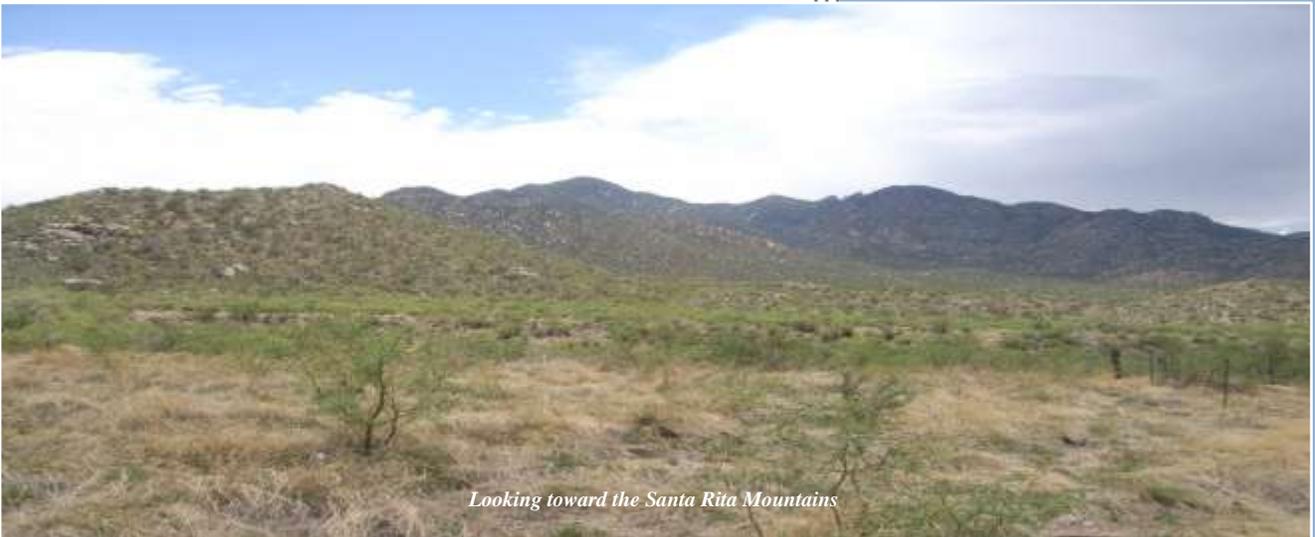


August 2012

Pima County Wildlife Connectivity Assessment: Detailed Linkages

Santa Rita – Sierrita Linkage Design



Looking toward the Santa Rita Mountains

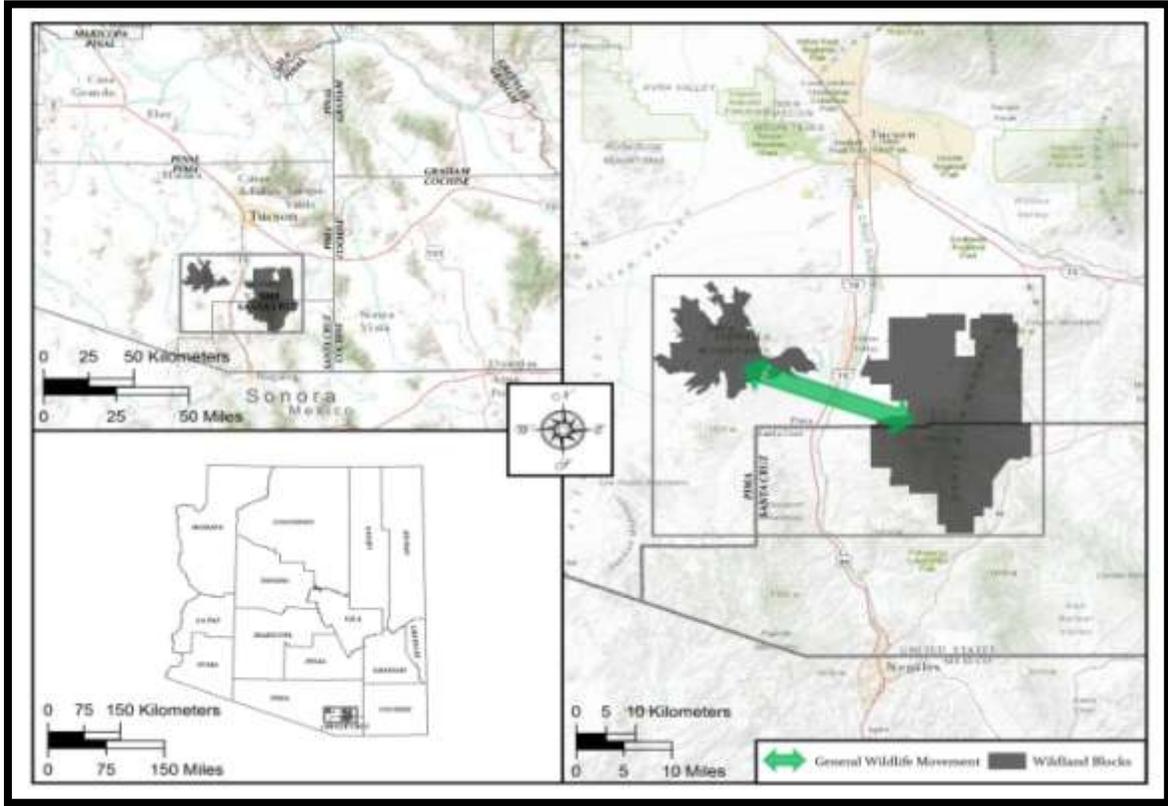
Arizona Game and Fish Department



Regional Transportation Authority of
Pima County



Santa Rita – Sierrita Linkage Design



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Arizona Wildlife Linkages Workgroup:

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

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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 two wildland blocks south of Tucson, Arizona: the Santa Rita Mountains (Santa Rita), and the Sierrita Mountains (Sierrita). This linkage design facilitates movement and reproduction of wildlife between the Santa Rita and Sierrita wildland blocks (see *Figure 1* below).

This linkage design is based on a focal species approach. We identified 18 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™. Focal species, in which habitat and/or corridors were modeled as part of this report, include ten 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 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 18 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 Santa Rita and Sierrita 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.

The Santa Rita – Sierrita linkage currently contains many large obstacles to wildlife movement. The Santa Cruz Valley, in which this linkage passes through, is fragmented with development and major transportation routes. Interstate 19, a four-lane divided highway, passes directly through Santa Cruz Valley and the Santa Rita – Sierrita linkage design. The interstate is also flanked by a two lane frontage road both to its east and to its west. These barriers are further compounded by a Union Pacific rail line which splits the linkage design to the east of Interstate 19 and its frontage roads. The growing community of Green Valley also continues to threaten connectivity in the area.

Various enhancements would increase permeability of this area to wildlife. Retrofitting existing road structures to increase permeability to wildlife, the construction of new wildlife crossings structures, and fencing modifications to “wildlife-friendly” specifications, can improve the utility of the linkage design. Effective land-use planning, that incorporates the needs of wildlife, is also important to keep suitable habitat between wildland blocks, and on either side of road crossing structures.

This report contains recommendations to increase permeability for wildlife throughout the linkage design, ultimately allowing the movement of wildlife populations, and associated flow of genes, between the Santa Rita Mountains, and the Sierrita 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 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 also help motivate and inform watershed planning, habitat restoration, conservation easements, zoning, and land acquisition. Implementing this plan will take decades, and collaboration among county planners, land management agencies, resource management agencies, land conservancies, and private landowners.

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

This report can be particularly useful to transportation planners, such as the Regional Transportation Authority of Pima County (RTA), 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 Santa Rita – Sierrita linkage design

MAMMALS	Amphibians	REPTILES
*Badger	*Chiricahua Leopard Frog ^{HDMS/SDCP}	*Black-tailed Rattlesnake
*Black Bear	*Sonoran Desert Toad	*Desert Box Turtle ^{HDMS/SDCP}
*Black-tailed Jackrabbit		*Giant Spotted Whiptail ^{HDMS/SDCP}
*Coues' White-tailed Deer		*Gila Monster ^{HDMS}
*Jaguar ^{HDMS}		*Sonoran Desert Tortoise ^{HDMS}
*Javelina		*Sonoran Whipsnake
*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).

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).

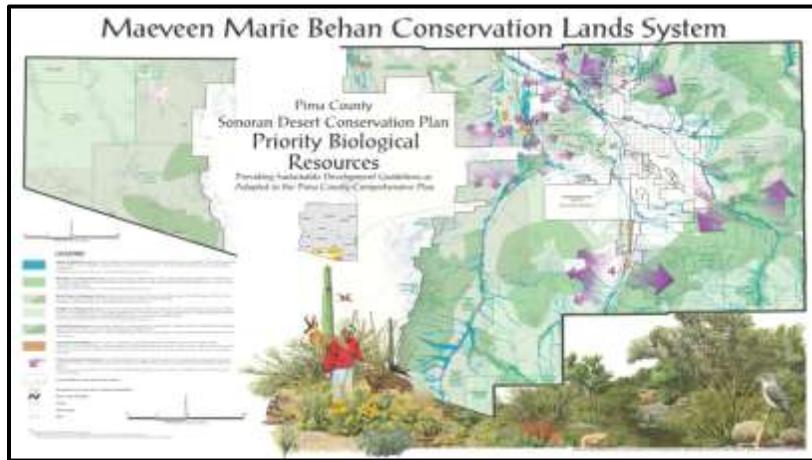


Figure 2: The Maeveen Marie Behan Conservation Lands System shows the biologically preferred reserve design and works to provide sustainable guidelines for future development. Critical Landscape Connections, or broadly-defined areas where wildlife connectivity is significantly compromised, but can still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

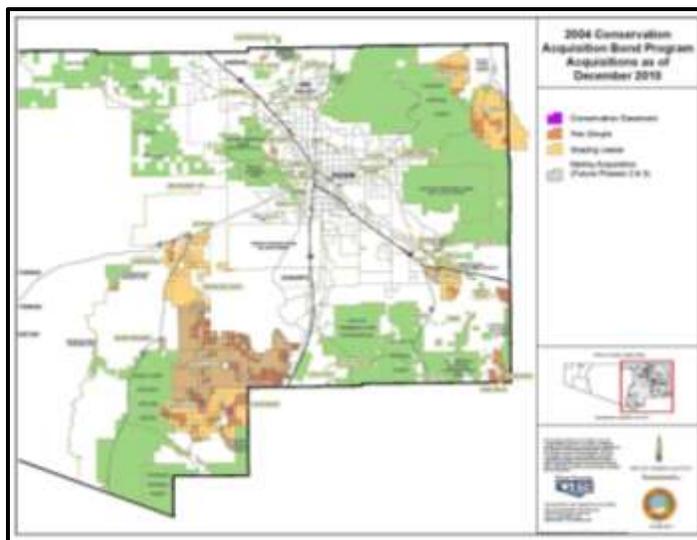


Figure 3: The 2004 Conservation Acquisition Bond Program was approved to help implement the Sonoran Desert Conservation Plan (Pima County 2011). Multi-use lands are important for habitat and wildlife conservation in the region.

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.corridor design.org) which provided the template for this report.

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

Overview of the Pima County Wildlife Connectivity Assessment

Continuing with the statewide strategy to identify and prioritize linkages at the county level for GIS modeling of wildlife connectivity, AGFD received funding from the Regional Transportation Authority of Pima County. This funding allowed AGFD to assemble current knowledge of wildlife linkages and barriers to wildlife movement across Pima County and to help build collaborative partnerships with local jurisdictions for eventual implementation efforts. To accomplish these tasks, AGFD joined with partner organizations (please see Acknowledgments for a list of members of the Pima County Wildlife Connectivity Workgroup) to initiate the Pima County Wildlife Connectivity Assessment. This project built on prior initiatives including the SDCP and AWLA. The Pima County Wildlife Connectivity Assessment (available at http://www.azgfd.gov/w_c/conn_Pima.shtml) represented a continuation of these previous efforts by identifying wildlife linkages at a finer scale that may have been overlooked in the earlier products, as well as those that will be useful for regional and local transportation or land-use planning efforts (see *Figure 5* below). With input gathered by the stakeholders at the workshops and with additional input by the Pima County Wildlife Connectivity Workgroup, five areas encompassing numerous wildlife linkages were suggested as priorities for the development of detailed linkage designs with specific recommendations for implementation. These priority areas largely followed the broadly-defined Critical Landscape Connections from the SDCP. The Santa Rita - Sierrita linkage planning area was one of these prioritized areas suggested to model, and works to address Critical Landscape Connection 4 (See *Overview of Regional Planning Efforts That Acknowledge the Importance of Conserving Wildlife Linkages* above). Other areas included Coyote – Ironwood – Tucson, Kitt Peak, Mexico – Tumacacori – Baboquivari, and Santa Catalina/Rincon – Galiuro.

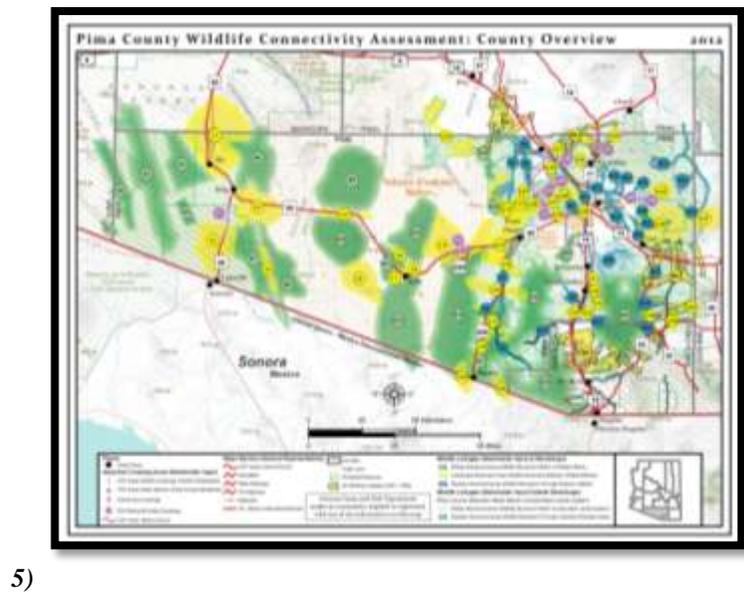
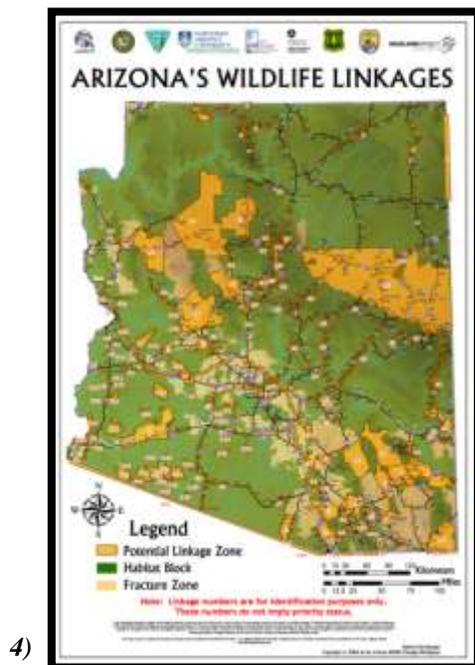


Figure 4 and Figure 5: Statewide map of wildlife linkages and barriers created by the Arizona Wildlife Linkages Workgroup (2006). County-wide map of wildlife linkage created for the Pima County Wildlife Connectivity Assessment: Report on Stakeholder Input (2012) (Maps: Courtesy Arizona Wildlife Linkages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

Ecological Significance and Existing Conservation Investments of the Santa Rita – Sierrita 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 Santa Rita – Sierrita Linkage Planning Area

The Santa Rita – Sierrita linkage planning area in Pima County 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.

Two wildland blocks exist here: the Santa Rita Mountains (Santa Rita), and the Sierrita Mountains (Sierrita). These wildland blocks are separated by various topographic features, including the flat lands of Santa Cruz Valley between the Santa Rita and Sierrita wildland blocks. Man-made features separating the blocks include: interstates, major roads, mines, railroads, and the growing community of Green Valley.

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 their ranges to historically used habitats. Providing connectivity is paramount in sustaining this unique area’s diverse natural heritage. 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):

Santa Rita Wildland Block

The Santa Rita wildland block encompasses over 200,000 acres of the Santa Rita Mountains, south of Tucson, Arizona. These mountains are dominated by encinal oak woodland, semi-desert grassland and steppe, mesquite upland scrub, paloverde-mixed cacti desert scrub, and pinyon-juniper woodland which comprise the largest percentages of its land cover classification. The wildland block is also comprised of miscellaneous desert scrub, creosotebush mixed desert and thorn scrub, and pine-oak forest and woodland, among various other land cover types. Elevation here ranges from 2,848 feet to 9,439 feet.

Sierrita Wildland Block

The Sierrita wildland block includes over 63,815 acres of land encompassing the Sierrita Mountains. The majority of the land cover within the wildland block is comprised of miscellaneous desert scrub, mesquite upland scrub, encinal oak woodland, chaparral, and semi-desert grassland and steppe. Paloverde-mixed cacti desert scrub, creosotebush mixed desert and thorn scrub, pinyon-juniper woodland, and wash also make up the wildland block, among various other land cover types. Elevation in this block ranges from 3,176 feet to 6,165 feet.

Conservation Investments in the Santa Rita – Sierrita Linkage Planning Area

The Santa Rita and Sierrita 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):

Santa Rita Wildland Block

The Santa Rita wildland block includes the Mt. Wrightson Wilderness, which is over 25,407 acres managed by the U.S. Forest Service. The over 53,158 acre Santa Rita Experimental Range (SRER), is also included in the wildland block. The SRER is administered by the University of Arizona. The SRER is a working natural laboratory for natural resource and rangeland management, and the University of Arizona (2012), has stated the mission of the SRER is, “To advance research and education on the ecology and management of desert rangelands through the secure, long-term access to research areas, state-of-the-art facilities, new discoveries, and research legacies.” Besides these areas, the wildland block includes over 148,447 acres of Coronado National Forest, managed by the U.S. Forest Service.

Sierrita Wildland Block

The Sierrita wildland block is partially managed for conservation by Pima County. Over 5,473 acres of Marley Ranch were included in the block. While much of Marley Ranch is still a working cattle ranch, Pima County actively manages much of the land for conservation (Pima County 2011). Similarly, 1,849 acres of Diamond Bell Ranch were included in the block, and serve as both a working ranch and conservation lands. Since the protected portions of the Sierrita Mountains are currently relatively small in size, and important wildlife habitat is located outside of these boundaries, the wildland block used for this analysis was increased in size by referencing the Pima County Hillside Development Overlay Zone Ordinance. This zone ordinance requires a permit for grading land with slope $\geq 15\%$ and may offer some conservation protection for mountainous areas located within State Trust and Private lands. This zone ordinance also includes the Initiation of Protection for Peaks and Ridges, which designates protection for peaks and ridges meeting certain criteria (Pima County 2012).

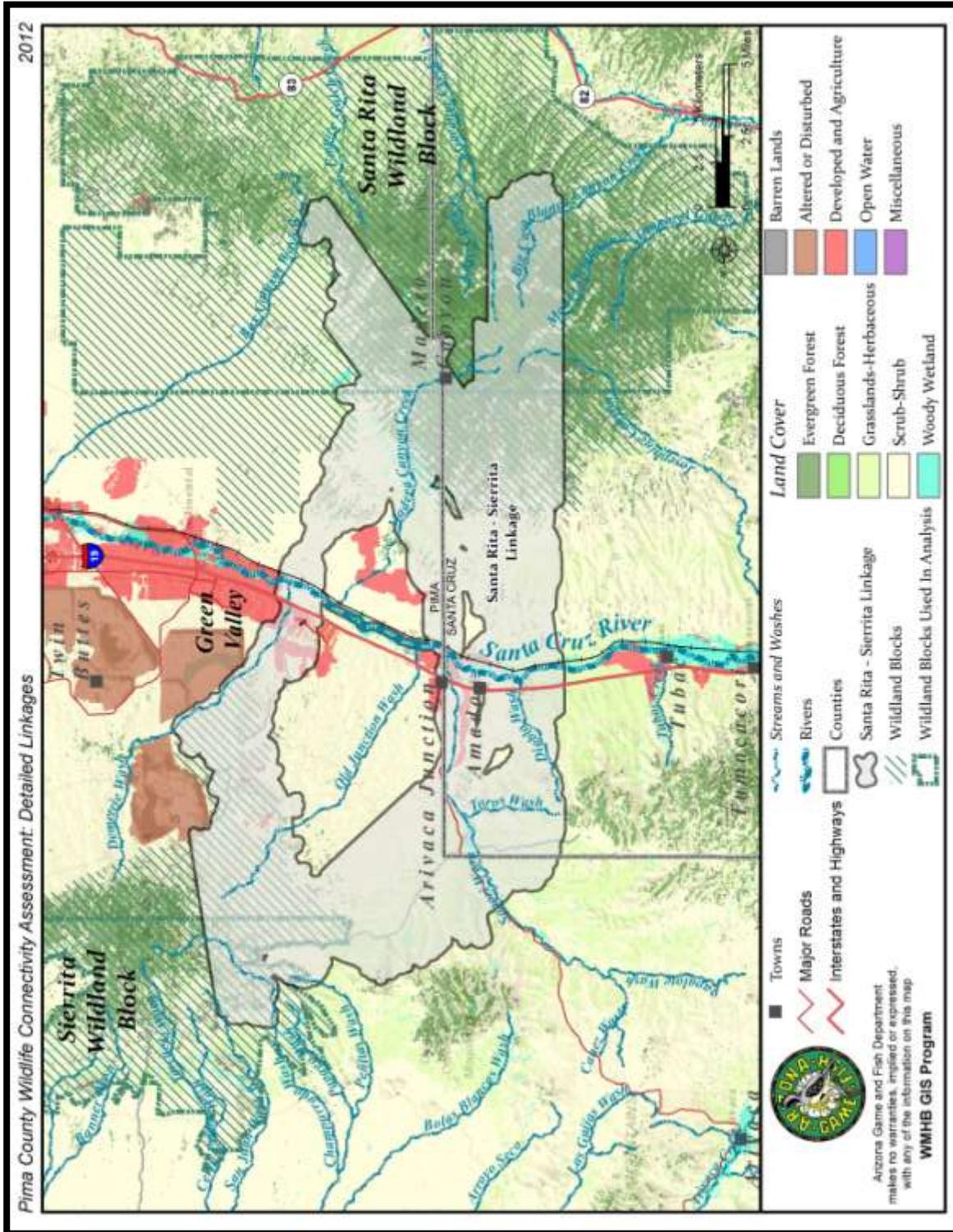


Figure 6: Land cover in the Santa Rita – Sierrita linkage design

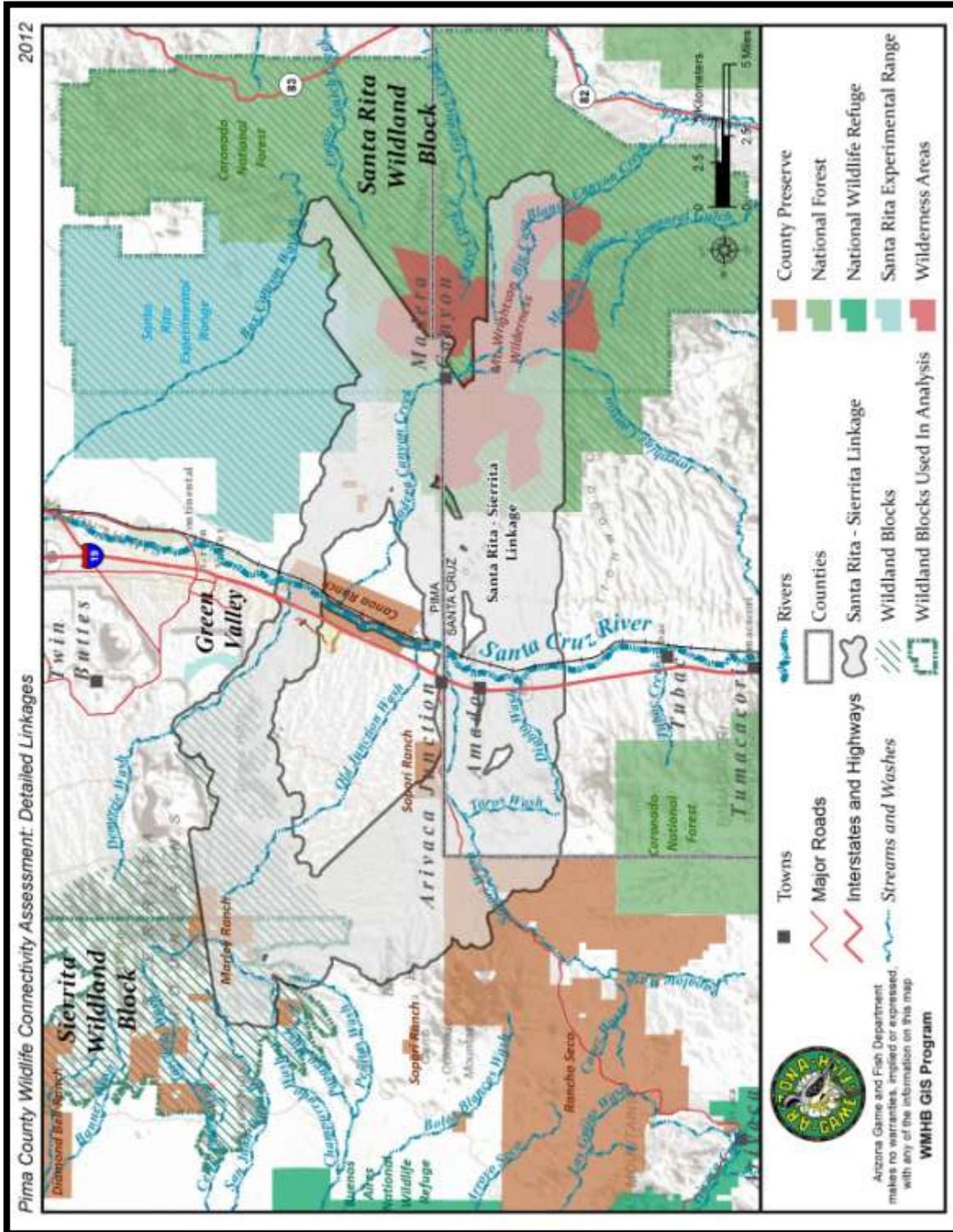


Figure 7: Existing conservation investments in the Santa Rita – Sierrita linkage design

The Santa Rita – Sierrita Linkage Design

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

One Linkage Provides Connectivity Across a Diverse Landscape

The Santa Rita – Sierrita Linkage

The Santa Rita – Sierrita linkage runs between the Santa Rita wildland block and the Sierrita wildland block, across the Santa Cruz Valley. It spans about 30 km (18.6 mi) in a straight-line between each wildland block used in this analysis. The linkage design encompasses 134,154 acres (54,290 ha) of land, of which over 45% is State Trust land, 27% is administered by the U.S. Forest Service, 27% is private land, and the rest by the U.S. Bureau of Land Management (see *Figure 1* for a map of the linkage design and land ownership at the beginning of this report). It is primarily composed of mesquite upland scrub (17.8%), semi-desert grassland and steppe (15.9%), paloverde-mixed cacti desert scrub (15.3%), miscellaneous desert scrub (11.1%), encinal oak woodland (10.3%) and pinyon-juniper woodland (6.7%), among various other land cover types (*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 average slope within the linkage is 18.2% (Range: 0 – 316.9%, SD: 20.0). Most of the land (50.1%) has flat-gentle slopes, with some of the land containing steep slopes (33.5%), and the rest a mix of canyon bottom and ridgetop. Most land aspects are well represented, with the exception of flat aspects.

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 Santa Rita and Sierrita wildland blocks is a severely fragmented landscape, and numerous barriers to wildlife connectivity exist:

Interstate 19/Frontage Roads/Union Pacific Railroad

An animal moving terrestrially between the Santa Rita and Sierrita wildland blocks eventually must cross the Union Pacific Railroad, a frontage road to the east of Interstate 19 (I-19), the northbound two-lane section of I-19, the southbound two-lane section of I-19, and the frontage road west of I-19. I-19 possesses high volumes of traffic, travelling at high speeds, and is a significant barrier to wildlife. I-19 mitigation recommendations are a focus later in this report. Although numerous culverts exist along this interstate within the linkage design, many of them may not be fit for use by wildlife. Furthermore, wildlife use of culverts in this area may be difficult due to the number of transportation routes that need to be traversed (two frontage roads and the divided interstate).

Stream Impediments

The Santa Cruz River provides valuable habitat within the Santa Rita – Sierrita linkage. Some riparian vegetation currently exists along this section of the Santa Cruz River within the linkage, partially due to effluent discharge from nearby wastewater treatment facilities. Natural perennial river flow has been lost

in the Santa Cruz River and its riparian habitats degraded from groundwater pumping and other human activities (Fabre and Cayla 2009). Continued habitat restoration made possible from effluent flows would greatly benefit the utility of the corridor.

Urban Development

The community of Green Valley, Arizona continues to grow and act as a barrier to wildlife movement through the Santa Cruz Valley. Specifically, development in the northern portion of the linkage design, threatens to sever connections between wildland blocks for numerous focal species.

Table 2: Approximate land cover found within the Santa Rita – Sierrita linkage design

Land Cover Group	Land Cover Class	% of Linkage Design
Deciduous Forest	Aspen Forest and Woodland	0.3%
Evergreen Forest	Conifer-Oak Forest and Woodland	0.6%
Evergreen Forest	Encinal (Oak Woodland)	10.3%
Evergreen Forest	Pine-Oak Forest and Woodland	3.5%
Evergreen Forest	Pinyon-Juniper Woodland	6.7%
Grasslands-Herbaceous	Semi-Desert Grassland and Steppe	15.9%
Scrub-Shrub	Chaparral	3.2%
Scrub-Shrub	Creosotebush, Mixed Desert and Thorn Scrub	5.1%
Scrub-Shrub	Creosotebush-White Bursage Desert Scrub	1.7%
Scrub-Shrub	Desert Scrub (misc)	11.1%
Scrub-Shrub	Mesquite Upland Scrub	17.8%
Scrub-Shrub	Paloverde-Mixed Cacti Desert Scrub	15.3%
Woody Wetland	Riparian Mesquite Bosque	1.0%
Woody Wetland	Riparian Woodland and Shrubland	1.4%
Barren Lands	Bedrock Cliff and Outcrop	1.4%
Barren Lands	Wash	2.1%
Developed and Agriculture	Agriculture	0.7%
Developed and Agriculture	Developed, Medium - High Intensity	0.7%
Developed and Agriculture	Developed, Open Space - Low Intensity	0.9%
Altered or Disturbed	Recently Mined or Quarried	0.1%

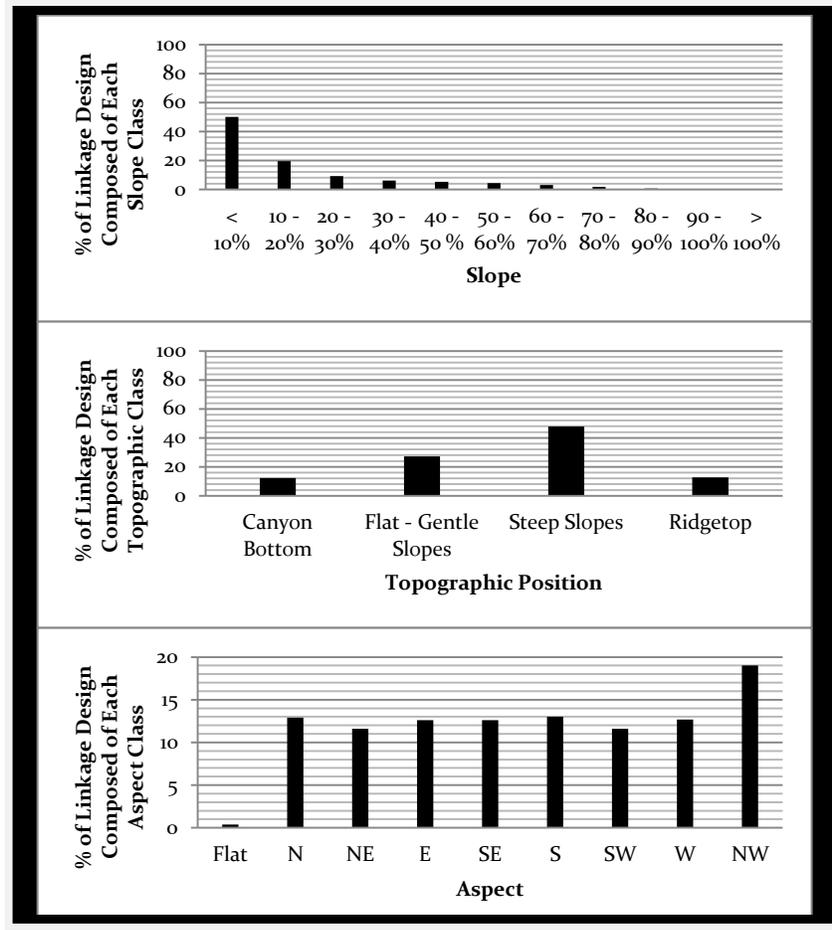


Figure 8: Topographic diversity encompassed by Santa Rita – Sierrita linkage design: a) Topographic position, b) Slope, c) Aspect

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 Santa Rita wildland block, and Sierrita wildland block, it is essential to consider the entire linkage design, including conserving the land within the linkage. **Indeed, investment in a crossing structure would be futile if habitat between the crossing structure and either wildland block is lost.**

All of the waypoints referenced for each section on barriers refer to the following maps (see *Figure 9* below):

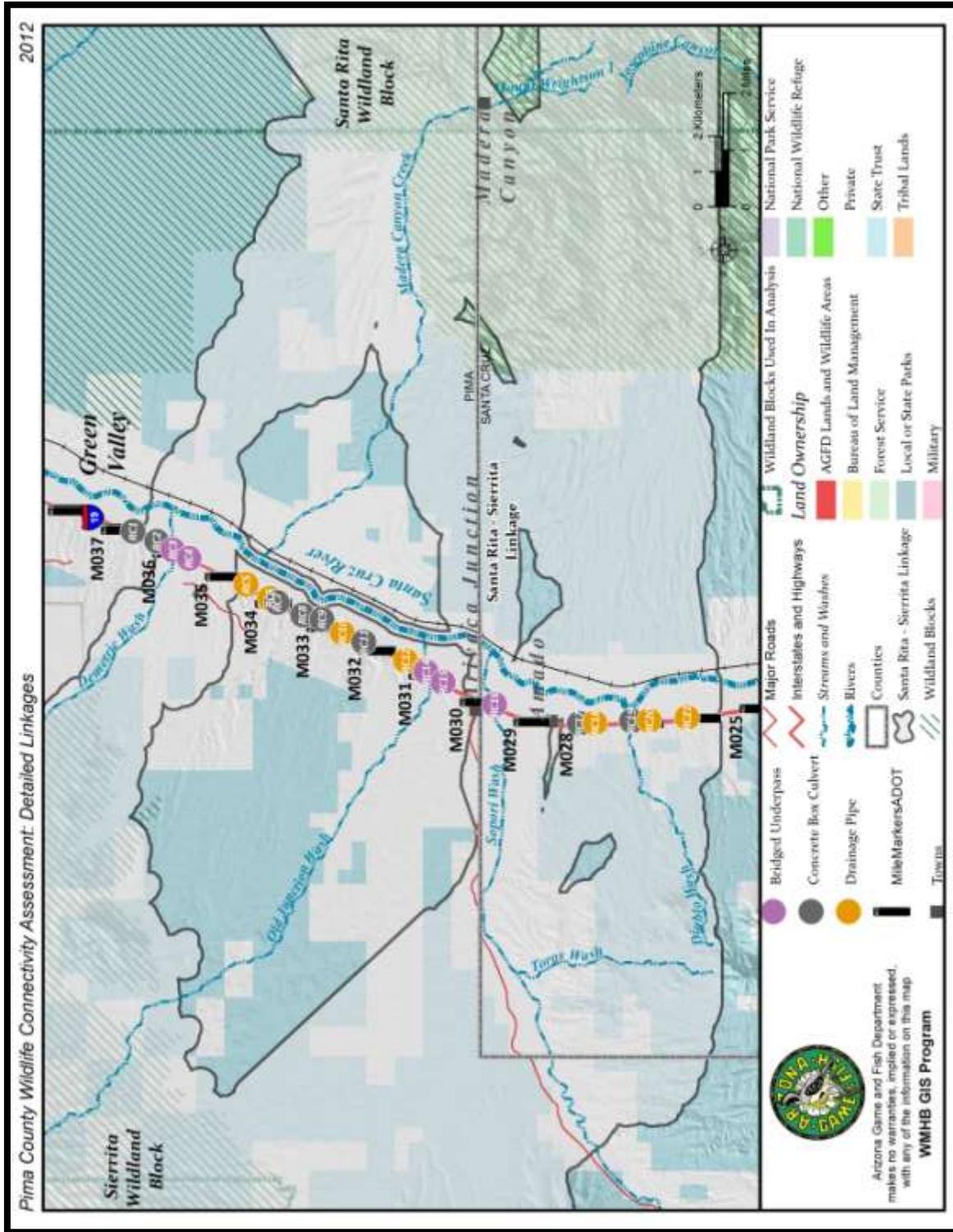


Figure 9: Road structures within the Santa Rita – Sierrita linkage design

Impacts of Roads on Wildlife

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

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

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

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

Mitigation for Roads

Wildlife crossing structures that have been used in North America and Europe to facilitate movement through landscapes fragmented by roads include wildlife overpasses, bridges, culverts, and pipes (see *Figure 10* 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.

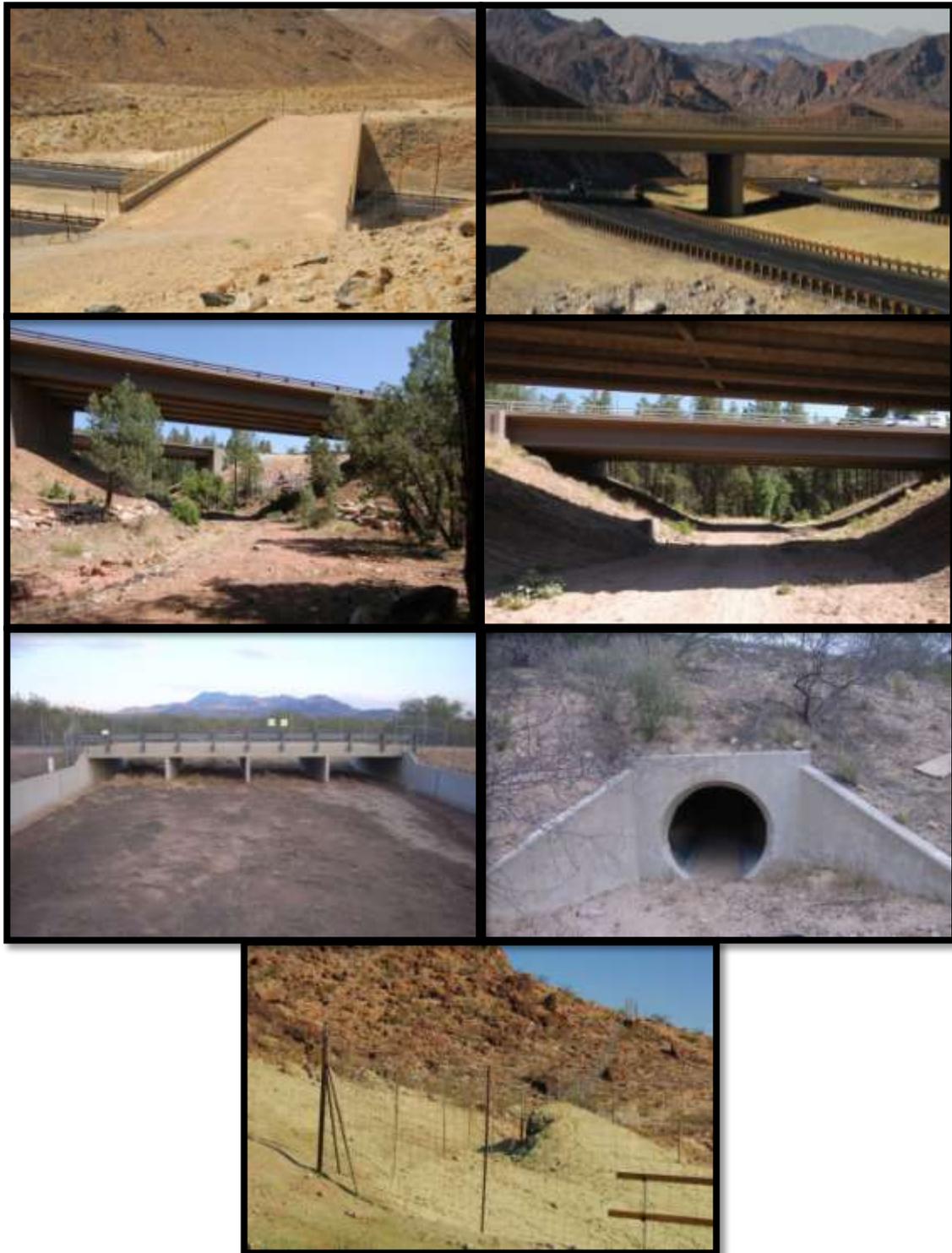


Figure 10: Potential road mitigations (from top to bottom) include: highway overpasses, bridges, culverts, and drainage pipes. Fencing (bottom) should be used to guide animals into crossing structures (Photographs courtesy George Andrejko and Dean Pokrajac, AGFD).

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 about 34 km (21 mi) of major roads and interstates in the linkage design (See *Table 4* below). We focused our field investigations on Interstate-19, as it may be the largest barrier to wildlife in the linkage design.

Table 4: Roads greater than 1 kilometer in length in the Santa Rita – Sierrita linkage design

Road Name	Kilometers	Miles
Arivaca Rd	13.8	8.6
Interstate 19	18.2	11.3
S Cam del Sol	1.6	1.0
Unknown	10.3	2.4

Recommendations for Crossing Structures in the Santa Rita – Sierrita Linkage Design

The following recommendations for retrofitting of existing structures are based on Lowery et al. (2010) culvert design specifications. Field observations were collected along the frontage road east of I-19 for safety purposes. These recommendations will improve wildlife connectivity across I-19, and its associated frontage roads, and refer to waypoints on the map at the beginning of this section (see *Figure 9* above):

I-19 and Frontage Roads

- Road structure RS1, near I-19 mile post 37, consists of a 3-cell concrete box culvert (see *Figure 11* below). The culvert openings are approximately 3 m (10 ft) raised from the ground. Also a 1.2 m wall compounds to the blocked access of the raised culvert on its eastern side. The dimensions of culvert openings were not measured due to blocked access. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of herpetofauna, based on the location near biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake. This should be done to the specifications of culverts and associated barriers for herpetofauna referenced above. Culvert openings should be accessible at ground-level, and not impeded by additional drainage walls, which block wildlife access.
- Road structure RS2, between I-19 mile posts 36 – 37, consists of a 2-cell concrete box culvert (see *Figure 12* below). Each cell is approximately 1.8 m (6 ft) in height, and 1.2 m (4 ft) in width. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of herpetofauna, based on the location of biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake. This should be done to the specifications of culverts and associated barriers for herpetofauna referenced above.
- Road structure RS3, near I-19 mile post 36, Demetrie Wash Bridge (see *Figure 13* below), are large bridged underpasses of I-19 that spans Demetrie Wash, and should be considered a priority structure for wildlife movement between wildland blocks across I-19. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted with barriers, based on specifications for herpetofauna referenced above, to decrease road mortality of herpetofauna on I-19. This is based on the location of

biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake. Also, small ledges, 0.6m (2 ft) and 1.2 m (4 ft) in height, are located on the eastern side of the bridges underpass, across Demetrie Wash. These ledges may partially block movement of herpetofauna through the road structure, and should be removed, or ground-filled.

- Road structure RS4, between I-19 mile posts 35 – 36, consists of large bridged underpasses of I-19 spanning an unnamed wash (see *Figure 14* below), and should be considered a priority structure for wildlife movement between wildland blocks across I-19. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted with barriers, based on specifications for herpetofauna referenced above, to decrease road mortality of herpetofauna on I-19. This is based on the location of biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake.
- Road structure RS5, between I-19 mile posts 34 – 35, consists of a concrete drainage pipe (see *Figure 15* below). The pipe measures 1.5 m (5 ft) in diameter. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of herpetofauna, based on the location near biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake. This should be done to the specifications of culverts and associated barriers for herpetofauna referenced above.
- Road structure RS6 – RS13, between I-19 mile posts 131 – 134 (see *Figures 16 – 23* below), are located outside of the linkage design. We do not provide retrofitting recommendations for these culverts/pipes, as these structures are not within the biologically best corridors for any focal species.
- Road structure RS14, Old Junction Wash Bridge (see *Figure 24* below), near I-19 mile post 31, consists of large bridged underpass spanning I-19, and should be considered a priority structure for wildlife movement between wildland blocks. While this structure is outside of the linkage design, it is located near the biologically best corridor for mule deer, and may be permeable to wildlife in its current construction. These bridged underpasses should be retrofitted with fencing to guide wildlife towards the structure, based on specifications for large-sized mammals referenced above.
- Road structure RS15, consists of large bridged underpasses spanning and unknown wash along I-19, between I-19 mile posts 30 – 31 (not pictured), and should be considered a priority structure for wildlife movement between wildland blocks. While this structure is outside of the linkage design, it is located near the biologically best corridor for mule deer, and may be permeable to wildlife in its current construction. These bridged underpasses should be retrofitted with fencing to guide wildlife towards the structure, based on specifications for large-sized mammals referenced above.
- Road structure RS16, Sopori Wash Bride, consists of large bridged underpasses spanning Sopori Wash along I-19, between I-19 mile posts 29 – 30 (see *Figure 25* below), and should be considered a priority structure for wildlife movement between wildland blocks. These bridged underpasses should be retrofitted with fencing to guide wildlife towards the structure, based on the location of biologically best corridors for mule deer and white-nosed coati. Fencing specifications should follow those for medium and large-sized mammals referenced above.
- Road structure RS17, near I-19 mile post 28, consists of a 3-cell concrete box culvert (see *Figure 26* below). Each cell is approximately 1.8 m (6 ft) in height, and 3 m (10 ft) in width. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of large-sized mammals, based on the location of biologically best corridors for mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.

- Road structure RS18, between I-19 mile posts 27 – 28, consists of 3 drainage pipes (see *Figure 27* below). Each pipe measures 1.5 m (5 ft) in diameter, and were partially filled with gravel during the time of field observations. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of large-sized mammals, based on the location of biologically best corridors for mountain lion. This should be done to the specifications of culverts and associated fencing for large-sized mammals referenced above.
- Road structure RS19, between I-19 mile posts 27 – 28, consists of a 4-celled concrete box culvert (see *Figure 28* below). Each cell measures 1.5 m (5 ft) in height and 3.5 m (11.5 ft) in width. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of herpetofauna, and medium and large-sized mammals, based on the location of biologically best corridors for badger, Coues' white-tailed deer, desert box turtle, jaguar, kit fox, and mountain lion. This should be done to the specifications of culverts and associated barriers/fencing for herpetofauna, and medium and large-sized mammals referenced above.
- Road structure RS20, near I-19 mile post 27, consists of 2 drainage pipes (see *Figure 29* below). Each pipe measures 1.8 m (6 ft) in diameter. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of medium and large-sized mammals, based on the location of biologically best corridors for badger, Coues' white-tailed deer, jaguar, kit fox, 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 RS21, between I-19 mile posts 26 – 27, consists of a drainage pipe (see *Figure 30* below). The pipe measures 1.2 m (4 ft) in diameter. It is important to note that there was water present at this structure during time of field observations. This structure, and all associated structures along both sections of the divided interstate, as well as the western frontage road, should be retrofitted to accommodate movements of herpetofauna (amphibians), and medium and large-sized mammals, based on the location of biologically best corridors for badger, Chiricahua leopard frog, Coues' white-tailed deer, jaguar, kit fox, and mountain lion. This should be done to the specifications of culverts and associated barriers/fencing for herpetofauna, and medium and large-sized mammals referenced above.



Figure 11: Concrete box culvert under frontage road east of I-19 (RS1)



Figure 12: Concrete box culvert under frontage road east of I-19 (RS2)



Figure 13: Demetrie Wash Bridge along I-19 (RS3)



Figure 14: I-19 Bridge spanning unknown wash (RS4)



Figure 15: Drainage pipe under frontage road east of I-19 (RS5)



Figure 16: Drainage pipe under frontage road east of I-19 (RS6)



Figure 17: Concrete box culvert under frontage road east of I-19 (RS7)



Figure 18: Concrete box culvert under frontage road east of I-19 (RS8)



Figure 19: Concrete box culvert under frontage road east of I-19 (RS9)



Figure 20: Drainage pipes under frontage road east of I-19 (RS10)



Figure 21: Concrete box culvert under frontage road east of I-19 (RS11)



Figure 22: Drainage pipes under frontage road east of I-19 (RS12)



Figure 23: Drainage pipes under frontage road east of I-19 (RS13)



Figure 24: Old Junction Wash Bridge along I-19 (RS16)



Figure 25: Sopori Wash Bridge along I-19 (RS16)



Figure 26: Concrete box culvert under frontage road east of I-19 (RS17)



Figure 27: Drainage pipes under frontage road east of I-19 (RS18)



Figure 28: Concrete box culvert under frontage road east of I-19 (RS19)



Figure 29: Drainage pipes under frontage road east of I-19 (RS20)



Figure 30: Drainage pipe under frontage road east of I-19 (RS21)

Impacts of Stream and Riparian Impediments on Wildlife

Importance of Riparian Systems in the Southwest

Riparian systems are one of the rarest habitat types in North America. In the arid Southwest, about 80% of all animals use riparian resources and habitats at some life stage, and more than 50% of breeding birds nest chiefly in riparian habitats (Krueper 1996). They are of particular value in lowlands (below 5,000 feet) as a source of direct sustenance for diverse animal species (Krueper 1993). The Santa Cruz River (see *Figure 31* below), provides important habitat for many species within the linkage design.

Stream Impediments in the Linkage Design

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

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

Recommendations and Guidelines for Mitigating Stream Impediments

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

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

from perennial waters (Kupferberg 1997; Kiesecker and Blaustein 1998; Maret et al. 2006).

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

- 7) **Enforce existing regulations.** We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and of regulations restricting farming, gravel mining, and building in streams and floodplains. Restricted activities within the buffer should include OHV use which disturbs soils, damages vegetation, and disrupts wildlife (Webb and Wilshire 1983).



Figure 31: Intermittent section of the Santa Cruz River

Urban Development as Barriers to Movement

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

- Development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which “hear” ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.
- Removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (see *Figure 32* below). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

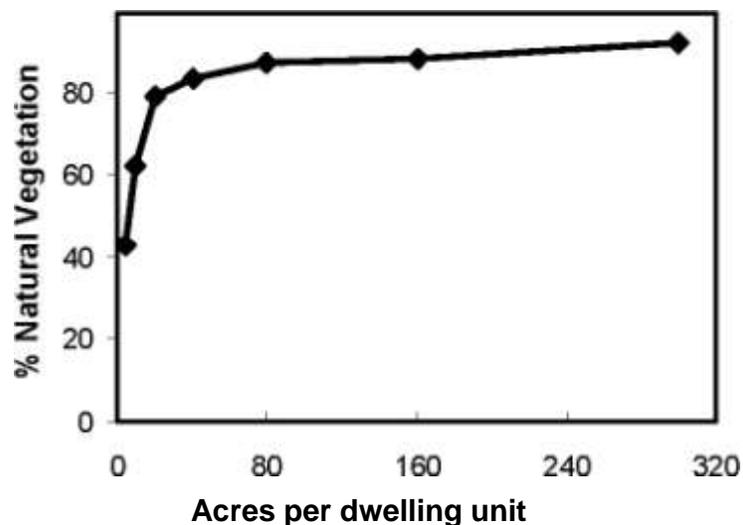


Figure 32: Percent natural vegetation declines rapidly at housing densities greater than 1 dwelling unit per 40 acres (Source: CBI 2005).

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

- Increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (Van der Zee et. al 1992).
- Increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- Increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- Subsidized “suburban native predators” such as raccoons, foxes, and crows that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soule 1999).
- Spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- Perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).
- Mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Sauvajot et. al 2006).
- Artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- Conflicts with native herbivores that feed on ornamental plants (Knickerbocker and Waithaka 2005).
- Noise, which may disturb or repel some animals and present a barrier to movement (Minto 1968, Liddle 1997, Singer 1978).
- Disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006).

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

Urban Barriers in the Linkage Design

The Santa Rita – Sierrita linkage design is currently threatened by the growing community of Green Valley. Development within the linkage design is of special concern in the following area:

- In the northern portion of the linkage design, development from Green Valley threatens to sever connectivity for numerous species of herpetofauna. Google Earth (see *Figure 33* below) shows

high-density development occurring throughout this portion of the linkage, and in-between major washes which are important for connectivity. For example, Demetrie Wash provides important habitat for a variety of species, as shown by the biologically best corridors for Gila monster, Sonoran desert tortoise, and Sonoran whipsnake. It is imperative that effective land use planning which considers wildlife and urban barrier mitigation take place within this portion of the linkage, in order to allow wildlife connectivity between the Santa Rita and Sierrita wildland blocks.

Guidelines and Recommendations for Mitigation of Urban Barriers

In addition to the preceding comments specific to the linkage design, we offer the following recommendations to reduce the barrier effects of urban development:

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

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

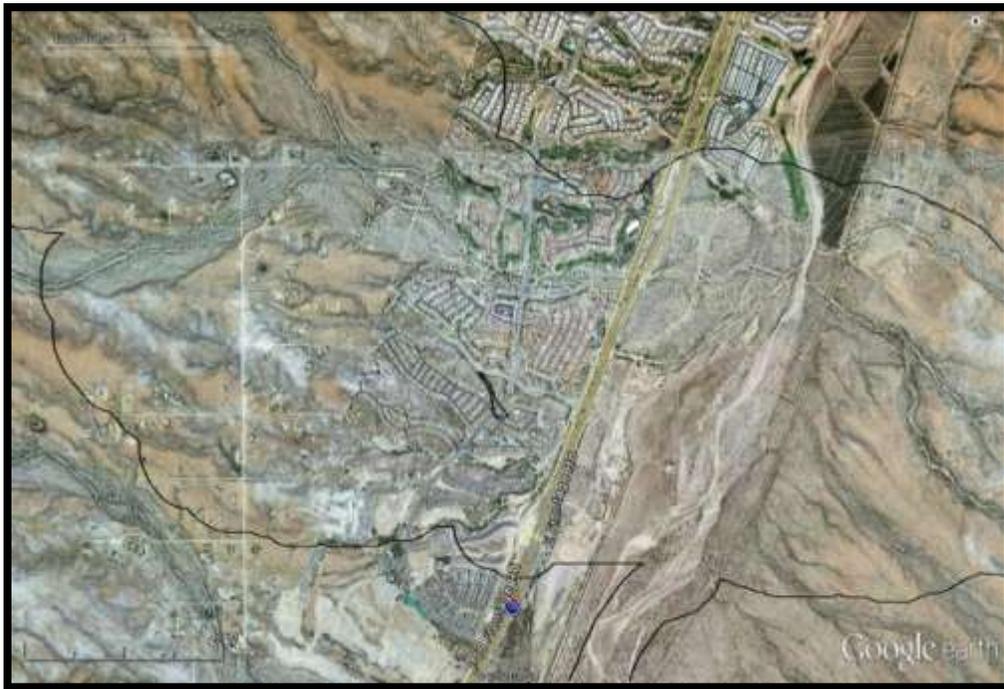


Figure 33: Development within the northern portion of the Santa Rita – Sierrita linkage design

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 area¹. 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 34 below*):

- *Vegetation and land cover.* We used the Southwest Regional GAP Analysis (ReGAP) data, merging some classes to create 46 vegetation and land cover classes as described in *Appendix E*. This dataset was originally classified in 2001 using imagery from previous years. Since, significant development occurred since ReGAP was published, the dataset was updated to represent development using imagery from 2010. This was done by digitizing developed areas on privately owned lands located in areas previously classified in ReGAP as non-developed classes. The digitized areas were then appended to the land cover raster dataset.
- *Elevation.* We used the USGS National Elevation Dataset digital elevation model.
- *Topographic position.* We characterized each pixel as ridge, canyon bottom, flat to gentle slope, or steep slope.
- *Straight-line distance from the nearest paved road or railroad.* Distance from roads reflects risk of being struck by vehicles as well as noise, light, pets, pollution, and other human-caused disturbances.

To create a habitat suitability map, we assigned each of the 46 vegetation classes (and each of 4 topographic positions, and each of several elevation classes and distance-to-road classes) a score from 0 (worst) to 100 (best), where 0-30 is strongly avoided (0 = absolute non-habitat), 30 - 60 may be occasionally used by cannot sustain a breeding population (30 = lowest value associated with occasional use for non-breeding activities), 60-80 is suboptimal but used (60 = lowest value associated with consistent use and breeding), and 80-100 is optimal (80 = lowest score typically associated with successful breeding and 100 = best habitat, highest survival and reproductive success). Whenever possible we recruited biologists with the greatest expertise in each species to assign these scores (see *Acknowledgements*). When no expert was available for a species, three biologists independently assigned scores and, after discussing differences among their individual scores, were allowed to adjust their scores before the three scores were averaged. Regardless of whether the scores were generated by a species expert or our biologists, the scorer first reviewed the literature on habitat selection by the focal species².

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 mean³ using the 4 weighted scores to produce an overall habitat suitability score that was also scaled 1-10 (USFWS 1981). For each pixel of the landscape, the weighted geometric mean was calculated by raising each factor by its weight, and multiplying the factors:

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

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

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

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

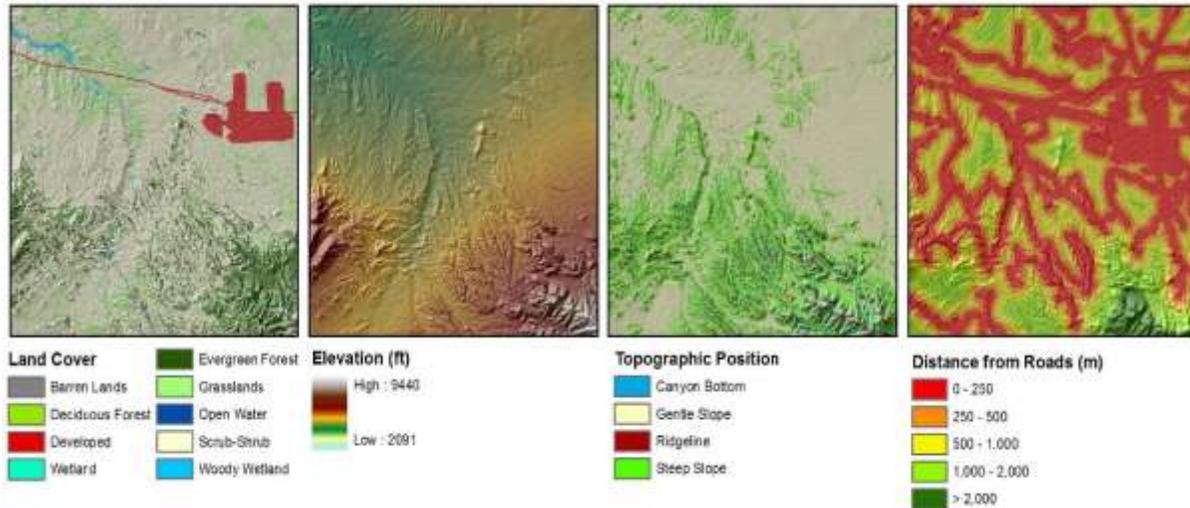


Figure 34: Example moving window analysis which calculates the average habitat suitability surrounding a pixel. a) original habitat suitability model, b) 3x3-pixel moving window, c) 200m radius moving window

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 m², 0.81 ha) for less-mobile species, and within a 200-m radius (12.6 ha) for more-mobile species⁴. 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 touch⁶. 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 pixel⁷. 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 35* 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 dispersal⁸ 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*.

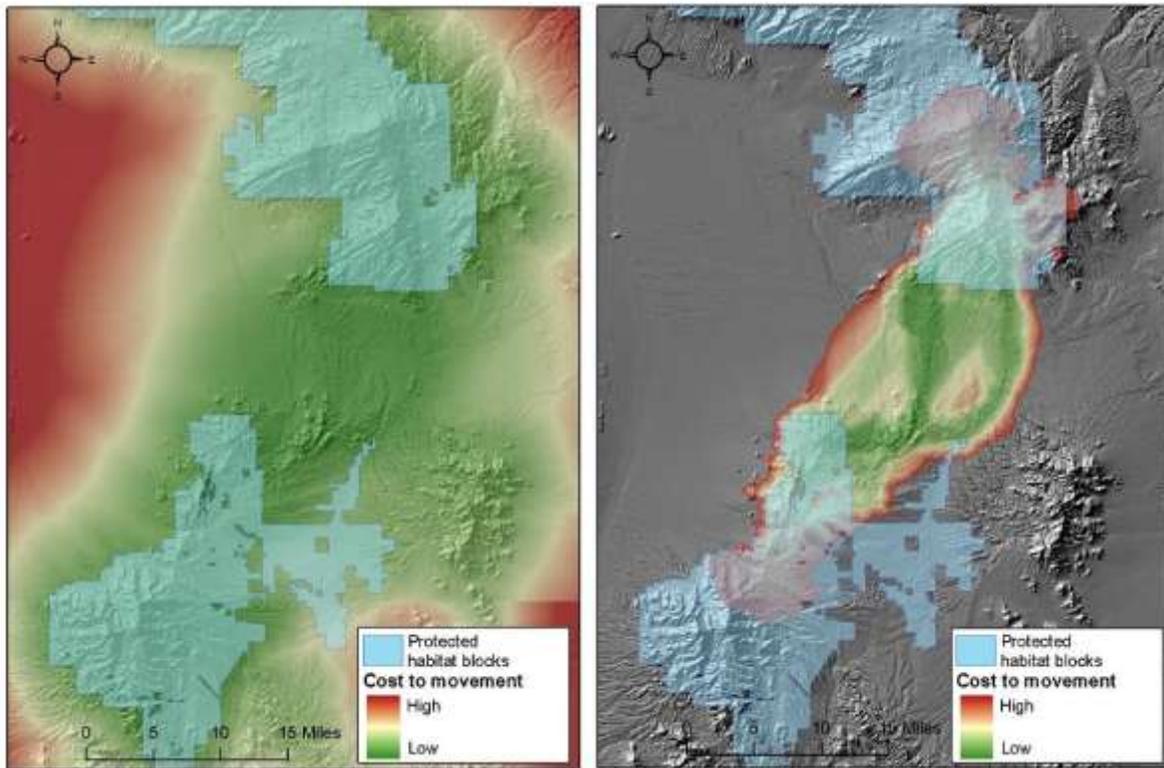


Figure 35: a) Landscape permeability layer for entire landscape, b) biologically best corridor composed of most permeable 10% of landscape

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

Minimum Linkage Width

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

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

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

Field Investigations

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

Appendix B: Individual Species Modeling Parameters

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

	Badger	Black Bear	Black-tailed Jackrabbit	Black-tailed Rattlesnake	Chiricahua Leopard Frog
Factor Weights					
<i>Land Cover</i>	65	75	70	0	55
<i>Elevation</i>	7	10	10	0	25
<i>Topography</i>	15	10	10	90	10
<i>Distance from Roads</i>	13	5	10	10	10
Land Cover					
<i>Conifer-Oak Forest and Woodland</i>	48	100	28		0
<i>Encinal</i>	48	100	50		44
<i>Mixed Conifer Forest and Woodland</i>	44	78	11		33
<i>Pine-Oak Forest and Woodland</i>	52	100	50		44
<i>Pinyon-Juniper Woodland</i>	67	44	67		44
<i>Ponderosa Pine Woodland</i>	52	67	44		44
<i>Spruce-Fir Forest and Woodland</i>	44	67	17		33
<i>Aspen Forest and Woodland</i>	41	56	22		33
<i>Juniper Savanna</i>	89	33	78		44
<i>Montane-Subalpine Grassland</i>	93	67	33		44
<i>Semi-Desert Grassland and Steppe</i>	100	56	72		44
<i>Big Sagebrush Shrubland</i>	78	33	89		0
<i>Blackbrush-Mormon-tea Shrubland</i>	74	22	67		0
<i>Chaparral</i>	52	78	50		44
<i>Creosotebush, Mixed Desert and Thorn Scrub</i>	89	44	94		0
<i>Creosotebush-White Bursage Desert Scrub</i>	89	11	94		0
<i>Desert Scrub (misc)</i>	74	56	100		0
<i>Gambel Oak-Mixed Montane Shrubland</i>	59	78	56		0
<i>Mat Saltbush Shrubland</i>	63	0	67		0
<i>Mesquite Upland Scrub</i>	74	44	72		44
<i>Mixed Low Sagebrush Shrubland</i>	74	22	89		0
<i>Paloverde-Mixed Cacti Desert Scrub</i>	63	56	100		0
<i>Pinyon-Juniper Shrubland</i>	70	44	78		44
<i>Sand Shrubland</i>	70	0	78		0
<i>Stabilized Coppice Dune and Sand Flat Scrub</i>	67	0	78		0
<i>Greasewood Flat</i>	41	11	61		0
<i>Riparian Mesquite Bosque</i>	41	56	61		44
<i>Riparian Woodland and Shrubland</i>	41	56	67		44
<i>Arid West Emergent Marsh</i>	26	56	11		100
<i>Active and Stabilized Dune</i>	22	0	61		0
<i>Badland</i>	37	0	22		0
<i>Barren Lands, Non-specific</i>	33	0	28		0
<i>Bedrock Cliff and Outcrop</i>	15	0	28		0
<i>Cliff and Canyon</i>	11	0	28		0

	Badger	Black Bear	Black-tailed Jackrabbit	Black-tailed Rattlesnake	Chiricahua Leopard Frog
<i>Mixed Bedrock Canyon and Tableland</i>	11	0	22		0
<i>Playa</i>	15	0	22		44
<i>Volcanic Rock Land and Cinder Land</i>	0	0	17		0
<i>Warm Desert Pavement</i>	11	0	17		0
<i>Wash</i>	22	22	56		44
<i>Invasive Grassland or Forbland</i>	63	0	61		44
<i>Invasive Riparian Woodland and Shrubland</i>	26	0	56		44
<i>Recently Mined or Quarried</i>	7	0	0		0
<i>Agriculture</i>	48	44	50		44
<i>Developed, Medium - High Intensity</i>	0	0	11		33
<i>Developed, Open Space - Low Intensity</i>	30	0	44		44
<i>Open Water</i>	7	0	11		89
Elevation (ft)					
	0 - 1676: 100	0 - 762: 22	0 - 1829: 100		0 - 1006: 0
	1676 - 2438: 78	762 - 1219: 44	1829 - 2438: 67		1006 - 1829 : 100
	2438 - 4000: 44	1219 - 1981: 100	2438 - 4000: 22		1829 - 2743: 89
		1981 - 2591: 89			2743 - 4000: 78
		2591 - 4000: 67			
Topographic Position					
<i>Canyon Bottom</i>	56	78	72	100	100
<i>Flat - Gentle Slopes</i>	100	44	94	11	100
<i>Steep Slope</i>	26	78	67	100	44
<i>Ridgetop</i>	37	67	67	100	33
Distance from Roads					
	0 - 250: 44	0 - 100: 11	0 - 250: 11	0 - 35: 0	0 - 100: 22
	250 - 15000: 100	100 - 500: 67	250 - 500: 44	35 - 500: 56	100 - 500: 56
		500 - 1500: 100	500 - 1000: 78	500 - 15000: 100	500 - 1000: 78
			1000 - 15000: 100	100	1000 - 15000: 100

	Coues' White-tailed Deer	Desert Box Turtle	Giant Spotted Whiptail	Gila Monster	Jaguar
Factor Weights					
<i>Land Cover</i>	65	40	70	70	60
<i>Elevation</i>	5	15	30	10	5
<i>Topography</i>	15	20	0	10	15
<i>Distance from Roads</i>	15	25	0	10	20
Land Cover					
<i>Conifer-Oak Forest and Woodland</i>	89	0	0	28	89
<i>Encinal</i>	100	44	44	50	89
<i>Mixed Conifer Forest and Woodland</i>	72	0	0	11	78
<i>Pine-Oak Forest and Woodland</i>	89	0	0	50	78
<i>Pinyon-Juniper Woodland</i>	83	0	0	44	89
<i>Ponderosa Pine Woodland</i>	61	0	0	0	67
<i>Spruce-Fir Forest and Woodland</i>	50	0	0	0	67
<i>Aspen Forest and Woodland</i>	56	0	0	0	44
<i>Juniper Savanna</i>	83	33	0	0	78
<i>Montane-Subalpine Grassland</i>	50	0	0	0	67
<i>Semi-Desert Grassland and Steppe</i>	44	89	33	56	100
<i>Big Sagebrush Shrubland</i>	17	0	0	0	67
<i>Blackbrush-Mormon-tea Shrubland</i>	22	0	0	0	56
<i>Chaparral</i>	78	44	67	44	67
<i>Creosotebush, Mixed Desert and Thorn Scrub</i>	56	56	67	78	89
<i>Creosotebush-White Bursage Desert Scrub</i>	33	44	0	33	67
<i>Desert Scrub (misc)</i>	50	56	0	78	67
<i>Gambel Oak-Mixed Montane Shrubland</i>	94	0	0	0	78
<i>Mat Saltbush Shrubland</i>	22	0	0	0	56
<i>Mesquite Upland Scrub</i>	72	78	33	67	67
<i>Mixed Low Sagebrush Shrubland</i>	22	0	0	0	44
<i>Paloverde-Mixed Cacti Desert Scrub</i>	22	56	0	100	56
<i>Pinyon-Juniper Shrubland</i>	83	0	0	44	67
<i>Sand Shrubland</i>	17	89	0	0	44
<i>Stabilized Coppice Dune and Sand Flat Scrub</i>	22	89	0	0	44
<i>Greasewood Flat</i>	61	0	0	0	78
<i>Riparian Mesquite Bosque</i>	78	100	67	56	100
<i>Riparian Woodland and Shrubland</i>	89	100	100	56	100
<i>Arid West Emergent Marsh</i>	56	78	89	89	89
<i>Active and Stabilized Dune</i>	6	0	0	0	11

	Coues' White-tailed Deer	Desert Box Turtle	Giant Spotted Whiptail	Gila Monster	Jaguar
<i>Badland</i>	6	0	0	0	11
<i>Barren Lands, Non-specific</i>	0	33	0	0	0
<i>Bedrock Cliff and Outcrop</i>	22	0	0	0	44
<i>Cliff and Canyon</i>	22	0	0	89	0
<i>Mixed Bedrock Canyon and Tableland</i>	11	0	0	89	0
<i>Playa</i>	6	33	0	89	0
<i>Volcanic Rock Land and Cinder Land</i>	6	0	0	0	11
<i>Warm Desert Pavement</i>	0	0	0	100	11
<i>Wash</i>	22	33	56	44	22
<i>Invasive Grassland or Forbland</i>	44	56	0	78	56
<i>Invasive Riparian Woodland and Shrubland</i>	67	89	0	67	78
<i>Recently Mined or Quarried</i>	11	0	0	0	0
<i>Agriculture</i>	33	56	67	0	11
<i>Developed, Medium - High Intensity</i>	0	0	67	11	0
<i>Developed, Open Space - Low Intensity</i>	17	56	78	100	0
<i>Open Water</i>	33	56	89	0	33
Elevation (ft)					
	0 - 610: 33	0 - 579: 0	0 - 610: 0	0 - 518: 67	0 - 1219: 78
	610 - 914: 44	579 - 792: 67	610 - 701: 56	518 - 1219: 100	1219 - 1829: 100
	914 - 1219: 89	792 - 1676: 100	701 - 1219: 100	1219 - 1463: 67	1829 - 2438: 78
	1219 - 1829: 100	1676 - 1981: 56	1219 - 1402: 67	1463 - 1737: 33	2438 - 4000: 67
	1829 - 2438: 78	1981 - 4000: 11	1402 - 1524: 11	1737 - 4000: 0	
	2438 - 4000: 33		1524 - 4000: 0		
Topographic Position		78	0	100	100
<i>Canyon Bottom</i>	100	100	44	56	56
<i>Flat - Gentle Slopes</i>	61	67	0	100	89
<i>Steep Slope</i>	94	67	0	100	67
<i>Ridgetop</i>	67		0		
Distance from Roads		0 - 500: 56		0 - 1000: 56	0 - 250: 1
	0 - 610: 33	500 - 1500: 78		1000 - 3000: 78	250 - 500: 33
	610 - 914: 44	500 - 15000: 100		3000 - 15000: 100	500 - 1000: 56
	914 - 1219: 89				1000 - 2000: 89
	1219 - 1829: 100				2000 - 15000: 100
	1829 - 2438: 78				
	2438 - 4000: 33				

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

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

	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake	White-nosed Coati
Factor Weights				
<i>Land Cover</i>	5	30	30	95
<i>Elevation</i>	50	25	10	0
<i>Topography</i>	25	40	45	0
<i>Distance from Roads</i>	20	5	15	5
Land Cover				
<i>Conifer-Oak Forest and Woodland</i>	0	0	0	89
<i>Encinal</i>	33	33	100	100
<i>Mixed Conifer Forest and Woodland</i>	0	0	0	100
<i>Pine-Oak Forest and Woodland</i>	0	0	100	89
<i>Pinyon-Juniper Woodland</i>	0	0	100	89
<i>Ponderosa Pine Woodland</i>	0	0	56	89
<i>Spruce-Fir Forest and Woodland</i>	0	0	0	33
<i>Aspen Forest and Woodland</i>	0	0	0	33
<i>Juniper Savanna</i>	67	0	78	56
<i>Montane-Subalpine Grassland</i>	0	0	0	33
<i>Semi-Desert Grassland and Steppe</i>	89	22	89	33
<i>Big Sagebrush Shrubland</i>	0	0	0	33
<i>Blackbrush-Mormon-tea Shrubland</i>	0	0	0	33
<i>Chaparral</i>	67	0	100	56
<i>Creosotebush, Mixed Desert and Thorn Scrub</i>	89	44	89	56
<i>Creosotebush-White Bursage Desert Scrub</i>	67	56	33	33
<i>Desert Scrub (misc)</i>	89	67	78	22
<i>Gambel Oak-Mixed Montane Shrubland</i>	0	0	0	67
<i>Mat Saltbush Shrubland</i>	0	0	0	11
<i>Mesquite Upland Scrub</i>	100	33	89	78
<i>Mixed Low Sagebrush Shrubland</i>	0	0	0	44
<i>Paloverde-Mixed Cacti Desert Scrub</i>	100	100	100	44
<i>Pinyon-Juniper Shrubland</i>	67	0	100	78
<i>Sand Shrubland</i>	89	0	0	11
<i>Stabilized Coppice Dune and Sand Flat Scrub</i>	89	0	0	11
<i>Greasewood Flat</i>	0	44	0	56
<i>Riparian Mesquite Bosque</i>	100	56	89	89
<i>Riparian Woodland and Shrubland</i>	89	0	89	100
<i>Arid West Emergent Marsh</i>	56	0	78	78
<i>Active and Stabilized Dune</i>	33	0	0	11
<i>Badland</i>	0	0	0	11
<i>Barren Lands, Non-specific</i>	33	0	0	11
<i>Bedrock Cliff and Outcrop</i>	56	0	78	33
<i>Cliff and Canyon</i>	56	0	56	67
<i>Mixed Bedrock Canyon and Tableland</i>	56	0	0	44
<i>Playa</i>	78	22	0	0

	Sonoran Desert Toad	Sonoran Desert Tortoise	Sonoran Whipsnake	White-nosed Coati
<i>Volcanic Rock Land and Cinder Land</i>	0	0	67	33
<i>Warm Desert Pavement</i>	56	44	0	33
<i>Wash</i>	78	78	67	56
<i>Invasive Grassland or Forbland</i>	78	11	22	33
<i>Invasive Riparian Woodland and Shrubland</i>	78	0	0	67
<i>Recently Mined or Quarried</i>	67	0	0	11
<i>Agriculture</i>	67	0	0	56
Developed, Medium - High Intensity	44	0	0	11
Developed, Open Space - Low Intensity	67	33	56	33
Open Water	67	0	0	0
<i>Elevation (ft)</i>				
	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	
<i>Topographic Position</i>				
Canyon Bottom	100	100	100	
Flat - Gentle Slopes	100	100	33	
Steep Slope	44	44	100	
Ridgetop	44	44	100	
<i>Distance from Roads</i>				
	0 - 200: 5	0 - 250: 56	0 - 500: 56	0 - 500: 22
	200 - 1000: 67	250 - 500: 67	500 - 1000: 67	500 - 1000: 78
	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

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 km² (Long 1973). Goodrich and Buskirk (1998) found an average home range of 12.3 km² for males and 3.4 km² 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 km². Messick and Hornocker (1981) found an average home range of 2.4 km² for adult males and 1.6 km² 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 km², 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 km², 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.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for badger in the BBC used within the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100.0, with an average suitability of 89.5 (S.D: 14.9; see *Figure 36* below). Most of the BBC (99.7%) is occupied by a potential population core (see *Figure 37* below). Most of the BBC (91.5%) was greater than its estimated needed minimum width (see *Figure 83* below). The BBC was measured at 46.0 km (28.6 mi) in length between wildland blocks used for analysis.

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

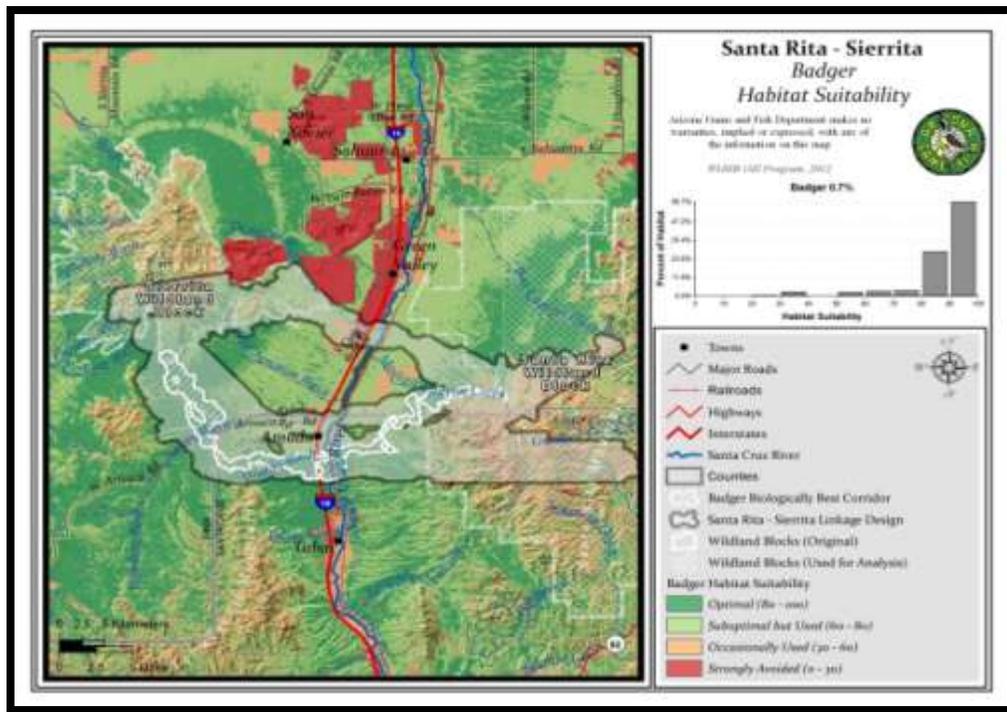


Figure 36: Map of Santa Rita – Sierrita habitat suitability for badger

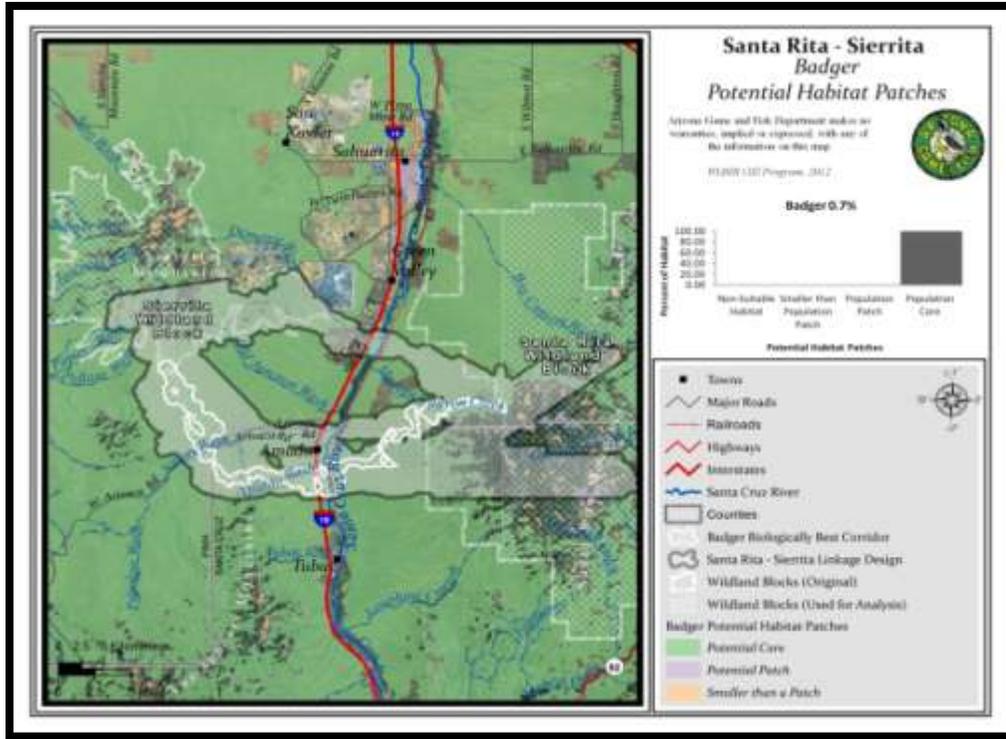


Figure 37: Map of Santa Rita – Sierrita potential habitat patches for badger

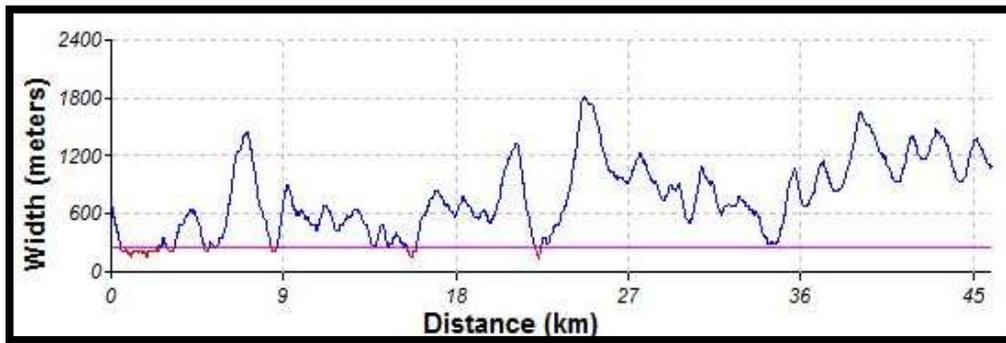


Figure 38: Width along the Santa Rita – Sierrita badger biologically best corridor

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).

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).

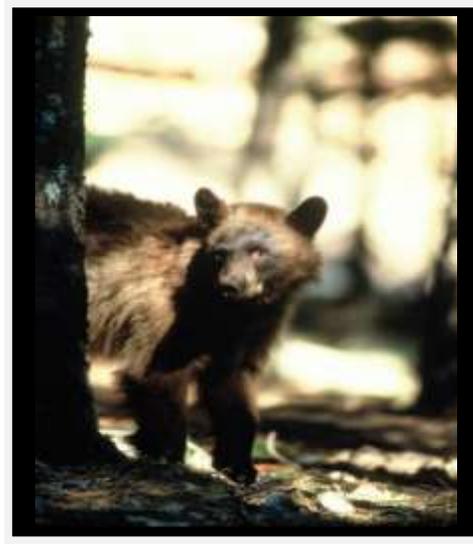


Photo courtesy George Andrejko, AGFD

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. However, because black bear distribution in the Sierrita Mountains may be limited, a biologically best corridor for black bear was not included in the linkage design.

Results and Discussion

Union of biologically best corridors – Optimal habitat for black bear is captured in the steep terrain of both the Santa Rita and Sierrita Mountains, and additional occasionally used habitat is captured in the linkage design (see *Figure 39* below). Potential population cores for black bear are also captured in the linkage design in the steep terrain of the Santa Rita and Sierrita Mountains (see *Figure 40* below).

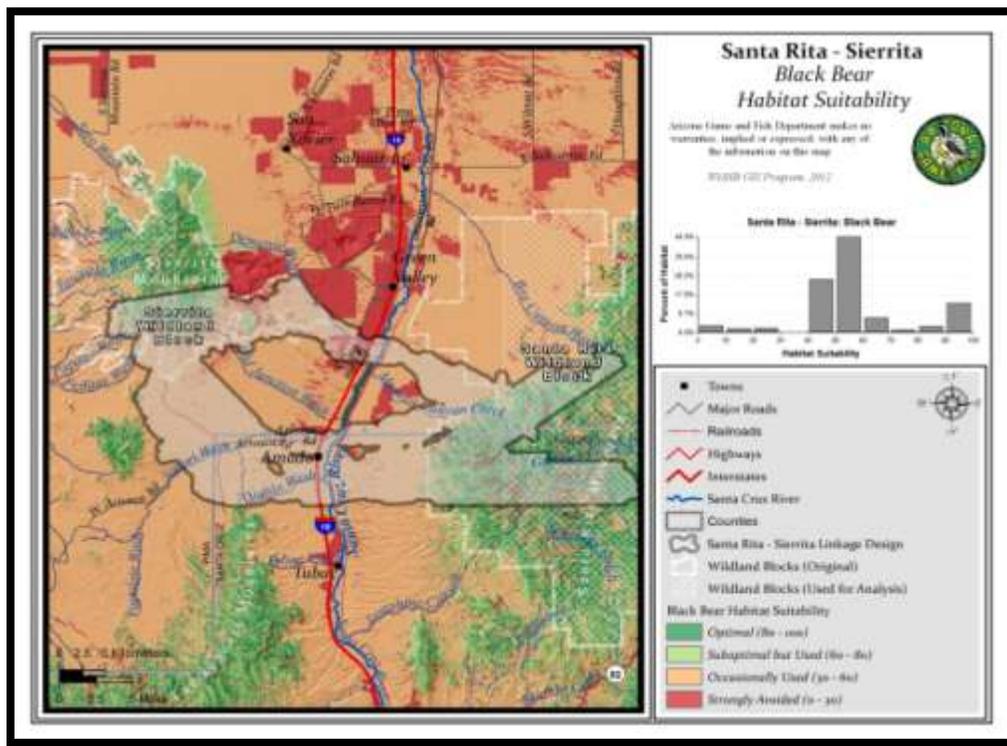


Figure 39: Map of Santa Rita – Sierrita habitat suitability for black bear

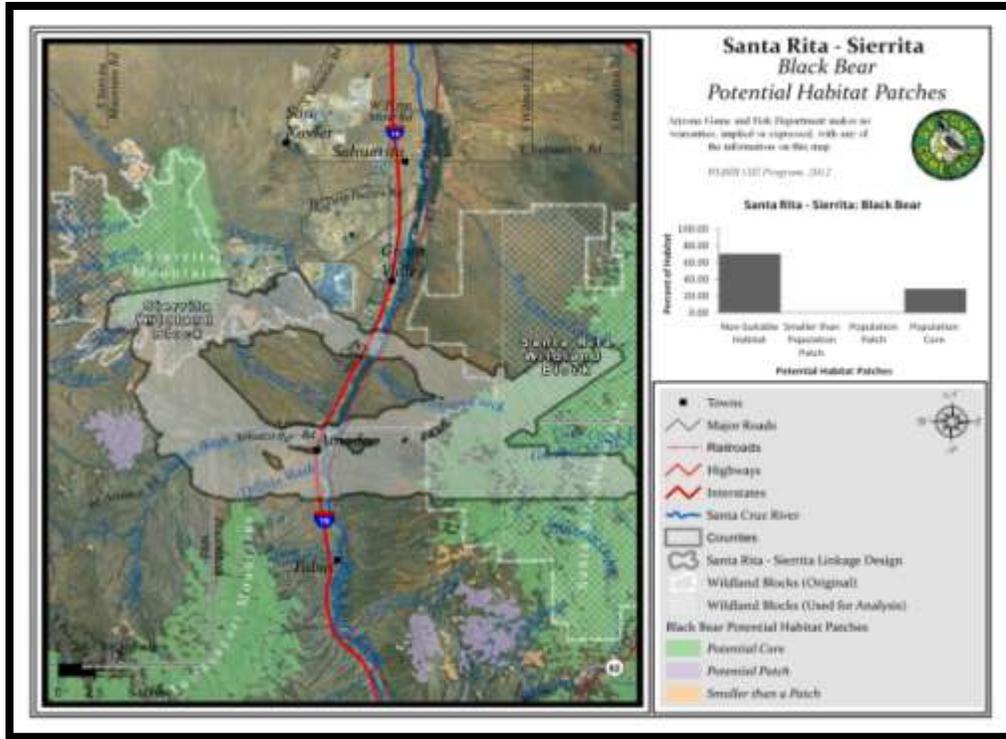


Figure 40: Map of Santa Rita – Sierrita potential habitat patches for black bear

Black-tailed Jackrabbit, *Lepus californius*

Justification for Selection

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

Distribution

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

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).



Photo courtesy George Andrejko, AGFD

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. However, a biologically best corridor for black-tailed jackrabbit was not included, due to its length, and additional suitable habitat throughout the rest of the linkage design.

Results and Discussion

Union of biologically best corridors – The linkage design captures mostly optimal and suboptimal but used habitat for black-tailed jackrabbit (see *Figure 41* below). Almost the entire linkage design captures potential population cores for black-tailed jackrabbit (see *Figure 42* below).

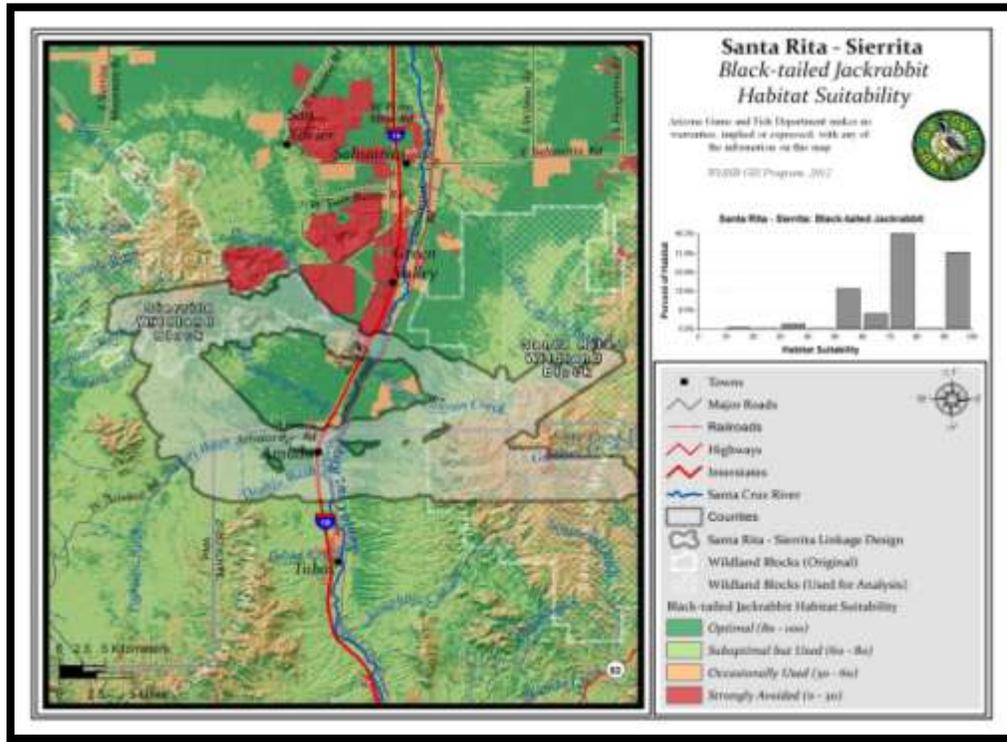


Figure 41: Map of Santa Rita – Sierrita habitat suitability for black-tailed jackrabbit

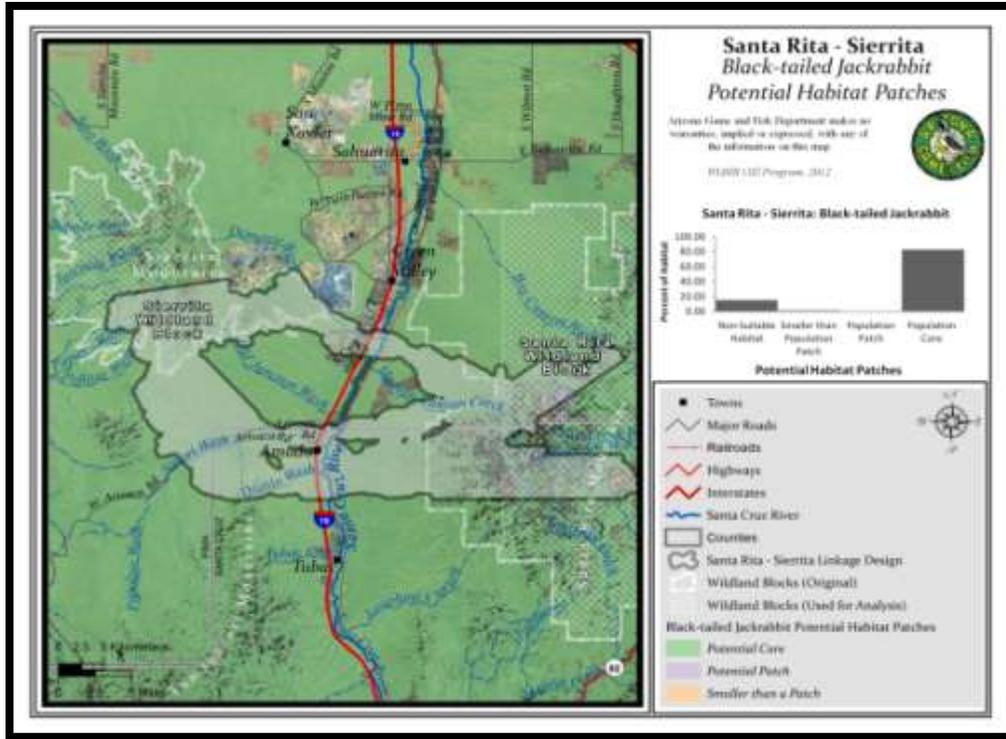


Figure 42: Map of Santa Rita – Sierrita potential habitat patches for black-tailed jackrabbit

Black-tailed Rattlesnake, *Crotalus molossus*

Justification for Selection

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

Distribution

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



Photo courtesy Randy Babb, AGFD

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – While this species is a vegetation generalist, it is strongly associated with rocks and outcrops on mountain slopes, and rarely seen at any distance from these environments (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team). Because of this strong topographic association, topography received an importance weight of 90%, while distance from roads received a weight of 10%. For specific scores of classes within each of these factors, see *Table 7*.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. However, a biologically best corridor for black-tailed rattlesnake was not included in the linkage design due to dispersal distance of similar species (Matt Goode and Phil Rosen, personal comm. to CorridorDesign Team), and length between potential patches within the biologically best corridor.

Results and Discussion

Union of biologically best corridors – The linkage design captures some optimal and strongly avoided habitat for black-tailed rattlesnake (see *Figure 43* below). The linkage design also captures potential population cores for the species (see *Figure 44* below). Connectivity for this species may still exist in the southern portion of the linkage design, where potential cores are within possible dispersal distances. However, the Union Pacific Railroad, along with Interstate 19 and its associated frontage roads, are major barriers to black-tailed rattlesnake movements.

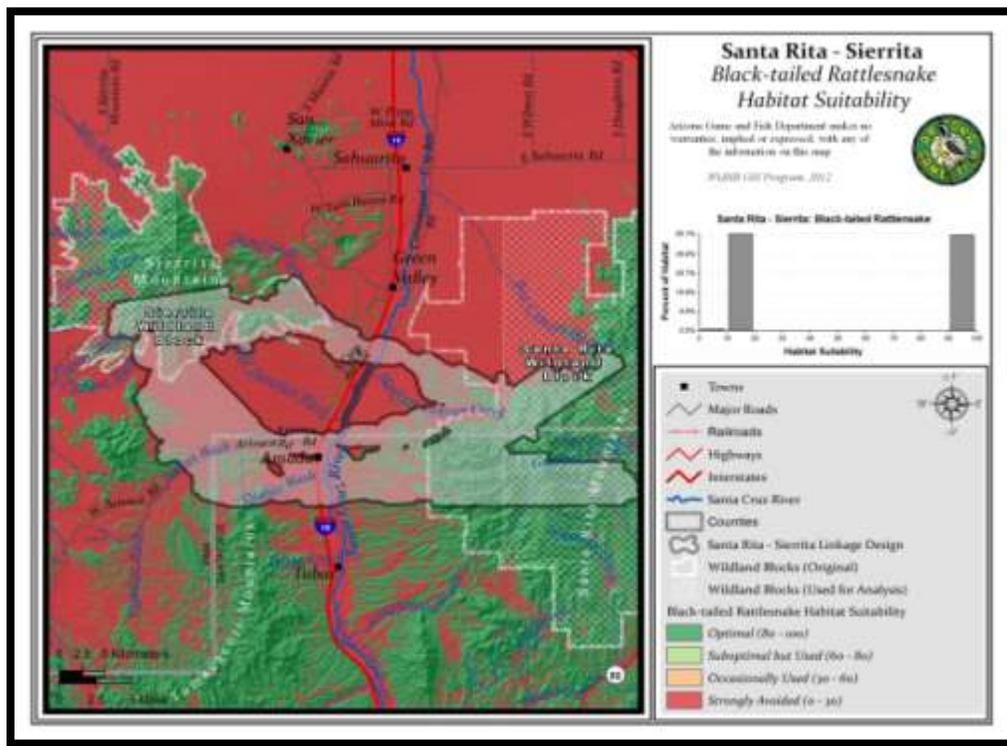


Figure 43: Map of Santa Rita – Sierrita habitat suitability for black-tailed rattlesnake

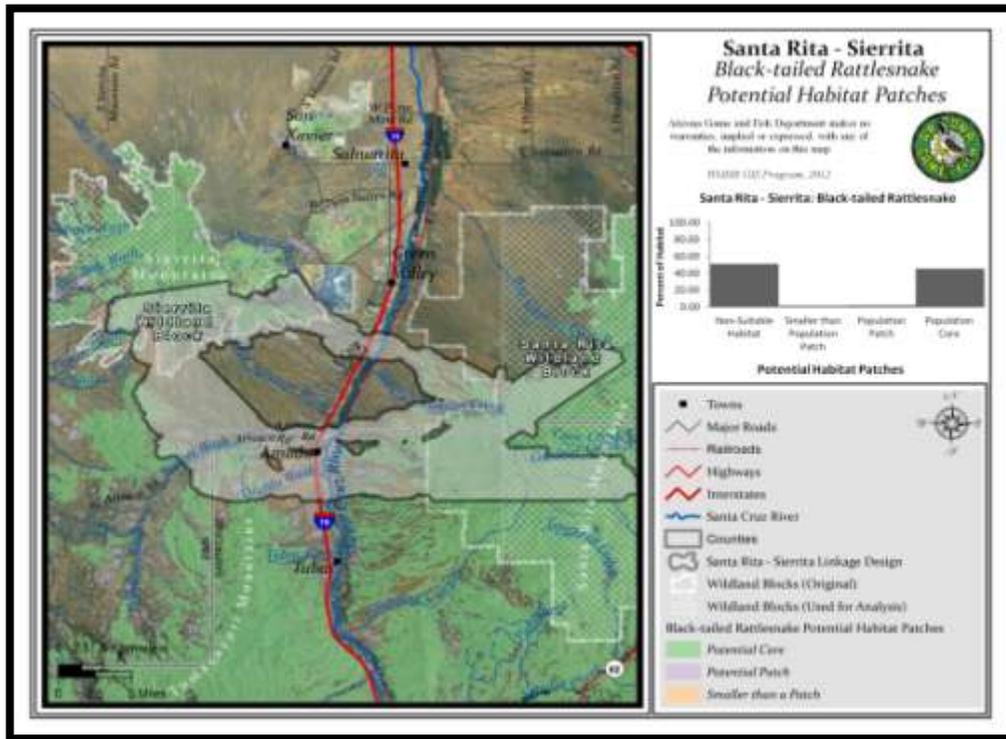


Figure 44: Map of Santa Rita – Sierrita potential habitat patches for black-tailed rattlesnake

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

Justification for Selection

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).



Photo courtesy Christina Akins, AGFD

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 were classified as a corridor dweller due to observed dispersal distances (Pima Co., Arizona 2001), and distance between wildland blocks used in this analysis.

Results and Discussion

Initial biologically best corridor – Modeling results indicate some suitable habitat for Chiricahua leopard frog in the BBC used within the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 63.7, with an average suitability of 53.0 (S.D: 22.1; see *Figure 45* below). Some of the BBC (59.0%) is occupied by potential population cores, with a small portion occupying potential patches (0.2%), and the rest containing non-suitable habitat (see *Figure 46* below). All of the BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 47* below). The BBC was measured at 36.8 km (22.9 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures mostly additional suboptimal but used habitat and strongly avoided habitat for Chiricahua leopard frog. Some additional potential population cores are also captured.

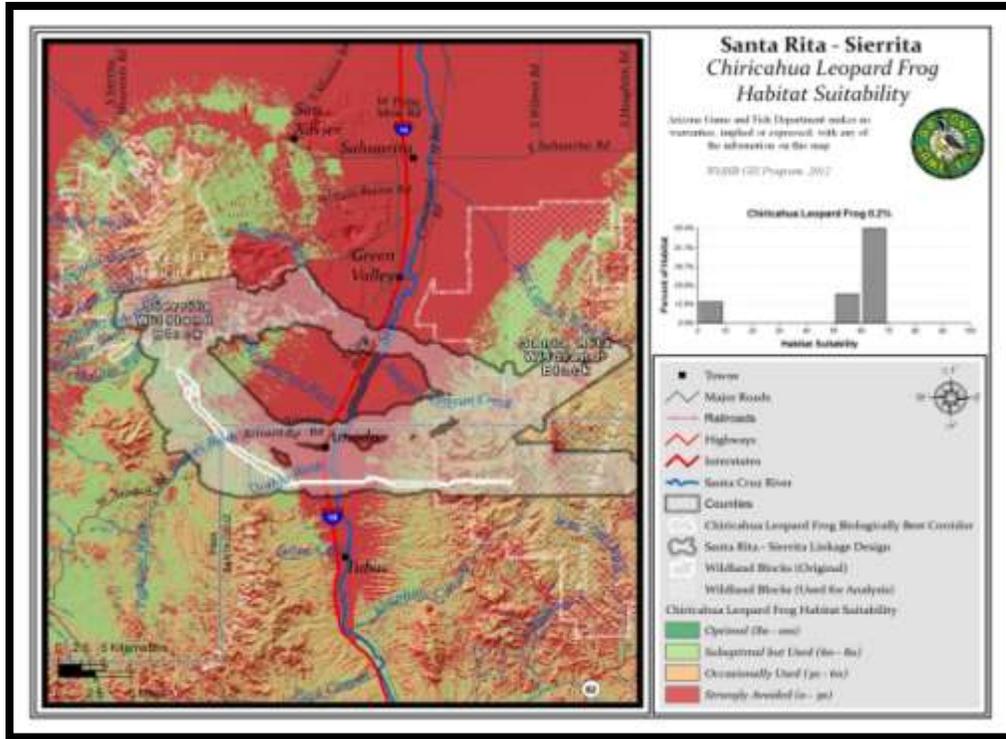


Figure 45: Map of Santa Rita – Sierrita habitat suitability for Chiricahua leopard frog

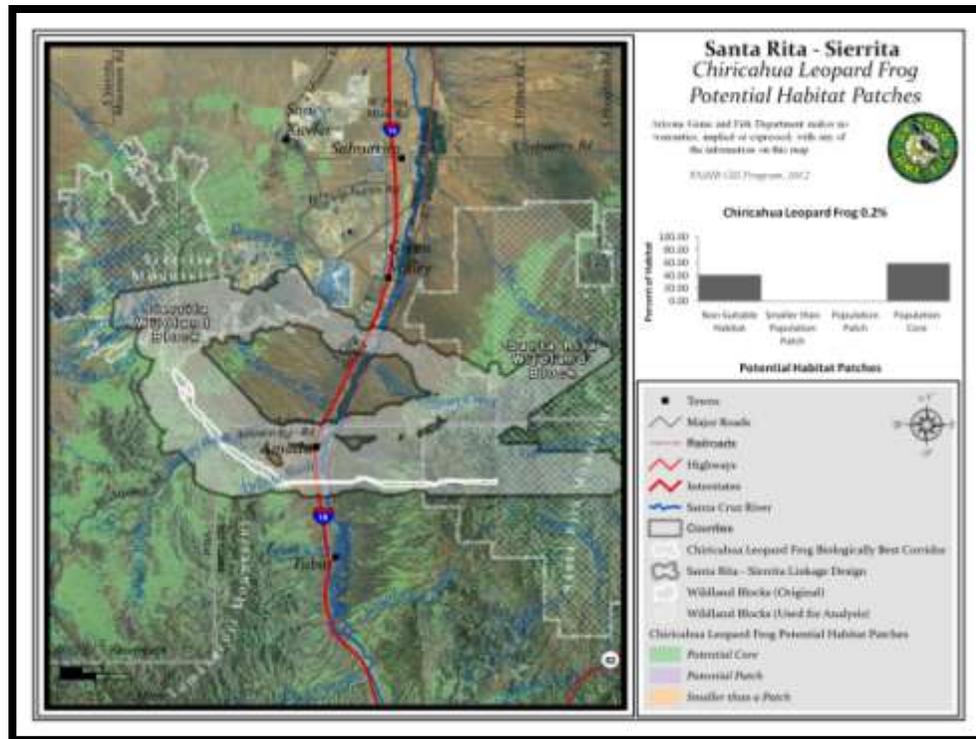


Figure 46: Map of Santa Rita – Sierrita potential habitat patches for Chiricahua leopard frog

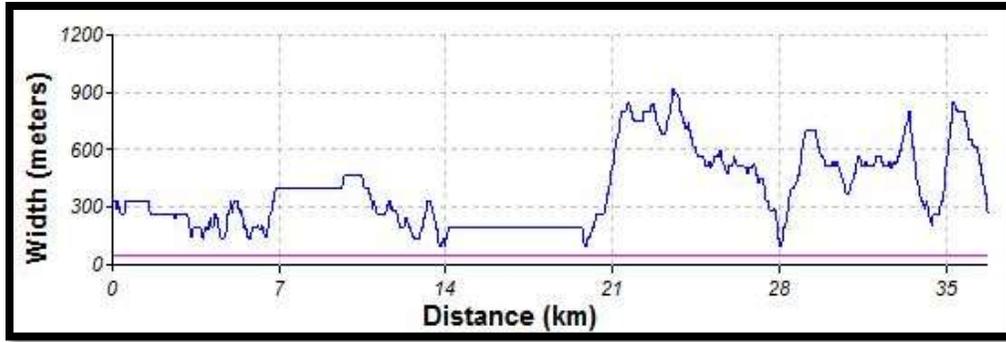


Figure 47: Width along the Santa Rita – Sierrita Chiricahua leopard frog biologically best corridor

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. The original biologically best corridor for this species was trimmed to eliminate “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for Coues’ white-tailed deer in the trimmed BBC used within the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100.0, with an average suitability of 71.9 within the trimmed BBC (S.D: 19.3; see *Figure 48* below). Most of the trimmed BBC (68.7%) is occupied by a potential population core, with a small portion containing potential habitat patches (5.4%) and suitable habitat smaller than a patch (3.2%), and the rest containing non-suitable habitat (see *Figure 49* below). All of the trimmed BBC (100.0%) was greater than its estimated needed minimum width (see *Figure 50* below). The trimmed BBC was measured at 38.9 km (24.2 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional suitable habitat and potential population cores for Coues’ white-tailed deer.

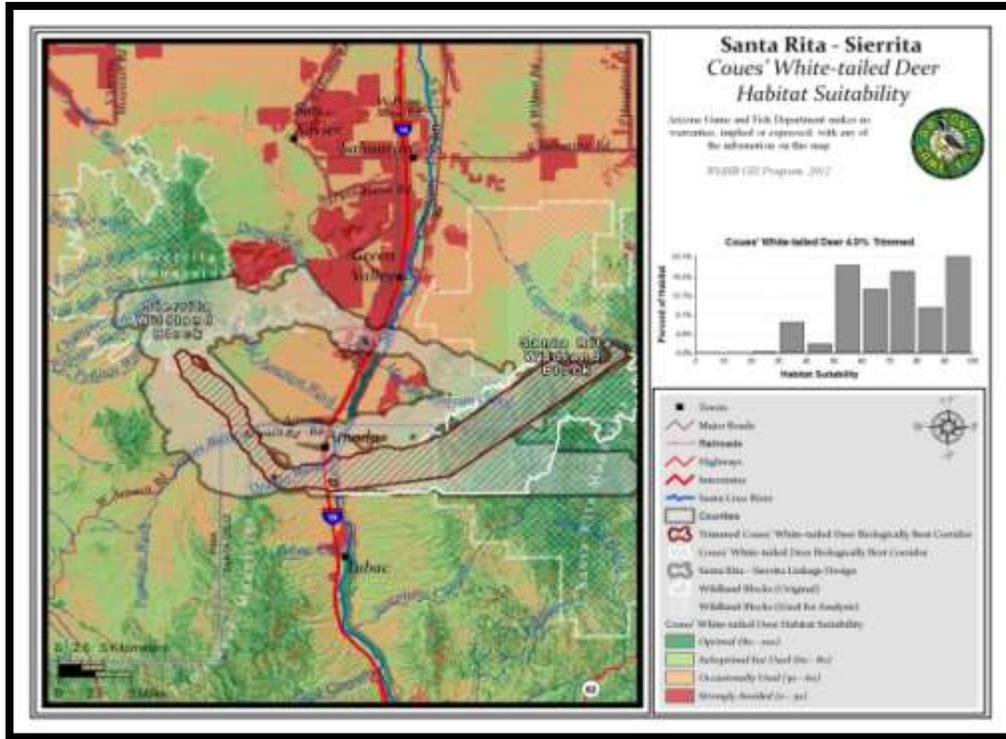


Figure 48: Map of Santa Rita – Sierrita habitat suitability for Coues' white-tailed deer

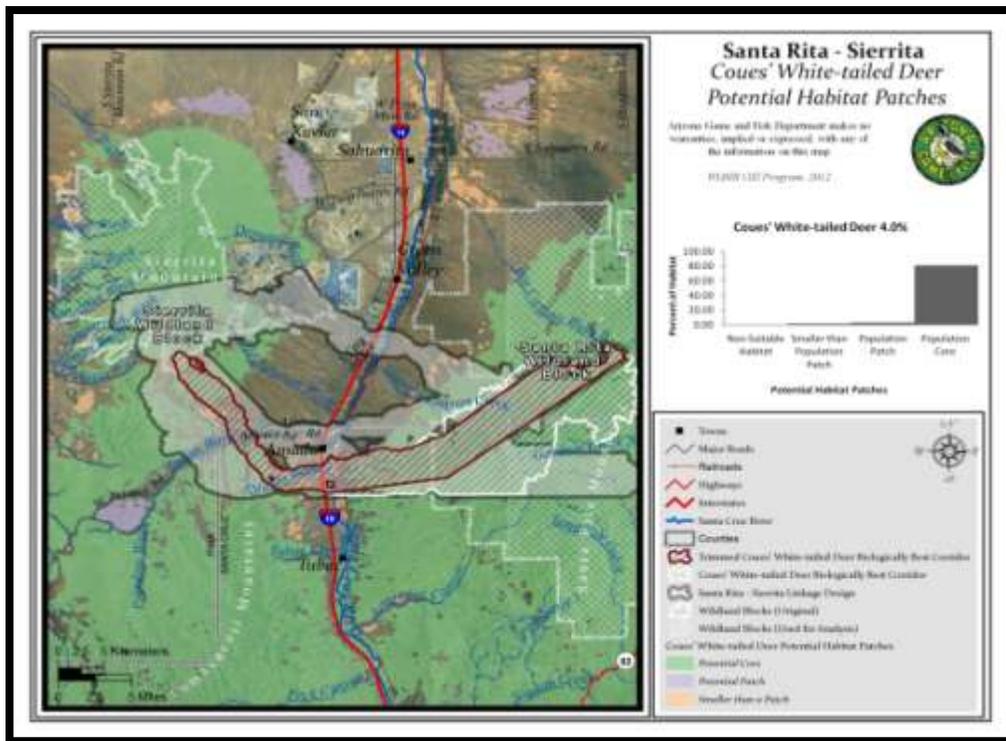


Figure 49: Map of Santa Rita – Sierrita potential habitat patches for Coues' white-tailed deer

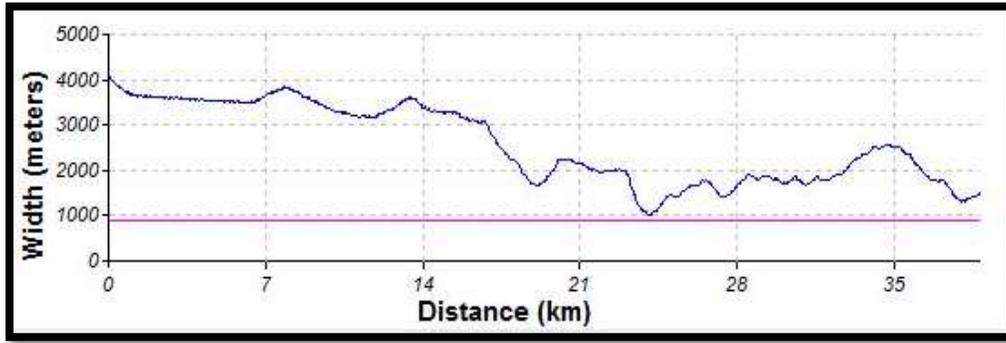


Figure 50: Width along the Santa Rita – Sierrita Coues’ white-tailed deer trimmed biologically best corridor

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).

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).



Photo courtesy George Andrejko, AGFD

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).

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for desert box turtle within the BBC used in the Santa Rita – Sierrita linkage. Habitat suitability scores ranged from 0 to 100, with an average suitability of 88.3 (S.D: 9.2; see *Figure 51* below). Almost the BBC (99.4%) is occupied by potential population cores (see *Figure 52* below). Most of the BBC (91.5%) was greater than its estimated needed minimum width (see *Figure 53* below). The corridor was measured at 40.0 km (24.9 mi) in length between wildland blocks used for analysis.

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

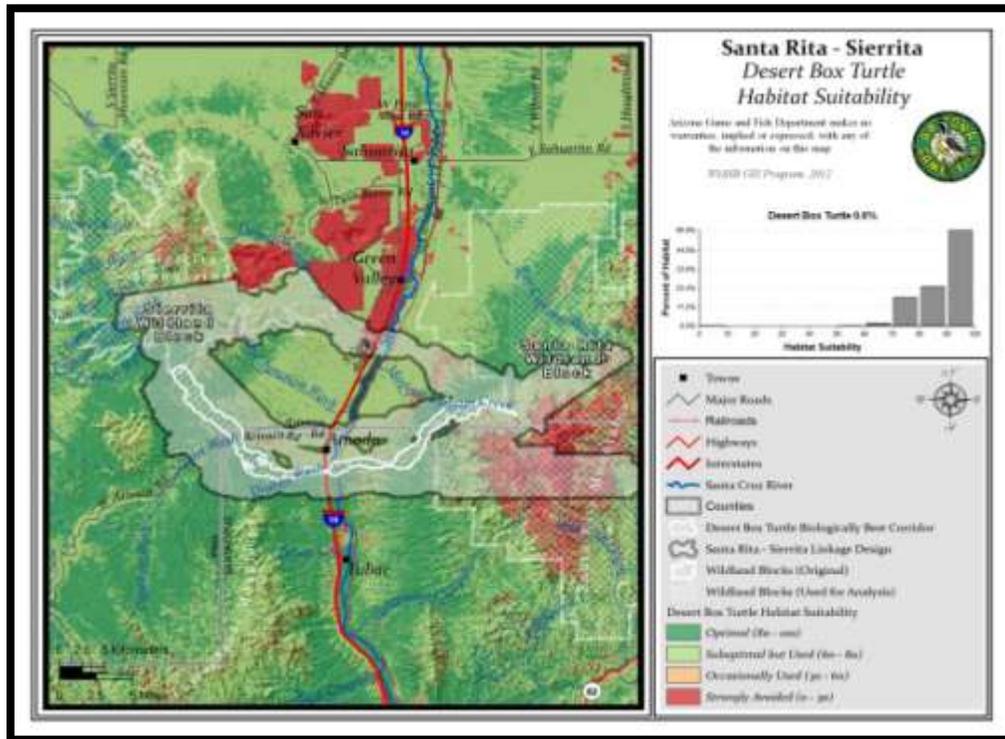


Figure 51: Map of Santa Rita – Sierrita habitat suitability for desert box turtle

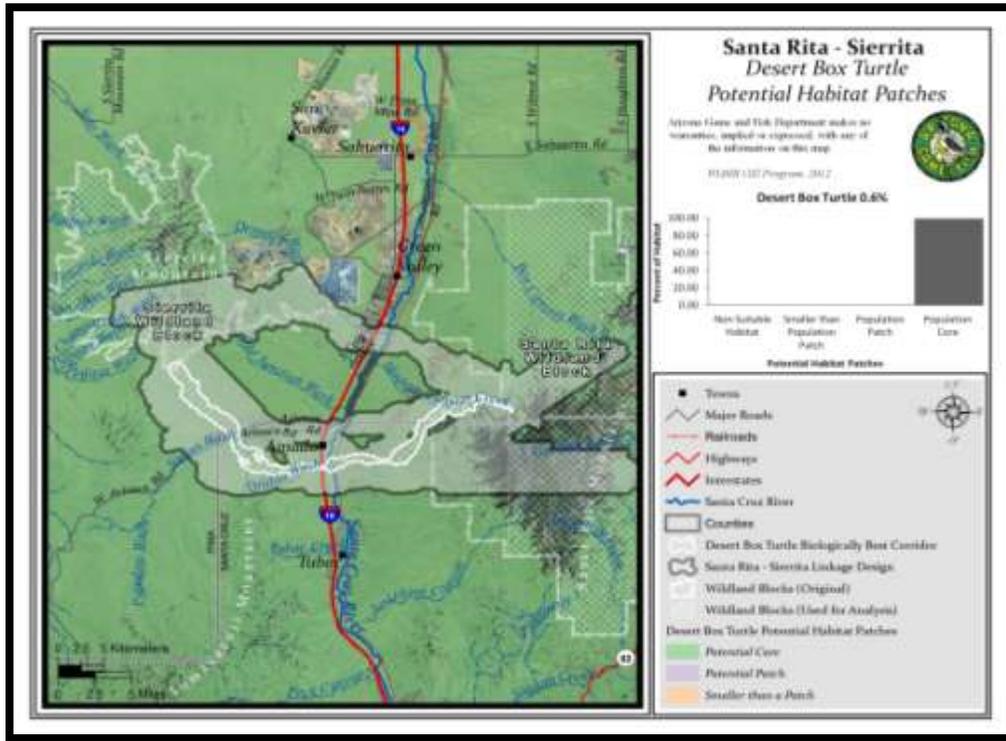


Figure 52: Map of Santa Rita – Sierrita potential habitat patches for desert box turtle

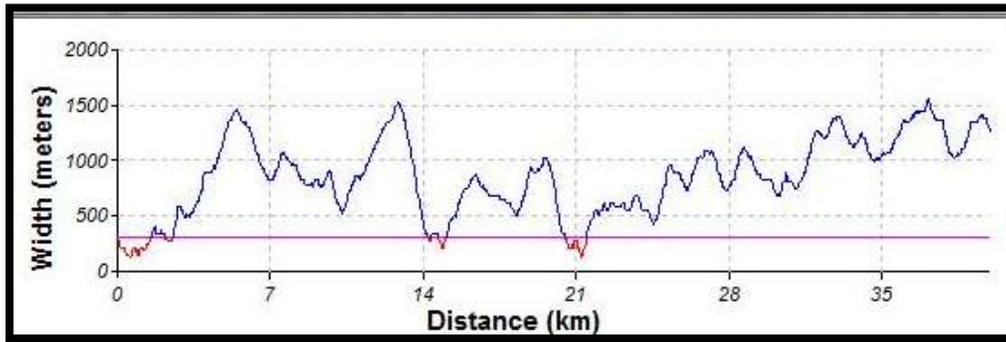


Figure 53: Width along the Santa Rita – Sierrita desert box turtle biologically best corridor

Giant Spotted Whiptail, *Aspidoscelis burti stictogrammus*

Justification for Selection

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



Photo courtesy Randy Babb, AGFD

Distribution

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

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 70%, while elevation received a weight of 30%. 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. However, we did not include a biologically best corridor for giant spotted whiptail in the linkage design, due to it occurring mostly within the matrix.

Results and Discussion

Union of biologically best corridors – Although the linkage design captures mostly strongly avoided and occasionally used habitat for giant spotted whiptail, some additional suboptimal but used and optimal habitat is captured, mostly along the Santa Cruz River (see *Figure 54* below). Some additional potential population cores are also captured by the linkage design, again mostly along the Santa Cruz River (see *Figure 55* below).

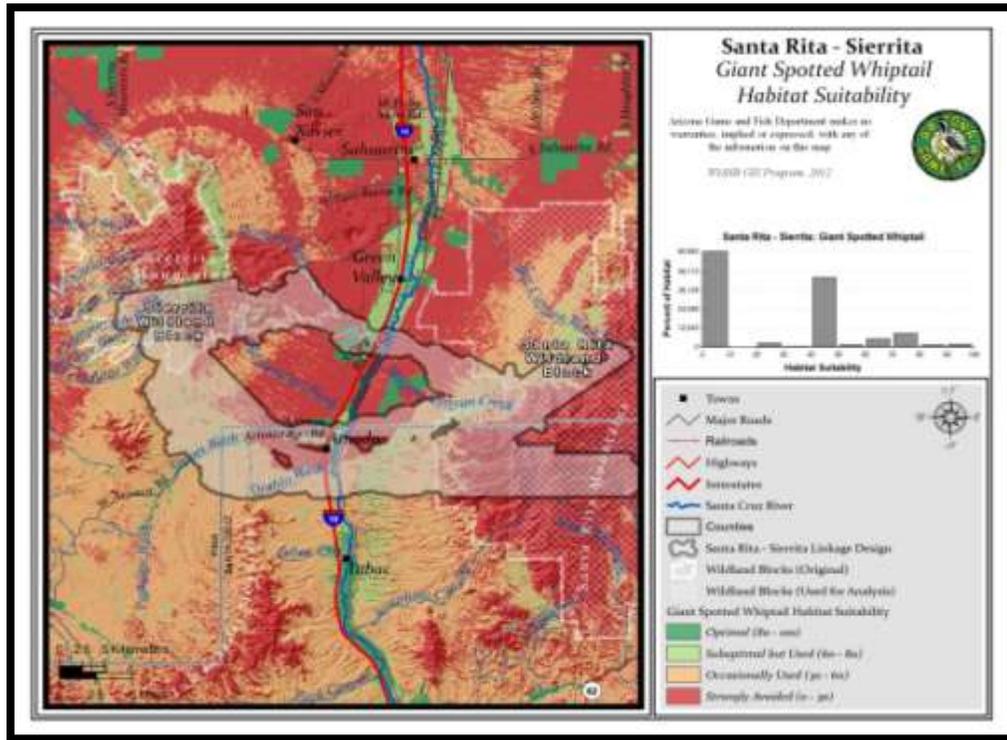


Figure 54: Map of Santa Rita – Sierrita habitat suitability for giant spotted whiptail

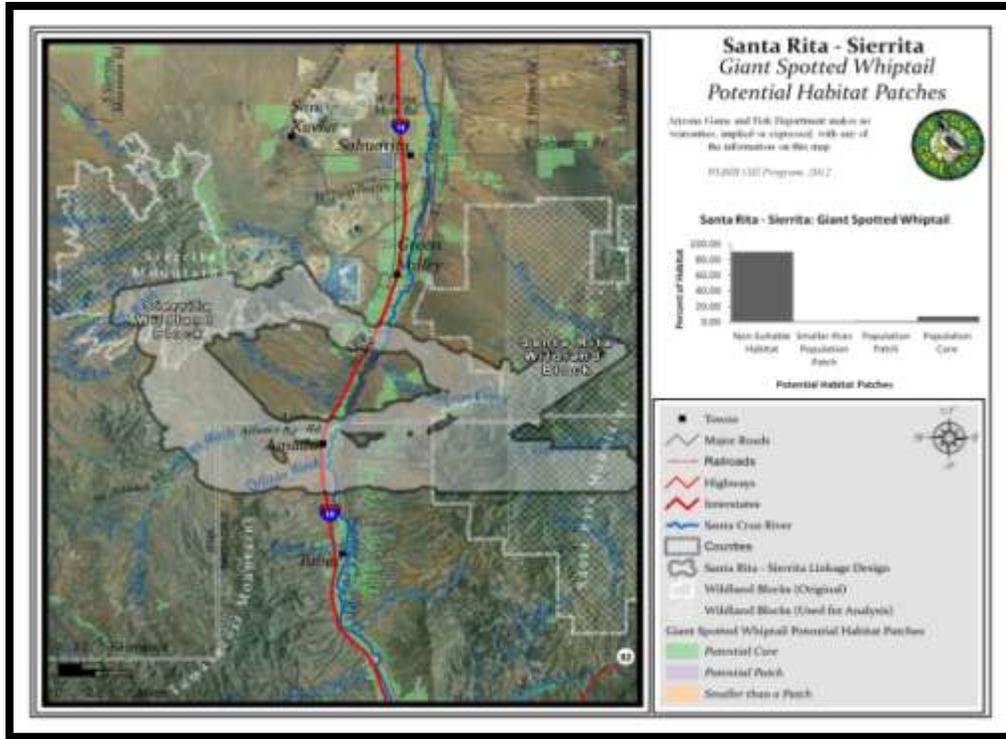


Figure 55: Map of Santa Rita – Sierrita potential habitat patches for giant spotted whiptail

Gila Monster, *Heloderma suspectum*

Justification for Selection

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

Distribution

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



Photo courtesy Randy Babb, AGFD

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for Gila monster in the BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100, with an average suitability of 83.0 (S.D: 11.5; see *Figure 56* below). Almost the entire BBC (99.4%) is

occupied by potential population cores (see *Figure 57* below). Most of the BBC (90.6%) was greater than its estimated needed minimum width (see *Figure 58* below). The corridor was measured at 34.9 km (21.7 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional optimal and suboptimal but used habitat for Gila monster.

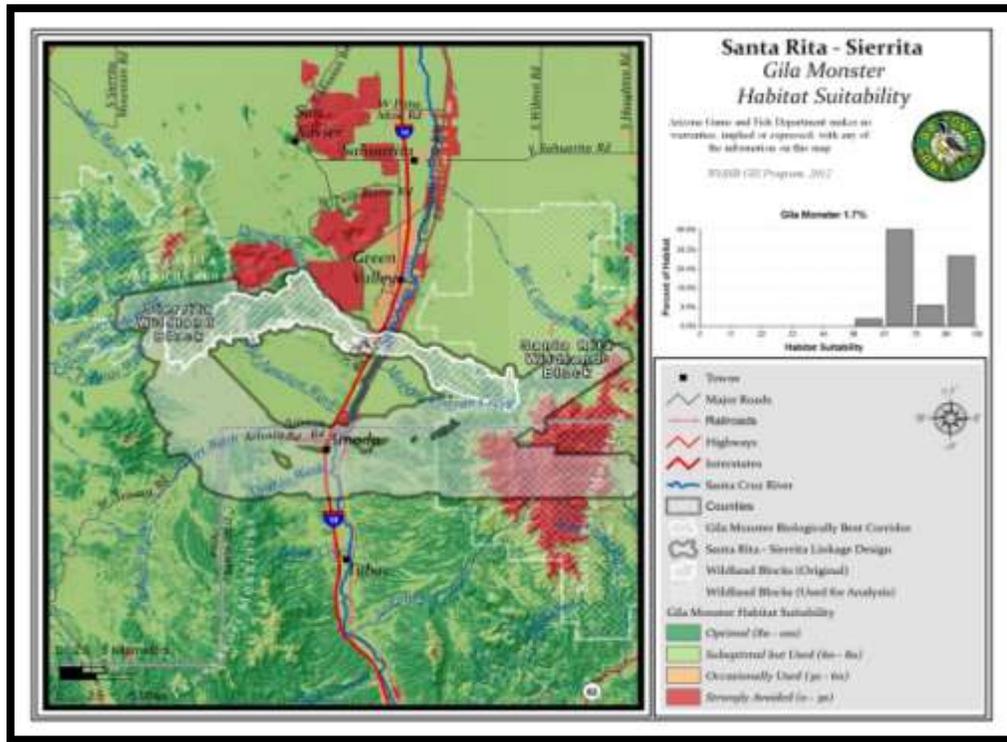


Figure 56: Map of Santa Rita – Sierrita habitat suitability for Gila monster

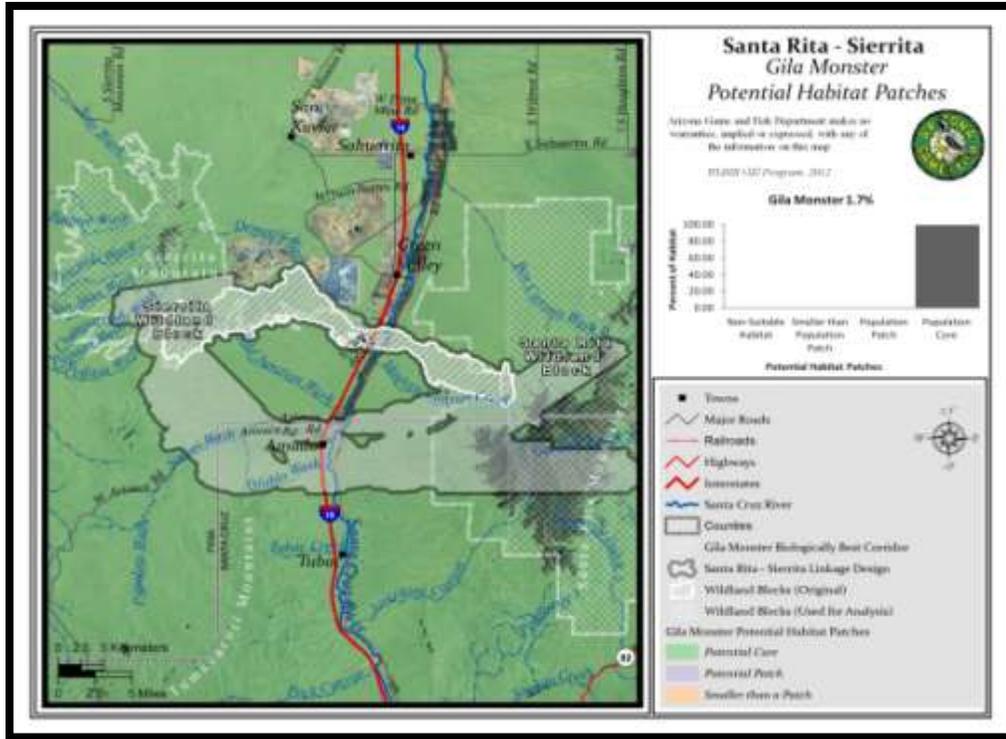


Figure 57: Map of Santa Rita – Sierrita potential habitat patches for Gila monster

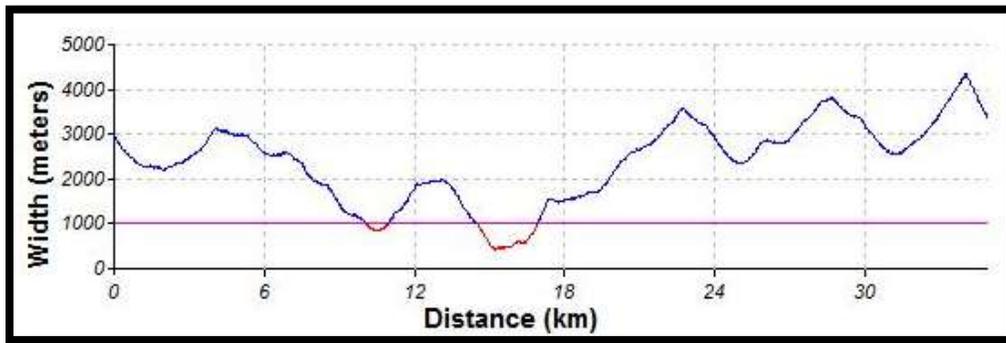


Figure 58: Width along the Santa Rita – Sierrita Gila monster biologically best corridor

Jaguar, *Panthera onca*

Justification for Selection

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



Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

Jaguars are adaptable to a variety of conditions, and are most often found in areas with sufficient prey, cover, and water supply (Seymour 1989). Within Arizona, habitat preferences are not clear; however, the species appears to prefer scrub and grasslands, evergreen forest, and conifer forest & woodlands (Hatten et al. 2003). It has been suggested that their apparent preference for grasslands may reflect movement corridors from the Sierra Madres of Mexico into southeast Arizona, rather than a preference for this habitat type (Hatten et al. 2003). Jaguars have a strong preference for water, and are often found within several kilometers of a water source such as perennial rivers or cienegas (Hatten et al. 2003; 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 km², with smaller home ranges in rain forests, and larger home ranges recorded in open habitats (Arizona Game and Fish Department 2004). In Brazil, the average density of jaguars was approximately one animal per 25 km², with one female ranging up to 38 km², and one male ranging more than 90 km² (Schaller & Crawshaw 1980).

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum patch size for jaguar was defined as 41 km² and minimum core size as 205 km². To determine potential habitat patches and cores, the habitat suitability model for this species was first averaged using a 200m radius moving window analysis due to the species' large spatial requirements.

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. 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 in the BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100, with an average suitability of 80.8 (S.D: 15.5; see *Figure 59* below). The majority of the BBC (68.9%) encompasses a potential population core, with some of it occupying potential habitat patches (26.2%), and the rest containing non-suitable habitat (see *Figure 60* below). Most of the BBC (91.7%) was greater than its estimated needed minimum width (see *Figure 61* below). The corridor was measured at 39.9 km (24.8 mi) in length between wildland blocks used for analysis.

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

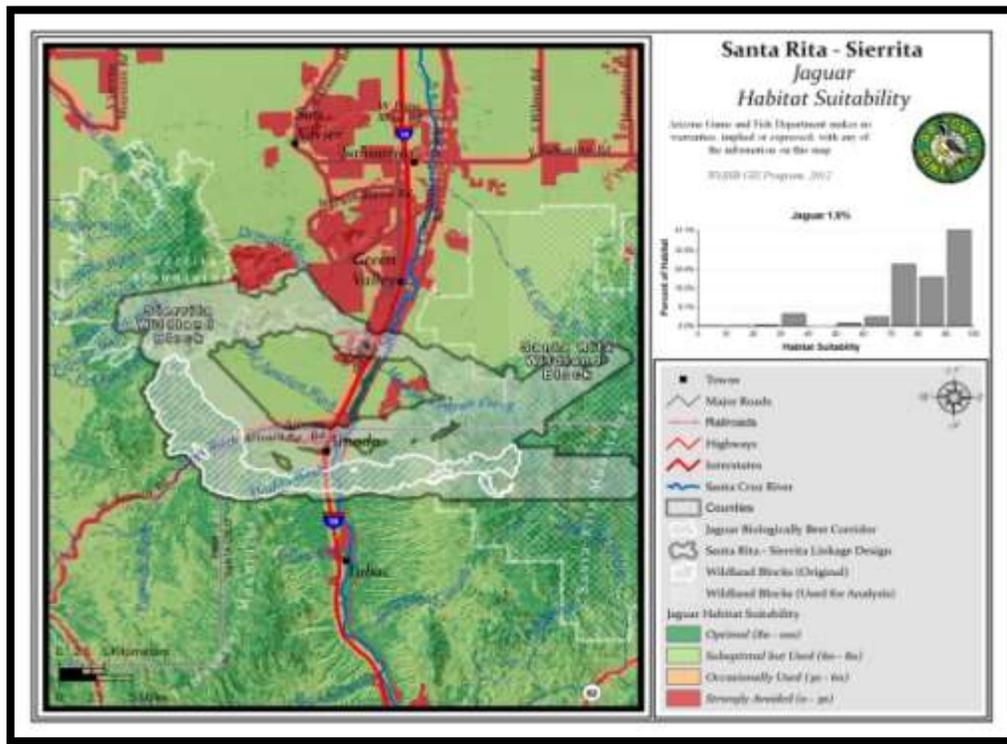


Figure 59: Map of Santa Rita – Sierrita habitat suitability for jaguar

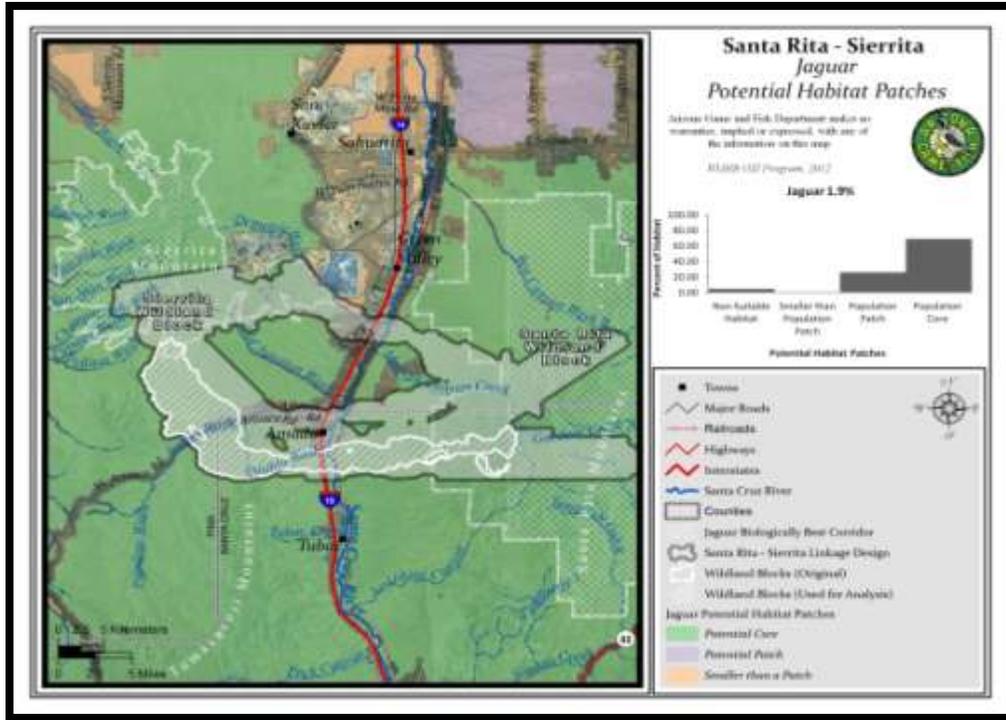


Figure 60: Map of Santa Rita – Sierrita potential habitat patches for jaguar

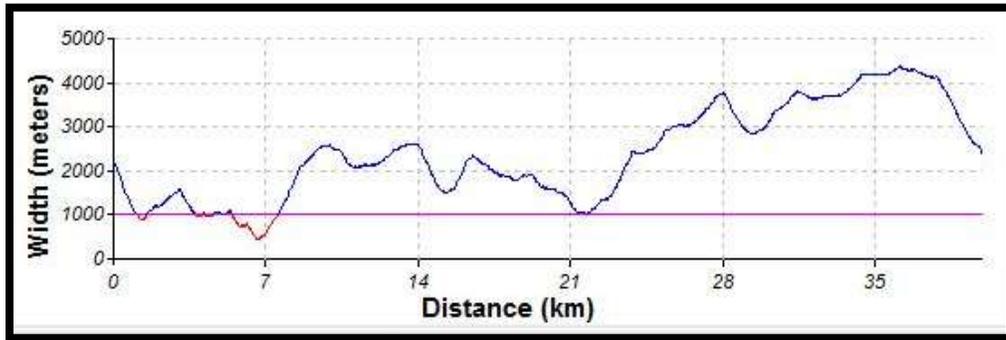


Figure 61: Width along the Santa Rita – Sierrita jaguar biologically best corridor

Javelina, *Tayassu tajacu*

Justification for Selection

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



Photo courtesy George Andrejko, AGFD

Distribution

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

Habitat Associations

Javelina have adapted to a variety of plant communities, varied topography, and diverse climatic conditions (Ticer et al. 2001). However, javelina confine themselves to habitats with dense vegetation (Ticer et al. 2001; Hoffmeister 1986; NatureServe 2005), and rarely are found above the oak forests on mountain ranges (Hoffmeister 1986). Javelina prefer habitat types such as areas of open woodland overstory with shrubland understory, desert scrub, and thickets along creeks and old stream beds (Ticer et al. 1998; Hoffmeister 1986). They also will forage in chaparral (Neal 1959; Johnson and Johnson 1964). Prickly pear cactus provides shelter, food, and water (Ticer et al. 2001; Hoffmeister 1986). Other plants in javelina habitat include palo verde, jojob, ocotillo, catclaw, and mesquite (Hoffmeister 1986). Javelina habituate well to human development, as long as dense vegetation is available (Ticer et al. 2001). Their elevation range is from 2000 to 6500 feet (New Mexico Department of Game and Fish 2002).

Spatial Patterns

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

Conceptual Basis for Model Development

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

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. However, a biologically best corridor was not included for this in the linkage design, due to its partial overlap of I-19, along with additional optimal habitat for javelina throughout the majority of the linkage design.

Results and Discussion

Union of biologically best corridors – The linkage design captures additional optimal and suboptimal but used habitat for javelin (see Figure 62 below). The linkage design also is almost entirely comprised of potential population cores (see Figure 63 below).

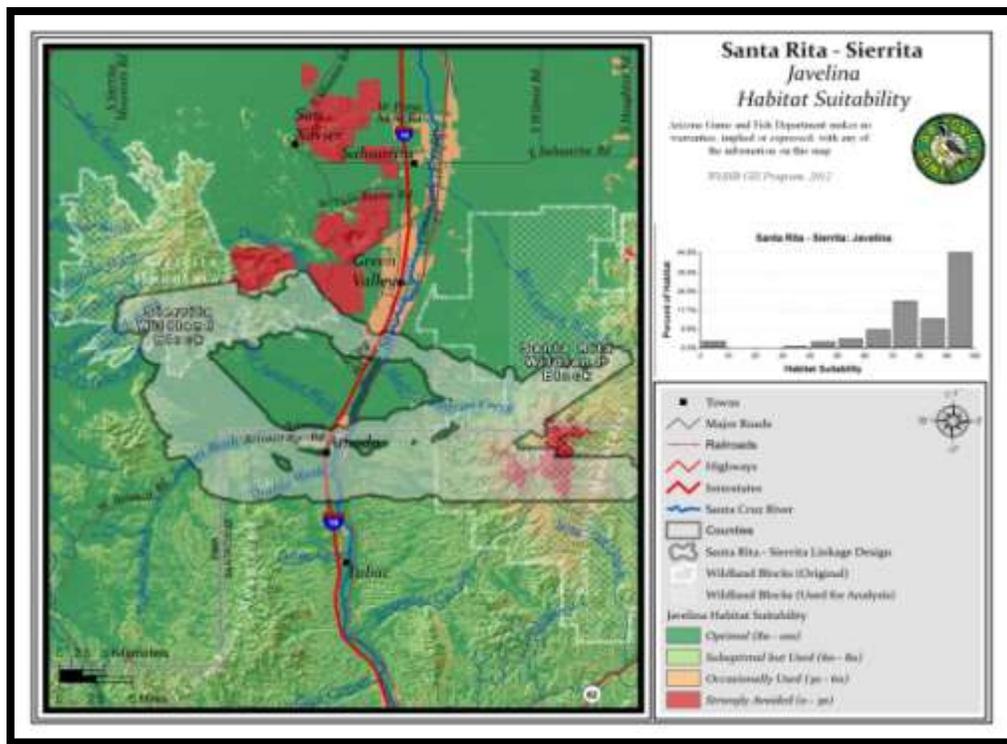


Figure 62: Map of Santa Rita – Sierrita habitat suitability for javelina



Figure 63: Map of Santa Rita – Sierrita potential habitat patches for javelina

Kit Fox, *Vulpes macrotis*

Justification for Selection

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

Distribution and Status

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



Photo courtesy George Andrejko, AGFD

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

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

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for kit fox in the BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 17.1 to 100, with an average suitability of 89.4 (S.D: 16.9; see *Figure 64* below). Almost the entire BBC (99.9%) encompasses a potential population core (see *Figure 65* below). Most of the BBC (91.5%) was greater than its estimated needed minimum width (see *Figure 66* below). The corridor was measured at 45.2 km (28.1 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional optimal, suboptimal but used, and occasionally used habitat for kit fox. Almost the entire linkage design encompasses potential population cores.

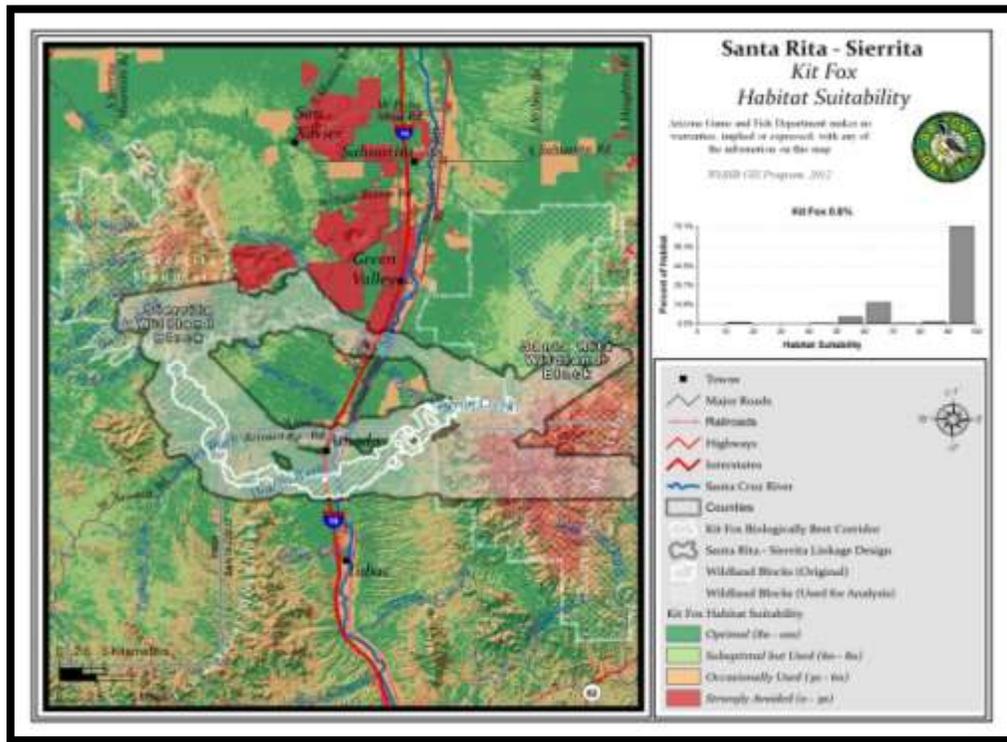


Figure 64: Map of Santa Rita – Sierrita habitat suitability for kit fox

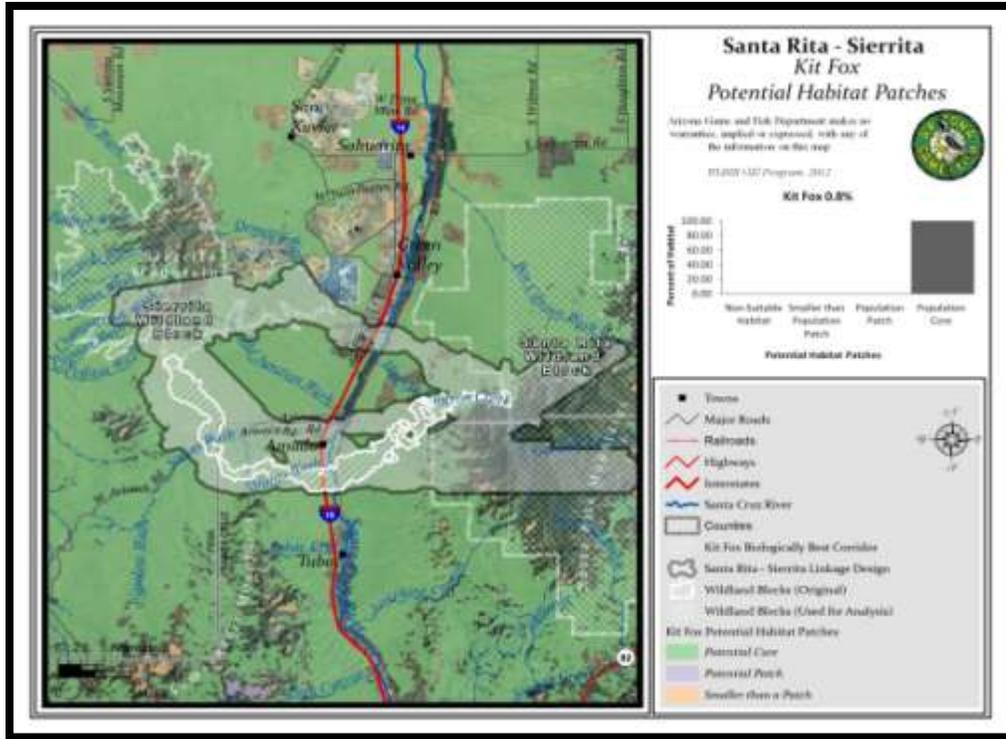


Figure 65: Map of Santa Rita – Sierrita potential habitat patches for kit fox

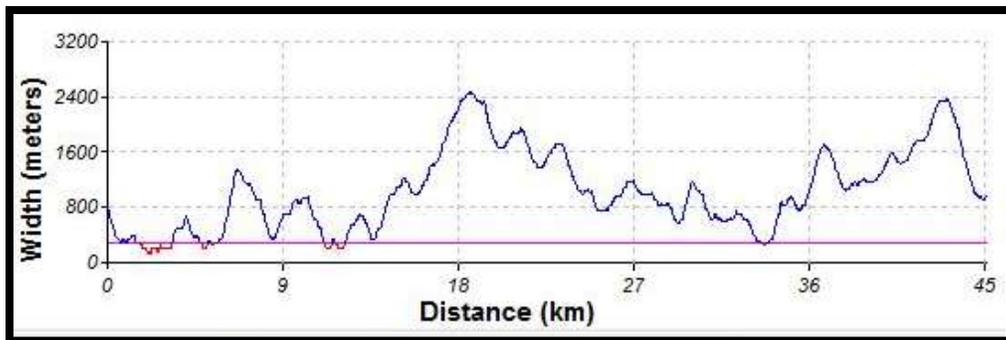


Figure 66: Width along the Santa Rita – Sierrita kit fox biologically best corridor

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).

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).



Photo courtesy George Andrejko, AGFD

Habitat Associations

Mountain lions are associated with mountainous areas with rocky cliffs and bluffs (Hoffmeister 1986; New Mexico Department of Game and Fish 2002). They use a diverse range of habitats, including conifer, hardwood, mixed forests, shrubland, chaparral, and desert environments (NatureServe 2005). They are also found in pinyon/juniper on benches and mesa tops (New Mexico Department of Game and Fish 2002). Mountain lions are found at elevations ranging from 0 to 4,000 m (Currier 1983).

Spatial Patterns

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

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum patch size for mountain lions was defined as 79 km², based on an average home range estimate for a female in excellent habitat (Logan and Sweanor 2001; Dickson and Beier 2002). Minimum core size was defined as 395 km², or five times minimum patch size.

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

Biologically best corridor analysis – We used the methods described in Appendix A to identify the biologically best corridor for this species. Mountain lion 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 was trimmed to eliminate “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for mountain lion in the trimmed BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100, with an average suitability of 75.0 (S.D: 19.8; see *Figure 67* below). Most of the trimmed BBC (76.2%) is occupied by a potential population core, with a small portion (4.2) occupying suitable habitat smaller than a patch, and the rest non-suitable habitat (see *Figure 68* below). Almost all of the trimmed BBC (92.0%) was greater than its estimated needed minimum width (see *Figure 69* below). The trimmed corridor was measured at 34.8 km (21.6 mi) in length between wildland blocks used for analysis.

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

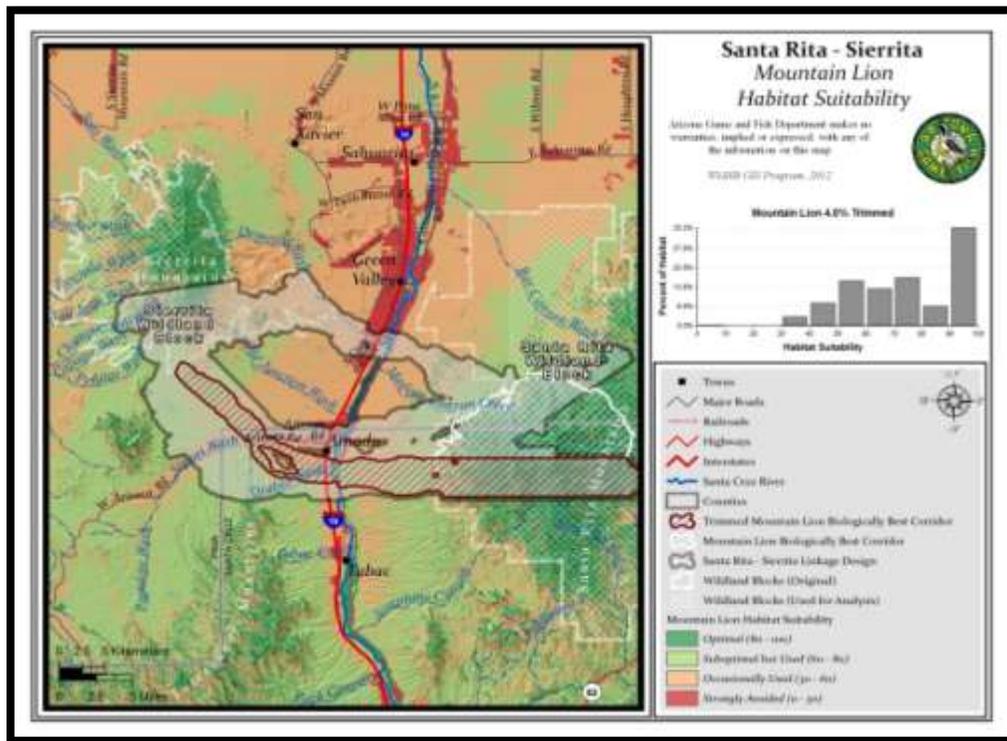


Figure 67: Map of Santa Rita – Sierrita habitat suitability for mountain lion

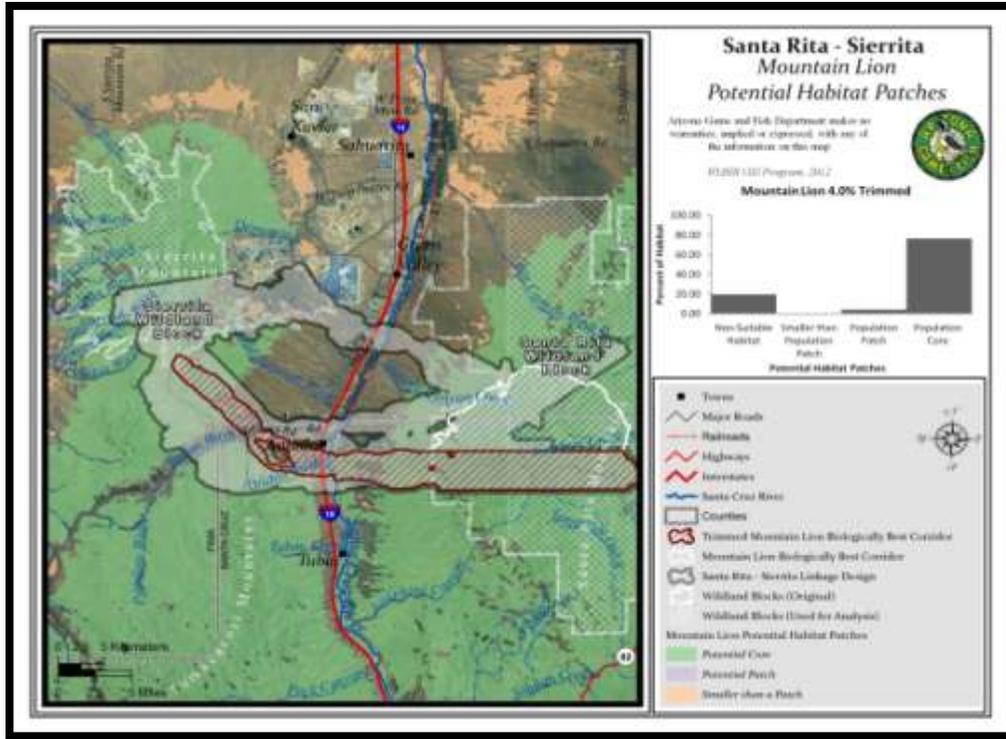


Figure 68: Map of Santa Rita – Sierrita potential habitat patches for mountain lion

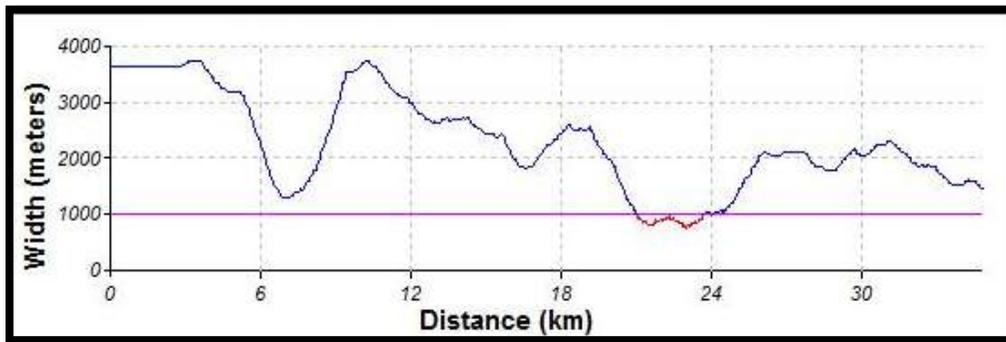


Figure 69: Width along the Santa Rita – Sierrita trimmed mountain lion biologically best corridor

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).

Distribution

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



Photo courtesy George Andrejko, AGFD

Habitat Associations

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

Spatial Patterns

The home ranges of mule deer vary depending upon the availability of food and cover (Hoffmeister 1986). Home ranges of mule deer in Arizona Chaparral habitat vary from 2.6 to 5.8 km², with bucks' home ranges averaging 5.2 km² and does slightly smaller (Swank 1958, as reported by Hoffmeister 1986). Average home ranges for desert mule deer are larger. Deer that require seasonal migration movements use approximately the same winter and summer home ranges in consecutive years (Anderson and Wallmo 1984). Dispersal distances for male mule deer have been recorded from 97 to 217 km, and females have moved 180 km (Anderson and Wallmo 1984). Two desert mule deer yearlings were found to disperse 18.8 and 44.4 km (Scarborough and Krausman 1988).

Conceptual Basis for Model Development

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

Patch size and configuration analysis – Minimum patch size for mule deer was defined as 9 km² and minimum core size as 45 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. 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 was trimmed to eliminate “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for mule deer in the trimmed BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 89.5, with an average suitability of 78.4 (S.D: 19.8; see *Figure 70* below). The entire trimmed BBC (100.0%) is occupied by a potential population core (see *Figure 71* below). Almost all of BBC (93.1%) was greater than its estimated needed minimum width (see *Figure 72* below). The corridor was measured at 35.3 km (21.9 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 mule deer.

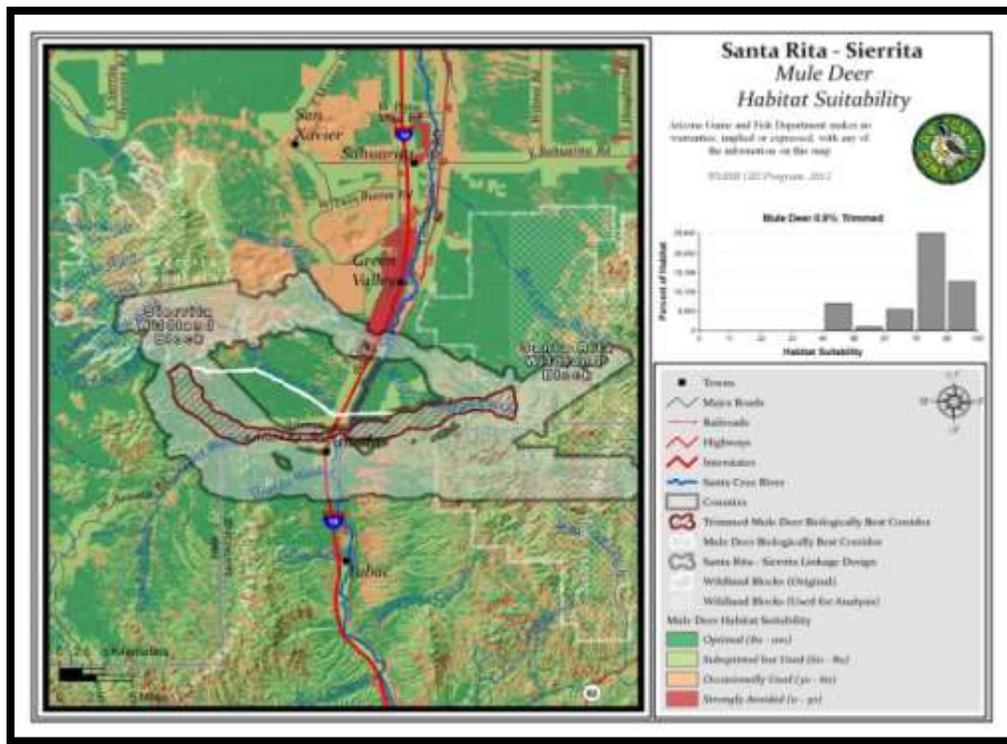


Figure 70: Map of Santa Rita – Sierrita habitat suitability for mule deer

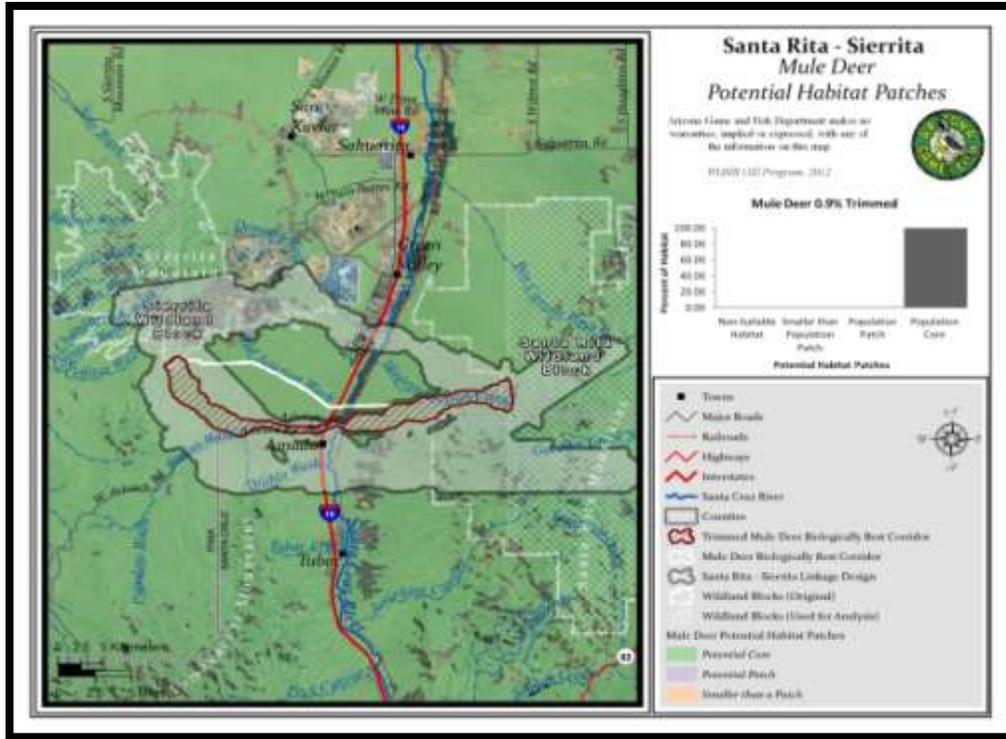


Figure 71: Map of Santa Rita – Sierrita potential habitat patches for mule deer

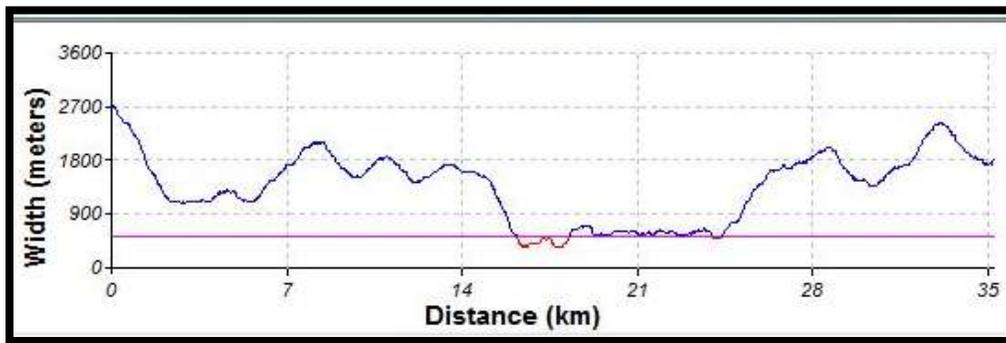


Figure 72: Width along the Santa Rita – Sierrita mule deer biologically best corridor

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

Justification for Selection

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

Distribution

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



Photo courtesy Randy Babb, AGFD

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. However, a biologically best corridor for Sonoran desert toad was not included in the linkage design, due to its long length, and suitable habitat available in other portions of the linkage.

Results and Discussion

Union of biologically best corridors – The linkage design captures additional optimal, suboptimal but used, and occasionally used habitat for Sonoran desert toad (see *Figure 73* below). Some additional potential population cores are also captured by the linkage design, especially in the northern portion (see *Figure 74* below).

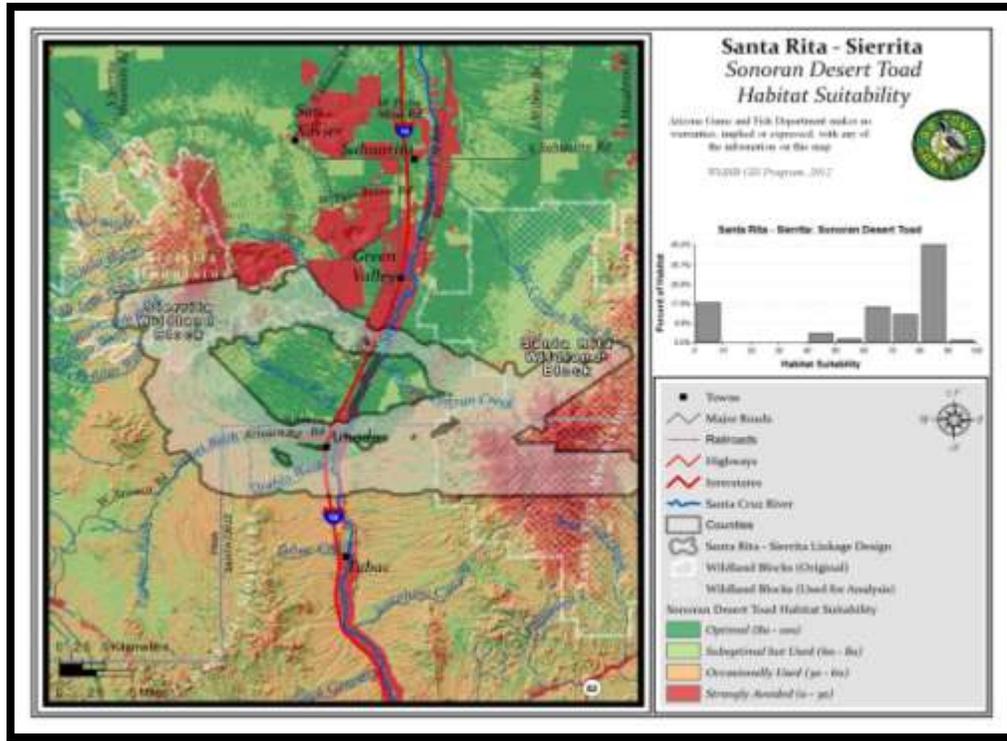


Figure 73: Map of Santa Rita – Sierrita habitat suitability for Sonoran desert toad

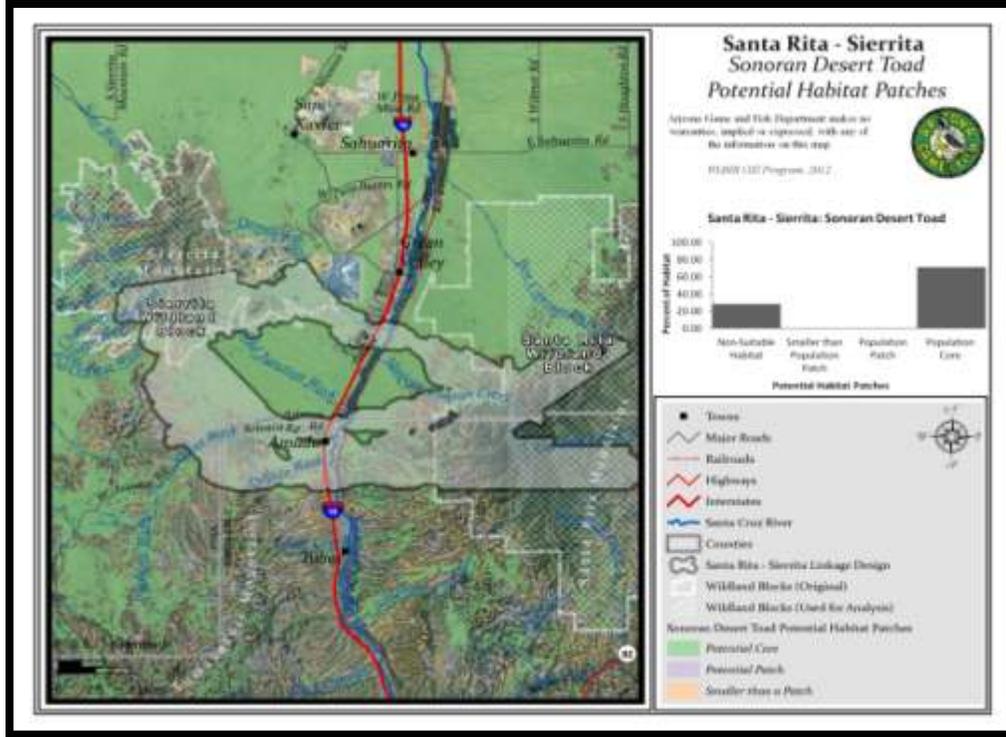


Figure 74: Map of Santa Rita – Sierrita potential habitat patches for Sonoran desert toad

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

Justification for Selection

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

Distribution

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



Photo courtesy Audrey Owens, AGFD

Habitat Associations

Tortoises are dependent on soil type and rock formations for shelter. Typical tortoise habitat in the Sonoran Desert is rocky outcrops (Bailey et al. 1995) and bajadas. Zylstra and Steidl (2008) found that tortoises occupied east-facing slopes, and are less likely to occupy north facing slopes. However, AGFD unpublished data has found juveniles mostly on north-facing slopes, and adults on west-facing slopes. Desert tortoises also use burrows excavated into hardened caliche along incised washes (Averill-Murray et al. 2002a). Desert tortoises are obligate herbivores (Ofstedal 2002) so vegetation is an important part of their habitat. However, desert tortoises also occur over a wide range of vegetation (Sinaloan thornscrub - Mojave Desert), so vegetation is therefore a variable resource. Desert tortoises eat both annual and perennial plants. Diets of Sonoran desert tortoises vary among populations in response to seasonal availability of plant species and in response to precipitation amounts (Martin and van Devender 2002). They have even been observed consuming dried plant materials during periods of drought (Averill-Murray et al. 2002b). Optimal habitat is within Arizona Upland Sonoran desert scrub and 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 suitable habitat for Sonoran desert tortoise in the BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100, with an average suitability of 63.7 (S.D: 24.6; see *Figure 75* below). Most of the BBC (67.9%) is occupied by potential population cores, with a small portion occupied by suitable habitat smaller than a patch (1.4%; see *Figure 76* below). Almost all of BBC (93.0%) was greater than its estimated needed minimum width (see *Figure 77* below). The corridor was measured at 34.6 km (21.5 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 additional potential population cores.

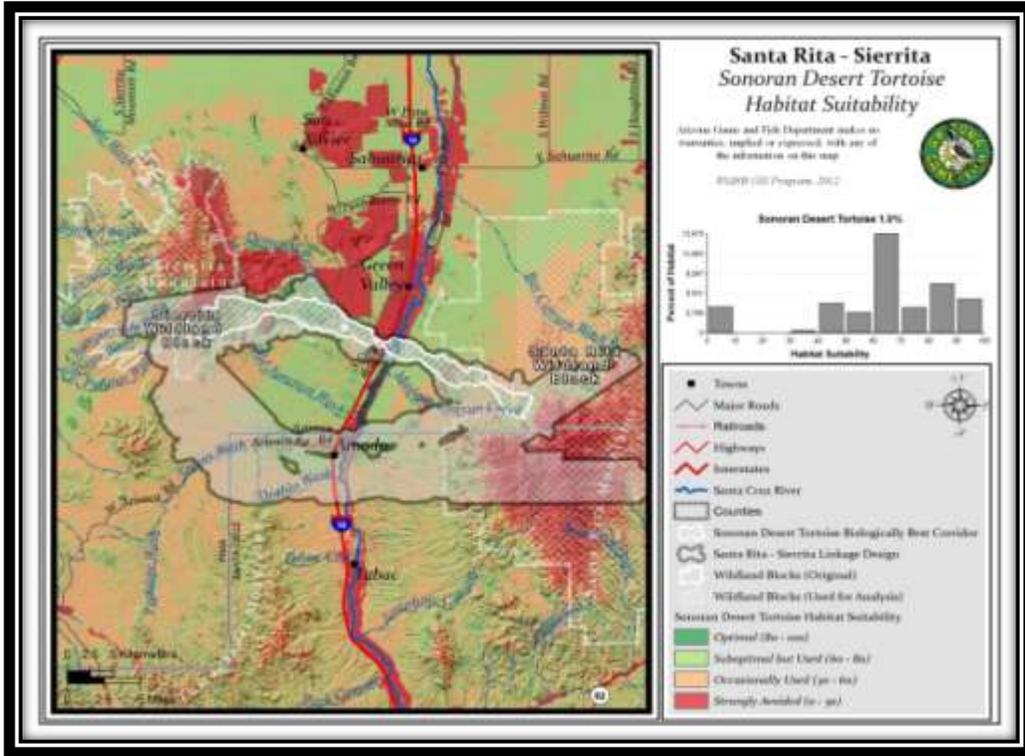


Figure 75: Map of Santa Rita – Sierrita habitat suitability for Sonoran desert tortoise

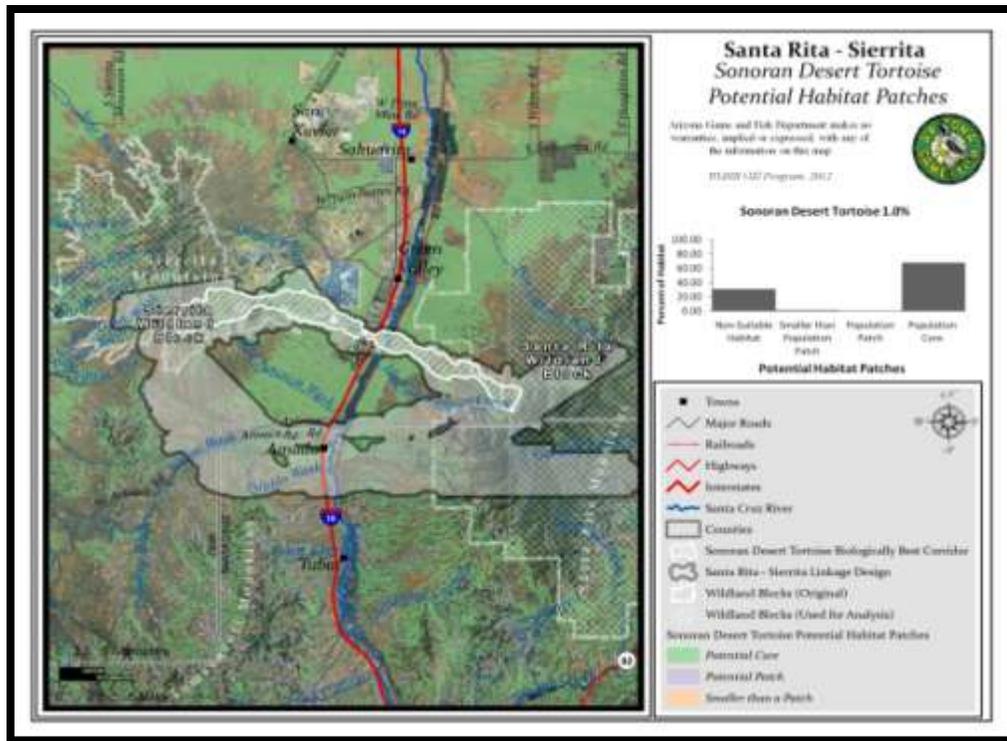


Figure 76: Map of Santa Rita – Sierrita potential habitat patches for Sonoran desert tortoise



Figure 77: Width along the Santa Rita – Sierrita 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).

Distribution

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



Photo courtesy Randy Babb, AGFD

Habitat Associations

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

Spatial Patterns

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

Conceptual Basis for Model Development

Habitat suitability model – Vegetation received an importance weight of 30%, while elevation, topography, and distance from roads received weights of 10%, 45%, and 15%, respectively. For specific scores of classes within each of these factors, see *Table 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 “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate ample suitable habitat for Sonoran whipsnake in the trimmed BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100, with an average suitability of 80.3 (S.D: 19.6; see *Figure 78* below). Most of the trimmed BBC (83.1%) is occupied by potential population cores, with a small portion (0.4%) occupying suitable habitat smaller than a patch, and the rest non-suitable habitat (see *Figure 79* below). Most of the trimmed BBC (90.0%) was greater than its estimated needed minimum width (see *Figure 80* below). The trimmed corridor was measured at 34.3 km (21.3 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 whipsnake, as well as additional potential population cores.

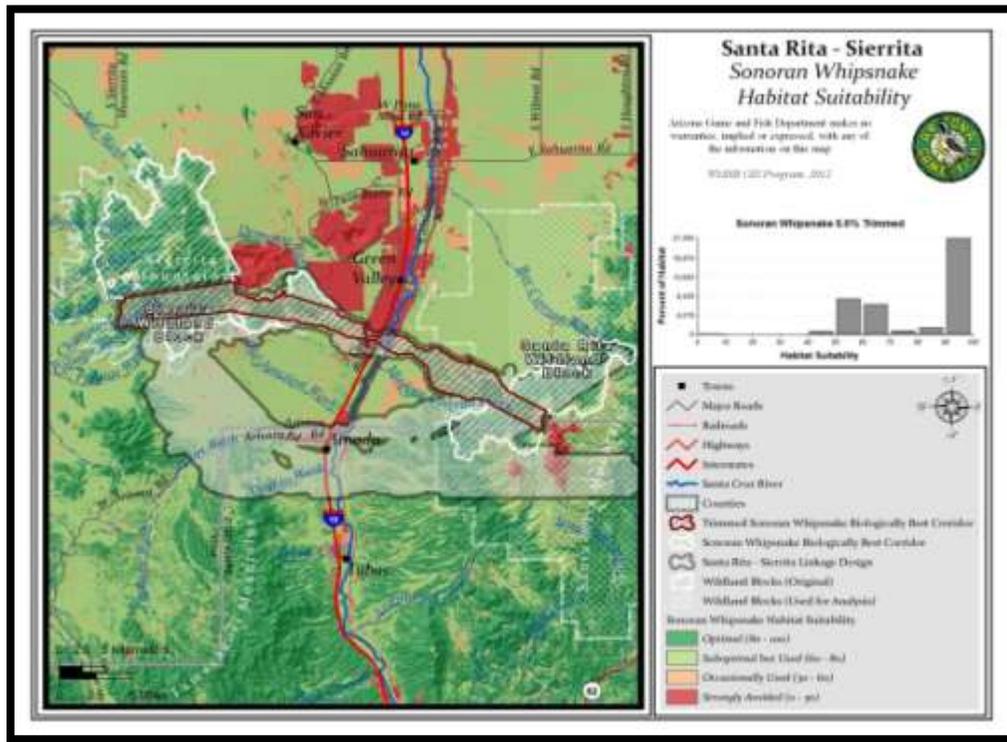


Figure 78: Map of Santa Rita – Sierrita habitat suitability for Sonoran whipsnake

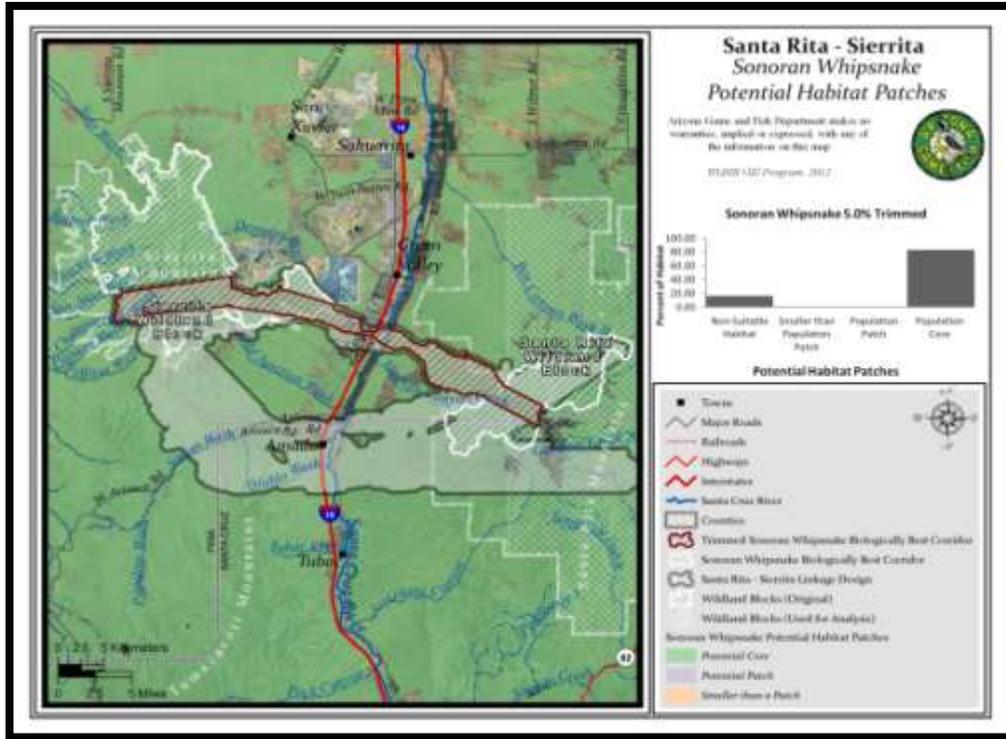


Figure 79: Map of Santa Rita – Sierrita potential habitat patches for Sonoran whipsnake

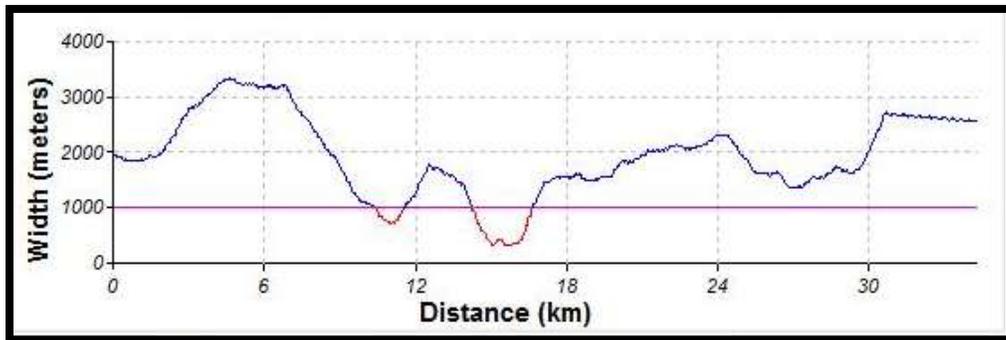


Figure 80: Width along the Santa Rita – Sierrita trimmed Sonoran whipsnake biologically best corridor

White-nosed Coati, *Nasua narica*

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.

Distribution

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



Photo courtesy George Andrejko, AGFD

Habitat Associations

Coatis are primarily a forest species, preferring shrubby and woodland habitats with good horizontal cover (Gompper 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 (Gompper 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 to 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 km² (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). The original biologically best corridor for this species was trimmed to eliminate “bubble” areas resulting from increasing the width of the other portions of the corridor.

Results and Discussion

Initial biologically best corridor – Modeling results indicate suitable habitat for white-nosed coati in the trimmed BBC used in the Santa Rita – Sierrita linkage design. Habitat suitability scores ranged from 0 to 100.0, with an average suitability of 64.1 (S.D: 23.2; see *Figure 81* below). Some of the trimmed BBC (38.0%) is occupied by potential population cores, while a small portion is occupied by potential habitat patches (10.3%) and suitable habitat smaller than a patch (6.3%), and the rest occupied by non-suitable habitat (see *Figure 82* below). Most of the trimmed BBC (99.0%) was greater than its estimated needed minimum width (see *Figure 83* below). The trimmed corridor was measured at 35.1 km (21.8 mi) in length between wildland blocks used for analysis.

Union of biologically best corridors – The linkage design captures additional optimal, suboptimal but used, and occasionally used habitat for white-nosed coati, as well as additional potential population cores and potential habitat patches.

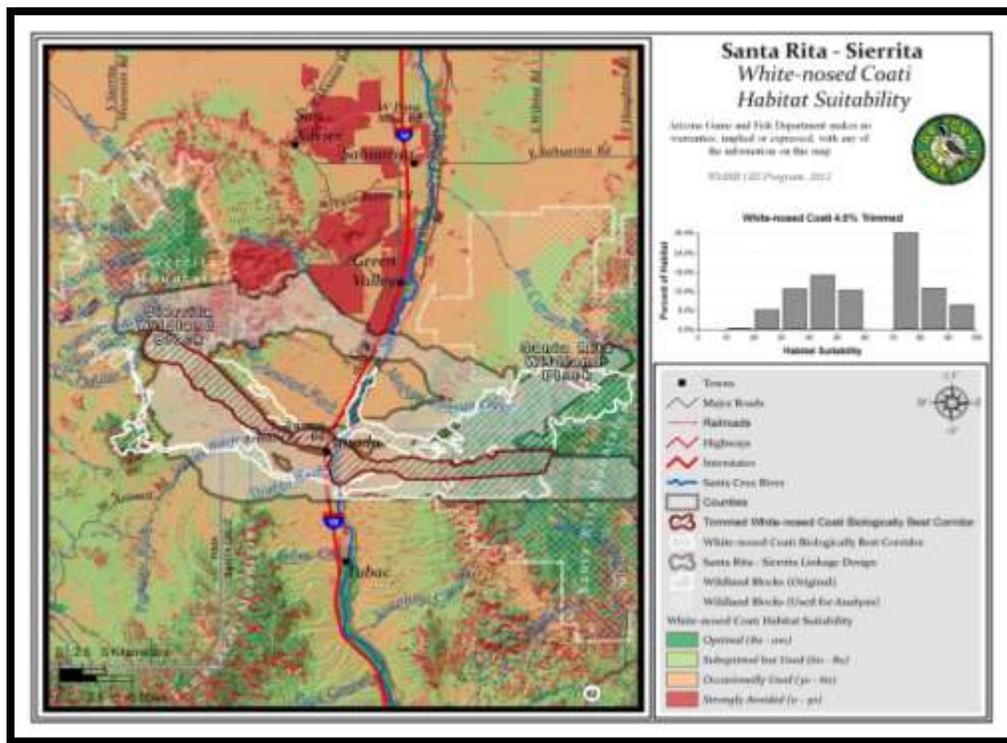


Figure 81: Map of Santa Rita – Sierrita habitat suitability for white-nosed coati

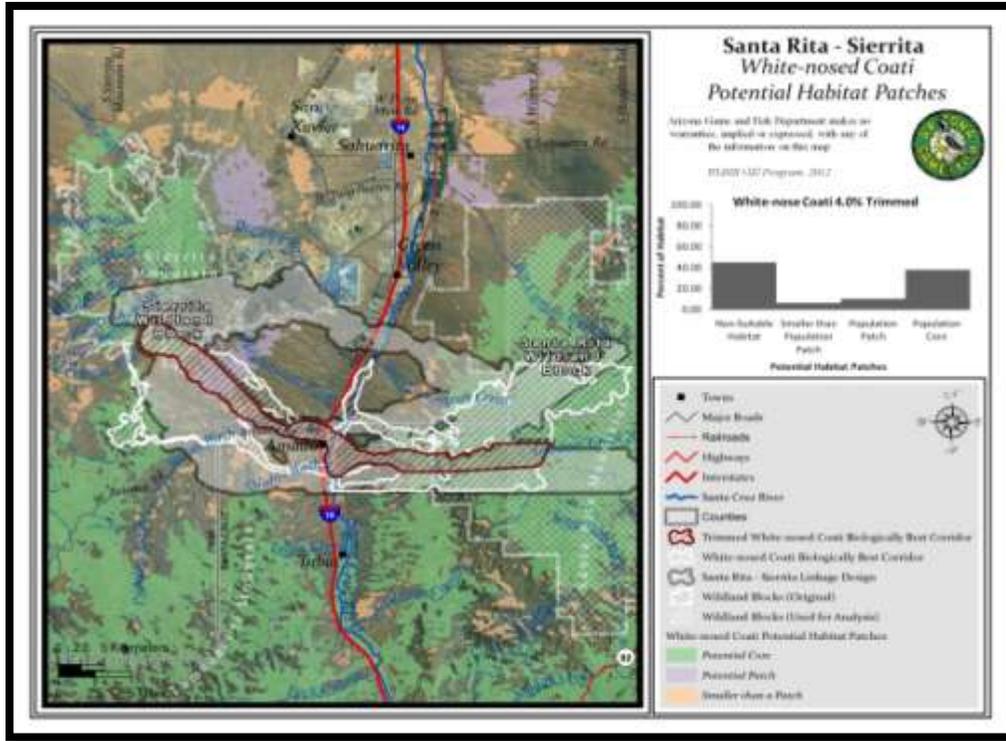


Figure 82: Map of Santa Rita – Sierrita potential habitat patches for white-nosed coati

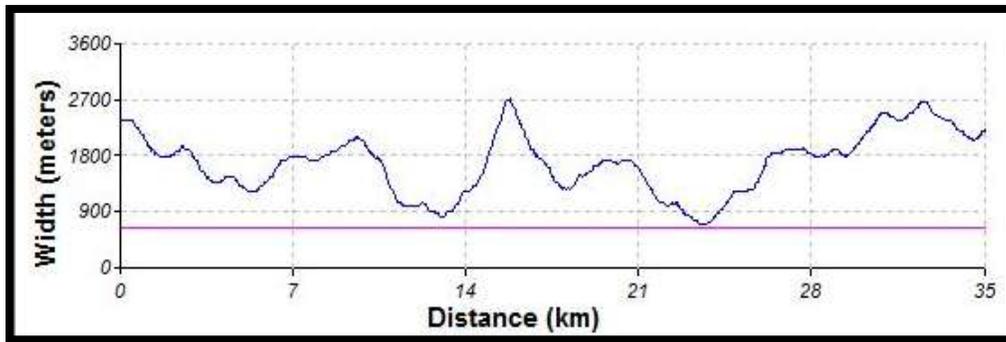


Figure 83: Width along the Santa Rita – Sierrita trimmed white-nosed coati biologically best corridor

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

Taxonomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Amphibian	Chiricahua Leopard Frog	<i>Lithobates chiricahuensis</i>	LT			WSC	Yes	Yes
Amphibian	Lowland Leopard Frog	<i>Rana yavapaiensis</i>	SC	S	S	WSC	Yes	Yes
Amphibian	Tarahumara Frog	<i>Rana tarahumarae</i>	SC	S		WSC		
Amphibian	Western Barking Frog	<i>Craugastor augusti cactorum</i>		S		WSC		
Bird	American Peregrine Falcon	<i>Falco peregrinus anatum</i>	SC	S	S	WSC		
Bird	Black-and-white Warbler	<i>Mniotilta varia</i>						
Bird	Black-capped Gnatcatcher	<i>Poliotilta nigriceps</i>				WSC		
Bird	Blue-throated Hummingbird	<i>Lampornis clemenciae</i>						
Bird	Buff-collared Nightjar	<i>Caprimulgus ridgwayi</i>		S				
Bird	Bullock's Oriole	<i>Icterus bullockii</i>						
Bird	Crested Caracara	<i>Caracara cheriway</i>				WSC		
Bird	Elegant Trogon	<i>Trogon elegans</i>				WSC		
Bird	Five-striped Sparrow	<i>Amphispiza quinquestriata</i>						
Bird	Golden Eagle	<i>Aquila chrysaetos</i>			S			
Bird	Mexican Spotted Owl	<i>Strix occidentalis lucida</i>	LT			WSC		Yes
Bird	Northern Beardless-Tyrannulet	<i>Camptostoma imberbe</i>		S				
Bird	Northern Goshawk	<i>Accipiter gentilis</i>	SC	S	S	WSC		
Bird	Northern Gray Hawk	<i>Buteo nitidus maxima</i>	SC	S		WSC		
Bird	Southwestern Willow Flycatcher	<i>Empidonax traillii extimus</i>	LE			WSC		Yes
Bird	Swainson's Thrush	<i>Catharus ustulatus</i>						
Bird	Tropical Kingbird	<i>Tyrannus melancholicus</i>				WSC		
Bird	Yellow-billed Cuckoo (Western U.S. DPS)	<i>Coccyzus americanus</i>	PS:C	S		WSC		Yes
Bird	Zone-tailed Hawk	<i>Buteo albonotatus</i>		S				

Taxonomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Invertebrate	Aqua Caliente Talussnail	<i>Sonorella santaritana</i>						Yes
Invertebrate	Arizona Cave Amphipod	<i>Stygobromus arizonensis</i>	SC		S			
Invertebrate	Arizona Giant Skipper	<i>Agathymus aryxna</i>						
Invertebrate	Arizona Metalmark	<i>Calephelis arizonensis</i>						
Invertebrate	Chiricahua Pine White	<i>Neophasia terlooii</i>						
Invertebrate	Doubtful Canyon Talussnail	<i>Sonorella waltoni</i>						Yes
Invertebrate	Huachuca Talussnail	<i>Sonorella huachucana</i>						Yes
Invertebrate	Madera Talussnail	<i>Sonorella clappi</i>						Yes
Invertebrate	Sabino Canyon Dancer	<i>Argia sabino</i>	SC	S				
Invertebrate	Santa Rita Talussnail	<i>Sonorella walkeri</i>						Yes
Invertebrate	Sonoran Talussnail	<i>Sonorella magdalenensis</i>						Yes
Invertebrate	Stephan's Heterelmis Riffle Beetle	<i>Heterelmis stephani</i>	C	S				
Mammal	Arizona Shrew	<i>Sorex arizonae</i>	SC	S		WSC		Yes
Mammal	Botta's Pocket Gopher	<i>Thomomys bottae</i>						
Mammal	California Leaf-nosed Bat	<i>Macrotus californicus</i>	SC	S	S	WSC		Yes
Mammal	Cave Myotis	<i>Myotis velifer</i>	SC		S			
Mammal	High Netting Concentration	Bat Foraging Area						
Mammal	Hoary Bat	<i>Lasiurus cinereus</i>						
Mammal	Lesser Long-nosed Bat	<i>Leptonycteris curasoae yerbabuena</i>	LE			WSC		Yes
Mammal	Mexican Long-tongued Bat	<i>Choeronycteris mexicana</i>	SC	S	S	WSC		Yes
Mammal	Mexican Opossum	<i>Didelphis virginiana californica</i>						
Mammal	Mexican Woodrat	<i>Neotoma mexicana</i>						
Mammal	Pale Townsend's Big-eared Bat	<i>Corynorhinus townsendii pallescens</i>	SC	S	S			Yes
Mammal	Plains Harvest Mouse	<i>Reithrodontomys montanus</i>		S				
Mammal		Bat Colony						
Plant	American Rabbitfoot Grass	<i>Polypogon elongatus</i>						
Plant	Arizona Crested coralroot	<i>Hexalectris spicata var. arizonica</i>		S		SR		
Plant	Arizona Fleabane	<i>Erigeron arizonicus</i>						
Plant	Arizona Giant Sedge	<i>Carex ultra</i>		S	S			
Plant	Arizona Manihot	<i>Manihot davisiae</i>		S				
Plant	Bartram Stonecrop	<i>Graptopetalum bartramii</i>	SC	S	S	SR		
Plant	Box Canyon Muhly	<i>Muhlenbergia dubioides</i>		S				
Plant	Chihuahuan Sedge	<i>Carex chihuahuensis</i>		S				
Plant	Chiricahua Mountain Brookweed	<i>Samolus vagans</i>		S				
Plant	Chiricahua Rock Cress	<i>Arabis tricornuta</i>		S				
Plant	Crested Coralroot	<i>Hexalectris spicata</i>				SR		

Taxonomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Plant	Engelmann Adders Tongue	<i>Ophioglossum engelmannii</i>						
Plant	Huachuca Groundsel	<i>Senecio multidentatus</i> var. <i>huachucanus</i>		S		HS		
Plant	Huachuca Morning Glory	<i>Ipomoea plummerae</i> var. <i>cuneifolia</i>						
Plant	Huachuca Mountain Lupine	<i>Lupinus huachucanus</i>		S				
Plant	Knotleaf Flower	<i>Phyllanthus polygonoides</i>						
Plant	Lemmon Lily	<i>Lilium parryi</i>	SC	S		SR		
Plant	Lemmon Milkweed	<i>Asclepias lemmonii</i>		S				
Plant	Lemmon's Aster	<i>Aster potosinus</i>						
Plant	Madrean Adders Mouth	<i>Malaxis corymbosa</i>				SR		
Plant	Mexican Fringed Gentian	<i>Gentianopsis macrantha</i>						
Plant	Mexican Hemlock Parsley	<i>Conioselinum mexicanum</i>	SC	S				
Plant	Mock-pennyroyal	<i>Hedeoma dentatum</i>						
Plant	Nodding Blue-eyed Grass	<i>Sisyrinchium cernuum</i>		S				
Plant	Pima Indian Mallow	<i>Abutilon parishii</i>	SC	S	S	SR		
Plant	Pima Pineapple Cactus	<i>Coryphantha scheeri</i> var. <i>robustispina</i>	LE			HS		Yes
Plant	Pringle Hawkweed	<i>Hieracium pringlei</i>	SC					
Plant	Pringle's Fleabane	<i>Erigeron pringlei</i>						
Plant	Purple Adder's Mouth	<i>Malaxis porphyrea</i>				SR		
Plant	Saiya	<i>Amoreuxia gonzalezii</i>	SC	S		HS		
Plant	See: Ayenia jaliscana	<i>Ayenia glabra</i>						
Plant	Seemann Groundsel	<i>Senecio carlomasonii</i>						
Plant	Shade Violet	<i>Viola umbraticola</i>				S		
Plant	Sonoran Noseburn	<i>Tragia laciniata</i>		S				
Plant	Stag-horn Cholla	<i>Opuntia versicolor</i>				SR		
Plant	Superb Beardtongue	<i>Penstemon superbus</i>						
Plant	Thurber Hoary Pea	<i>Tephrosia thurberi</i>						
Plant	Thurber Tithonia	<i>Tithonia thurberi</i>						
Plant	Tropical Spiny Phlox	<i>Loeselia glandulosa</i>						
Plant	Trumpet Morning-glory	<i>Ipomoea tenuiloba</i>						
Plant	Weeping Muhly	<i>Muhlenbergia xerophila</i>		S				
Plant	Wilcox Fishhook Cactus	<i>Mammillaria wrightii</i> var. <i>wilcoxii</i>				SR		
Plant	Woodland Sunbonnets	<i>Leibnitzia lyrata</i>						
Plant	Woolly Fleabane	<i>Laennecia eriophylla</i>						
Plant	Wright's Snakeweed	<i>Gutierrezia wrightii</i>						
Reptile	Arizona Ridge-nosed Rattlesnake	<i>Crotalus willardi willardi</i>		S		WSC		

Taxonomic Group	Common Name	Scientific Name	ESA	USFS	BLM	STATE	Corridor Design	SDCP
Reptile	Banded Rock Rattlesnake	<i>Crotalus lepidus klauberi</i>						
Reptile	Brown Vinesnake	<i>Oxybelis aeneus</i>		S		WSC		
Reptile	Chihuahuan Black-headed Snake	<i>Tantilla wilcoxi</i>						
Reptile	Giant Spotted Whiptail	<i>Aspidoscelis burti stictogrammus</i>	SC	S			Yes	Yes
Reptile	Greater Short-horned Lizard	<i>Phrynosoma hernandesi</i>						
Reptile	Hooded Nightsnake	<i>Hypsiglena sp. nov.</i>						
Reptile	Mountain Skink	<i>Plestiodon callicephalus</i>		S				
Reptile	Northern Green Ratsnake	<i>Senticolis triaspis intermedia</i>		S				
Reptile	Slevin's Bunchgrass Lizard	<i>Sceloporus slevini</i>		S	S			
Reptile	Sonoran Desert Tortoise	<i>Gopherus agassizii</i> (Sonoran Population)	C	S		WSC	Yes	
Reptile	Twin-spotted Rattlesnake	<i>Crotalus pricei</i>		S				
Reptile	Giant Spotted Whiptail	<i>Aspidoscelis burti stictogrammus</i>	SC	S			Yes	Yes
Reptile	Greater Short-horned Lizard	<i>Phrynosoma hernandesi</i>						

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 84* below):

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

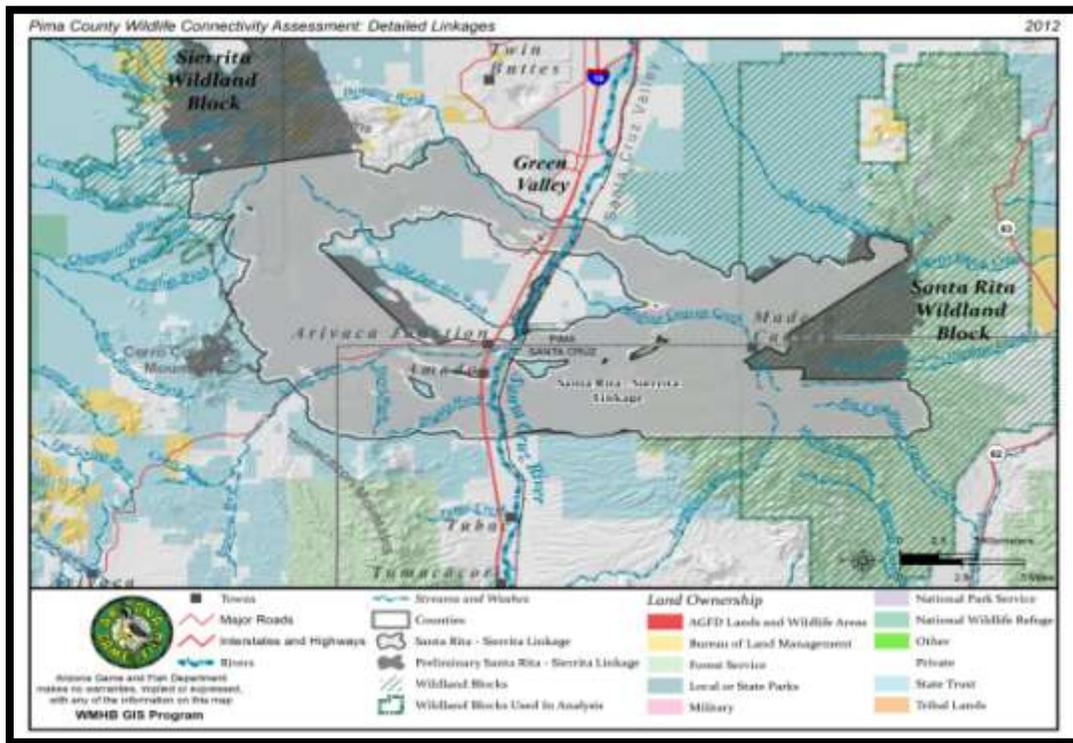


Figure 84: Progression of the Santa Rita – Sierrita linkage design

Appendix F: Update and Description of Land Cover

Vegetation classes have been derived from the Southwest Regional GAP analysis (ReGAP) land cover layer. To simplify the layer from 77 to 46 classes, we grouped similar vegetation classes into slightly broader classes by removing geographic and environmental modifiers (e.g. Chihuahuan Mixed Salt Desert Scrub and Inter-Mountain Basins Mixed Salt Desert Scrub got lumped into “Desert Scrub”, Subalpine Dry-Mesic Spruce-Fir Forest and Woodland was simplified to Spruce-Fir Forest and Woodland).

As mentioned in the Linkage Design Methods (Appendix A), ReGAP was originally classified in 2001 using imagery from previous years. However, significant development had occurred throughout the State since that time. Since development can impact wildlife by fragmenting habitat, and is a major category in ReGAP driving these corridor models, using this dataset for analysis without addressing this issue would have ignored the impact of development in our linkage design. In order to properly address recent levels of development, private lands where development is most likely to occur, previously categorized as non-developed in ReGAP were examined. Areas with development present were digitized and categorized according to ReGAP as Developed, Open Space – Low Intensity, or Developed, Open Space – High Intensity based on ReGAP descriptions (see below). These areas were then appended to the land cover raster used in the analysis.

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

DECIDUOUS FOREST (1 CLASS) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Aspen Forest and Woodland – Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions. Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand, and secondarily is limited by the length of the growing season or low temperatures. These are upland forests and woodlands dominated by *Populus tremuloides* without a significant conifer component (<25% relative tree cover)

EVERGREEN FOREST (4 CLASSES) – Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Conifer-Oak Forest and Woodland – This system occurs at the upper elevations in the Sierra Madre Occidentale and Sierra Madre Orientale. In the U.S., it is restricted to north and east aspects at high elevations (1980-2440 m) in the Sky Islands (Chiricahua, Huachuca, Pinaleno, Santa Catalina, and Santa Rita mountains) and along the Nantanes Rim. The vegetation is characterized by large- and small-patch forests and woodlands dominated by *Pseudotsuga menziesii*, *Abies coahuilensis*, or *Abies concolor* and Madrean oaks such as *Quercus hypoleucoides* and *Quercus rugosa*. It is similar to Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland

Encinal (Oak Woodland) – Encinal occurs on foothills, canyons, bajadas and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, extending north into Trans-Pecos Texas, southern New Mexico and sub-Mogollon Arizona. These woodlands are dominated by Madrean evergreen oaks along a low-slope transition below Madrean Pine-Oak Forest and Woodland (CES305.796) and Madrean Pinyon-Juniper Woodland (CES305.797). Lower elevation stands are typically open woodlands or savannas where

they transition into desert grasslands, chaparral or in some cases desertscrub. Common evergreen oak species include *Quercus arizonica*, *Quercus emoryi*, *Quercus intricata*, *Quercus grisea*, *Quercus oblongifolia*, *Quercus toumeyii*, and in Mexico *Quercus chihuahuensis* and *Quercus albocincta*. Madrean pine, Arizona cypress, pinyon and juniper trees may be present, but do not codominate. Chaparral species such as *Arctostaphylos pungens*, *Cercocarpus montanus*, *Purshia* spp., *Garrya wrightii*, *Quercus turbinella*, *Frangula betulifolia* (= *Rhamnus betulifolia*), or *Rhus* spp. may be present but do not dominate. The graminoid layer is usually prominent between trees in grassland or steppe that is dominated by warm-season grasses such as *Aristida* spp., *Bouteloua gracilis*, *Bouteloua curtipendula*, *Bouteloua rothrockii*, *Digitaria californica*, *Eragrostis intermedia*, *Hilaria belangeri*, *Leptochloa dubia*, *Muhlenbergia* spp., *Pleuraphis jamesii*, or *Schizachyrium cirratum*, species typical of Chihuahuan Piedmont Semi-Desert Grassland (CES302.735). This system includes seral stands dominated by shrubby Madrean oaks typically with a strong graminoid layer. In transition areas with drier chaparral systems, stands of chaparral are not dominated by Madrean oaks, however, Madrean Encinal may extend down along drainages.

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

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

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

Semi-Desert Grassland and Shrub Steppe – Comprised of *Semi-Desert Shrub Steppe* and *Piedmont Semi-Desert Grassland and Steppe*. Semi-Desert Shrub is typically dominated by graminoids (>25% cover) with an open shrub layer, but includes sparse mixed shrublands without a strong graminoid layer. Steppe Piedmont Semi-Desert Grassland and Steppe is a broadly defined desert grassland, mixed shrub-succulent or xeromorphic tree savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico [Apacherian region], but extends west to the Sonoran Desert, north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is found on gently sloping bajadas that supported frequent fire throughout the Sky Islands and on mesas and steeper piedmont and foothill slopes in the Chihuahuan Desert. It is characterized by a typically diverse perennial grasses. Common grass species include *Bouteloua eriopoda*, *B. hirsuta*, *B. rothrockii*, *B. curtipendula*, *B. gracilis*, *Eragrostis intermedia*, *Muhlenbergia porteri*, *Muhlenbergia setifolia*, *Pleuraphis jamesii*, *Pleuraphis mutica*, and *Sporobolus airoides*, succulent species of *Agave*, *Dasyllirion*, and *Yucca*, and tall shrub/short tree species of *Prosopis* and various oaks (e.g., *Quercus grisea*, *Quercus emoryi*, *Quercus arizonica*).

SCRUB-SHRUB (6 CLASSES) – Areas dominated by shrubs, less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

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

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

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

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

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

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

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

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

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

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

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

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

Wash

DEVELOPED AND AGRICULTURE (3 CLASSES) –

Agriculture

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

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

ALTERED OR DISTURBED (1 CLASS) –

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

Appendix G: Literature Cited

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Appendix H: Data Requests

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

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

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