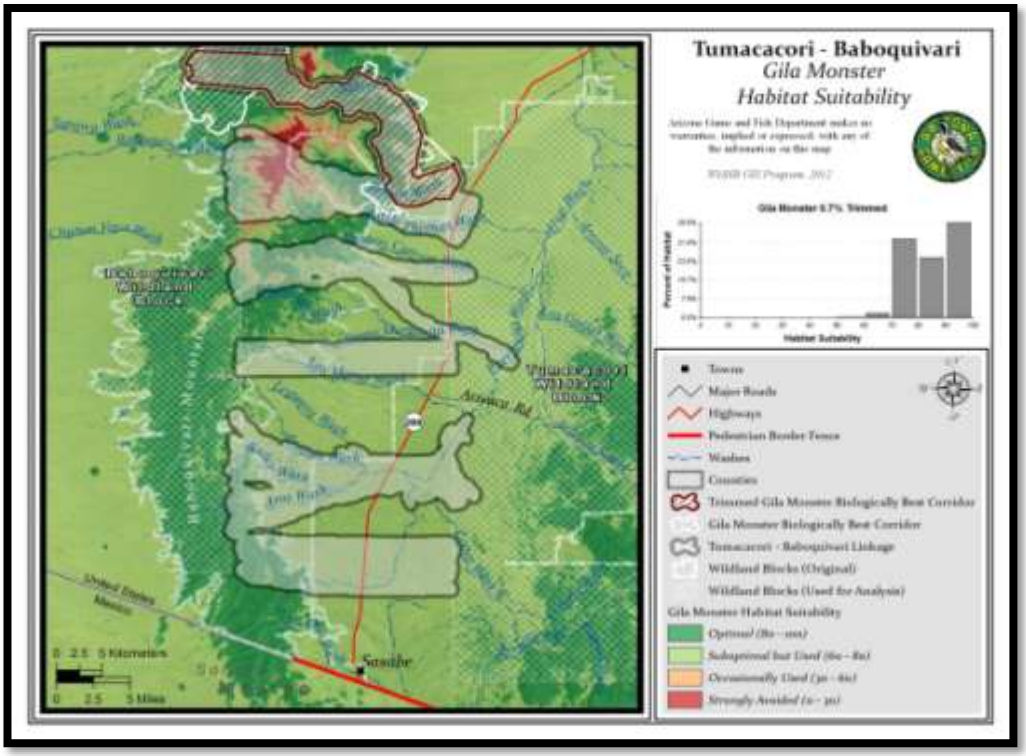

Figure 82: *Map of Tumacacori – Baboquivari habitat suitability for Gila monster*

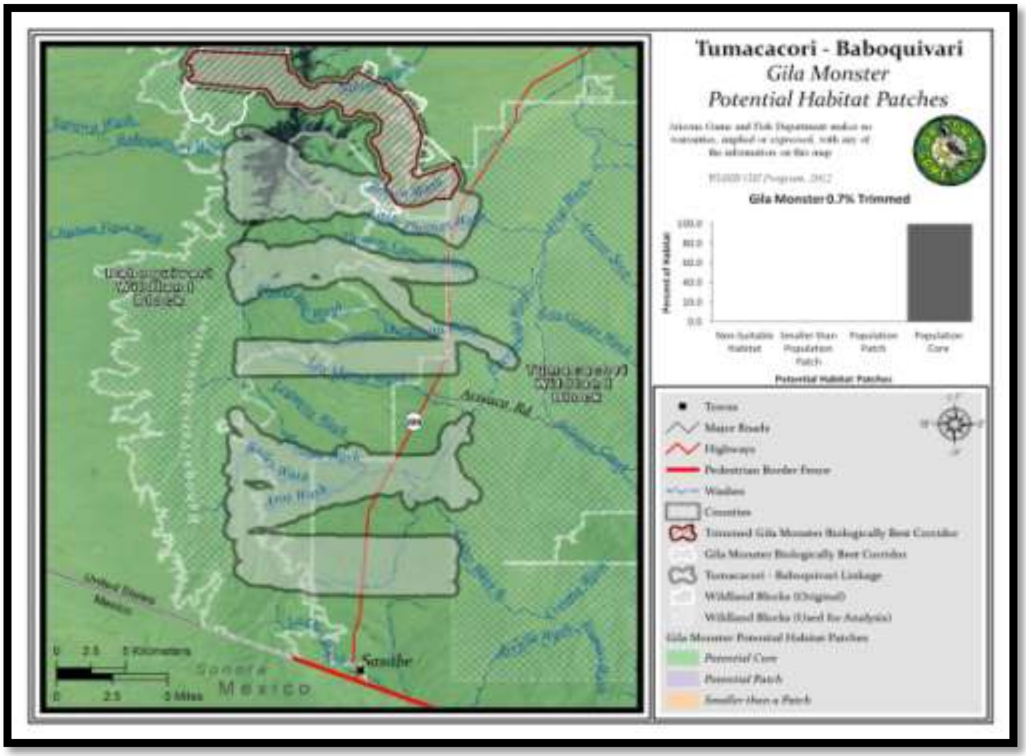

Figure 83: *Map of Tumacacori – Baboquivari potential habitat patches for Gila monster*

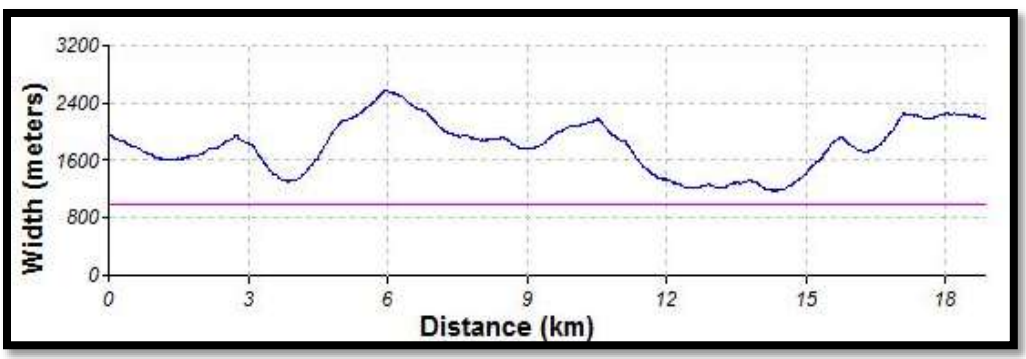

Figure 84: *Width along the Tumacacori – Baboquivari Gila monster trimmed biologically best corridor*

Jaguar, *Panthera onca*

Justification for Selection

Photo courtesy George Andrejko, AGFD

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

Distribution

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

Habitat Associations

Jaguars are adaptable to a variety of conditions, and are most often found in areas with sufficient prey, cover, and water supply (Seymour 1989). Within Arizona, habitat preferences are not clear; however, the species appears to prefer scrub and grasslands, evergreen forest, and conifer forest and 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; Arizona Game and Fish Department 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^2, 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^2, with one female ranging up to 38 km^2, and one male ranging more than 90 km^2 (Schaller & Crawshaw 1980).

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum patch size for jaguar was defined as 41 km^2 and minimum core size as 205 km^2. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Jaguar was classified as passage species in this analysis due to large home range sizes (Arizona Game and Fish Department 2004), and distance between wildland blocks.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for jaguar within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 93.2, with an average suitability of 81.5 (S.D: 13.5; see *Figure 85* below). Most of the BBC (97.3%) is occupied by potential population cores (see *Figure 86* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 87* below). The corridor was measured at 19.5 km (12.1 mi) in length between wildland blocks used for analysis. Suitable habitat for Gila monster also exists within the BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 0.0 to 98.8, with an average suitability of 76.4 (S.D: 15.4; see *Figure 88* below). Most of the BBC (92.9%) is occupied by potential population cores (see *Figure 89* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 90* below). The corridor was measured at 14.0 km (8.7 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for jaguar, as well as potential population cores.

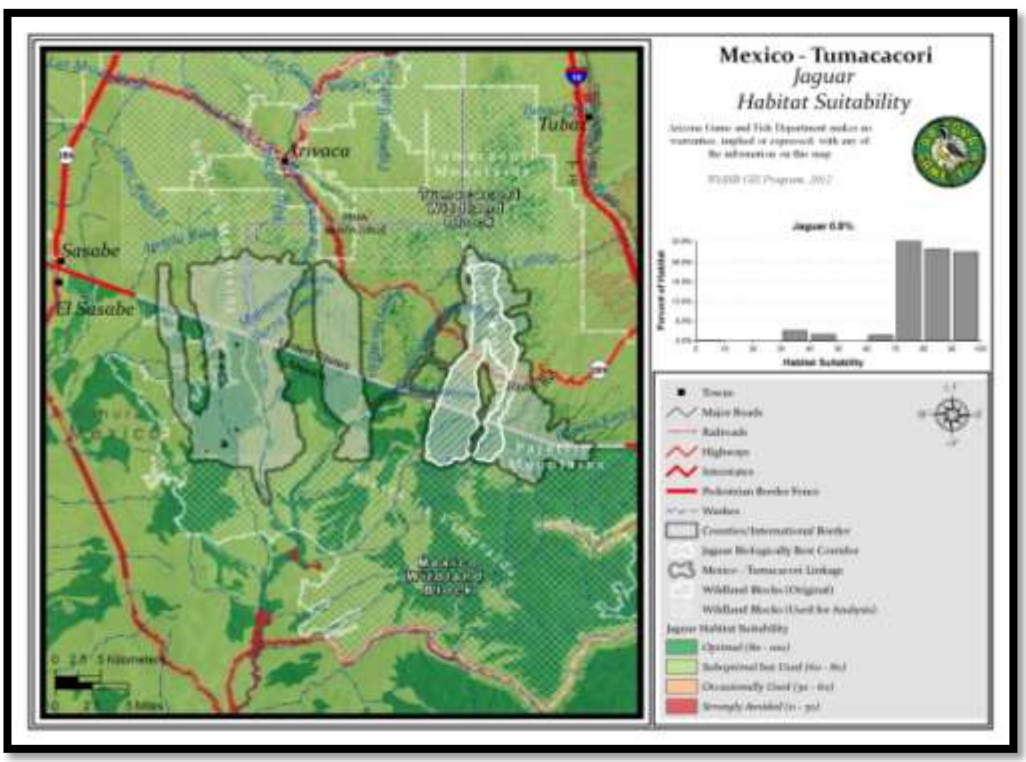

Figure 85: *Map of Mexico – Tumacacori habitat suitability for jaguar*

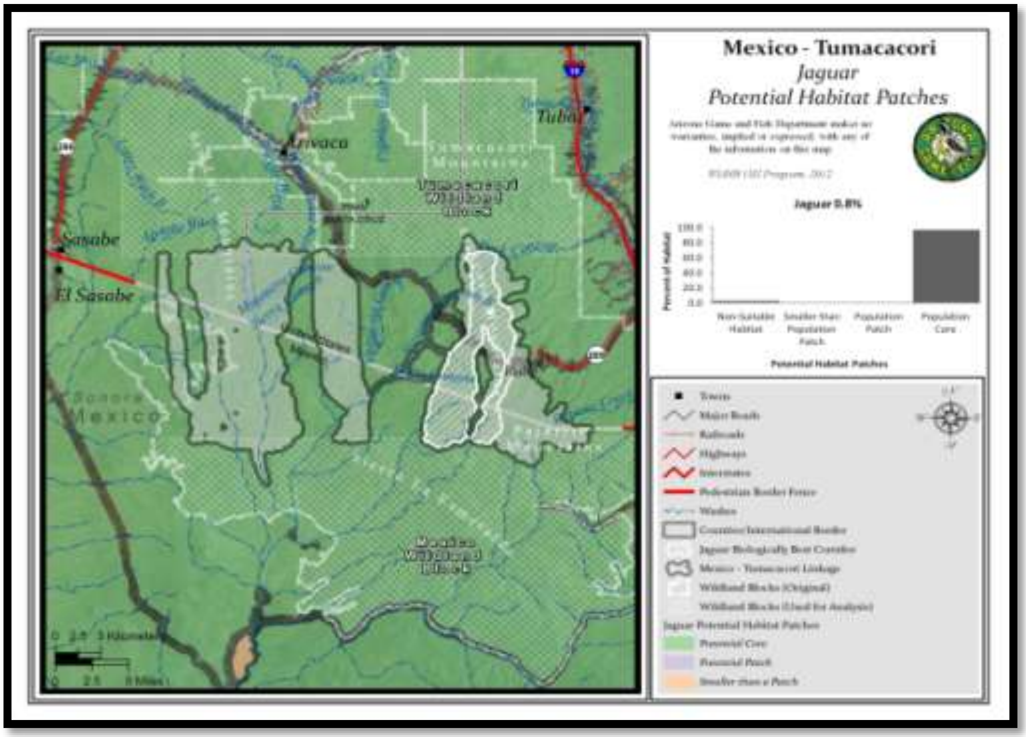

__Figure 86:__ Map of Mexico – Tumacacori potential habitat patches for jaguar

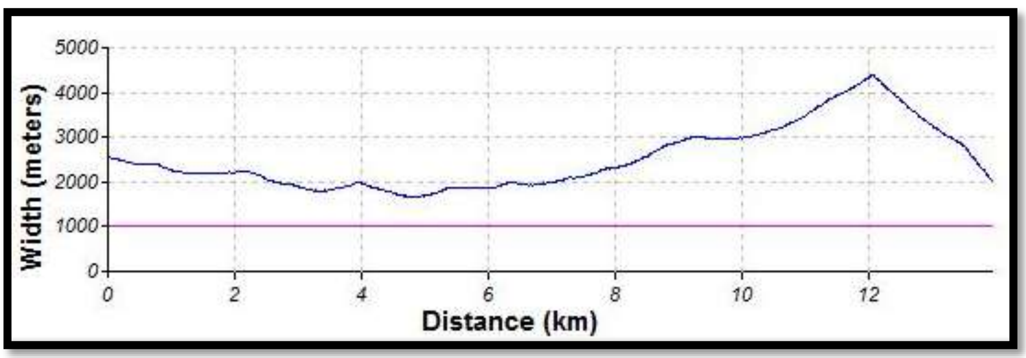

__Figure 87:__ Width along the Mexico – Tumacacori jaguar biologically best corridor

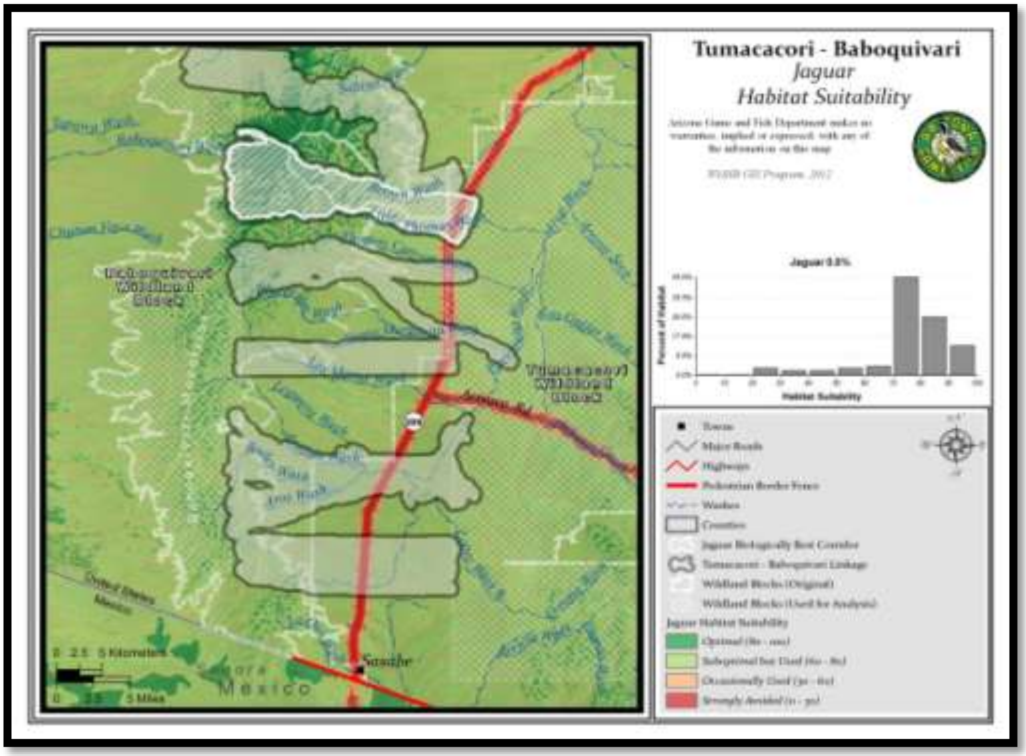

Figure 88: *Map of Tumacacori – Baboquivari habitat suitability for jaguar*

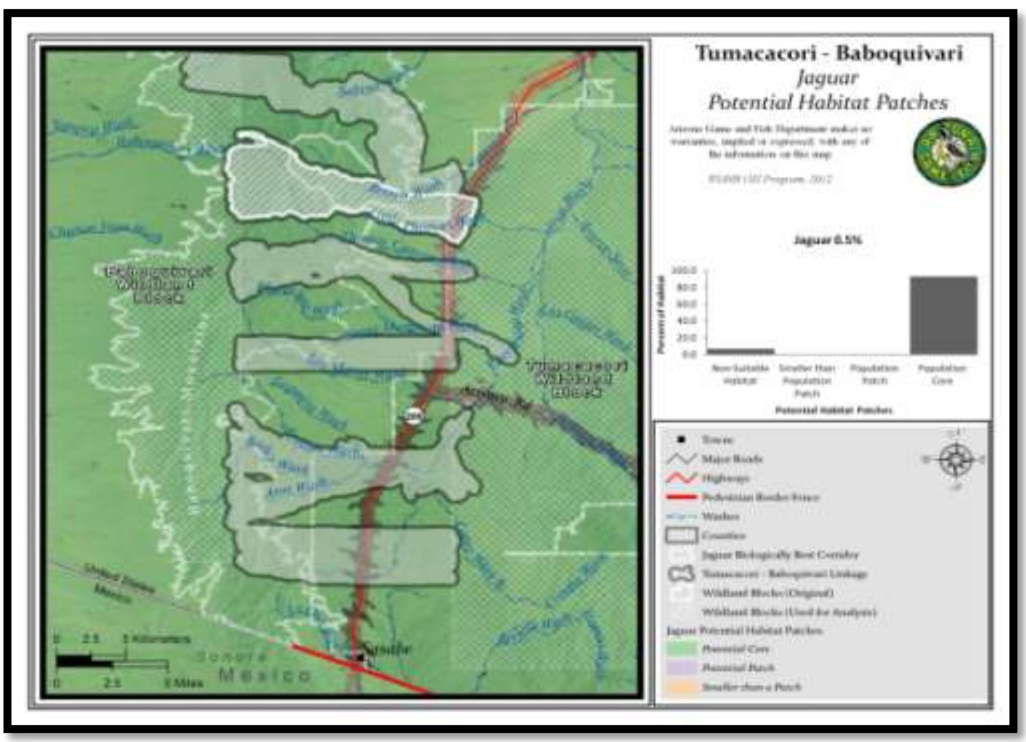

Figure 89: *Map of Tumacacori – Baboquivari potential habitat patches for jaguar*

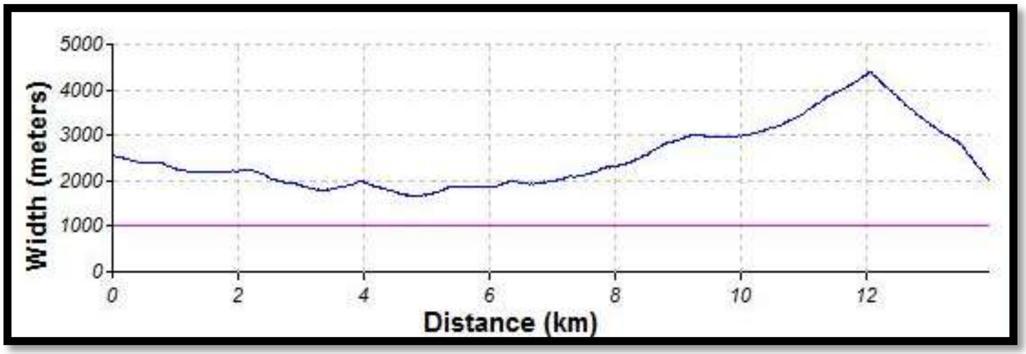

Figure 90: *Width along the Tumacacori – Baboquivari jaguar biologically best corridor*

Javelina, *Tayassu tajacu*

Justification for Selection

Young javelina are probably prey 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^2 in the Tortolita Mountains (Bigler 1974), 4.93 km^2 near Prescott (Ticer et al. 1998), and between 1.9 and 5.5 ha in the Tonto Basin (Ockenfels and Day 1990). Dispersal of javelina has not been adequately studied, but they are known to be capable of extensive movements of up to several kilometers (NatureServe 2005).

Conceptual Basis for Model Development

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

Patch size 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 was classified as a passage species for this analysis due to their known capability of extensive movements (NatureServe 2005), and distance between wildland blocks. The biologically best corridor used in the Tumacacori – Baboquivari linkage was trimmed to eliminate additional strands that did not provide habitat connectivity for other focal species.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for javelina within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 100.0, with an average suitability of 86.9 (S.D: 9.8; see *Figure 91* below). Most of the BBC (97.3%) is occupied by potential population cores (see *Figure 92* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 93* below). The corridor was measured at 19.7 km (12.2 mi) in length between wildland blocks used for analysis. Suitable habitat for javelina also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 62.6 to 100.0, with an average suitability of 92.1 (S.D: 5.5; see *Figure 94* below). The entire trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 95* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 96 be*low). The trimmed corridor was measured at 16.2 km (10.1 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for javelina, as well as potential population cores.

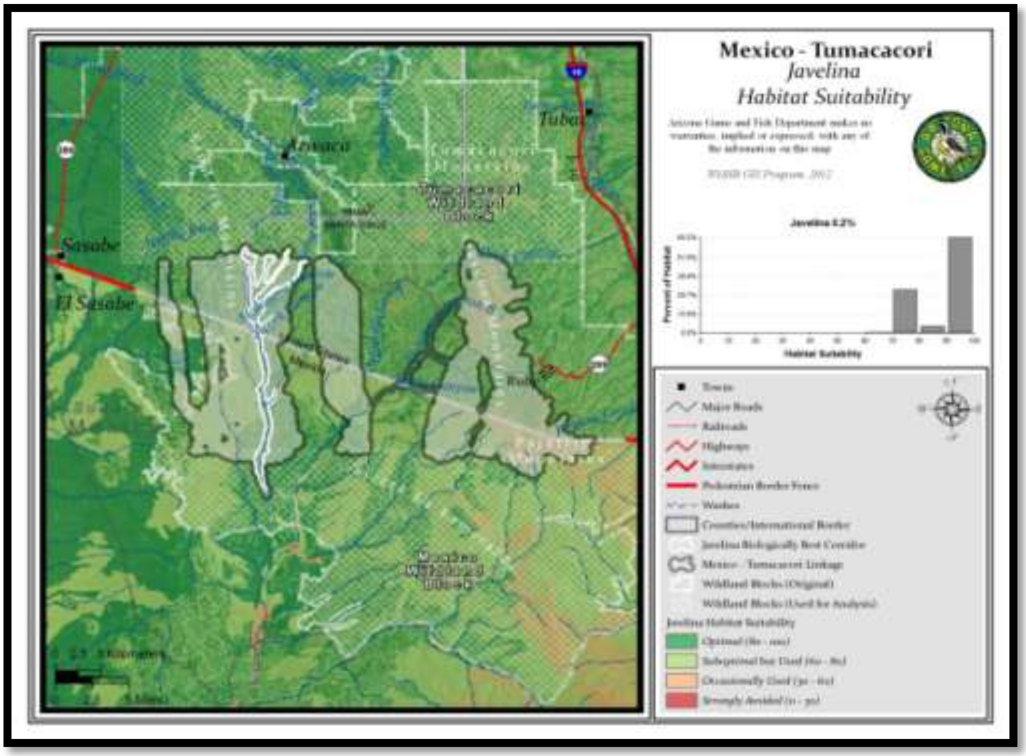

Figure 91: *Map of Mexico – Tumacacori habitat suitability for javelina*

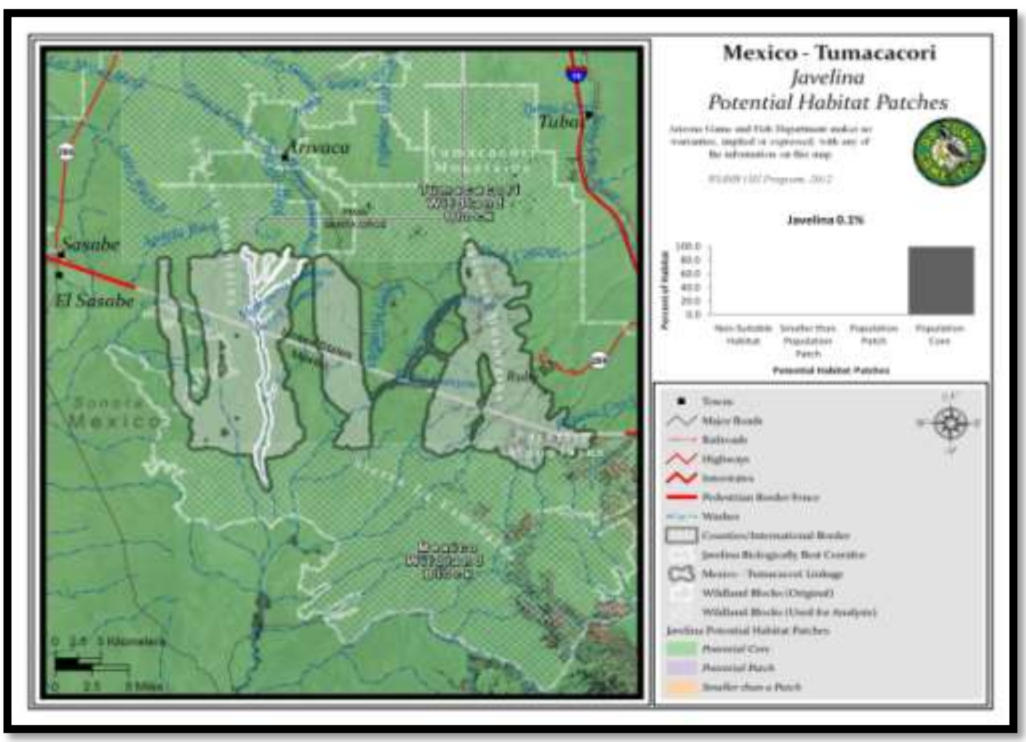

Figure 92: Map of Mexico – Tumacacori potential habitat patches for javelina

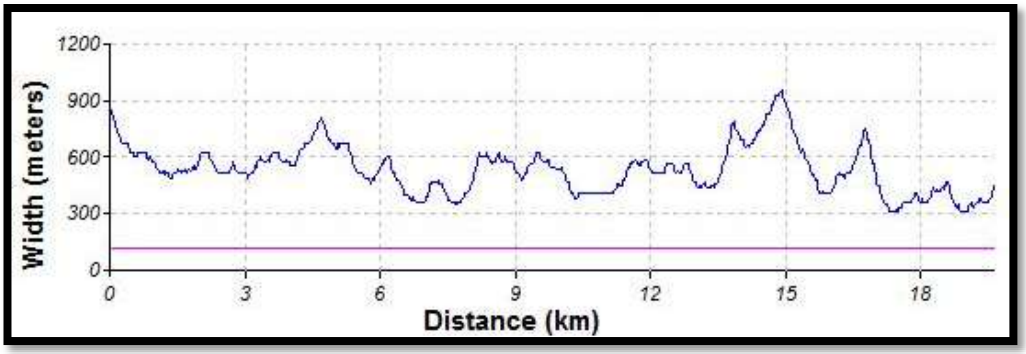

Figure 93: *Width along the Mexico – Tumacacori javelina biologically best corridor*

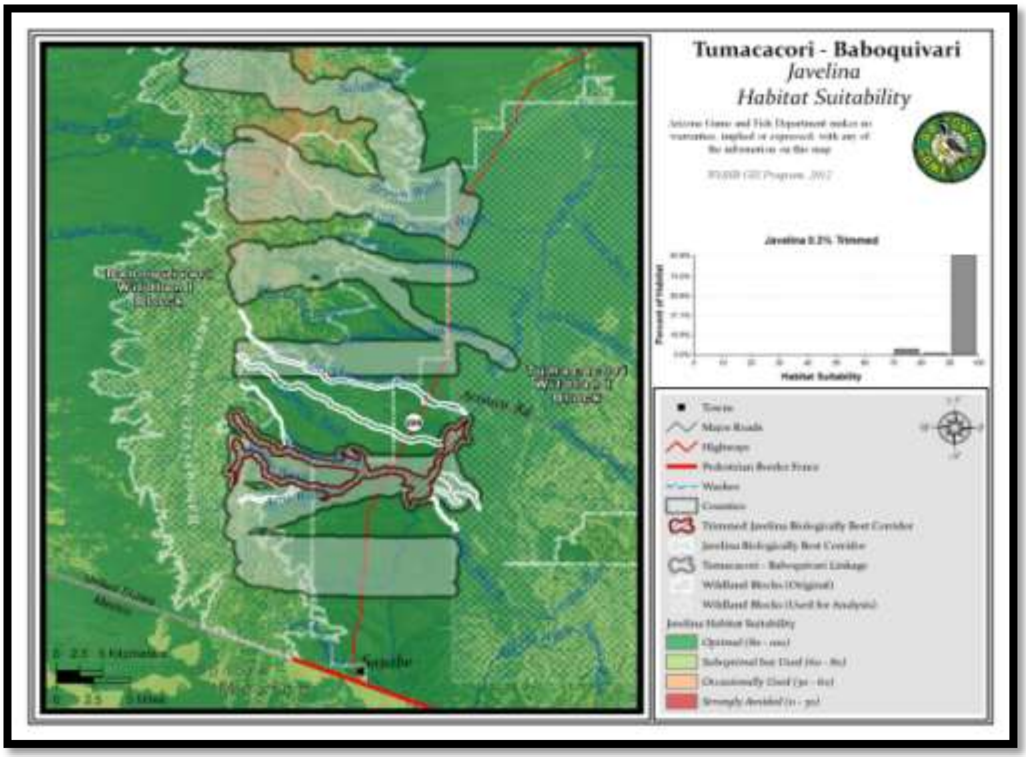

Figure 94: *Map of Tumacacori – Baboquivari habitat suitability for javelina*

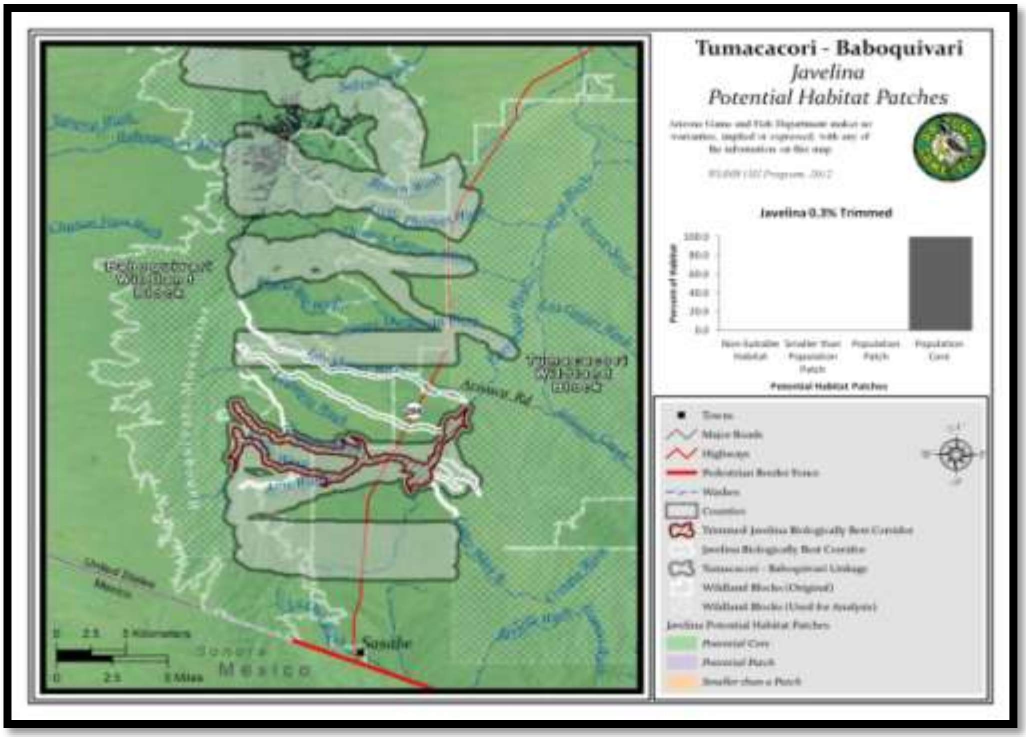

Figure 95: *Map of Tumacacori – Baboquivari potential habitat patches for javelina*

Figure 96: *Width along the Tumacacori – Baboquivari trimmed javelina biologically best corridor*

Kit Fox, *Vulpes macrotis*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution and Status

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Kit fox were classified as a passage species due to their large home range size (McGrew 1979; Arjo et al. 2003). The biologically best corridors used in the linkage design were trimmed to eliminate additional strands that did not provide habitat connectivity for other focal species.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for kit fox within the trimmed BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 91.6, with an average suitability of 87.0 (S.D: 6.4; see *Figure 97* below). All of the trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 98* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 99* below). The trimmed corridor was measured at 19.8 km (12.3 mi) in length between wildland blocks used for analysis. Suitable habitat for kit fox also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 28.8 to 84.6, with an average suitability of 83.0 (S.D: 6.7; see *Figure 100* below). The entire trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 101* below). Most of the trimmed BBC (91.6%) was greater than its estimated needed minimum width (see *Figure 102 be*low). The trimmed corridor was measured at 12.7 km (7.9 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for kit fox, as well as potential population cores.

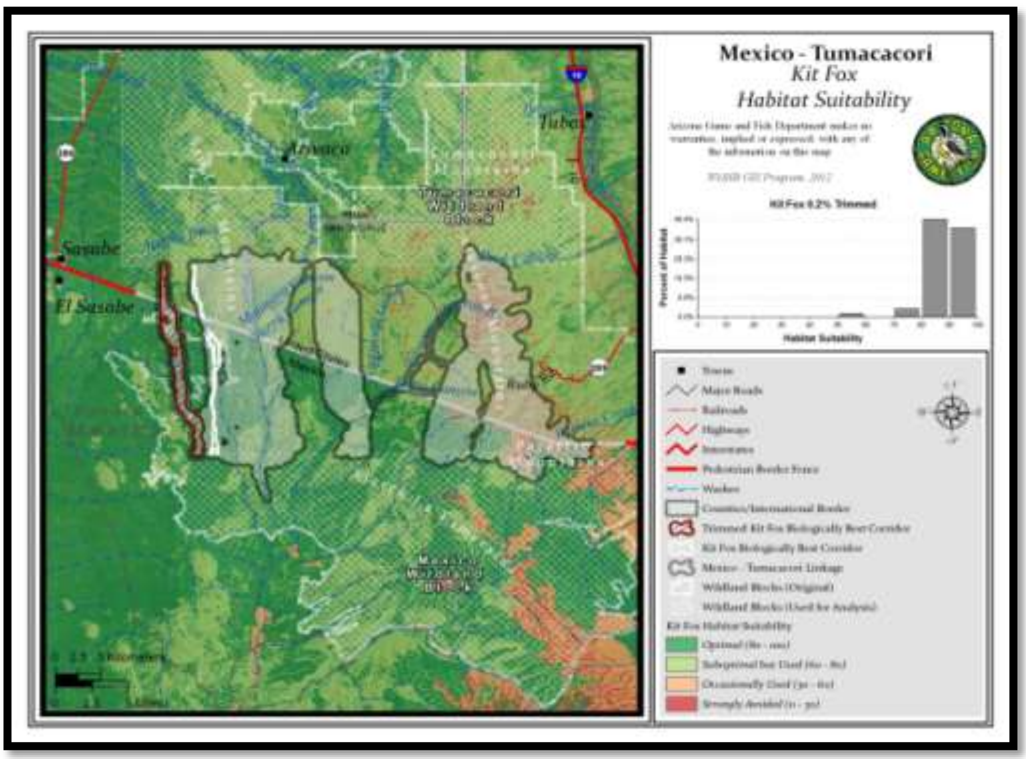

Figure 97: *Map of Mexico – Tumacacori habitat suitability for kit fox*

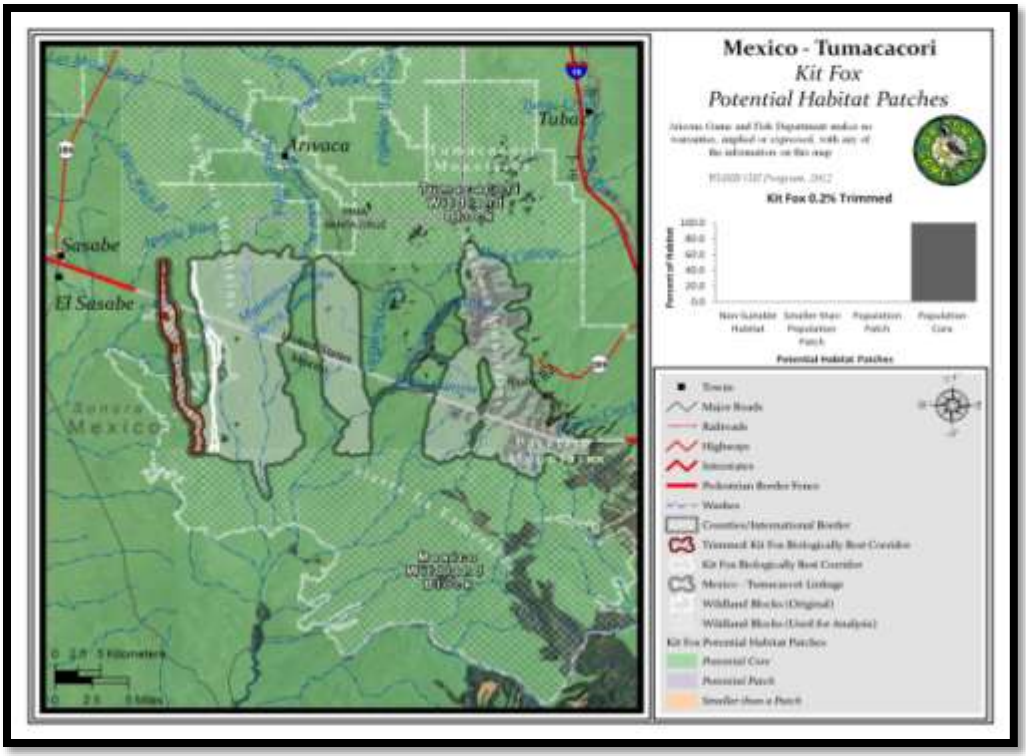

Figure 98: *Map of Mexico – Tumacacori potential habitat patches for kit fox*

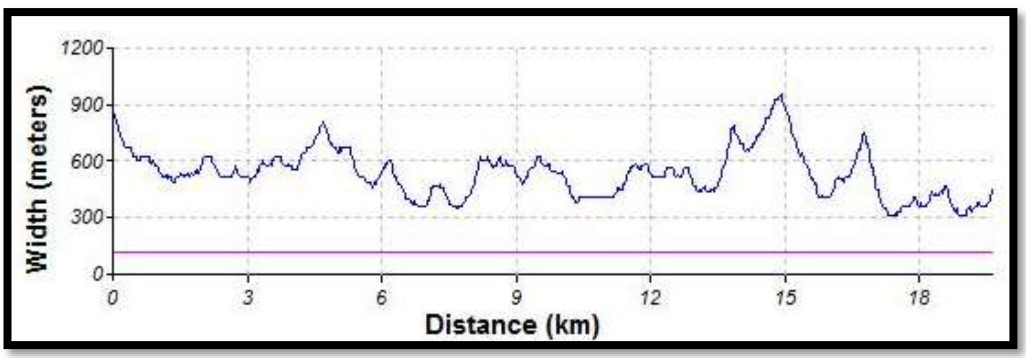

Figure 99: *Width along the Mexico – Tumacacori trimmed kit fox biologically best corridor*

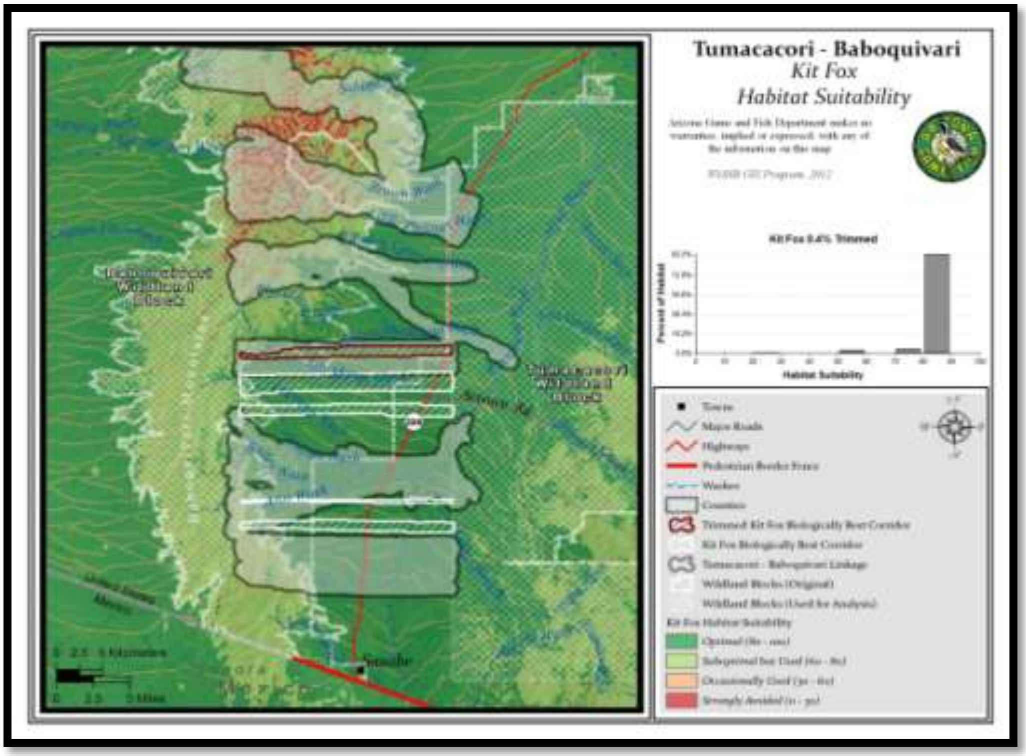

Figure 100: *Map of Tumacacori – Baboquivari habitat suitability for kit fox*

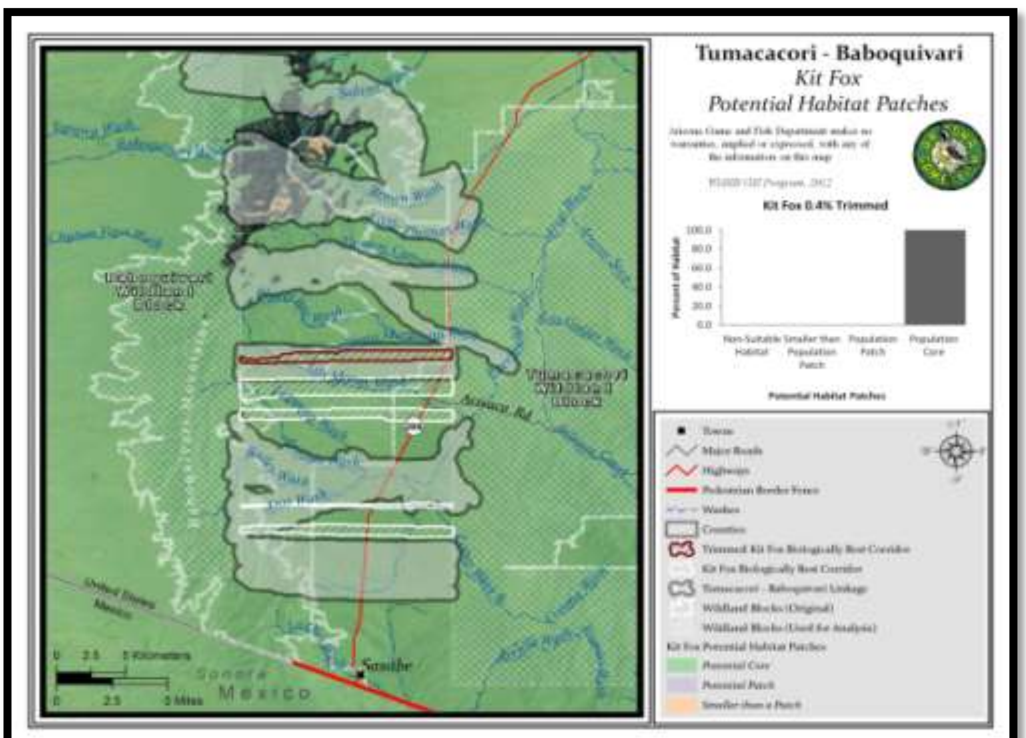

Figure 101: *Map of Tumacacori – Baboquivari potential habitat patches for kit fox*

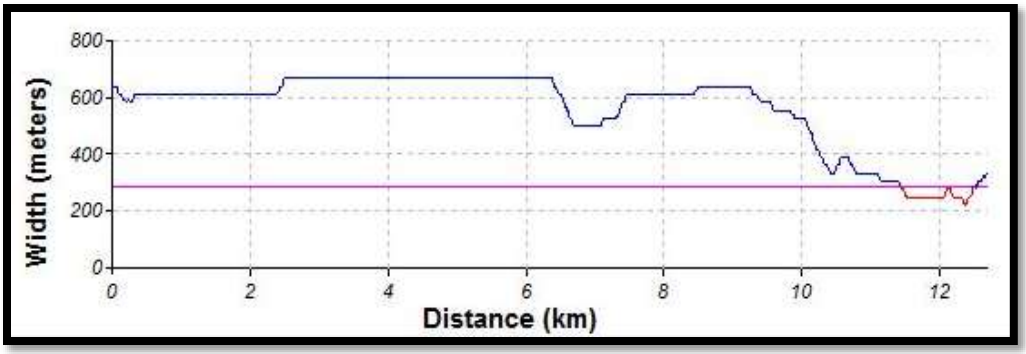

Figure 102: *Width along the Tumacacori – Baboquivari trimmed kit fox biologically best corridor*

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^2 for males and 69.9 km^2 for females (Logan and Sweanor 2001). This study also reported daily movements averaging 4.1 km for males and 1.5 km for females (Logan and Sweanor 2001). Dispersal rates for juvenile mountain lions also vary between males and females. Logan and Sweanor's study found males dispersed an average of 102.6 km from their natal sites, and females dispersed an average of 34.6 km. A mountain lion population requires 1000 - 2200 km^2 of available habitat in order to persist for 100 years (Beier 1993). These minimum areas would support about 15-20 adult cougars (Beier 1993).

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum patch size for mountain lions was defined as 79 km^2, based on an average home range estimate for a female in excellent habitat (Logan and Sweanor 2001; Dickson and Beier 2002). Minimum core size was defined as 395 km^2, or five times minimum patch size.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Mountain lion was classified as a passage species for this analysis based on large home range sizes (Logan and Sweanor 2001; Dickson and Beier 2002). The original biologically best corridor for this species used in the Tumacacori – Baboquivari linkage was trimmed to eliminate additional strands that did not benefit the habitat connectivity of other species.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for mountain lion within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 100.0, with an average suitability of 79.4 (S.D: 19.7; see *Figure 103* below). Most of the BBC (95.9%) is occupied by potential population cores (see *Figure 104* below). Most of the BBC (98.3%) was greater than its estimated needed minimum width (see *Figure 105* below). The corridor was measured at 21.0 km (13.0 mi) in length between wildland blocks used for analysis. Suitable habitat for mountain lion also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 15.4 to 82.0, with an average suitability of 59.1 (S.D: 6.0; see *Figure 106* below). Some of the trimmed BBC (52.4%) is occupied by potential population cores, with some occupied by suitable habitat smaller than a patch (5.1%), and the rest by non-suitable habitat (see *Figure 107* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 108 be*low). The trimmed corridor was measured at 12.8 km (8.0 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for mountain lion, as well as potential population cores.

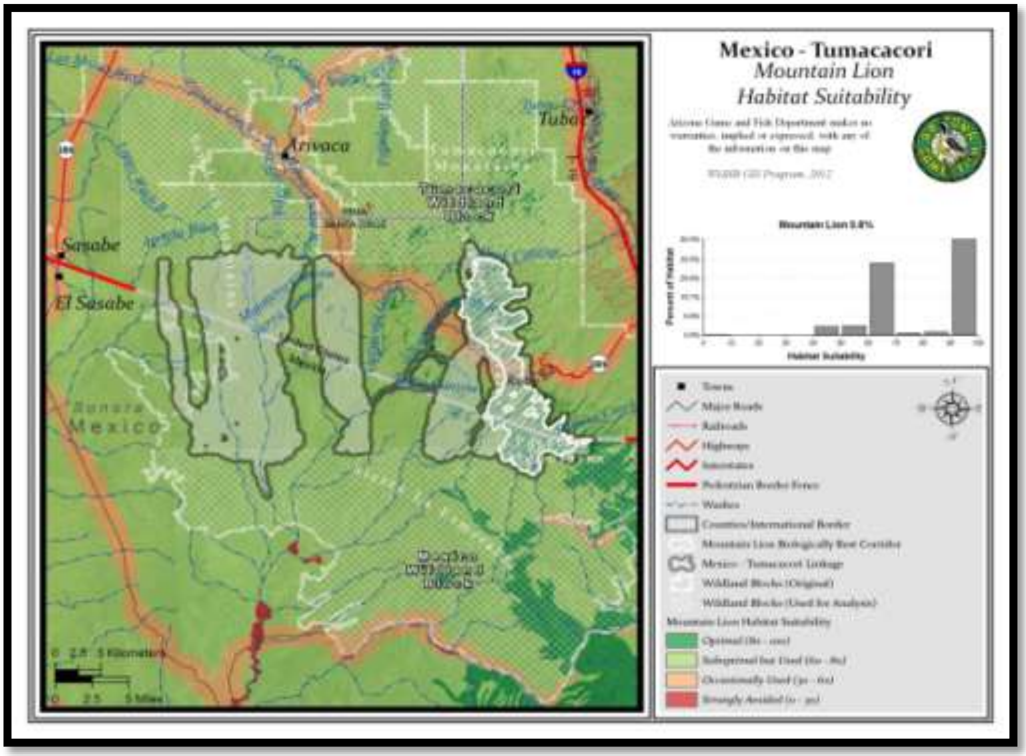

Figure 103: *Map of Mexico – Tumacacori habitat suitability for mountain lion*

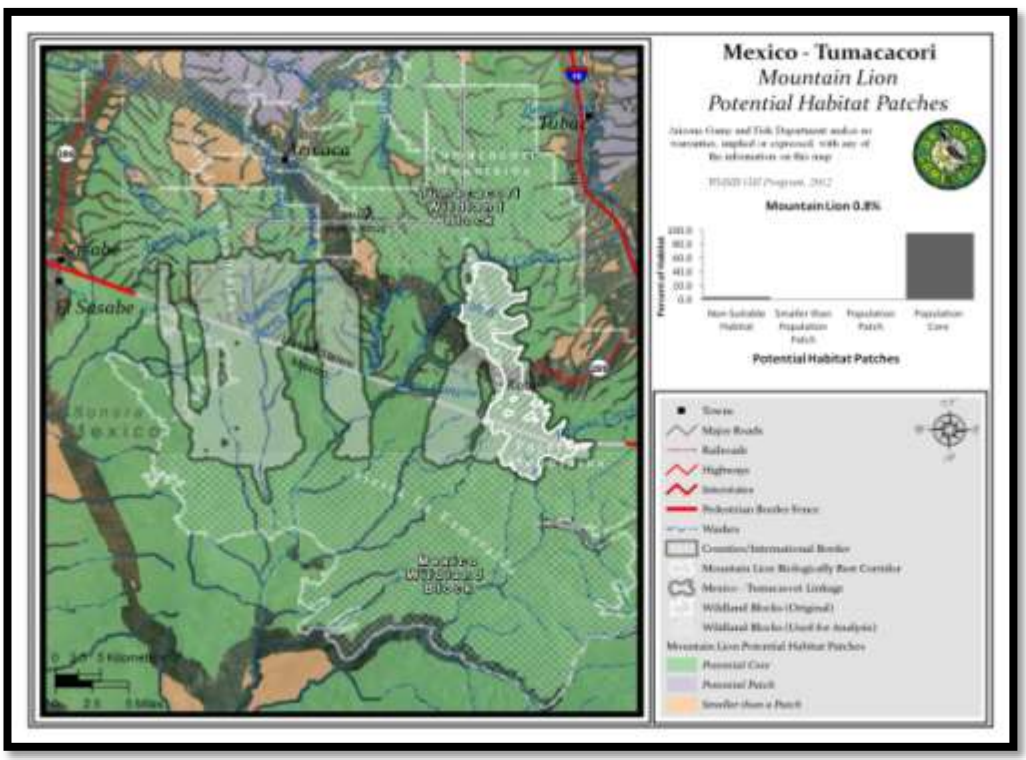

Figure 104: *Map of Mexico – Tumacacori potential habitat patches for mountain lion*

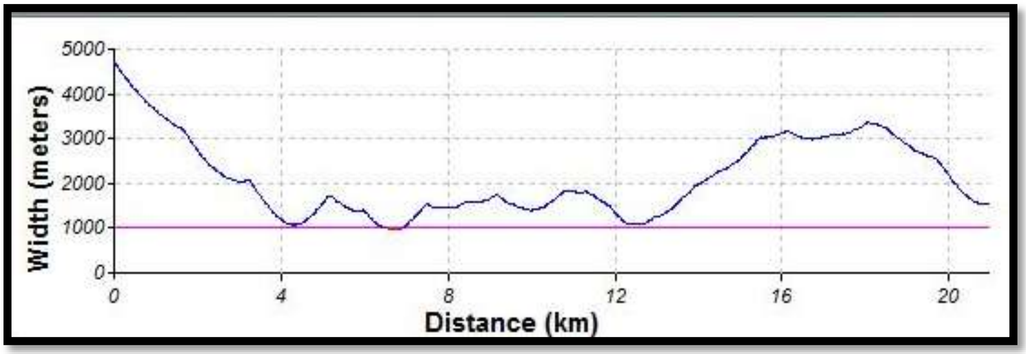

Figure 105: *Width along the Mexico – Tumacacori mountain lion biologically best corridor*

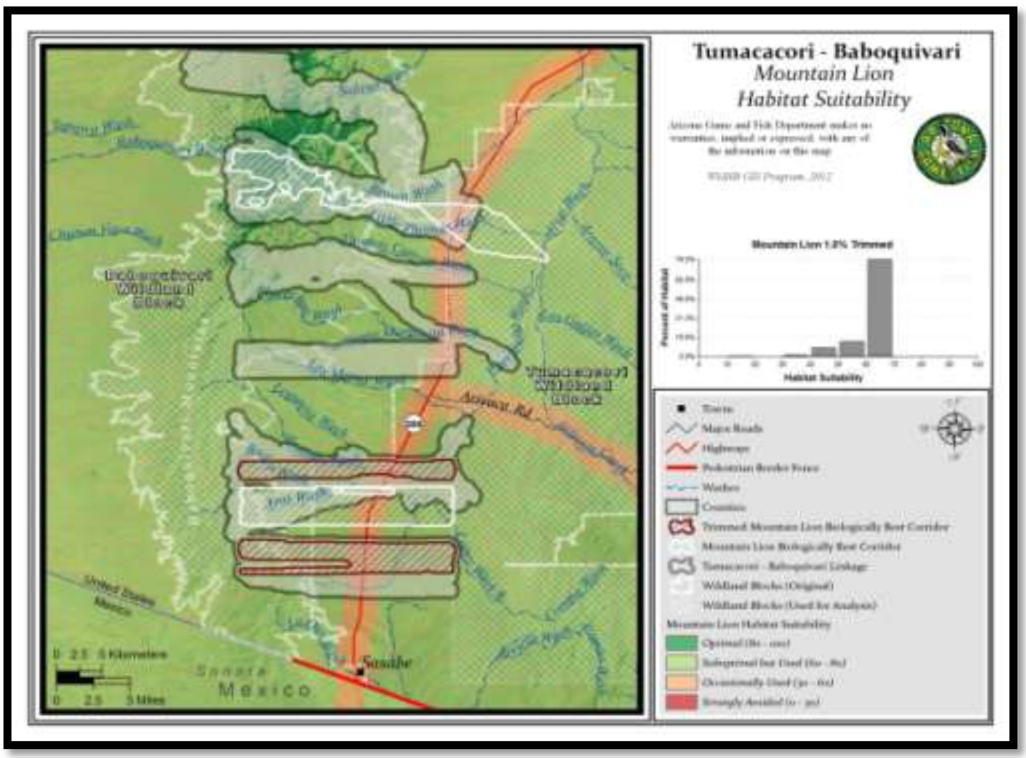

Figure 106: *Map of Tumacacori – Baboquivari habitat suitability for mountain lion*

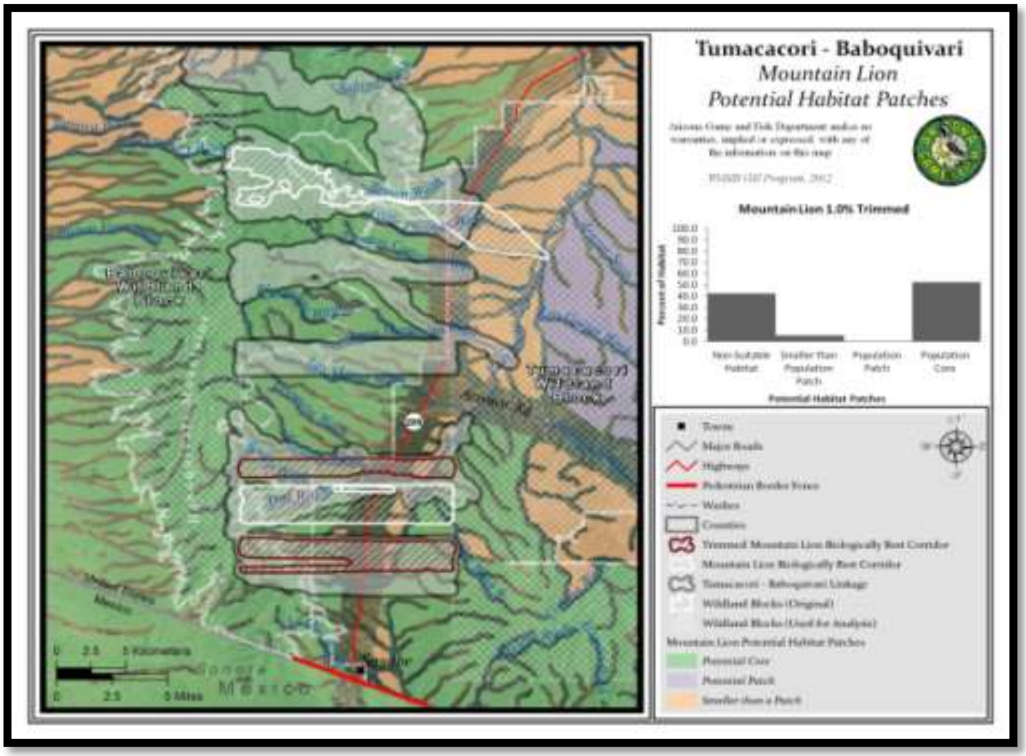

Figure 107: *Map of Tumacacori – Baboquivari potential habitat patches for mountain lion*

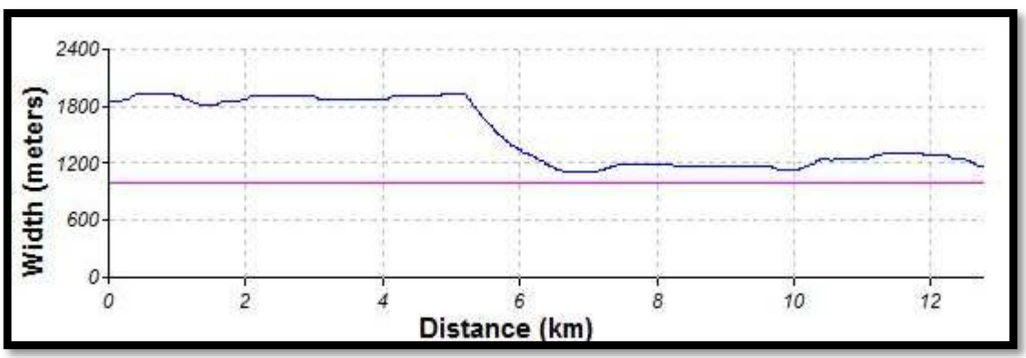

Figure 108: *Width along the Tumacacori – Baboquivari trimmed mountain lion biologically best corridor*

Mule Deer, *Odocoileus hemionus*

Justification for Selection

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

Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Mule deer was classified as a passage species for this analysis based on recorded dispersal distances (Anderson and Wallmo 1984; Scarbrough and Krausman 1988) and distance between wildland blocks. The original biologically best corridor for this species used in the Tumacacori – Baboquivari linkage was trimmed to eliminate additional strands that did not provide habitat connectivity for other focal species.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for mule deer within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 89.5, with an average suitability of 67.1 (S.D: 9.3; see *Figure 109* below). Most of the BBC (99.9%) is occupied by potential population cores (see *Figure 110* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 111* below). The trimmed corridor was measured at 19.4 km (12.1 mi) in length between wildland blocks used for analysis. Suitable habitat for mule deer also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 39.2 to 89.5, with an average suitability of 66.6 (S.D: 8.1; see *Figure 112* below). Most of the trimmed BBC (99.5%) is occupied by potential population cores (see *Figure 113* below). The majority of the trimmed BBC (80.5%) was greater than its estimated needed minimum width (see *Figure 114 below*). The trimmed corridor was measured at 13.9 km (8.6 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for mule deer, as well as potential population cores.

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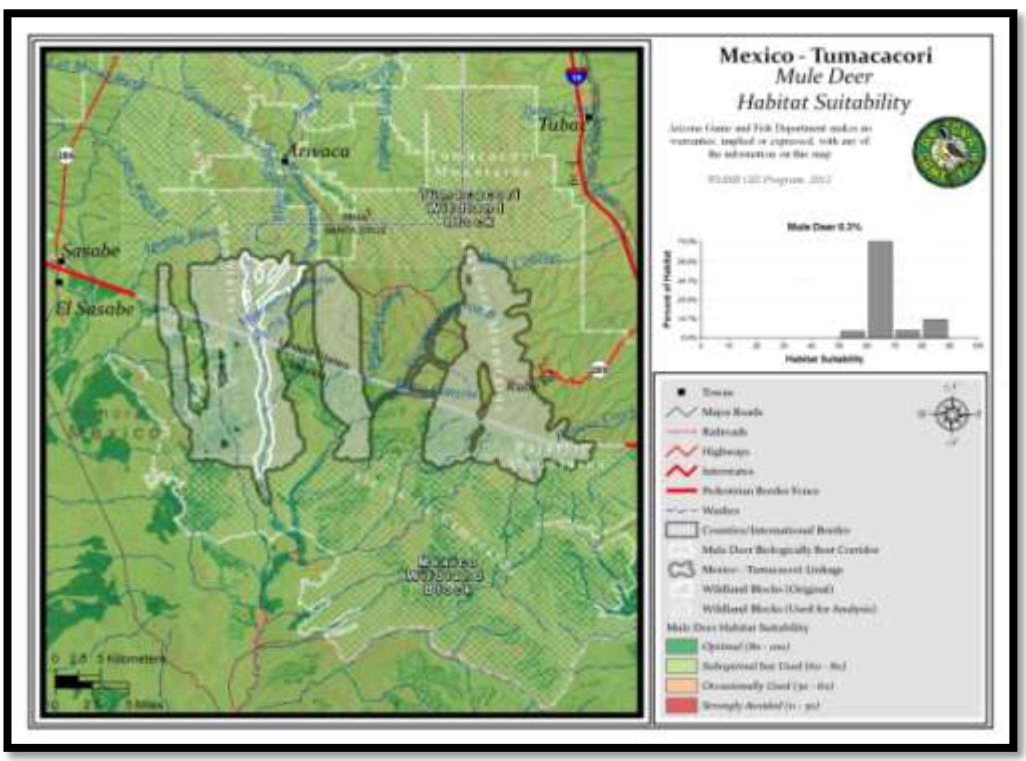

Figure 109: *Map of Mexico – Tumacacori habitat suitability for mule deer*

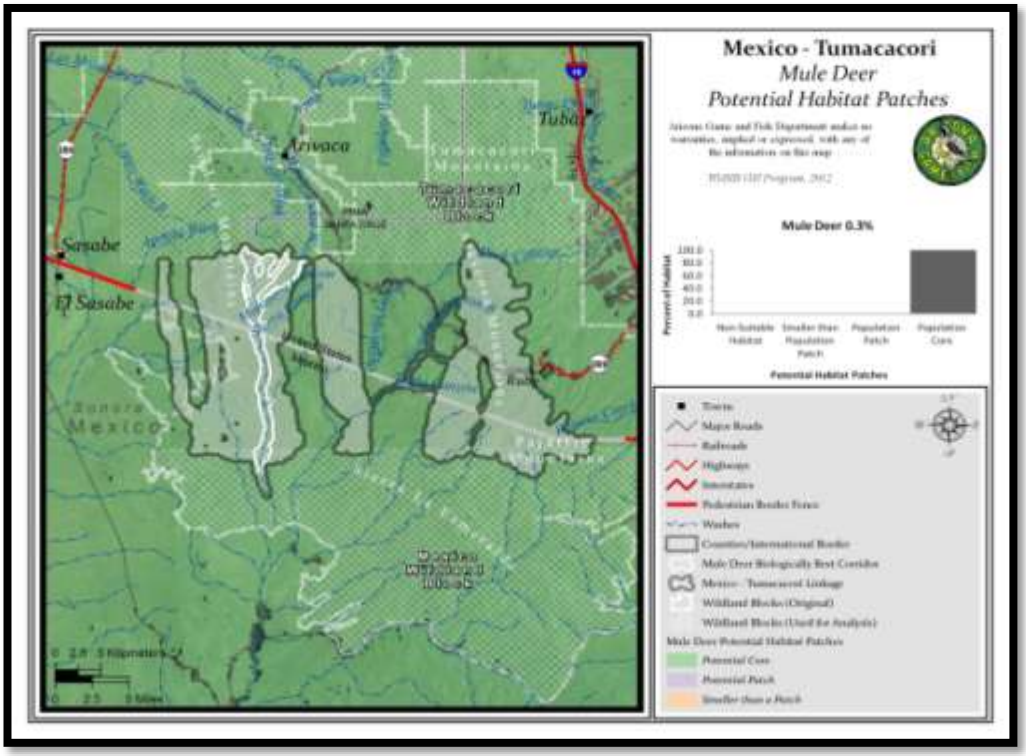

Figure 110: *Map of Mexico – Tumacacori potential habitat patches for mule deer*

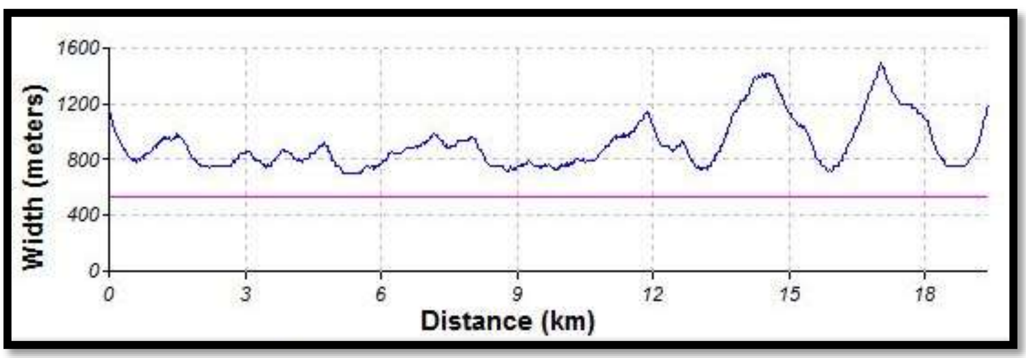

Figure 111: *Width along the Mexico – Tumacacori mule deer biologically best corridor*

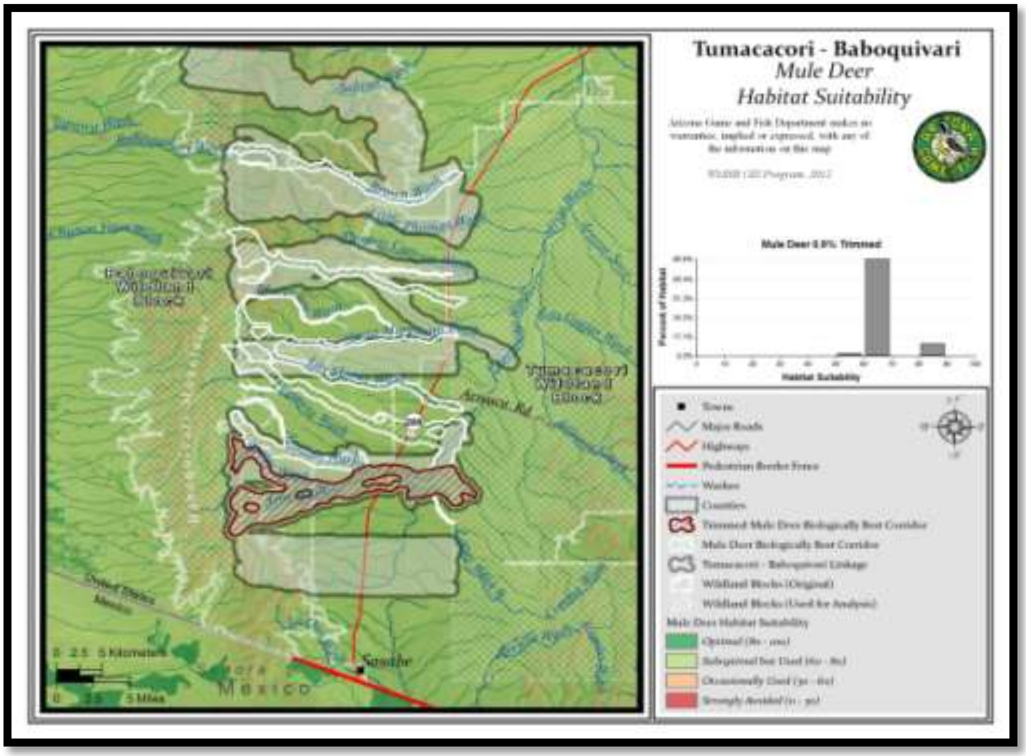

__Figure 112:__ Map of Tumacacori - Baboquivari habitat suitability for mule deer

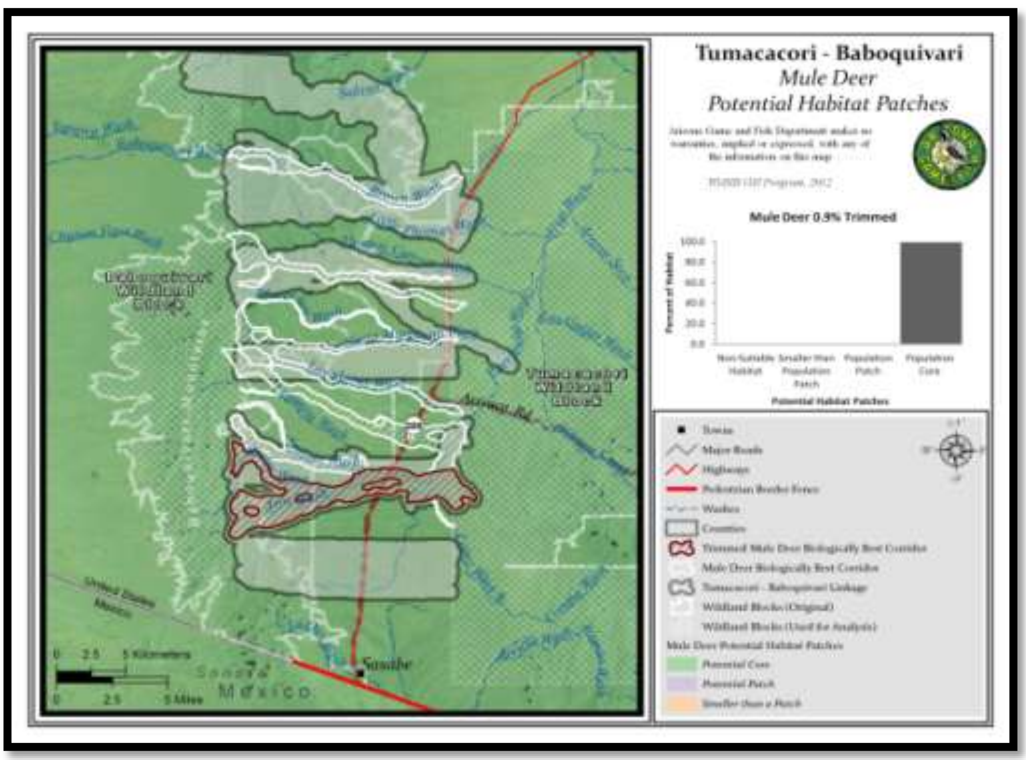

__Figure 113:__ Map of Tumacacori - Baboquivari potential habitat patches for mule deer

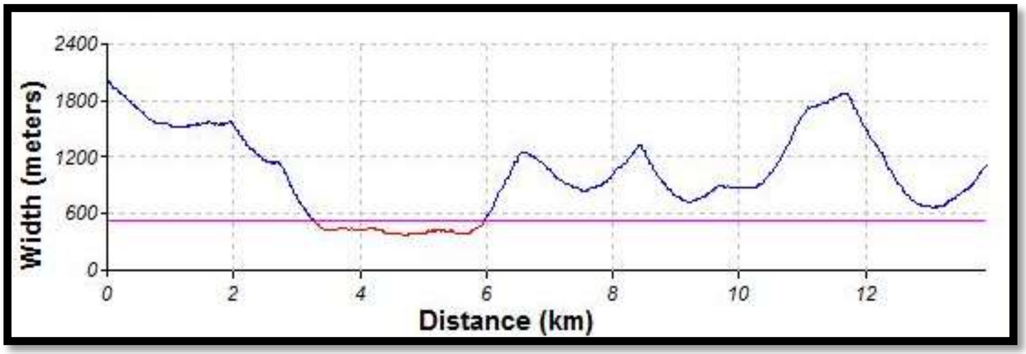

Figure 114: *Width along the Tumacacori – Baboquivari mule deer trimmed biologically best corridor*

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

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 25 ha, and minimum potential core size was defined as 100 ha (Rosen and Mauz 2001; Phil Rosen, personal comm. with CorridorDesign Team). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Although long distance movements (5 km) seem likely for Sonoran desert toad (Phil Rosen, personal comm. with CorridorDesign Team), the species was classified as a corridor dweller for this analysis due to distance between wildland blocks. Biologically best corridors were trimmed to eliminate additional strands that did not benefit habitat connectivity for other focal species.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for Sonoran desert toad within the trimmed BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 92.5, with an average suitability of 77.8 (S.D: 12.6; see *Figure 115* below). Most of the trimmed BBC (99.8%) is occupied by potential population cores (see *Figure 116* below). Most of the trimmed BBC (92.0%) was greater than its estimated needed minimum width (see *Figure 117* below). The trimmed corridor was measured at 19.1 km (11.9 mi) in length between wildland blocks used for analysis. Suitable habitat for Sonoran desert toad also exists within the trimmed BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 62.8 to 89.5, with an average suitability of 88.5 (S.D: 4.0; see *Figure 118* below). The entire trimmed BBC (100.0%) is occupied by potential population cores (see *Figure 119* below). Most of the trimmed BBC (95.9%) was greater than its estimated needed minimum width (see *Figure 120 be*low). The trimmed corridor was measured at 12.8 km (8.0 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and suboptimal but used habitat for Sonoran desert toad, as well as potential population cores.

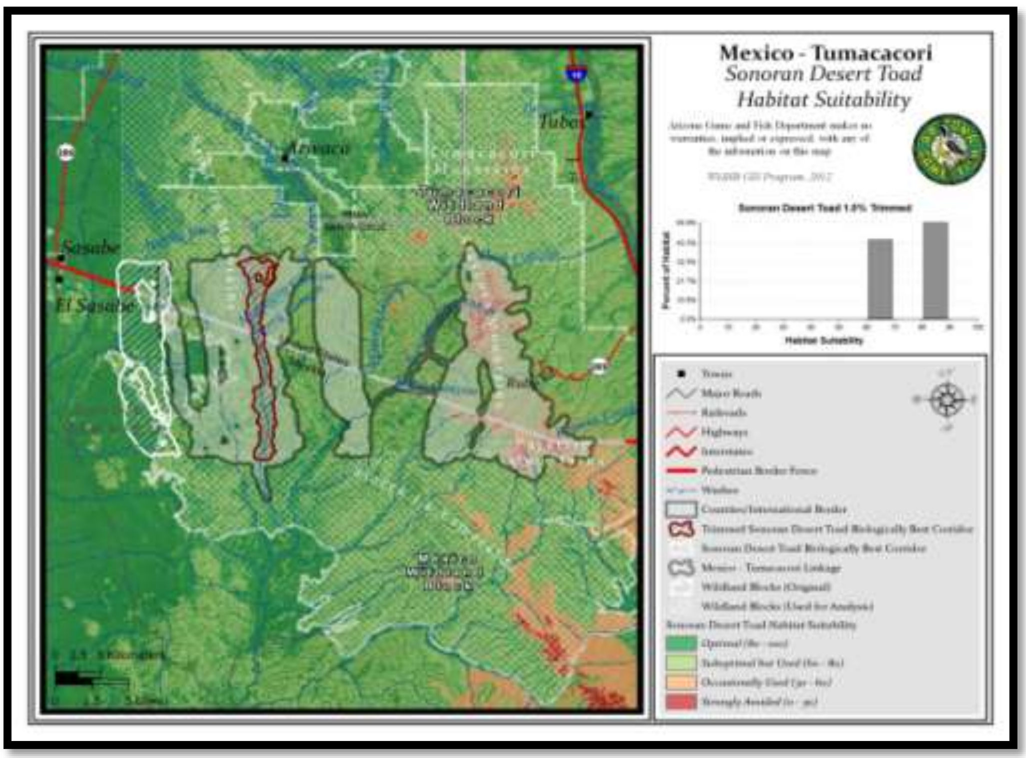

***Figure 115**: Map of Mexico – Tumacacori habitat suitability for Sonoran desert toad*

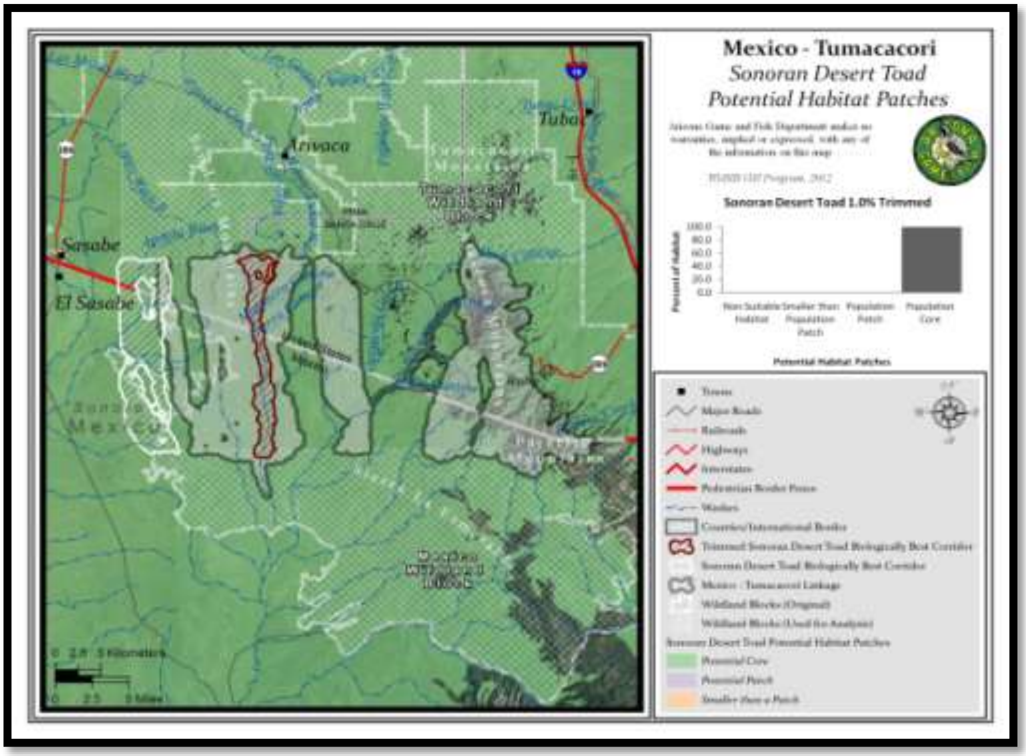

Figure 116: *Map of Mexico – Tumacacori potential habitat patches for Sonoran desert toad*

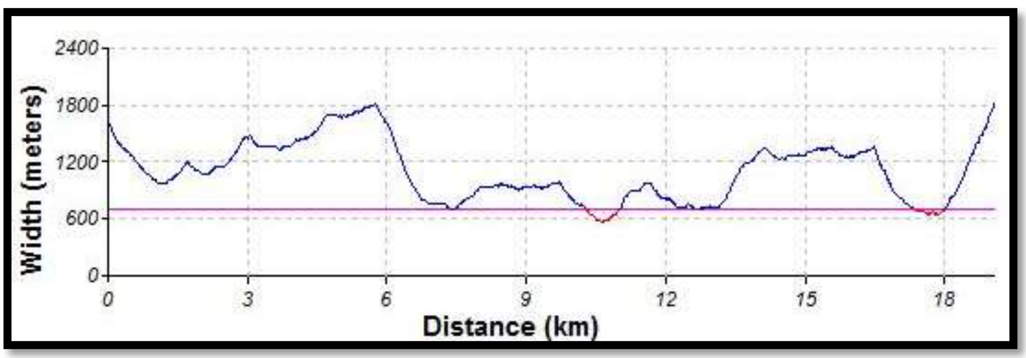

Figure 117: *Width along the Mexico – Tumacacori trimmed Sonoran desert toad biologically best corridor*

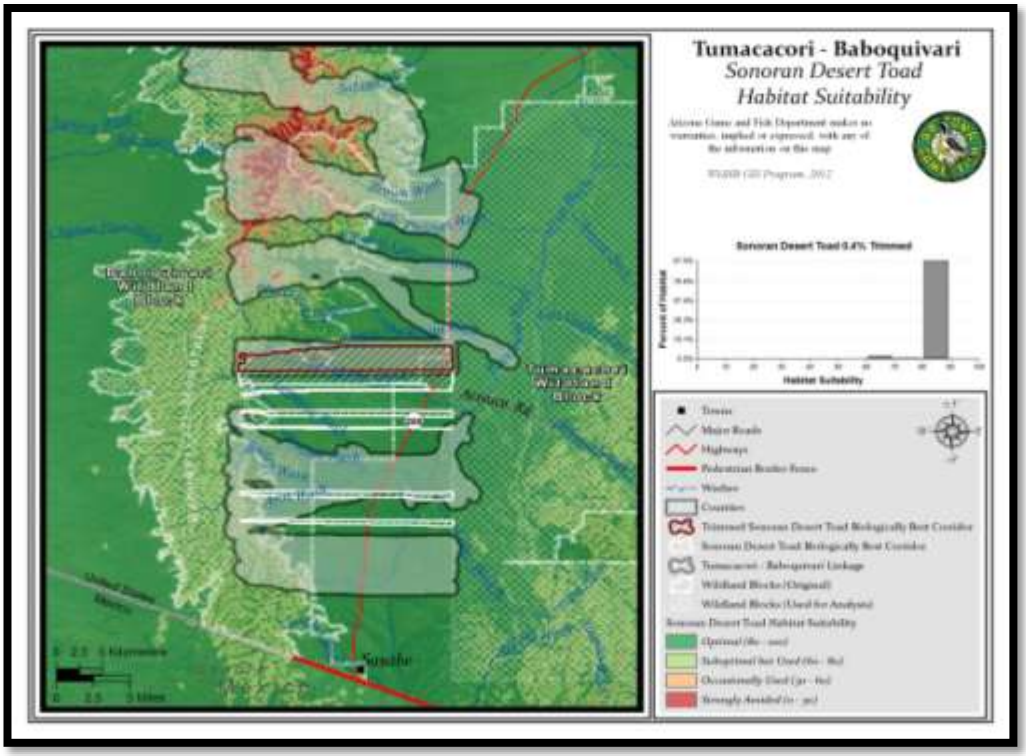

***Figure 118**: Map of Tumacacori – Baboquivari habitat suitability for Sonoran desert toad*

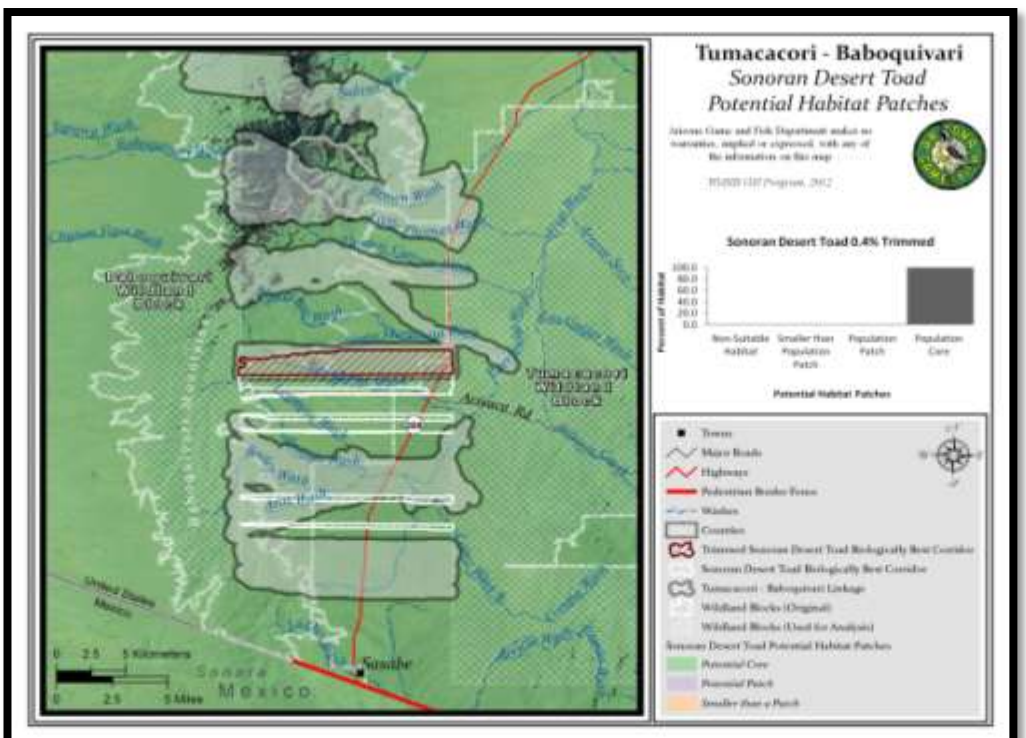

***Figure 119:** Map of Tumacacori – Baboquivari potential habitat patches for Sonoran desert toad*

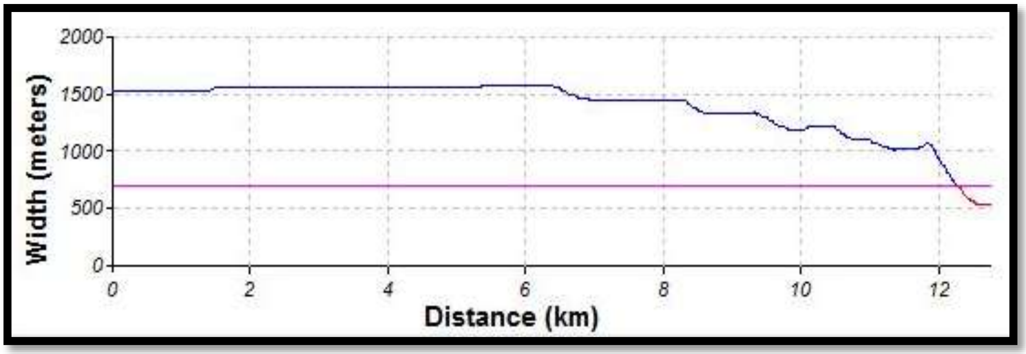

Figure 120: *Width along the Tumacacori – Baboquivari trimmed Sonoran desert toad biologically best corridor*

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

Justification for Selection

Photo courtesy Audrey Owens, AGFD

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.

Habitat Associations

Tortoises are dependent on soil type and rock formations for shelter. Typical tortoise habitat in the Sonoran Desert is rocky outcrops (Bailey et al. 1995) and bajadas. Zylstra and Steidl (2008) found that tortoises occupied east-facing slopes, and are less likely to occupy north facing slopes. However, AGFD unpublished data has found juveniles mostly on north-facing slopes, and adults on west-facing slopes. Desert tortoises also use burrows excavated into hardened caliche along incised washes (Averill-Murray et al. 2002a). Desert tortoises are obligate herbivores (Oftedal 2002) so vegetation is an important part of their habitat. However, desert tortoises also occur over a wide range of vegetation (Sinaloan thornscrub - Mojave Desert), so vegetation is therefore a variable resource. Desert tortoises eat both annual and perennial plants. Diets of Sonoran desert tortoises vary among populations in response to seasonal availability of plan species and in response to precipitation amounts (Martin and van Devender 2002). They have even been observed consuming dried plant materials during periods of drought (Averill-Murray et al. 2002b). Optimal habitat is within Arizona Upland Sonoran desert scrub and Move desert scrub, between elevations of 900 and 4,200 feet. However, there have been populations observed in an oak woodland forest at 5,200 feet in the Rincon, Atascosa and Pajarito mountains (van Devender 2002, U.S. Fish and Wildlife Service 2010a), and one in the ponderosa pine dominated coniferous community in the Rincon Mountains at 7,808 feet (Aslan et al. 2003).

Spatial Patterns

Mean home range estimates (minimum convex polygon) from 5 different studies at 6 different sites across the Sonoran Desert are between 7 and 23 ha (Averill-Murray et al. 2002b). Density of tortoise populations can range from 20 to upwards of 150 individuals per square mile (from 23 Sonoran Desert populations, Averill-Murray et al. 2002b). Desert tortoises are a long-lived species, with estimates of longevity between 60 and 100 years, and a generation time of 12 to 15 years (U.S. Fish and Wildlife Service 2010a). While long-distance movements of desert tortoises appear uncommon, but a few have been observed and are likely important for the long-term viability of populations (Edwards et al. 2004). Desert tortoises may move more than 30km during long-distance movements (Barrett et al. 1990; Averill-Murray and Klug 2000; Edwards 2003).

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Although long-distance tortoise movements may occur and are likely important for the species (Barrett et al. 1990; Averill-Murray and Klug 2000; Edwards 2003), Sonoran desert tortoise was classified as a corridor dweller in this analysis due to small home range sizes (Averill-Murray et al. 2002b).

Results and Discussion

Initial biologically best corridor – Modeling results indicate some suitable habitat for Sonoran desert tortoise within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 87.2, with an average suitability of 66.2 (S.D: 12.8; see *Figure 121* below). Most of the BBC (77.7%) is occupied by potential population cores, with the rest non-suitable habitat (see *Figure 122* below). Most of the BBC (94.4%) was greater than its estimated needed minimum width (see *Figure 123* below). The corridor was measured at 19.0 km (11.8 mi) in length between wildland blocks used for analysis. Suitable habitat for Sonoran desert tortoise also exists within the BBC used in the Tumacacori – Baboquivari linkage. Habitat suitability scores range from 19.4 to 87.2, with an average suitability of 61.0 (S.D: 13.8; see *Figure 124* below). Some of the BBC (46.5%) is occupied by potential population cores, with most of the rest non-suitable habitat (see *Figure 125* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 126 be*low). The trimmed corridor was measured at 13.9 km (8.6 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional suboptimal but used and occasionally used habitat for Sonoran desert tortoise, as well as some potential population cores.

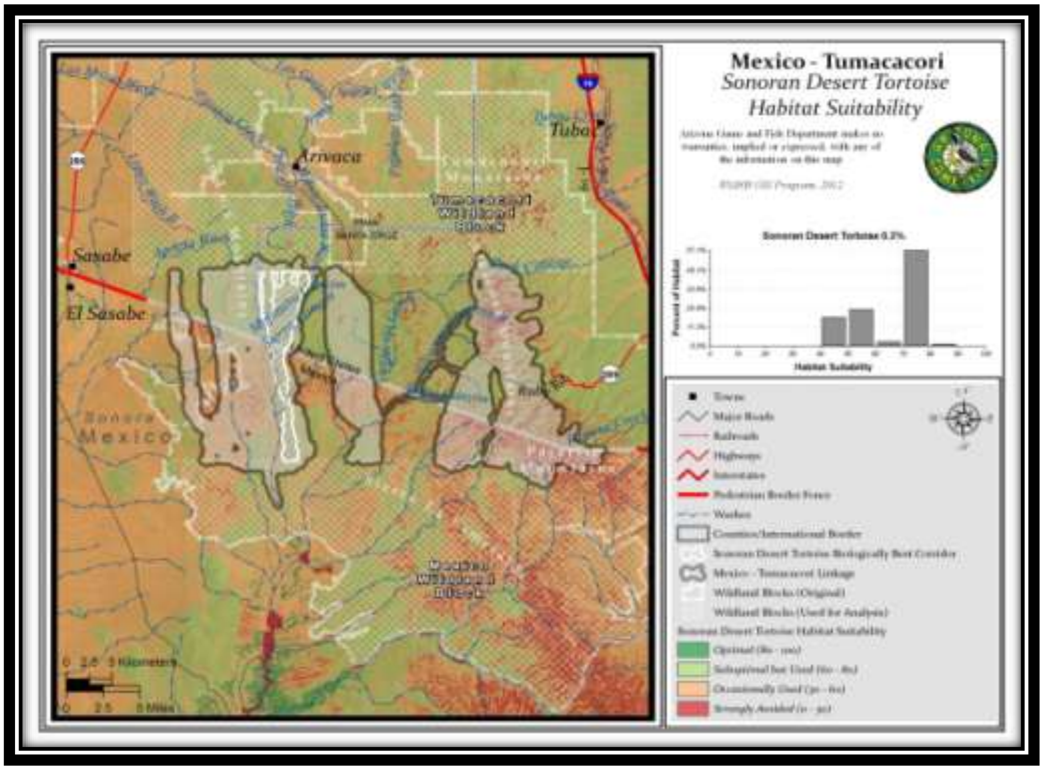

Figure 121: *Map of Mexico – Tumacacori habitat suitability for Sonoran desert tortoise*

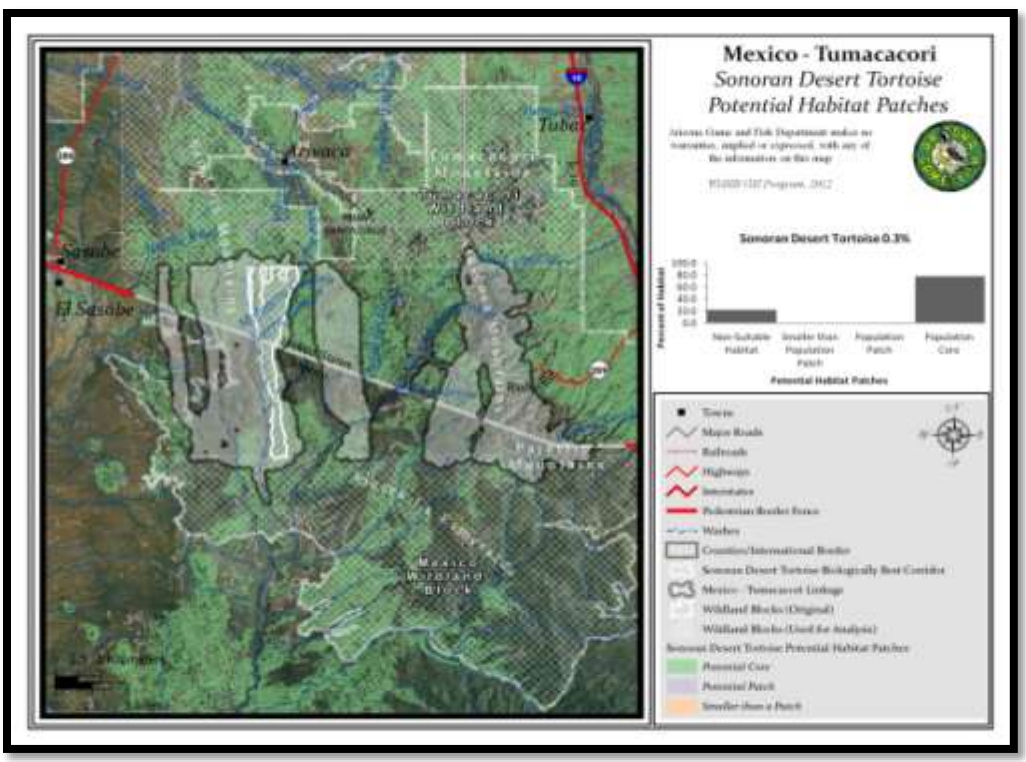

Figure 122: *Map of Mexico – Tumacacori potential habitat patches for Sonoran desert tortoise*

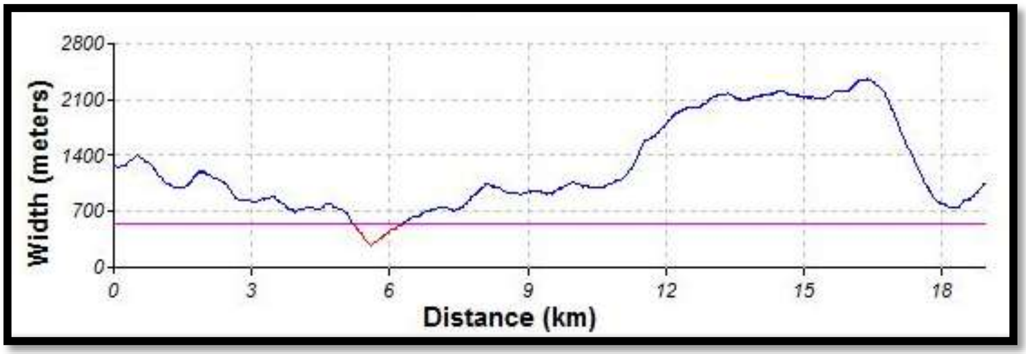

__Figure 123:__ Width along the Mexico – Tumacacori Sonoran desert tortoise biologically best corridor

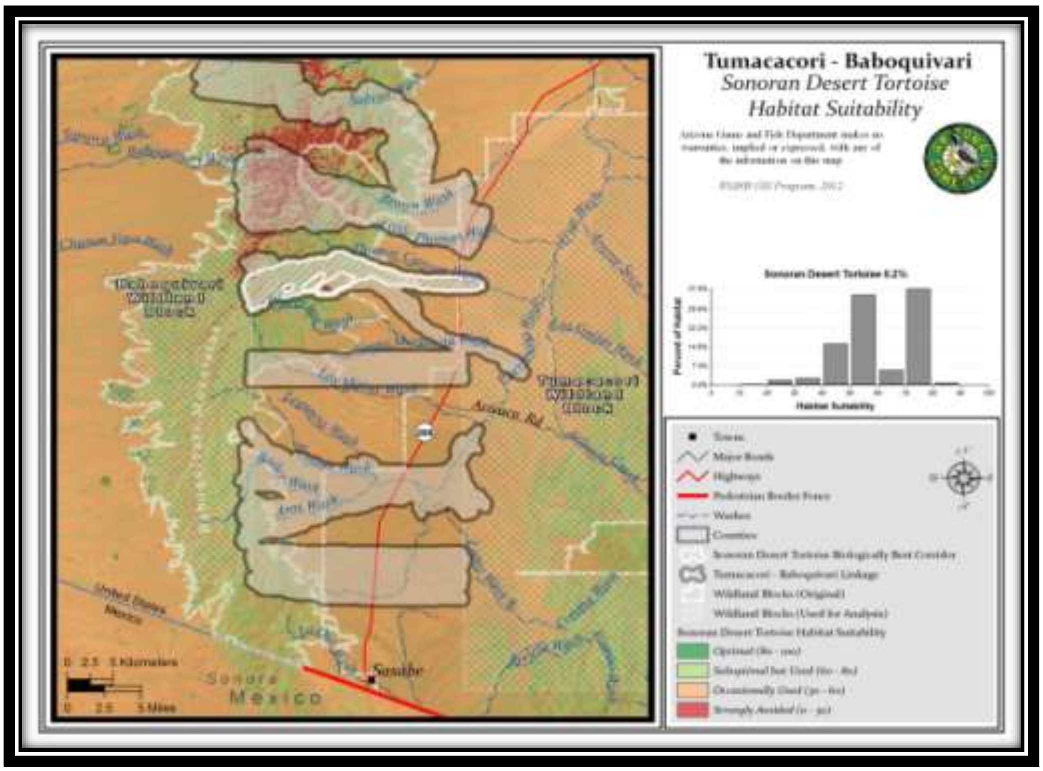

__Figure 124:__ Map of Tumacacori - Baboquivari habitat suitability for Sonoran desert tortoise

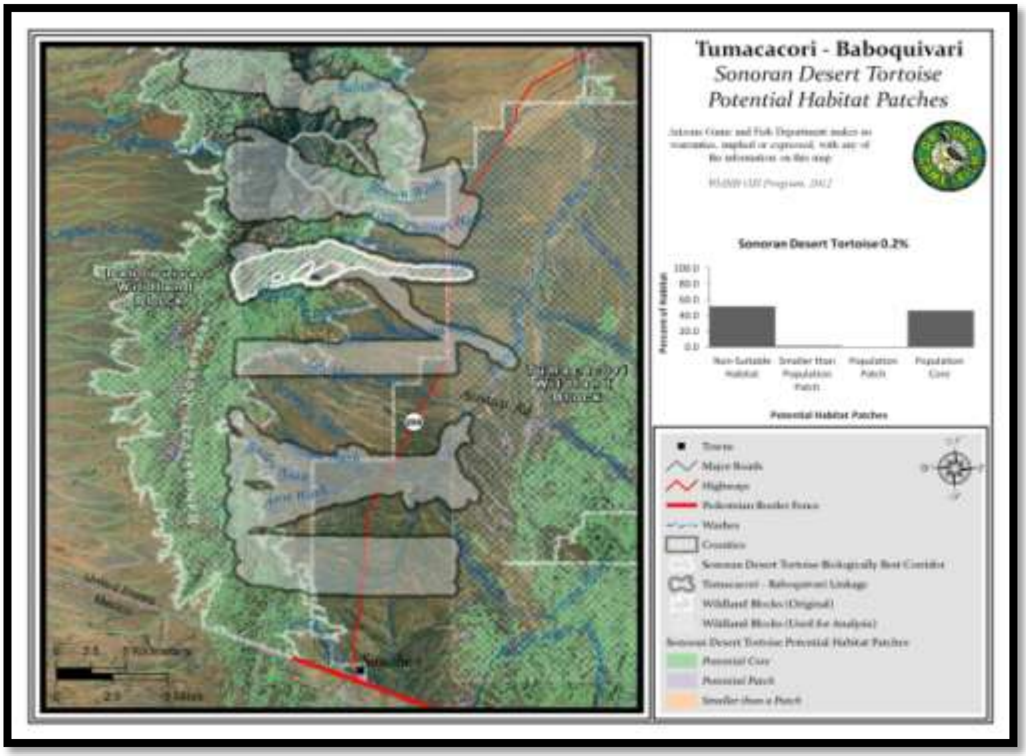

Figure 125: *Map of Tumacacori - Baboquivari potential habitat patches for Sonoran desert tortoise*

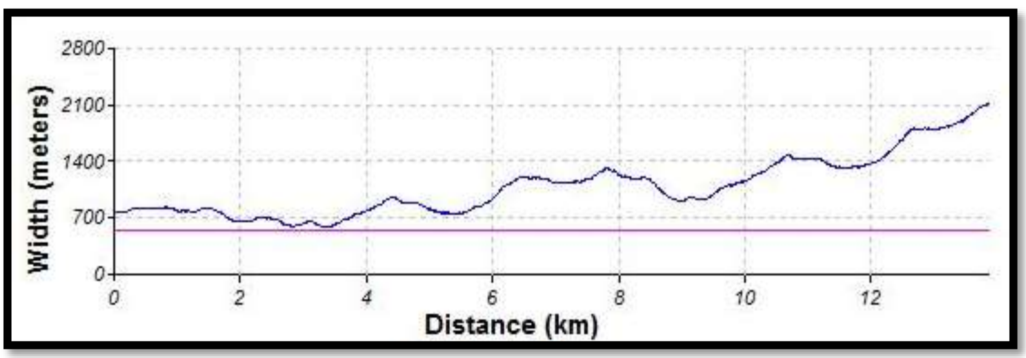

Figure 126: *Width along the Tumacacori – Baboquivari Sonoran desert tortoise biologically best corridor*

Sonoran Whipsnake, *Masticophis bilineatus*

Justification for Selection

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

Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 10%, 45%, and 15%, respectively. For specific scores of classes within each of these factors, see *Table 5*.

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 50 ha, and minimum potential core size was defined as 250 ha (Phil Rosen, personal comm. with CorridorDesign Team). To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 3x3 neighborhood moving window analysis.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Sonoran whipsnake was classified as a corridor dweller based on length of assumed movement events (Phil Rosen, personal comm. with CorridorDesign Team). The original biologically best corridor for this species was trimmed to eliminate additional strands in the Mexico – Tumacacori linkage that did little to provide habitat connectivity for other focal species. A biologically best corridor was also not included in the Tumacacori – Baboquivari due to its length and similar habitat in other portions of the linkage design.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for Sonoran whipsnake within the trimmed BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 96.6, with an average suitability of 88.1 (S.D: 14.1; see *Figure 127* below). Most of the trimmed BBC (96.9%) is occupied by potential population cores (see *Figure 128* below). Most of the trimmed BBC (85.5%) was greater than its estimated needed minimum width (see *Figure 129* below). The trimmed corridor was measured at 21.1 km (13.1 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional optimal and occasionally used habitat for Sonoran whipsnake, as well as potential population cores in steeper terrain. This is especially true in the Tumacacori – Baboquivari linkage, which captures optimal habitat and potential population cores in the Tumacacori Highlands and Baboquivari Mountains (see *Figure 130* and *Figure 131* below).

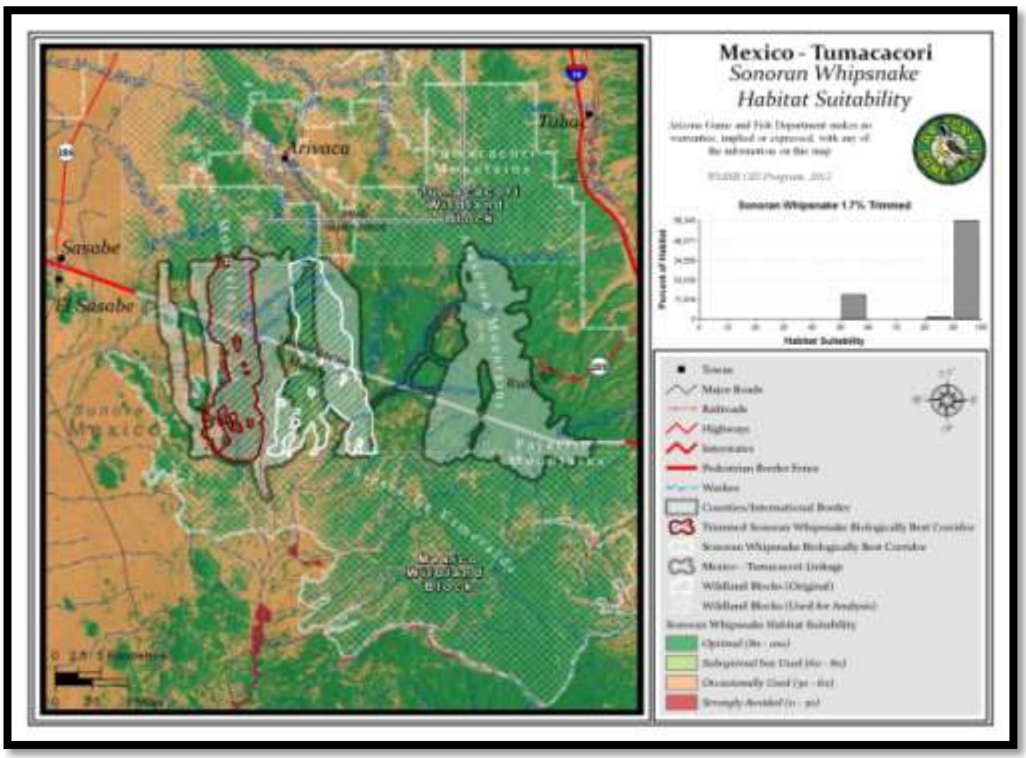

Figure 127: *Map of Mexico – Tumacacori habitat suitability for Sonoran whipsnake*

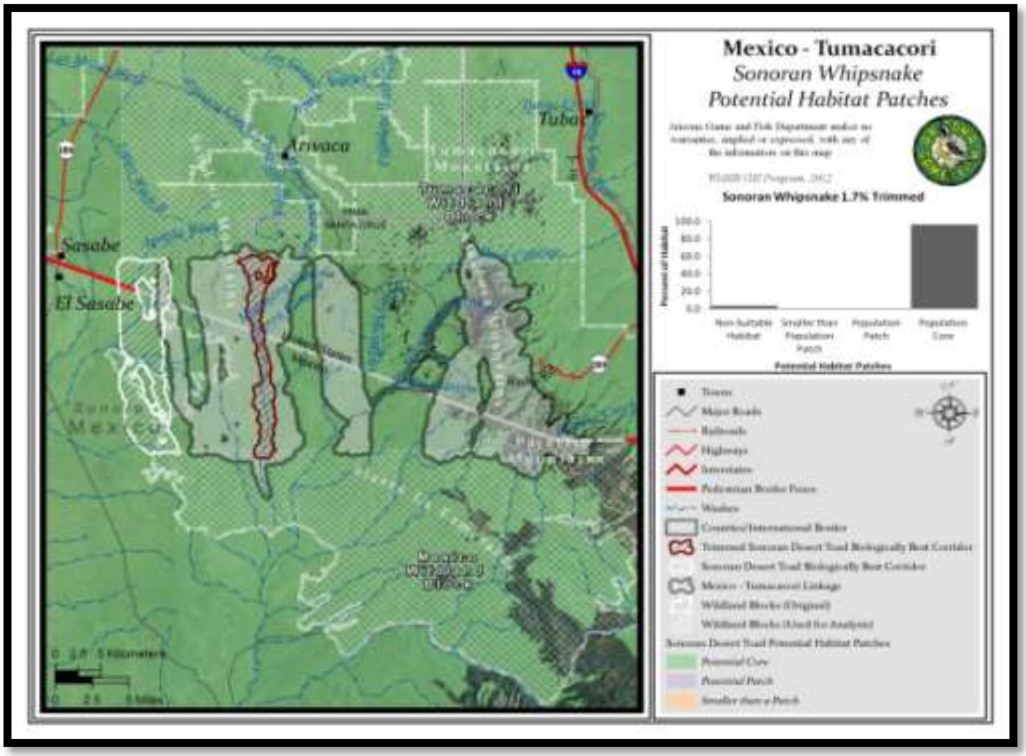

Figure 128: *Map of Mexico – Tumacacori potential habitat patches for Sonoran whipsnake*

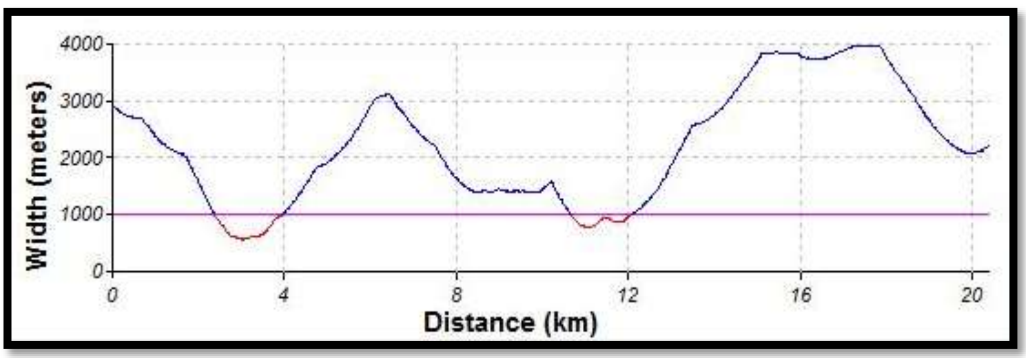

Figure 129: *Width along the Mexico – Tumacacori trimmed Sonoran whipsnake biologically best corridor*

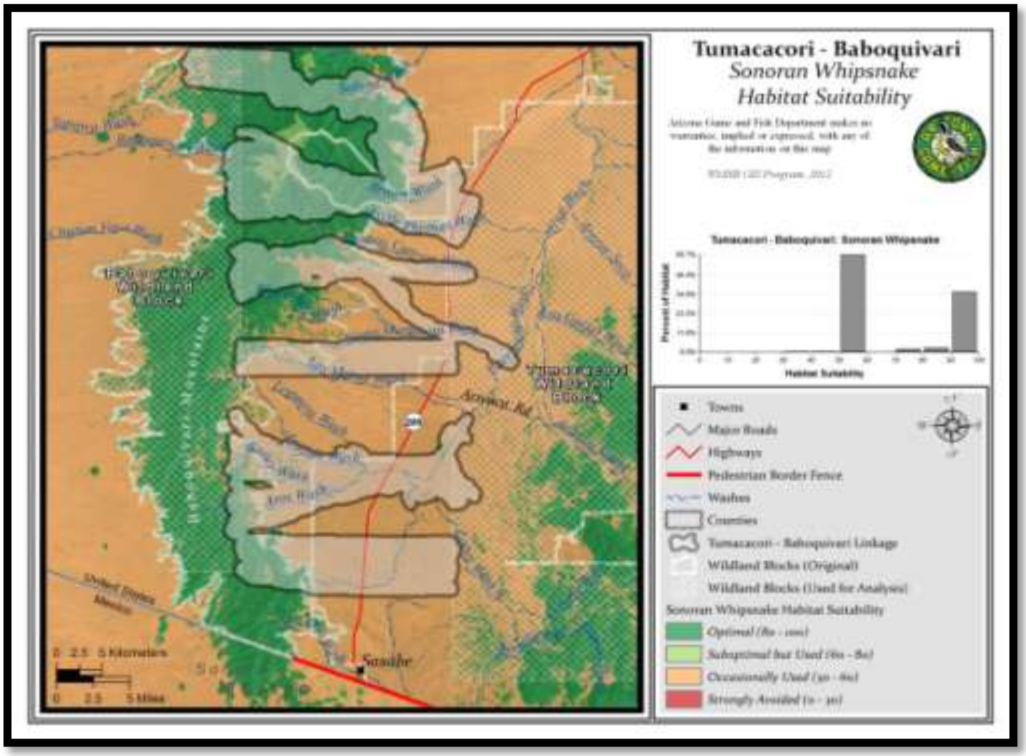

Figure 130: *Map of Tumacacori – Baboquivari habitat suitability for Sonoran whipsnake*

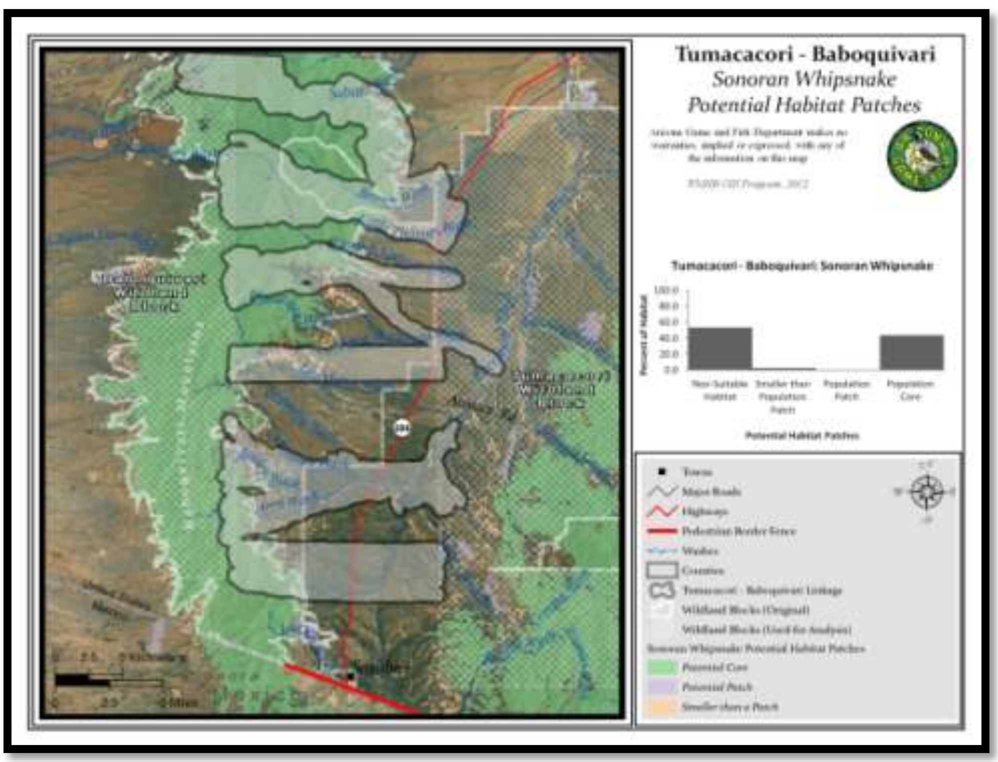

Figure 131: *Map of Tumacacori – Baboquivari potential habitat patches for Sonoran whipsnake*

White-nosed Coati, *Nassau maraca*

Justification for Selection

White-nosed coatis are primarily forest species, and may serve as prey for top carnivores such as mountain lion (New Mexico Game and Fish Department 2004). They also appear to be dispersal-limited, and sensitive to roads and habitat fragmentation.

Photo courtesy George Andrejko, AGFD

Distribution

White-nosed coatis are found in southern Arizona and New Mexico, and Texas, and throughout Mexico and Central America (Gompers 1995). In Arizona, coatis are found as far north as the Gila River, and throughout southeastern Arizonan forests.

Habitat Associations

Coatis are primarily a forest species, preferring shrubby and woodland habitats with good horizontal cover (Gompers 1995; C. Hass, personal comm.). While they do not have strong topographic preferences, they are generally found within several miles of water, and prefer riparian habitats if available (Gompers 1995). In Arizona, elevation places no constraints on habitat use, as this species are found from sea level to mountains exceeding 10,000 feet. While they are not a desert species, coatis will move through desert scrub and shrublands when moving between forested areas (Hoffmeister 1986).

Spatial Patterns

Female coatis and their yearlings (both sexes) live in groups of up 25 individuals, while males are solitary most of the year (Hoffmeister 1986). In southeastern Arizona, average home range of coati troops was calculated as 13.57 km^2 (Hass 2002). Home ranges of males overlapped other males up to 61% and overlapped troops up to 67%, while home ranges of troops overlapped each other up to 80% (Hass 2002). Virtually nothing is known about dispersal distance in coatis, and radioed animals have not dispersed more than a few kilometers (Christine Hass, personal comm.). Females are philopatric, but males have been observed at large distances from known coati habitat, and tend to get hit by cars. While successful dispersal of any distance is unknown, it is thought that males may disperse up to 5 km (Christine Hass, personal comm. with CorridorDesign Team).

Conceptual Basis for Model Development

Habitat suitability model – Due to this species' strong vegetation preferences, vegetation received an importance weight of 95%, while distance from roads received a weight of 5%. For specific scores of classes within each of these factors, see *Table 5*. 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.

Patch size and configuration analysis – Minimum potential habitat patch size was defined as 13.6 km2, the average home range observed in southeastern Arizona by Hass (2002). Minimum potential habitat core size was defined as 68 km2, or five times minimum patch size. To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the large spatial requirements for coati groups.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. White-nosed coati was classified as a passage species based on large home range size (Hass 2002). However, a biologically best corridor for white-nosed coati was not included in the Tumacacori – Baboquivari linkage, due to distances between potential population cores and patches.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for white-nosed coati within the BBC used in the Mexico – Tumacacori linkage. Habitat suitability scores range from 0.0 to 92.4, with an average suitability of 71.8 (S.D: 21.8; see *Figure 132* below). Some of the BBC (63.2%) is occupied by potential habitat patches, with some (15.4%) occupied by suitable habitat smaller than a patch, and the rest non-suitable habitat (see *Figure 133* below). Most of the trimmed BBC (90.3%) was greater than its estimated needed minimum width (see *Figure 134* below). The corridor was measured at 23.2 km (14.4 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional occasional use habitat for white-nosed coati. The northern portion of the Tumacacori – Baboquivari linkage captures additional optimal habitat and potential habitat patches (See *Figure 135* and *Figure 136* below).

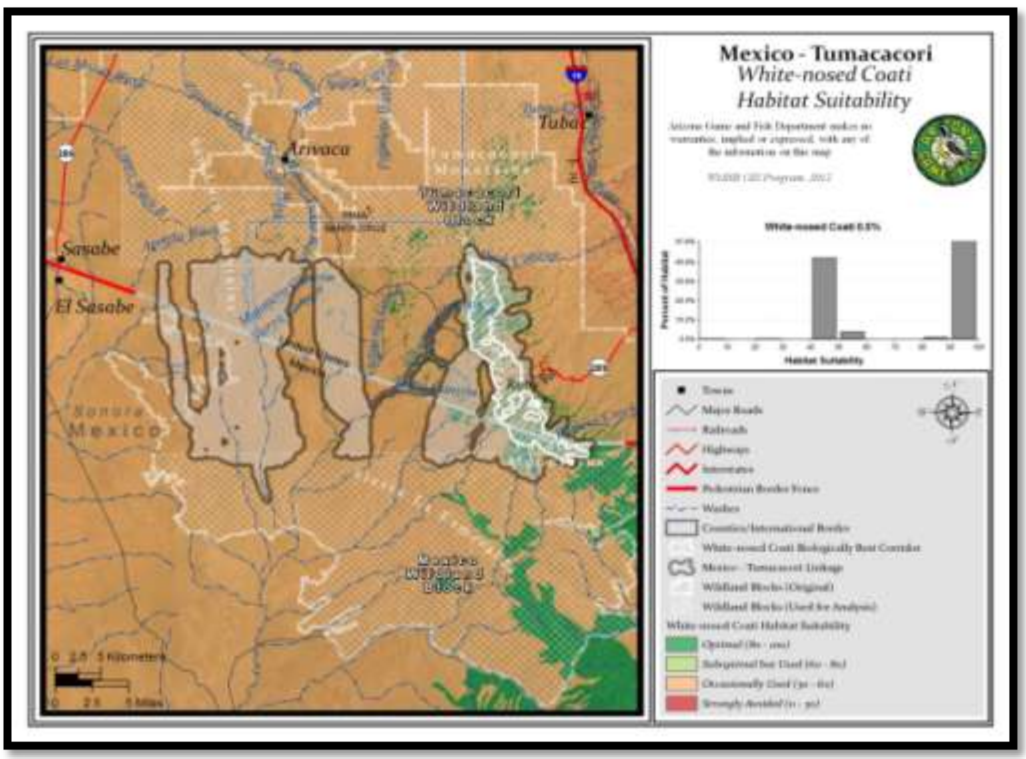

Figure 132: *Map of Mexico – Tumacacori habitat suitability for white-nosed coati*

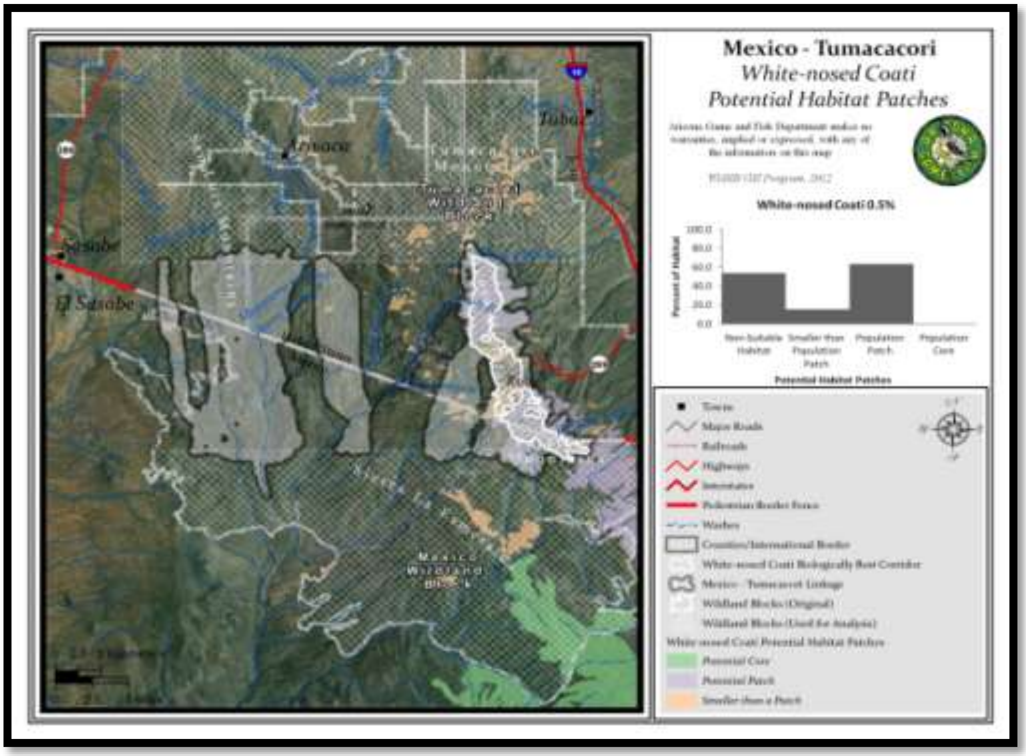

Figure 133: *Map of Mexico – Tumacacori potential habitat patches for white-nosed coati*

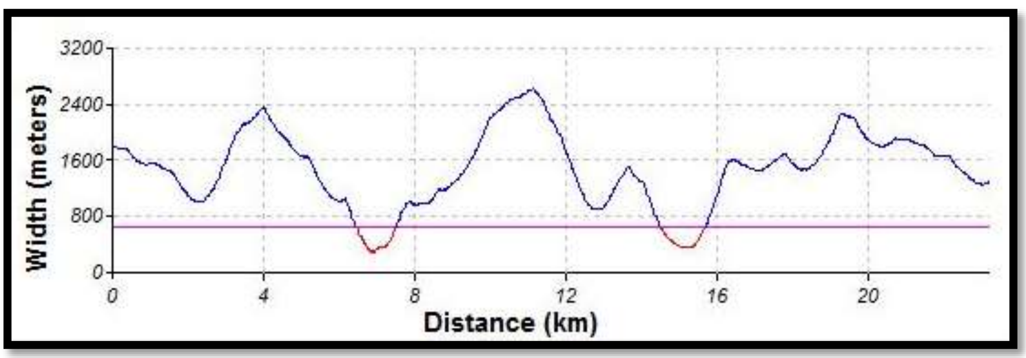

Figure 134: *Width along the Mexico – Tumacacori white-nosed coati biologically best corridor*

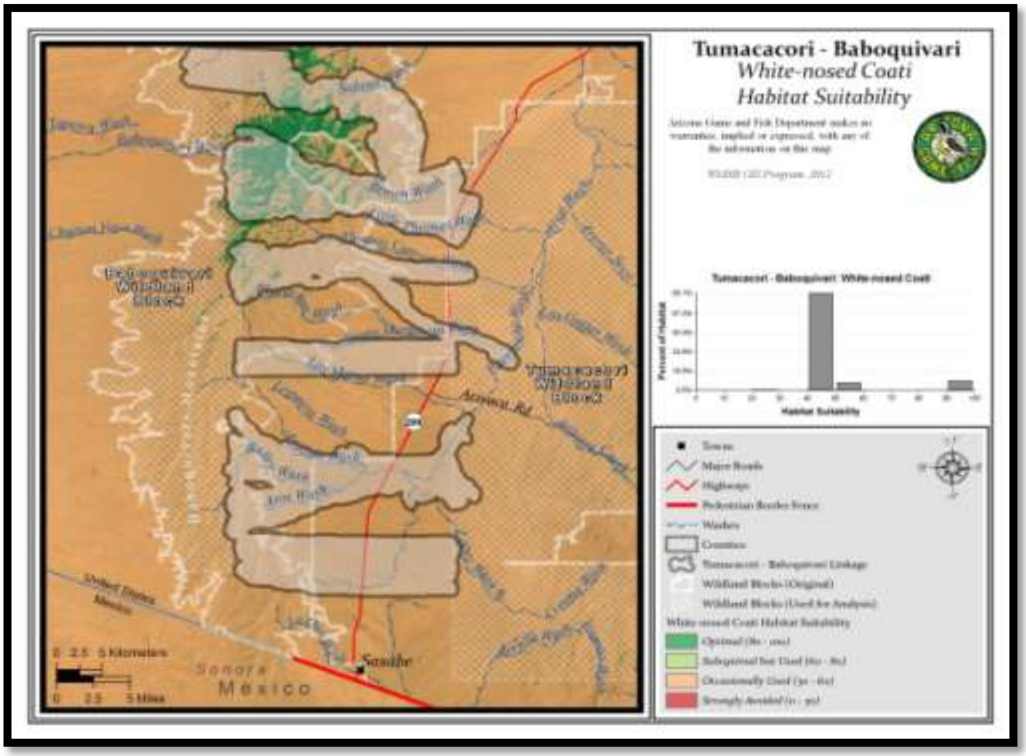

Figure 135: *Map of Tumacacori – Baboquivari habitat suitability for white-nosed coati*

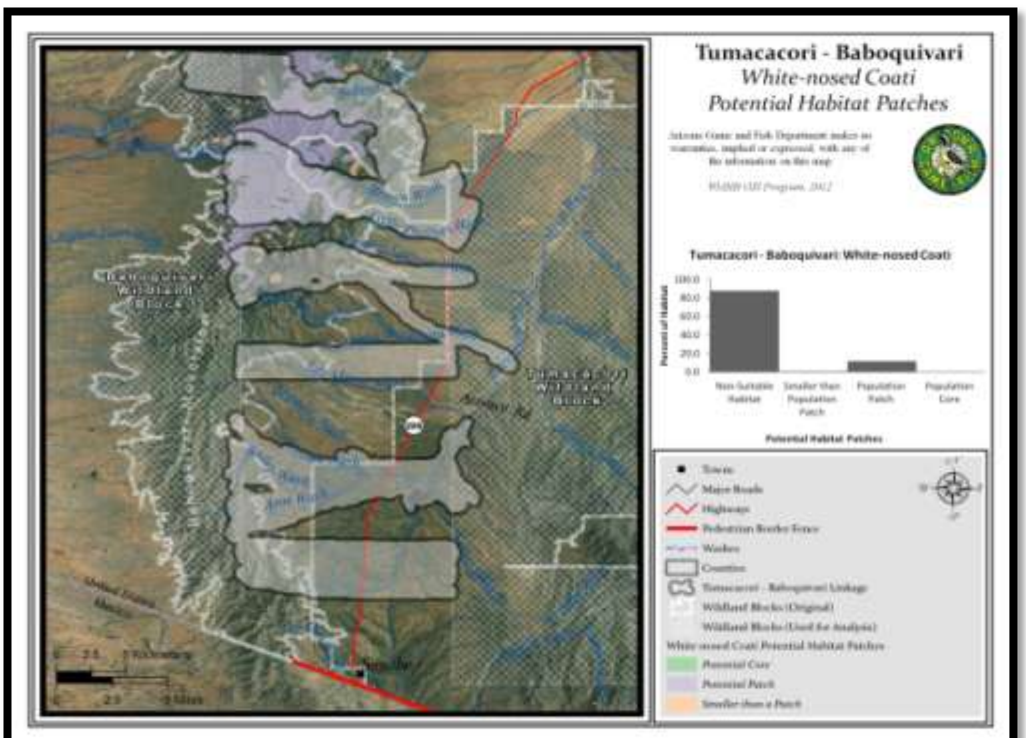

Figure 136: *Map of Tumacacori – Baboquivari potential habitat patches for white-nosed coati*

Appendix D: Species Occurrence in the Linkage Design

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

Table 6: *Species occurrence in the linkage design as identified through Arizona Heritage Data Management System element occurrence data*

Taxanomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Amphibian	Chiricahua Leopard Frog	*Lithobates chiricahuensis*	LT			WSC	Yes	Yes
Amphibian	Lowland Leopard Frog	*Rana yavapaiensis*	SC	S	S	WSC	Yes	Yes
Amphibian	Western Barking Frog	*Craugastor augusti cactorum*		S		WSC		
Amphibian	Western Narrow-mouthed Toad	*Gastrophryne olivacea*		S	S	WSC		
Bird	American Peregrine Falcon	*Falco peregrinus anatum*	SC	S	S	WSC		
Bird	Arizona grasshopper sparrow	*Ammodramus savannarum ammolegus*		S	S			
Bird	Azure Bluebird	*Sialia sialis fulva*						
Bird	Baird's Sparrow	*Ammodramus bairdii*	SC	S		WSC		
Bird	Buff-collared Nightjar	*Caprimulgus ridgwayi*		S				
Bird	Cactus Ferruginous Pygmy-owl	*Glaucidium brasilianum cactorum*	SC	S	S	WSC		Yes
Bird	Elegant Trogon	*Trogon elegans*				WSC		
Bird	Five-striped Sparrow	*Amphispiza quinquestriata*						
Bird	Golden Eagle	*Aquila chrysaetos*			S			
Bird	Long-eared Owl	*Asio otus*						
Bird	Masked Bobwhite	*Colinus virginianus ridgwayi*	LE			WSC		Yes
Bird	Mexican Spotted Owl	*Strix occidentalis lucida*	LT			WSC		Yes
Bird	Northern Beardless-Tyrannulet	*Camptostoma imberbe*		S				
Bird	Northern Gray Hawk	*Buteo nitidus maxima*	SC	S		WSC		
Bird	Rose-throated Becard	*Pachyramphus aglaiae*		S		WSC		
Bird	Rufous-winged Sparrow	*Peucaea carpalis*						Yes
Bird	Swainson's Hawk	*Buteo swainsoni*		S				Yes
Bird	Thick-billed Kingbird	*Tyrannus crassirostris*		S		WSC		
Bird	Yellow-billed Cuckoo (Western U.S. DPS)	*Coccyzus americanus*	PS:C	S		WSC		Yes

Taxonomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Bird	Zone-tailed Hawk	*Buteo albonotatus*		S				
Fish	Sonora Chub	*Gila ditaenia*	LT			WSC		
Invertebrate	Arizona Metalmark	*Calephelis arizonensis*						
Invertebrate	Baboquivari Talussnail	*Sonorella baboquivariensis*						Yes
Invertebrate	Evening Talussnail	*Sonorella vespertina*						Yes
Invertebrate	Sabino Canyon Dancer	*Argia sabino*	SC	S				
Mammal	Cave Myotis	*Myotis velifer*	SC		S			
Mammal	Hog-nosed Skunk	*Conepatus leuconotus leuconotus*						
Mammal	Jaguar	*Panthera onca*	LE			WSC	Yes	Yes
Mammal	Mexican Long-tongued Bat	*Choeronycteris mexicana*	SC	S	S	WSC		Yes
Mammal	Mexican Opossum	*Didelphis virginiana californica*						
Mammal	Pale Townsend's Big-eared Bat	*Corynorhinus townsendii pallescens*	SC	S	S			Yes
Mammal	Pocketed Free-tailed Bat	*Nyctinomops femorosaccus*		S				
Mammal	Underwood's Bonneted Bat	*Eumops underwoodi*	SC					
Mammal	Yellow-nosed Cotton Rat	*Sigmodon ochrognathus*	SC	S				
Mammal		*Bat Colony*						
Plant	Alamos Deer Vetch	*Lotus alamosanus*		S				
Plant	Arid Throne Fleabane	*Erigeron arisolius*		S				
Plant	Arizona Giant Sedge	*Carex ultra*		S	S			
Plant	Arizona Manihot	*Manihot davisiae*		S				
Plant	Arizona Passionflower	*Passiflora arizonica*		S				
Plant	Baboquivari Giant Hyssop	*Agastache rupestris*						
Plant	Ball Moss	*Tillandsia recurvata*						
Plant	Bartram Stonecrop	*Graptopetalum bartramii*	SC	S	S	SR		
Plant	Beardless Chinch Weed	*Pectis imberbis*	SC	S				
Plant	Beguiling Mexican Daisy	*Lagascea decipiens*						
Plant	Box Canyon Muhly	*Muhlenbergia dubioides*		S				
Plant	Catalina Beardtongue	*Penstemon discolor*		S		HS		
Plant	Chihuahuan Sedge	*Carex chihuahuensis*		S				
Plant	Chiltepin	*Capsicum annuum* var. *glabriusculum*		S				
Plant	Chiricahua Mountain Brookweed	*Samolus vagans*		S				
Plant	Chisos Coral-root	*Hexalectris revoluta*		S				
Plant	Common Bee Brush	*Aloysia gratissima*						
Plant	Dalhouse Spleenwort	*Asplenium dalhousiae*			S			
Plant	Engelmann Adders Tongue	*Ophioglossum engelmannii*						
Plant	False Indian Mallow	*Anoda abutiloides*						

Taxanomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Plant	Gentry Indigo Bush	*Dalea tentaculoides*	SC	S	S	HS		Yes
Plant	Goodding Ash	*Fraxinus gooddingii*						
Plant	Henrya	*Henrya insularis*						
Plant	Hoary Cloak Fern	*Argyrochosma incana*						
Plant	Kearney's Blue-star	*Amsonia kearneyana*	LE			HS		Yes
Plant	Large-flowered Blue Star	*Amsonia grandiflora*	SC	S				
Plant	Lemmon Cloak Fern	*Notholaena lemmonii*	SC					
Plant	Lumholtz Nightshade	*Solanum lumholtzianum*						
Plant	Lumholtz's Prairie-clover	*Dalea lumholtzii*						
Plant	Mexican Gama Grass	*Tripsacum lanceolatum*						
Plant	Mexican Lobelia	*Lobelia laxiflora*				SR		
Plant	Mexican Rosary Bean	*Rhynchosia precatoria*						
Plant	Mexican Shrub Mallow	*Malvastrum bicuspidatum*						
Plant	Mock-pennyroyal	*Hedeoma dentatum*						
Plant	Mossy Passionflower	*Passiflora bryonioides*						
Plant	Nodding Blue-eyed Grass	*Sisyrinchium cernuum*		S				
Plant	Orinico Jute	*Corchorus hirtus*						
Plant	Palmer's Breadroot	*Pediomelum palmeri*						
Plant	Pan-american Snoutbean	*Rhynchosia edulis*						
Plant	Pima Pineapple Cactus	*Coryphantha scheeri* var. *robustispina*	LE			HS		Yes
Plant	Plummer Onion	*Allium plummerae*				SR		
Plant	Pringle Lip Fern	*Cheilanthes pringlei*						
Plant	Pringle's Cluster-vine	*Jacquemontia pringlei*						
Plant	Prism Bouchea	*Bouchea prismatica*						
Plant	Rincon Milkweed Vine	*Gonolobus arizonicus*						
Plant	Ruby Bundleflower	*Desmanthus bicornutus*						
Plant	Saiya	*Amoreuxia gonzalezii*	SC	S		HS		
Plant	Santa Cruz Beehive Cactus	*Coryphantha recurvata*		S		HS		
Plant	Santa Cruz Star Leaf	*Choisya mollis*	SC	S				
Plant	Santa Cruz Striped Agave	*Agave parviflora* ssp. *parviflora*	SC	S		HS		
Plant	Seemann Groundsel	*Senecio carlomasonii*						
Plant	Sensitive Joint Vetch	*Aeschynomene villosa*						
Plant	Silky Pony Foot	*Dichondra repens* var. *sericea*						
Plant	Sinaloa Milkweed Vine	*Cynanchum ligulatum*						
Plant	Sonoran Noseburn	*Tragia laciniata*		S				
Plant	Sonoran Spleenwort	*Asplenium exiguum*						

Taxanomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Plant	Spiny Milkwort	*Polygala glochidiata*						
Plant	Stag-horn Cholla	*Opuntia versicolor*				SR		
Plant	Supine Bean	*Macroptilium supinum*	SC	S		SR		
Plant	Sweet Acacia	*Acacia farnesiana*						
Plant	Thurber Hoary Pea	*Tephrosia thurberi*						
Plant	Thurber Indian Mallow	*Abutilon thurberi*				SR		
Plant	Thurber Tithonia	*Tithonia thurberi*						
Plant	Thurber's Morning-glory	*Ipomoea thurberi*						
Plant	Tropical Glandular Croton	*Croton ciliatoglandulifer*						
Plant	Tropical Spiny Phlox	*Loeselia glandulosa*						
Plant	Trumpet Morning-glory	*Ipomoea tenuiloba*						
Plant	Virlet Paspalum	*Paspalum virletii*		S				
Plant	Weeping Muhly	*Muhlenbergia xerophila*		S				
Plant	Whisk Fern	*Psilotum nudum*		S		HS		
Plant	Wiggins Milkweed Vine	*Metastelma mexicanum*	SC	S				
Plant	Yellow Indian Mallow	*Abutilon reventum*						
Reptile	Brown Vinesnake	*Oxybelis aeneus*		S		WSC		
Reptile	Desert Box Turtle	*Terrapene ornata luteola*			S		Yes	Yes
Reptile	Giant Spotted Whiptail	*Aspidoscelis burti stictogrammus*	SC	S			Yes	Yes
Reptile	Greater Short-horned Lizard	*Phrynosoma hernandesi*						
Reptile	Hooded Nightsnake	*Hypsiglena sp. nov.*						
Reptile	Mountain Skink	*Plestiodon callicephalus*		S				
Reptile	Northern Green Ratsnake	*Senticolis triaspis intermedia*		S				
Reptile	Redback Whiptail	*Aspidoscelis xanthonota*	SC					Yes
Reptile	Sonoran Desert Tortoise	*Gopherus agassizii* (Sonoran Population)	C	S		WSC	Yes	Yes
Reptile	Sonoran Lyresnake	*Trimorphodon lambda*					Yes	
Reptile	Thornscrub Hook-nosed Snake	*Gyalopion quadrangulare*		S				
Reptile	Yaqui Black-headed Snake	*Tantilla yaquia*		S				

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 137* below):

- We trimmed biologically best corridors with “bubble areas” created from widening the strands to meet width requirements over 90% of the corridor where possible. Biologically best corridors with additional strands that did not provide additional habitat connectivity for other focal species were also trimmed. Some corridor dwellers were slightly below the ideal width kept along 90% of the corridor. This was due to certain habitat limitations that did not increase bottlenecks. Trimming biologically best corridors had little effect on the mean habitat suitability located within each corridor.
- We buffered the union of biologically best corridors 300m to remove modeling relicts and edge effects based on recommendations from Majka et al. (2007).
- We added stretches of the Sycamore Canyon, not already included in the linkage design, and buffered the stretch of the stream 200m to capture riparian habitat based on recommendations from Majka et al. (2007).

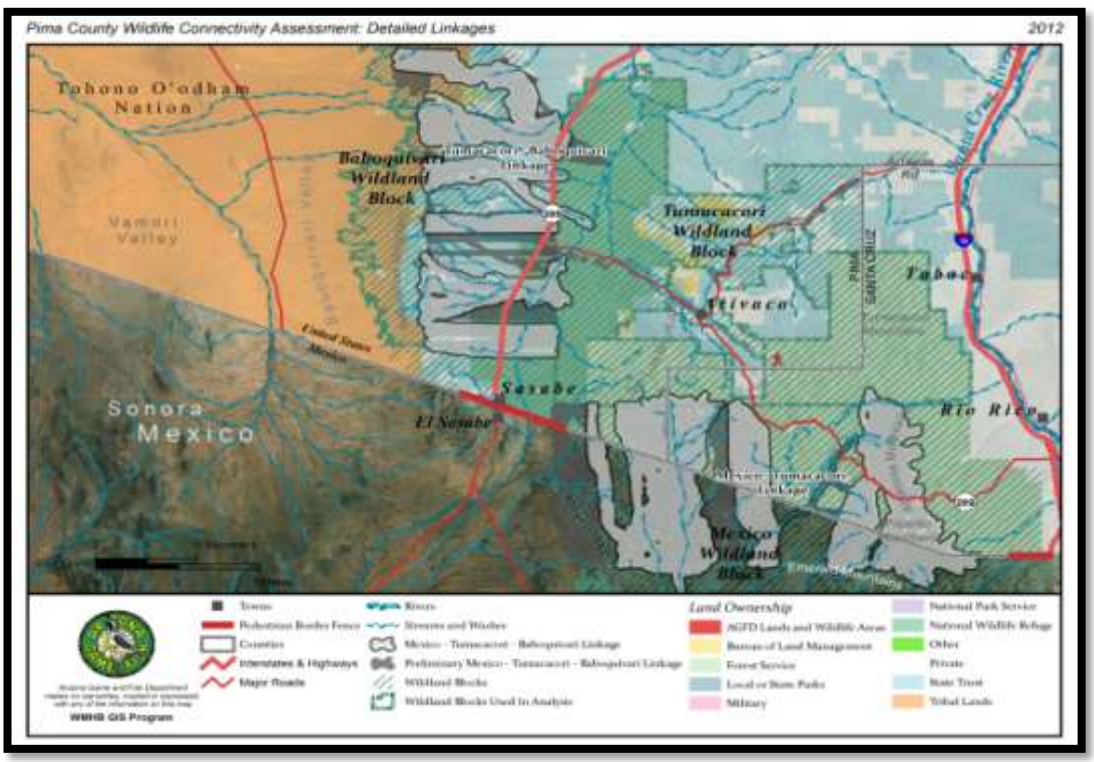

Figure 137: *Progression of the Mexico – Tumacacori – Baboquivari linkage design*

Appendix F: Description of Binational Land Cover

Vegetation classes have been derived from the USGS U.S.-Mexico Border Environmental Health Initiative (BEHI) Binational Land Cover Dataset 2001 layer. This layer includes eight land cover classes derived from the USGS National Land Cover Database 2001 and Mexico's Instituto Nacional de Estadistica, Geografia, e Informatica 1:250,000 Uso de Suelo y Vegetacion Serie III datasets.

As mentioned in the Linkage Design Methods (Appendix A), species scores compiled for land cover by the Corridor Design Team at Northern Arizona University, based on Southwest ReGAP land cover classes, were averaged to accommodate for fewer classes represented in the BEHI layer. Only Southwest ReGAP scores for land cover categories that were encompassed by categories represented in the BEHI laer, as determined through zonal statistics in GIS, were included in species averages. An additional land cover class, wash, was added to the land cover dataset, based on the BEHI international streams layer, due to wash being an important parameter for many species.

What follows is a description of each class found in the BEHI layer, based largely on the National Land Cover Database 2001 legend of classes document (Available from http://www.mrlc.gov/nlcd01_leg.php)

AGRICULTURE– Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75% to 100% of the cover.

BARREN – Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no"green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaces and scrubby than that in the green vegetated categories; lichen cover may be extensive

DEVELOPED – Areas characterized by high percentage (30% or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).

FOREST – Areas characterized by tree cover (natural or semi-natural wood vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.

GRASS/PASTURE – Areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75% to 100% of the cover.

SHRUB – Areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75% to 100% of the cover.

WASH – Areas added to the original BEHI land cover layer based on the location of streams/washes represented in the BEHI binational stream/wash layer.

WATER – Areas of open water or permanent ice/snow cover.

WETLANDS – Areas where the soil or substrate is periodically saturated with or covered with water.

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Appendix H: Data Requests

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

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

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