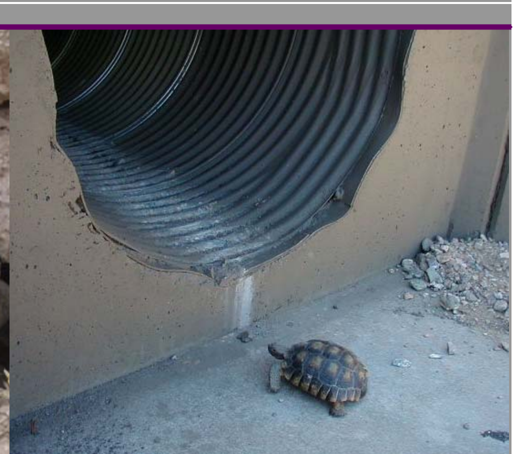
Assessment of Desert Tortoise Movement, Permeability, and Habitat Along the Proposed State Route 95 Realignment

Final Report 650
December 2012



Arizona Department of Transportation
Research Center

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Prepared for:
Arizona Department of Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AZ-12-650		

4. Title and Subtitle	5. Report Date
Assessment of Desert Tortoise Movement, Permeability, and Habitat along the Proposed State Route 95 Realignment	December 2012
	6. Performing Organization Code
7. Authors David D. Grandmaison, Raymond E. Schweinsburg, and Michael F. Ingraldi	8. Performing Organization Report No.
9. Performing Organization Name and Address Arizona Game and Fish Department Research Branch 5000 W. Carefree Highway Phoenix, AZ 85068	10. Work Unit No. 11. Contract or Grant No. SPR 000-1(173) 650
12. Sponsoring Agency Name and Address Research Center Arizona Department of Transportation 206 S. 17th Avenue, MD075R Phoenix, AZ 85007	13.Type of Report & Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

The goal of this study was to evaluate the effectiveness of highway mitigation for reducing road mortality of Morafka's desert tortoise (*Gopherus morafkai*; formerly, *G. agassizii*) and maintaining permeability in an effort to guide future mitigation within the range of the desert tortoise in Arizona. The research team examined existing wildlife-linkage mitigation measures along an 11-mi (17.7 km) stretch of U.S. Route 93 (US 93) and desert tortoise habitat relationships in the Black Mountains ecosystem to guide mitigation recommendations for the proposed realignment of State Route (SR) 95 between Interstate 40 (I-40) and SR 68. The work was performed in 2008 and 2009.

The team identified 561 breaches along the US 93 tortoise exclusion fencing due to erosion, undercutting, and siltation. Of the 25 culverts on US 93, 9 were nonfunctional due to their inaccessibility to desert tortoises. Camera systems deployed on 8 of the functional culverts detected no tortoise use. Five tortoise mortalities were documented during weekly road mortality surveys. Researchers identified a 0.22-mi road-effect zone on either side of the highway. The research team documented tortoises, tortoise sign, or both on 52 of the 660 plots surveyed within the Black Mountains ecosystem. The proportion of area occupied (PAO) by desert tortoises varied among soil subgroups, with Aridisol soil subgroups having the highest PAO estimates.

This report presents recommendations for improvements to the existing mitigation on US 93 and the proposed mitigation strategy for the planned realignment route of SR 95. These recommendations include maintenance and modification to fencing and culverts along US 93 and the placement of mitigation on the SR 95 realignment route.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
Desert tortoise, *Gopherus morafkai*, *Gopherus agassizii*, road-effect zone, fencing, wildlife underpass structures, monitoring, radio telemetry, habitat model, landscape ecology	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	145	

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ACRONYMS AND ABBREVIATIONS

° C	degree Celsius
° F	degree Fahrenheit
ac	acre
ACEC	Area of Critical Environmental Concern
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
AIC	Akaike's information criterion
AIDTT	Arizona Interagency Desert Tortoise Team
ANOVA	analysis of variance
amsl	above mean sea level
BBMM	Brownian bridge movement model
BLM	Bureau of Land Management
$\hat{c}$	variance inflation factor
df	degrees of freedom
DWASH	distance from highway segment centroid to nearest wash
ELEV	elevation at segment centroid
ESRI	Environmental Systems Research Institute
ft	foot
g	gram
GIS	geographic information system
GPS	Global Positioning System
ha	hectare
I-40	Interstate 40
km	kilometer
m	meter
MCP	minimum convex polygon
mi	mile
mm	millimeter
MP	milepost
N/A	not applicable
NAFTA	North American Free Trade Agreement
NCSS	National Cooperative Soil Survey
oz	ounce
P	probability
PAO	proportion of area occupied
PROPHAB	proportion of ReGAP landcover classes within highway segment
QAIC	quasi-likelihood Akaike's information criterion

R^2	coefficient of determination
ReGAP	Regional Gap Analysis Project
RTOPO	roadside topography
SD	standard deviation
SE	standard error
SR	State Route
US 93	U.S. Route 93
USFWS	U.S. Fish and Wildlife Service
VHF	very high frequency
w_i	Akaike weight
χ^2	chi-square
Z	standard score

ACKNOWLEDGMENTS

This study was funded by the Federal Highway Administration through the Arizona Department of Transportation (ADOT) Research Center and ADOT Roadway Predesign. The Bureau of Land Management (BLM) provided additional funding that made it possible to purchase and deploy Global Positioning System (GPS) tracking units on the U.S. Route 93 (US 93) study area for more detailed movement data collection. The research team thanks Ted Cordery, Tim Hughes, and Edward Walsh from the BLM Arizona State Office and Rebecca Peck and John Reid at the BLM Kingman Field Office for their commitment to making this project possible.

Many individuals at ADOT provided support and guidance during the course of this project and were instrumental to the success of the project, especially Estomih Kombe, Bruce Eilerts, Justin White, and Siobhan Nordhaugen out of the Phoenix headquarters. Julie Alpert, ADOT's Kingman District environmental coordinator, provided thoughtful and constructive comments during study design that helped improve the project substantially. The research team sincerely thanks Marc Kasper, Mike Enge, Josh Monson, and Mayra Moreno-Parrish from the Prescott Natural Resources Management Group for the time and effort they contributed to ensuring the field crew's safety and assisting with radio-telemetry efforts on the US 93 portion of the study. During a time of budgetary constraints and personnel shortages, their dependability maximized the efficiency and safety of our field efforts and is a testament to ADOT's commitment to the environment.

The Arizona Game and Fish Department's (AGFD) Kingman Region played an instrumental role in assisting with project development and logistical support. The research team would especially like to thank Bob Posey, Jeff Pebworth, Steve Goodman, Kevin Morgan, Trevor Buhr, Brian Carey, Janice Stroud, Micah White, Mike Rice, and Mary Wrench. Tom Jones, Cristina Jones, and Audrey Owens from the AGFD Nongame Program provided programmatic support and contributed their time to assist with volunteer coordination and data collection. Field personnel Scott Cambrin, Ron Mixan, Hillary Hoffman, Brandon Kell, Robert Randall, Scott Lillie, Melanie Banville, Michelle Crabb, Lesley Zizz, Nathan Shea, Kirby Bristow, Thorry Smith, Shaylon Stump, Steve McQueen, Christina Akins, Josh Fife, Nichole Blodgett, Kyle Thompson, and Will Lemon assisted with data collection under some of the most challenging conditions for fieldwork in Arizona. Renee Wilcox, Marcela Chavarria, Pamela Kennedy, Dean Treadwell, and Kari Ogren provided support that helped ensure the smooth execution of project administration. Jeff Gagnon, Joel Diamond, and Vincent Frary provided helpful reviews of this document.

The ADOT Research Center's Technical Advisory Committee provided many suggestions toward improving this project's effectiveness and applicability. Their tremendous support, oversight, and commitment throughout the duration of the project are greatly appreciated.

EXECUTIVE SUMMARY

The research team examined existing wildlife-linkage mitigation measures along an 11-mi (17.7 km) stretch of US 93 and habitat relationships of Morafka's desert tortoise (*Gopherus morafkai*; formerly, *G. agassizii*)—hereafter referred to as desert tortoise—in the Black Mountains ecosystem to guide route selection and mitigation recommendations for the proposed realignment of State Route (SR) 95 between Interstate 40 (I-40) and SR 68. The work was performed in 2008 and 2009. Specifically, the objectives were to:

- Determine the effectiveness of existing desert tortoise crossing structures and associated fencing on US 93.
- Develop a soil-based predictive model for desert tortoise occupancy within the Black Mountains ecosystem of Mohave County, Arizona, as a regional planning tool for tortoise mitigation.
- Identify areas along the proposed SR 95 realignment route for the placement of crossing structures and exclusion fencing to facilitate safe tortoise passage across the roadway.
- Develop management recommendations for maintaining desert tortoise permeability along the proposed alignment of SR 95.

The research team used a multifaceted approach to determine the effectiveness of existing mitigation efforts on US 93 between milepost (MP) 144 and MP 155. The team evaluated the current condition of the exclusion fencing and crossing structures and installed remotely triggered infrared cameras to determine whether functional crossing structures were being used by desert tortoises and other species. The team conducted weekly roadkill surveys to document the frequency and spatial pattern of desert tortoise mortality within the study area. The team also documented roadkill for other species within the project area to identify overall road mortality "hot spot" locations. Finally, the research team tracked tortoise movements using very high frequency (VHF) and GPS tracking units to examine the distribution of tortoise movements relative to the highway and crossing structures. Information from the US 93 study area was used to develop mitigation recommendations for the future realignment of SR 95.

The researchers tested the hypothesis that desert tortoise occupancy was related to soil subgroup designations to provide landscape-level information regarding the potential impacts of the proposed SR 95 realignment route. They used an occupancy modeling approach with desert tortoise surveys stratified among 11 soil subgroups within the Black Mountains ecosystem and examined variation in the proportion of area occupied (PAO). The researchers used these PAO estimates to evaluate the potential impact of various alignment alternatives and to identify locations along the alignments where mitigation would be appropriate for protecting the local desert tortoise population.

Finally, the research team monitored desert tortoise movements using VHF radio transmitters and GPS tracking units to identify existing movement patterns within the proposed SR 95 realignment zone. The team examined the impact of the existing transportation network on desert tortoise movements and compared soil subgroup composition of desert tortoise home ranges to the results of the landscape habitat modeling to further refine the recommendations for mitigating the impacts of the proposed alignments. The research included an alternative alignment evaluation based on estimates of PAO and provided recommendations regarding the location, installation, and maintenance of tortoise mitigation fencing and crossing structures.

The research team determined that the desert tortoise mitigation installed on US 93 has deteriorated to the point of limited functionality. While a number of the underpass crossing structures remain accessible to desert tortoises, a significant proportion are nonfunctional, and none were used by desert tortoises during the course of the study. In addition, numerous fencing breaches along the extent of the study area created ample opportunity for tortoises to access the highway at grade. Roadkill data indicated that road-related tortoise mortality is most likely to occur within the study area between MPs 150 and 153 and that repairs and maintenance should be made a priority along this segment of US 93. Examination of the spatial distribution of desert tortoise locations relative to the US 93 alignment suggests that there is a road-effect zone extending up to 0.22 mi (0.35 km). With proper repairs, the research team believes that the road-effect zone could be substantially reduced.

The evaluation of landscape-scale tortoise-habitat associations within the SR 95 realignment route suggests that desert tortoise occupancy was higher for soil subgroups with defined horizons (i.e., Aridisols) than soils lacking horizons (i.e., Entisols). Occupancy estimates for soil subgroups and desert tortoise home-range characteristics within the SR 95 realignment route were used to evaluate alignment impacts and prioritize locations for desert tortoise mitigation. The proposed alignments for the new SR 95 route along the western bajadas of the Black Mountains will impact tortoises that occupy habitat within the final route’s physical footprint. In addition, the final alignment has a high likelihood of creating a significant barrier to tortoise movements unless effective mitigation strategies are incorporated into the final highway design. Efforts should be made to minimize an alignment route through Typic Calciargid and Durinodic Haplocalcid soil subgroups. Crossing structures and exclusion fencing should be placed where the roadway intersects washes within these subgroups to facilitate movements underneath the highway. Access to the existing network of gravel roads also should be considered in the final highway design. Limited access (i.e., few traffic interchanges) to gravel roads within Typic Calciargid and Durinodic Haplocalcid soils should be evaluated, and where possible, traffic patterns should be directed to areas where impacts on important habitat features could be minimized.

1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 Desert Tortoise Habitat and Movement Characteristics

Habitat in the Sonoran Desert for Morafka's desert tortoise (*Gopherus morafkai*; formerly, *G. agassizii*)—hereafter referred to as desert tortoise—is typically characterized by volcanic outcrops, boulder-strewn hillsides, and mountain bajadas with large, deeply incised washes (Barrett 1990; Germano et al. 1994; Riedle et al. 2008) (Figure 1). Desert tortoises also occur within intermountain desert valleys, albeit at relatively lower density (Edwards et al. 2004; Averill-Murray and Averill-Murray 2005). The availability of suitable shelters (e.g., soil burrows, caliche caves, boulder piles) that provide nest sites, protection from predators, and refuge from extreme temperatures (Bury et al. 1994; Germano et al. 1994; Bailey et al. 1995) is a critical habitat component that drives differences in tortoise density (Fritts and Jennings 1994; Averill-Murray et al. 2002; Riedle et al. 2008). Given that desert tortoises spend approximately 98 percent of their life in subterranean shelter sites (Woodbury and Hardy 1948; Nagy and Medica 1986; Bailey et al. 1995), soils that allow for the construction of suitable shelter sites are a critical factor in tortoise distribution on the landscape (Woodbury and Hardy 1948).

Figure 1. Sonoran Desert Tortoise (*Gopherus morafkai*).

Desert tortoise home ranges, movements, and activity patterns vary both spatially and temporally. In the Sonoran Desert, tortoise home-range size varies between 2.6 and 25.8 ha (6.4 and 63.7 ac; Averill-Murray et al. 2002). Activity patterns typically follow seasonal variation in precipitation; tortoise activity is highest during the summer monsoon season (i.e., late July) and then gradually declines until tortoises return to hibernacula in October. During the summer rainy season, tortoises take advantage of new growth in perennial plants, germination of annuals, and the availability of free water on the landscape (Averill-Murray et al. 2002). Social behavior (e.g., male-male combat, courtship, mating) also peaks during and after the summer monsoon (Averill-Murray et al. 2002). Taken together, behaviors related to foraging, maintaining a positive water balance, and interacting socially with other tortoises involve movements at the local scale. In addition to tortoise activity within distinct home ranges, long-range dispersal movements serve to maintain gene flow among distinct desert tortoise metapopulations (Edwards et al. 2004).

1.1.2 General Impacts of Roads and Mitigation Strategies

Wildlife must move across the landscape to access their basic survival needs (i.e., food, water, shelter, mates). Anthropogenic barriers to wildlife movement, such as roads, pose a significant threat to the long-term persistence of wildlife populations worldwide (Noss 1983; Wilcox and Murphy 1985; Noss 1987). The direct and indirect effects of roads are some of the most pervasive forces for ecosystem change in the United States, resulting in habitat alteration, loss, and fragmentation (Noss and Cooperrider 1994; Trombulak and Frissell 2000). The expansion of the U.S. road system to approximately 3.9 million mi (6.3 million km) over the past century and the concomitant increase in traffic volume along the roadways have exacerbated these effects by creating nearly impenetrable barriers to wildlife movement (Noss and Cooperrider 1994; Forman and Alexander 1998; Forman et al. 2003). Overall, approximately 20 percent of the U.S. land base has been impacted by roadways (Forman and Alexander 1998; Ritters and Wickham 2003).

The impacts that roads have on wildlife populations include habitat loss within the road's physical footprint, reduced habitat quality adjacent to the roadway, increased exploitation of wildlife resources, direct mortality (i.e., roadkill), and reduced landscape connectivity (Spellerberg 1998; Trombulak and Frissell 2000; Forman et al. 2003). Since the 1950s, wildlife-crossing structures have been installed on North American roadways to mitigate these impacts; however, these structures have had mixed results that have been inadequately reported (Hardy et al. 2003; Cramer and Bissonette 2005; Glista et al. 2009). As a result, there is a lack of information regarding specific design features for successful wildlife-crossing structures (Transportation Research Board 2002). Nevertheless, there is an increasing interest in the use of wildlife-crossing structures as conservation tools for maintaining landscape connectivity (Clevenger and Wierzchowski 2006).

To be considered effective, a crossing structure should reduce roadkill following construction, maintenance, or enhancement of wildlife connectivity and should facilitate gene flow among distinct populations (Forman et al. 2003). From a wildlife conservation perspective, effective wildlife-crossing structures located within existing movement corridors or between otherwise intact habitat blocks can reduce the impacts of habitat fragmentation resulting from the isolation of core habitat (e.g., decreased population numbers, loss of genetic variation, loss of population viability, extirpation/extinction

[Lande 1988]). By facilitating animal movements between otherwise isolated populations, crossing structures help buffer populations from extinction and enable recolonization when adjacent metapopulations experience local extirpation (Lande 1988; Laurance 1991; Beier and Loe 1992; Hanski and Gilpin 1997). Dispersal among habitat blocks also benefits the gene pool by increasing genetic interchange and reducing the risk of inbreeding depression (Beier and Loe 1992; Bennett 1999).

Wildlife-crossing structures and exclusion fencing used to "funnel" animals to engineered crossing locations have the potential to make roads safer for motorists and wildlife by reducing animal-vehicle collisions and maintaining landscape connectivity (e.g., Clevenger et al. 2001; Dodd et al. 2007). From a public safety perspective, wildlife-crossing structures can reduce the amount of property damage and the number of lives lost from animal-vehicle collisions. In the United States, animal-vehicle collisions have resulted in hundreds of millions of dollars in property damage and approximately 200 motorist deaths annually (Bies 2007). In Arizona alone, 1481 animal-vehicle collisions were reported in 2008, resulting in 2 deaths and 212 injuries and over $1 million in costs associated with motorist fatalities/injuries and property damage (ADOT 2008). Granted, most collision-related human fatalities result from collisions with large mammals. However, it is conceivable that motorist responses to smaller animals, such as desert tortoises, on high-speed roadways could result in traffic accidents. In a recent study, Grandmaison and Frary (2012) found that between 16 and 61 percent of passing motorists responded to a desert tortoise placed on the road. This response varied from sudden slowing when the tortoise was detected to stopping and pulling over to move the tortoise off the road or to illegally collect it. Regardless of the response, motorist behavior when detecting a desert tortoise on a roadway has the potential to cause serious traffic hazards. The risk to motorist safety is likely elevated when vehicles are traveling at high speeds or when traffic levels are high.

1.1.3 Road-Related Impacts on Desert Tortoises

The impact of direct mortality from vehicle collisions is well documented for desert tortoises (Berry 1986a, 1986b; Boarman 1991; Boarman et al. 1993). For example, surveys conducted in the western Mojave Desert over a 2.5-year period documented 39 dead tortoises along a 15-mi (24.1 km) stretch of highway (Boarman et al. 1993). Similarly, surveys conducted along a 3-mi (4.8 km) section of Arizona's State Route (SR) 87 recorded 22 dead tortoises (AGFD, unpublished data). In southern Nevada von Seckendorff Hoff and Marlow (2002) detected a road-effect zone more than 2.5 mi (4.0 km) from the highway right-of-way, within which tortoise sign (e.g., live tortoises, tracks, scat, shelter sites) increased with distance to the roadway. Similar patterns have been documented in other parts of the Mojave Desert, although estimates regarding the extent of the road-effect zone have varied considerably. Nicholson (1979) documented a significant decrease in tortoise sign within 1.0 mi (1.6 km) of a roadway, while estimates presented by Karl (1989) showed an impact up to 1.5 mi (2.4 km). More recently, Boarman and Sazaki (2006) found a road-effect zone between 0.25 and 0.5 mi (0.4 and 0.8 km) of a highway. Traffic volume has been shown to influence the magnitude of roadway impacts to herpetofauna (Fahrig et al. 1995; Mazerolle 2004; Andrews and

Gibbons 2005) and may be responsible for the variability in the extent of road-effect zones documented for desert tortoises (von Seckendorff Hoff and Marlow 2002). Regardless, roads pose a serious challenge for desert tortoise conservation across the desert Southwest, a situation that has led the Arizona Interagency Desert Tortoise Team (AIDTT) to identify road-related impacts as significant threats to the viability of desert tortoise populations statewide (AIDTT 2000).

The susceptibility of desert tortoises to roadway impacts is related to tortoise biology and natural history. Desert tortoises occur at relatively low density, have low reproductive rates, and have low mobility—three characteristics that heighten their sensitivity to road-induced habitat loss (Trombulak and Frissell 2000). Gene flow among desert tortoise populations is important for long-term population persistence. Long-distance movements have been documented in the Sonoran Desert (Edwards 2003), and gene-flow estimates from southern Arizona indicate that tortoise populations historically exchanged individuals at a rate greater than one migrant per generation (Edwards et al. 2004). Anthropogenic barriers to dispersal, such as roads, reduce the likelihood of gene flow between desert tortoise populations (Edwards et al. 2004) unless successful mitigation can be implemented.

1.2 RESEARCH OBJECTIVES

This study addressed four objectives.

Objective 1. Determine the effectiveness of existing desert tortoise crossing structures and associated fencing on US 93.

Effectiveness monitoring improves our understanding of how various treatments influence parameters of interest and provides insight regarding treatment characteristics that could be manipulated for improving effectiveness. For example, monitoring the effectiveness of crossing structures could identify supplemental mitigation measures (e.g., fencing or culvert design modifications) that increase the use of the structures or reduce the frequency of desert tortoise roadkill. Only by monitoring crossing structure effectiveness can biologists determine whether additional modifications will be needed to achieve the goals set forth by mitigation objectives. As such, monitoring is a critical component in the development of successful crossing structures. This is especially true in the Sonoran Desert, where very little monitoring has occurred, thereby limiting the ability to implement data-driven management decisions regarding roadway mitigation.

Wildlife-crossing structures specifically designed for use by desert tortoises, along with directional exclusion fencing intended to funnel tortoises to the crossing structures, were installed along portions of US 93 (milepost [MP] 144 to MP 155) during the US 93 Boulders Reconstruction Project in response to concerns that road enhancements would negatively impact desert tortoises. The BLM requested the mitigation because US 93 bisects high-quality desert tortoise habitat. Subsequently, funding and staffing shortfalls limited the opportunity to monitor the effectiveness of these crossing structures in reducing tortoise mortality and maintaining connectivity. A cursory assessment of these crossing structures identified major deficiencies including fencing breaches and culvert undercutting, thereby limiting their usefulness (S. Goodman, AGFD, personal communication). Concerns regarding the effectiveness of these structures lead to the development of this research study. Without a thorough assessment of the structural status of these crossing structures and their influence on desert tortoise movements along this stretch of highway, there is no means for determining the success of mitigation efforts. In addition, without evaluating crossing structure use by tortoises, effective mitigation recommendations for future highway construction and enhancement in tortoise habitat are not possible.

To address this first objective, the research team began by evaluating the current condition of the exclusion fencing and crossing structures. The team then installed remotely triggered infrared cameras to determine whether functional crossing structures were being used by desert tortoises and other species. Researchers conducted weekly roadkill surveys to document the frequency and spatial pattern of desert tortoise (and other species) mortality within the study area. Finally, the researchers tracked tortoise movements using very high frequency (VHF) radio transmitters and GPS tracking units to examine the distribution of tortoise movements relative to the highway and crossing structures.

Objective 2. Develop a soil-based predictive model for desert tortoise occupancy within the Black Mountains ecosystem of Mohave County, Arizona, as a regional planning tool for tortoise mitigation.

The availability of shelter is a crucial component of desert tortoise habitat given that tortoises spend approximately 98 percent of their life inactive in these shelter sites (Nagy and Medica 1986). Shelter sites provide nest sites, protection from predators, and refuge from extreme temperatures (Bailey et al. 1995). Studies indicate that tortoise density is positively correlated with shelter site density in the Mojave Desert (Bury et al. 1994; Duda et al. 2002; Krzysik 2002) and the Sonoran Desert (Fritts and Jennings 1994; Averill-Murray et al. 2002; Riedle et al. 2008). Individual tortoises will use multiple shelter sites during a given season but have preferred shelters that are frequently reused (Woodbury and Hardy 1948).

Previous desert tortoise research within the Black Mountains ecosystem has identified a possible link between tortoise occurrence and soil type, specifically Aridisol soil subgroups. In a recent pilot study, desert tortoises and their sign (e.g., carcasses, scat, tracks) were found to be more abundant in areas with opportunities to burrow into or find naturally occurring cavities in the sides of washes within soil subgroups characterized by well-formed soil horizons (AGFD, unpublished data). These well-developed horizons, characteristic of Aridisol soils, provide structural integrity that prevents burrow collapse. This stability allows for the creation and maintenance of deep, permanent burrows that are considered vital for tortoise thermoregulation during climatic extremes. Soils without defined horizons, such as the Entisol soil order, tend to collapse soon after excavation and are too shallow for permanent burrow development.

To address this objective, the research team conducted desert tortoise occupancy surveys within each of the 11 soil subgroups found within the Black Mountains ecosystem. The researchers randomly located sixty 3 ha (7.4-ac) survey plots within each soil subgroup in order to conduct standardized surveys for desert tortoises and their sign. The researchers also categorized all potential and active tortoise shelter sites detected during surveys. The team estimated the proportion of area occupied (PAO) by desert tortoises at the soil order and subgroup levels. The team then evaluated a series of regression models to identify the influence of covariates, including landform, shelter availability, distance to wash, distance to road, year, season, and temperature on the probability of occupancy and detection.

Objective 3. Identify areas along the proposed SR 95 realignment route for the placement of crossing structures and exclusion fencing to facilitate safe tortoise passage across the roadway.

Research on wildlife crossings has generally taken two approaches: (1) identifying the species using crossing structures and their frequency of use and (2) using crossing data as an independent variable to identify factors that influence the use of crossing structures. Few studies have measured the performance of mitigation measures in meeting conservation goals (Dodd et al. 2007). Given the conservation goal inherent in the use of tortoise crossing structures as a mitigation measure, it is essential to obtain quantitative data regarding tortoise movements in an experimental (e.g., pre- and postconstruction) context as Dodd et al. (2007) did for elk (*Cervus elaphus*) along SR 260 in central Arizona.

To address this objective, the research team collected desert tortoise movement data with GPS tracking units along the proposed alignment for SR 95 and used those data to validate the soil models developed for Objective 2. Using this dataset, the team identified the geographic location of important desert tortoise habitat within the project area. The researchers then identified the locations where mitigation strategies, such as exclusion fencing and road crossings, should be implemented to reduce the impacts of the proposed highway realignment. In doing so, the researchers established a baseline dataset of preconstruction desert tortoise movement data throughout the project area that can be compared with postconstruction tortoise movements to evaluate the success of mitigation measures implemented as part of the highway construction.

Objective 4. Develop management recommendations for maintaining desert tortoise permeability along the proposed alignment of SR 95.

Using the insights obtained from this research study, the researchers developed recommendations regarding the need and placement for tortoise crossing structures and fencing to maintain and enhance current levels of permeability across the proposed realignment of SR 95. Recommendations include the specification and location of crossing structures and fencing needed to maintain permeability, as well as a monitoring plan to assess the success of these mitigation measures. The research team also provided recommendations for improvements to and maintenance of crossing structures and associated fencing along US 93.

1.3 REPORT ORGANIZATION

The purpose of this research project is to identify the effectiveness of current desert tortoise crossing structures and use that information to guide future efforts to mitigate the effects of roads on desert tortoise populations in Arizona. Specifically, the research team will apply insights gained from current crossing structures along US 93 to the mitigation planned for the realignment of SR 95 and future highway construction or modification in desert tortoise habitat. In the sections that follow, the team describes the specific objectives and results of the study and then synthesizes that information to provide recommendations for improving the existing mitigation along US 93 and for guiding future tortoise mitigation on SR 95. Recommendations developed from this study could be applied to other highways within Arizona where ADOT operations have the potential to impact desert tortoises and their habitat.

2.0 STUDY AREA

2.1 US 93

The first part of this research study was conducted on an 11-mi (17.7 km) stretch of US 93, between MPs 145 and 156 in Mohave and Yavapai counties, Arizona (latitude 34°29′–34°24′ N, longitude 113°23′–113°13′ W; Figure 2). The US 93 study area lies within Arizona Upland subdivision of the Sonoran Desert. Roadway elevations range from 2400 to 3400 ft (731.5 to 1036.6 m) above mean sea level (amsl). Vegetation adjacent to the highway is varied but dominated by a paloverde (*Parkinsonia* spp.)–mixed cacti association that includes saguaro cactus (*Carnegia gigantea*), barrel cactus (*Ferocactus wislizenii*), and prickly pear cactus (*Opuntia* spp.); a creosotebush–white bursage (*Larrea tridentata–Ambrosia dumosa*) association; and juniper (*Juniperus* spp.). Various annuals, perennial herbs, and grasses also exist within the study area. Brittlebush (*Encelia farinosa*), fairyduster (*Calliandra eriophylla*), buckwheat (*Eriogonum* spp.), wolfberry (*Lycium* spp.), ocotillo (*Fouquieria splendens*), beargrass (*Nolina* spp.), and ironwood (*Olneya tesota*) are common in the surrounding landscape.

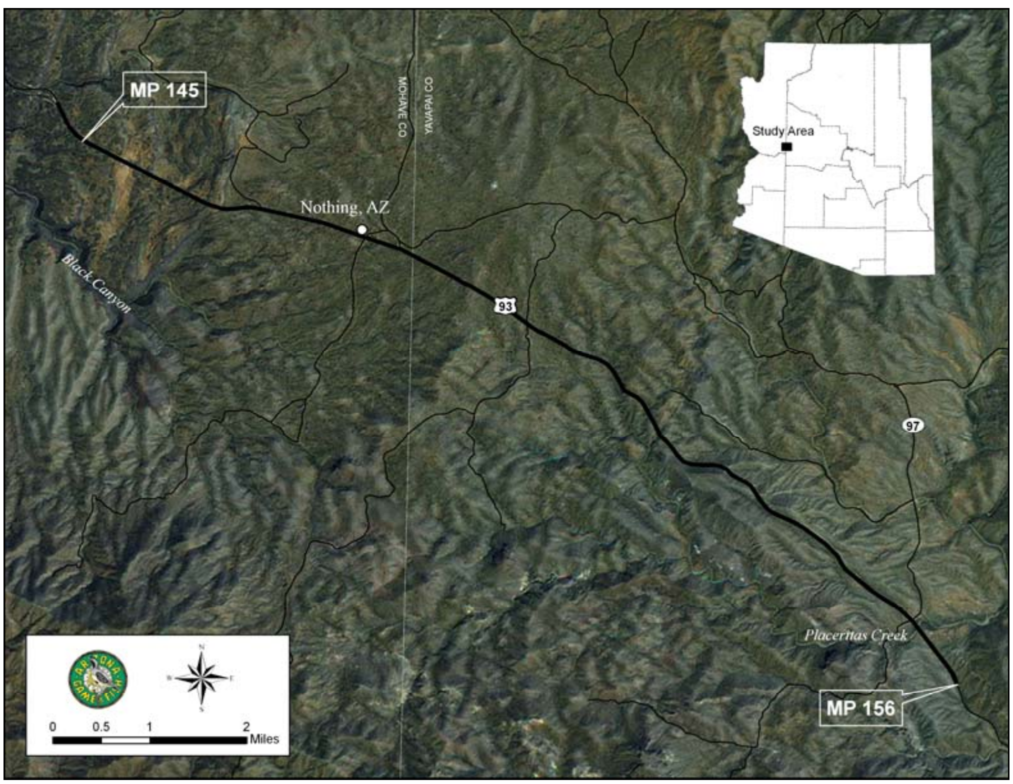


Figure 2. Location of the US 93 Study Area in Mohave and Yavapai Counties, Arizona.

The geomorphic context of the US 93 study area consists of a landscape with scattered granitic boulder piles, rock outcrops, and ridges interspersed among shallow to deep canyons and washes (Figure 3). The area is considered high-quality desert tortoise habitat given the abundance of boulder piles, which provide ample shelter sites for nesting, refuge from predators, and protection from extreme temperatures (Nagy and Medica 1986; Barrett 1990; Bailey et al. 1995; Germano et al. 1994).

Climatic conditions within the study area vary widely, with a mean maximum summer temperature of 105° F (40.6° C) in July and a mean minimum winter temperature of 38° F (3.3° C) in January. Annual precipitation averages 2.75 inches (7.0 cm) within Mohave County. The majority of the regional rainfall occurs in two distinct seasons, the winter rainy season and the summer monsoon season.

Figure 3. Desert Tortoise Habitat Adjacent to the US 93 Alignment.

US 93 is the primary highway route connecting the greater metropolitan Phoenix area to northwest Arizona, serving residents and commercial traffic between Wickenburg and Kingman. This route also supports recreational traffic associated with the Colorado River and the gaming industries of Laughlin and Las Vegas, Nevada. In addition, US 93 serves as a commercial route between Phoenix and Interstate 40 (I-40). US 93 is part of the National Highway System and has been designated as a North American Free Trade Agreement (NAFTA) highway corridor. As such, US 93 is planned for construction to interstate standards (ADOT 2004).

Before reconstruction, the majority of the highway was a two-lane undivided roadway, although limited passing lanes and four-lane divided sections existed. ADOT completed a corridor study for US 93 between Wickenburg and Kingman in 1992. The study recommended capacity and design improvements along the length of the corridor to accommodate projected future traffic volumes. The 1992 corridor study projected that traffic volume along US 93 would increase from 6000–6600 vehicles/day in 2000 to 8900–9400 vehicles/day by 2025 (ADOT 2010).

Following the corridor design study, ADOT, the Federal Highway Administration Arizona Division Office, and the BLM Kingman Field Office collaborated on the Boulders Reconstruction Project to improve highway capacity and motorist safety while maintaining ecological and scenic quality (Figure 4). The project converted 7.5 mi (12.1 km) of two-lane divided roadway to a four-lane divided highway and flattened the highway's vertical curves to improve visibility and enhance motorist safety between MPs 145 and 153.

Figure 4. US 93 Boulders Reconstruction Project Bisecting High-Quality Desert.

In addition to roadway improvements, the project included the installation of wire-mesh fabric to the bottom 18 inches of newly installed and existing game and right-of-way fencing on both sides of the highway to prevent desert tortoises from entering the roadway and to direct tortoises toward highway crossing structures (Figure 5; fencing specifications are included in Appendix A). Cross fencing was also installed in areas where culverts opened into habitat between the northbound and southbound lanes to prevent tortoises from accessing the road surface from the median.

Figure 5. Examples of Desert Tortoise Exclusion Fencing Installed during the US 93 Boulders Reconstruction Project.

2.2 SR 95

The second part of this research study was conducted within the proposed footprint of the SR 95 realignment on the eastern bajadas of the Black Mountains (Figure 6). The Black Mountains are a 75-mi-long (120.7 km) mountain range located in Mohave County in northwestern Arizona (Figure 7). The mountain range extends from the Lake Mead National Recreation Area at its northern extent to I-40 at its southern terminus. The Detrital Valley and the Colorado River define the range's east-west extent. The boundaries for this study included the Colorado River, Bullhead City, and SR 95 to the west; I-40 and US 93 to the south; Sacramento Wash and US 93 to the east; and Cottonwood Road to the north (Figure 7). The entire study area covered approximately 980 square mi (2538.2 square km).

The Black Mountains ecosystem is located in the northwestern extent of the Basin and Range province in Arizona, occupying the western third of Mohave County. The boundaries of the Black Mountains ecosystem include federal, state, and private lands. The Black Mountains Area of Critical Environmental Concern (ACEC) and three wilderness areas are designated within the Black Mountains ecosystem; two of the wilderness areas are located within the study area (Mount Nutt and Warm Springs wilderness areas). The ecosystem provides a myriad of recreational opportunities ranging from backcountry wilderness adventure to off-highway-vehicle use, wildlife observation, and horseback riding.

The Black Mountains are characterized by large mesas, ridges, steep cliffs, talus slopes, rocky foothills, and alluvial fans draining west to the Colorado River and east to Sacramento Wash. Elevations range from 5450 ft (1661.2 m) amsl at the range's highest point to 550 ft (167.6 m) amsl at the Colorado River. The elevation in Sacramento Valley is approximately 2000 ft (609.6 m) amsl. The climate is warm and dry, with summer temperatures reaching 120° F (48.9° C) and winter temperatures as low as 25° F (3.9° C). Annual precipitation averages 3 inches (7.6 cm). Vegetation within the Black Mountains ecosystem includes Mohave Desertscrub communities dominated by brittlebush and creosotebush on the western slopes and lower alluvial fans and Mojave yucca (*Yucca schidigera*) and blackbrush (*Coleogyne ramosissima*) to the east. Juniper trees are found at higher elevations within the range.

SR 95 is the primary north-south highway servicing the cities and towns on the east side of the Colorado River (Figure 6). The northern segment of the current SR 95 alignment is approximately 42 mi (67.6 km) long, beginning at I-40 just east of the Colorado River near Needles, California, and continuing north through Bullhead City, Arizona, where it connects to SR 68 at its northern terminus.

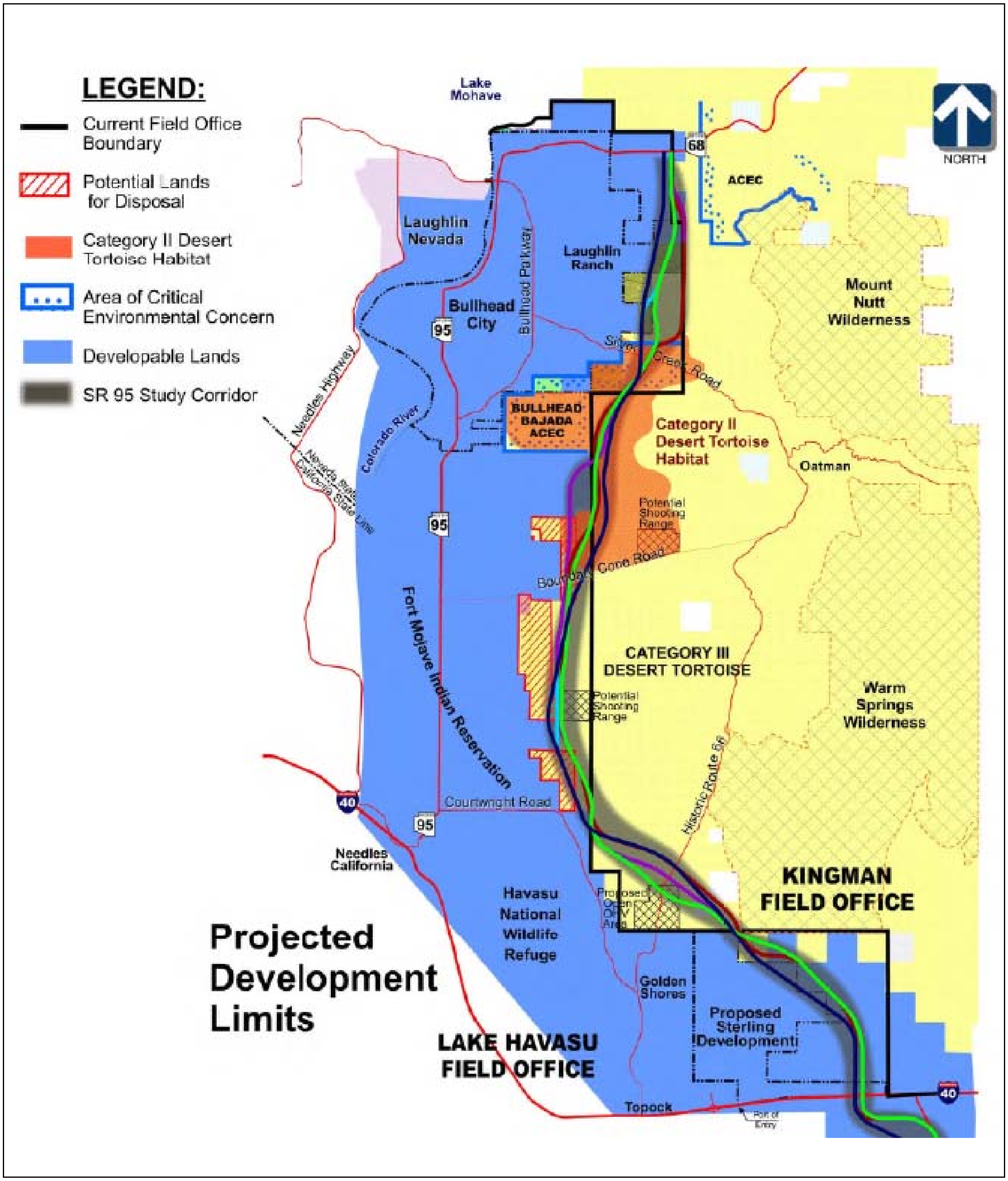


Figure 6. Proposed SR 95 Realignment Study Area in Mohave County, Arizona. (Source: ADOT 2010).

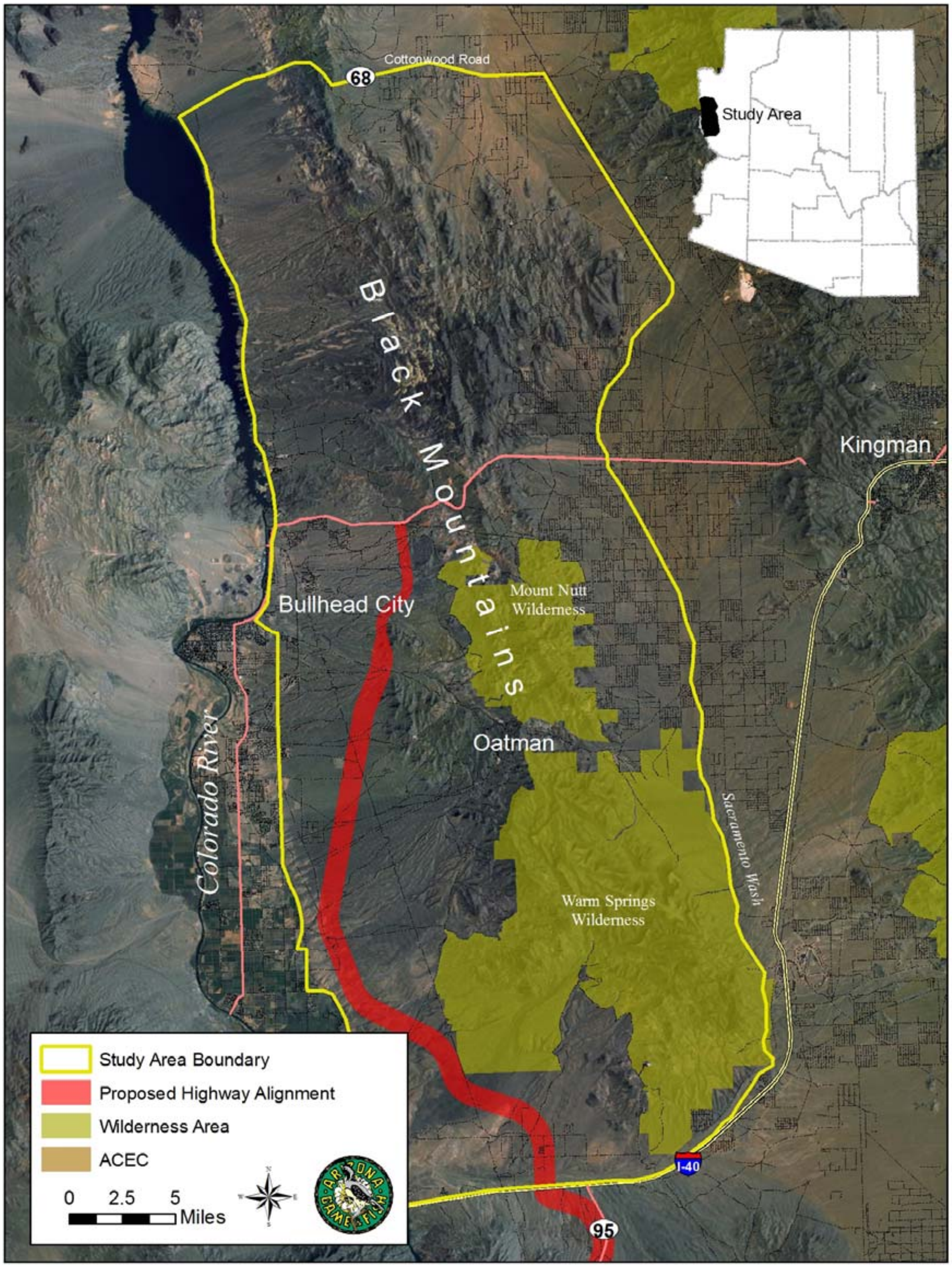


Figure 7. SR 95 Study Area in Mohave County, Arizona.

According to a feasibility study that ADOT conducted in 2005, a realignment of SR 95 is needed to improve the transportation system and enhance motorist safety. The existing SR 95 corridor experiences high traffic volume and congestion during peak traffic periods, making regional through-traffic difficult. Furthermore, the existing alignment fails to provide a contiguous north-south highway connection in western Arizona. Input from the project Technical Advisory Committee and the public resulted in the identification of a single 2-mi-wide (3.2 km) corridor for additional study (see Figure 6). This corridor was selected to maintain consistency with local development patterns and minimize habitat fragmentation of BLM-administered lands on the western slopes of the Black Mountains (ADOT 2005).

An estimated 744.5 square mi (1928.2 square km) of tortoise habitat have been designated within the Black Mountains ecosystem. The footprint of the proposed alignment directly impacts Category II (Table 1) tortoise habitat between Silver Creek Road and Boundary Cone Road (Figure 8). The proposed project corridor intersects Category II and Category III habitats for the desert tortoise as identified in the BLM resource management plans for the Lake Havasu and Kingman field offices, as well as the Lake Havasu Bullhead Bajada ACEC (Figure 8; Table 1). The proposed SR 95 realignment will impact desert tortoise habitat west of the Black Mountains, and this research study is the first data-driven effort to quantify that impact.

Table 1. BLM Desert Tortoise Habitat Category Goals and Criteria.

	Category I	**Category II**	**Category III**
Category goals	Maintain stable, viable populations and protect existing tortoise habitat values; increase populations, where possible	Maintain stable, viable populations and limit further declines in tortoise habitat values	Limit tortoise habitat and population declines to the extent possible by mitigating impacts
Criterion 1	Habitat area essential to maintenance of large viable populations	Habitat area may be essential to maintenance of viable populations	Habitat area not essential to maintenance of viable populations
Criterion 2	Conflicts resolvable	Most conflicts resolvable	Most conflicts not resolvable
Criterion 3	Medium to high density or low density contiguous with medium or high density	Medium to high density or low density contiguous with medium or high density	Low to medium density not contiguous with medium or high density
Criterion 4	Increasing, stable, or decreasing population	Stable or decreasing population	Stable or decreasing population

Source: AIDTT 1996.

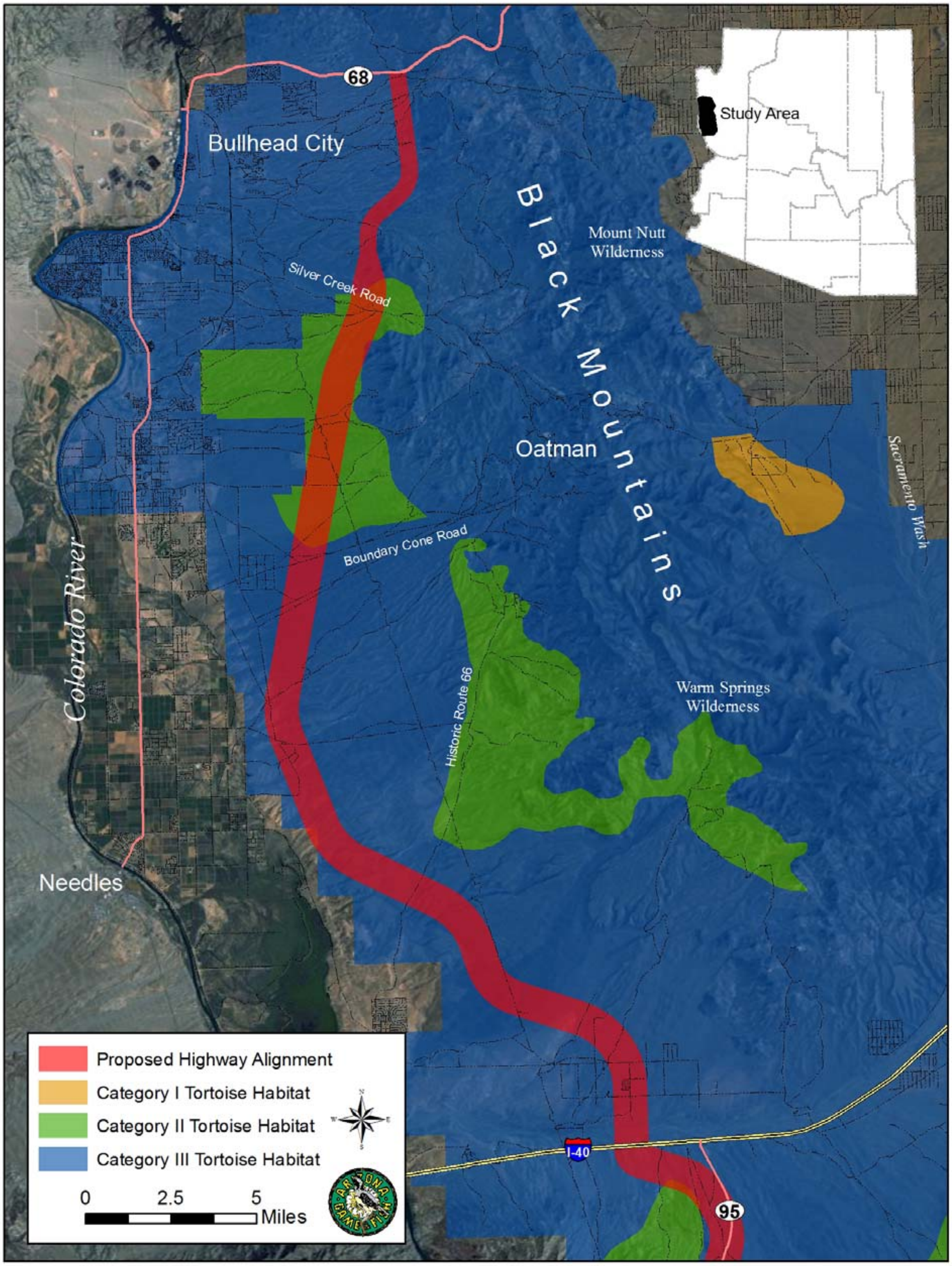


Figure 8. Bureau of Land Management Desert Tortoise Habitat Classifications within the SR 95 Realignment Project Area.

3.0 EFFECTIVENESS OF TORTOISE EXCLUSION FENCING AND CROSSING STRUCTURES

3.1 INTRODUCTION

Over the past few decades it has become increasingly apparent that transportation networks have significant impacts on wildlife populations (Forman et al. 2003). These impacts include habitat loss within the road's physical footprint, reduced habitat quality adjacent to the roadway, increased exploitation of wildlife resources, direct mortality (i.e., roadkill), and reduced landscape connectivity (Spellerberg 1998; Trombulak and Frissell 2000; Forman et al. 2003). Since the 1950s, wildlife-crossing structures have been installed on North American roadways to mitigate these impacts; however, these structures have had mixed results that have been inadequately reported (Hardy et al. 2003, Cramer and Bissonette 2005, Glista et al. 2009). As a result, there is a lack of information regarding specific design features of successful wildlife-crossing structures (Transportation Research Board 2002). Nevertheless, interest in using wildlife-crossing structures as conservation tools for maintaining landscape connectivity is increasing (Clevenger and Wierzchowski 2006).

Standard mitigation for road-related impacts on desert tortoise habitat in the Mojave Desert includes fencing designed to exclude tortoises from making at-grade crossings and to direct wandering tortoises toward highway underpass structures in order to reduce road-related mortality and maintain/increase permeability for tortoises (Boarman et al. 1993; Appendix A). This approach has had promising results in the Mojave Desert (Boarman 2010) and is becoming more common in the Sonoran Desert (e.g., SR 86, SR 87, US 93). On US 93, for example, underpass crossing structures specifically designed for use by desert tortoises were constructed between MPs 144 and 155 during the US 93 Boulders Reconstruction Project (Figure 9). These structures were connected with tortoise exclusion fencing along the right-of-way and in the median in an effort to funnel tortoises to the crossing structures. The effectiveness of this mitigation effort had not been evaluated before the initiation of this research study. However, a cursory assessment of the crossing structures identified major deficiencies (e.g., fencing breaches and culvert undercutting [Figure 10]) limiting their usefulness (S. Goodman, AGFD, personal communication).

Ideally, effectiveness monitoring includes collecting baseline data before implementing the conservation strategy to provide a temporal control with which to compare post implementation monitoring data and then comparing these data to a control site where the conservation strategy was not implemented (Clevenger and Waltho 2003; Hardy et al. 2003). Unfortunately, a lack of funding prohibited monitoring efforts to evaluate desert tortoise mitigation along US 93. While this inhibits a reliable evaluation of the overall impact of the mitigation strategy, information regarding the effectiveness of the existing mitigation can be inferred from culvert use by desert tortoises and the spatial pattern of desert tortoise roadkill within the project area.

Figure 9. Underpass Structure Designed to Facilitate Desert Tortoise Movement within the US 93 Project Area.

Figure 10. Examples of a Structural Fencing Breach (Left) Caused by Erosion and Biological Breach (Right) Caused by Animals Pushing through a Nonburied Fencing Segment.

The objective of this study was to evaluate the current effectiveness of exclusion fencing and underpass structures on US 93. The study used a multifaceted approach to determine the effectiveness of mitigation efforts between MP 144 and MP 155. The research team evaluated the current condition of the exclusion fencing and crossing structures and installed remotely triggered infrared cameras to determine whether functional crossing structures were being used by desert tortoises and other species. The researchers conducted weekly roadkill surveys to document the frequency and spatial pattern of desert tortoise mortality within the study area; they also documented roadkill for other species within the project area as an indicator for overall mortality hot-spot locations.

Finally, the team used VHF-telemetry and GPS tracking units to record tortoise movements in order to examine the distribution of tortoise spatial use relative to the highway and crossing structures.

3.2 METHODS

3.2.1 Identifying Deficiencies in the Mitigation Fencing and Crossing Structures

Researchers walked the entire length of mitigation fencing between MPs 144 and 155 (including the median) to visually assess the location of fencing breaches and deficiencies in underpass structures that would make them nonfunctional for desert tortoises. Structural (e.g., buried or missing fencing, erosion beneath fencing) and biological breaches (e.g., burrows and trails underneath the fencing; see Figure 10) were examined. Researchers recorded the nature of the breach (i.e., over the fence or under the fence) and the length of the fence deficiency, along with geographic coordinates for the breach location. Underpass structures within the study area were categorized as functional or nonfunctional for use by desert tortoises based on the absence or presence of a "perched" entrance (Figure 11) inhibiting tortoise access.

Figure 11. Example of a Perched Entrance to a Drainage Culvert Running Underneath US 93.

3.2.2 Evaluating Crossing-Structure Permeability on US 93

Once the initial inventory of mitigation fencing and crossing structures was completed, remotely triggered, passive infrared camera systems (PM75 RapidFire Professional Mono IR™) were installed at a sample of functional crossing structures to evaluate wildlife permeability. Cameras have been identified as the most cost-effective technique for monitoring crossing structure use by wildlife (Ford et al. 2008) and allow for more reliable identification of species activity than track monitoring (Swann et al. 2004). Camera systems were positioned at one end of each crossing structure so that animals approaching the culvert would be documented even if they did not ultimately use the structure for moving under the highway.

For each crossing structure monitored, researchers recorded the following: structure type (i.e., pipe culvert or concrete box culvert), structural dimensions (length, width, and height), openness ratio (cross-sectional area of a culvert divided by its length [Clevenger and Waltho 2000]), culvert placement (i.e., whether it runs under both northbound and southbound lanes or opens into the median), and percentage of natural substrate on the floor of the culvert.

3.2.3 Roadkill Surveys

The research team conducted weekly roadkill surveys between MPs 144 and 155 within the project area to investigate roadkill spatial patterns. Each week, researchers surveyed the northbound and southbound lanes to identify and record roadkill by wildlife type and highway location. Researchers conducted the surveys from all-terrain vehicles traveling ≤ 5 miles per hour along the shoulder and median, to maximize the detection of roadkill wildlife and maintain methodological consistency (Langen et al. 2007). This approach, in contrast to walking surveys, allowed the team to cover the entire study area in a single morning and provided the greatest level of safety. In areas where no substantial shoulder was available (mainly on the northbound lane west of Nothing, Arizona), ADOT's Prescott District Maintenance provided a safe work zone for the roadkill surveys; a "shadow" vehicle followed the researchers and used flashing warning lights to alert oncoming traffic of the team's presence on the roadway. Areas within the median (i.e., between the northbound and southbound lanes) and adjacent to the paved shoulder (i.e., from the edge of the pavements to about 8 to 10 ft [2.4 to 3.0 m] off the shoulder) were also surveyed to identify wildlife that may have been thrown from the pavement or moved off the highway before dying.

Wildlife roadkill locations were recorded with a GPS unit for spatial analysis (Langen et al. 2007). All roadkill detections were identified to the lowest taxonomic level possible, and either removed from the road or marked with a spot of orange survey paint to avoid their inclusion in subsequent surveys. Roadkill detections were categorized by taxonomic group (e.g., lizard, amphibian, snake, small mammal, avian) for further analysis.

3.2.4 Desert Tortoise Movement Patterns and Space Use

The research team, along with volunteers, conducted tortoise surveys within a 0.62-mi (1.0 km) buffer adjacent to portions of US 93 that had the highest probability of supporting desert tortoises based on known tortoise habitat characteristics (Barrett 1990; Germano et al. 1994; Averill-Murray and Averill-Murray 2005; Riedle et al. 2008). All shelter sites detected during these surveys were examined for tortoises and their sign.

The team implemented established guidelines (Berry and Christopher 2001) to prevent unnecessary stress and potential disease transmission for all tortoises captured during the surveys. Personnel handling tortoises wore a fresh pair of disposable gloves for each tortoise processed, and they sterilized all equipment with a veterinary disinfectant (chlorhexidine diacetate; AIDTT 1996) after processing each one. If a tortoise voided the contents of its bladder during handling or showed signs of extreme dehydration (e.g., sunken eyes, boney head, sunken forelimb muscles), the tortoise was rehydrated with a saline solution injection. Following standard AGFD handling guidelines and health screening protocols, the team examined tortoises for clinical signs of upper respiratory tract disease (characterized by nasal discharge, ocular discharge, palpebral edema, and conjunctivitis), shell anomalies, and parasites (Jones et al. 2005; Jones 2008). When feasible, the oral cavities were examined for clinical signs of herpesvirus (presence of plaque or open sores in the mouth).

The research team weighed all tortoises and measured their midline carapace length using calipers (± 0.04 inch [1.0 mm]) to provide an estimate of each tortoise's age based on size class. The marginal scutes of each tortoise were permanently notched with a unique pattern to identify individuals (Cagle 1939). Researchers avoided notching the bridge scutes since the notches in this area have the potential to weaken the carapace. In addition to the notches, the researchers also assigned each tortoise an identification number, which they applied to the areola of the fourth right costal scute with correction fluid and black permanent marker and covered with epoxy (Murray and Schwalbe 1997), to facilitate easy identification if recaptured. The researchers examined the morphological characteristics of all tortoises with a ≥7-inch (180 mm) midline carapace length to determine sex; tortoises with concave plastrons, long gular horns, long tails, and well-developed chin glands were classified as males.

Telonics™ radio transmitters were glued with epoxy to the first left costal scute of 11 desert tortoises and positioned below the highest point on the carapace (Boarman et al. 1998). The transmitter antenna was inserted into short 0.25-inch (6.3 mm) segments of shrink tubing glued to the marginal scutes. Sirtrack MicroGPS™ tracking units (Figure 12), each with a mean weight of 1.89 oz (53.5 g), were glued to the top of the carapace to ensure adequate communication with satellites for location data acquisition. Short pieces of electrical tape were placed over the scute margins to ensure that epoxy was not applied to the seams between scutes.

The team used handheld radio-telemetry techniques to locate the tortoises weekly to check the status of the GPS tracking units and monitor the condition of the tortoises, as well as to collect a standard set of data regarding microhabitat use for future analyses

(Grandmaison et al. 2010). The GPS tracking units collected positional data every 30 minutes during specified periods: 5 am to 10 am and 4 pm to 9 pm. The research team chose a short time interval between successive locations in order to identify specific highway crossing locations for any tortoises that successfully crossed the highway. GPS units were deployed for two-week intervals; after two weeks, the researchers removed the units, downloaded the data, and recharged the tracking unit batteries before redeploying the units on the same individual tortoises.

Figure 12. Sirtrack MicroGPS Tracking Unit Being Applied to a Desert Tortoise in the US 93 Study.

3.2.5 Statistical Analysis

Identifying Deficiencies in the Mitigation Fencing and Underpass Structures

The research team summarized the number and type of fencing deficiencies detected within the US 93 study area and examined fencing breaches relative to the presence or absence of drainage features (i.e., washes). The team categorized fencing deficiencies as "structural" or "biological" based on the probable cause of the deficiency and also described the characteristics that made the culverts "nonfunctional" for facilitating safe passage by desert tortoises.

Evaluating Crossing-Structure Permeability on US 93

Passage rates served as an index of crossing-structure permeability (Dodd et al. 2007). The researchers calculated passage rates as the ratio of successful wildlife crossings to the overall number of approaches (Dodd et al. 2007); mean passage rates were reported with a ± 1 standard error (SE). A successful crossing constituted either an animal entering the culvert without returning into view within two minutes of initial entry or an animal observed exiting the culvert without having been observed entering during the two minutes before being documented on camera. Conversely, a failed crossing attempt occurred when an animal approached the culvert but did not enter or when it entered the culvert but exited in less than two minutes. The research team obtained species-specific permeability estimates for each culvert where greater than 10 approaches were documented on camera. The team also summarized culvert characteristics for the culverts that were monitored.

Temporal, Spatial, and Habitat Characteristics of Roadkill Hot Spots on US 93

Species Composition and Temporal Patterns of Roadkill

To describe the temporal pattern in roadkill occurrence for the taxonomic groups (amphibians, lizards, snakes, and small mammals) detected on US 93, the research team compared roadkill frequency across years and months using a chi-square (χ^2) analysis (Zar 1999). The team used the Spearman rank correlation coefficient to evaluate the relationship between monthly precipitation and roadkill frequency for each taxonomic guild (Zar 1999). Precipitation data were obtained from the U.S. Department of Commerce's National Climatic Data Center (http://www7.ncdc.noaa.gov/IPS/). Given the documented relationship between roadkill and traffic volume, the researchers also examined the relationship between traffic volume and roadkill frequency using the Spearman rank correlation coefficient. Daily traffic data were obtained from ADOT traffic counting station #102090 (http://adot.ms2soft.com/tcds/tsearch.asp?loc=Adot&mod=). The researchers summarized daily traffic volume to obtain monthly estimates for analysis. April and June data were unavailable for this station or any nearby station and were thus omitted from the traffic volume analysis.

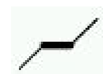
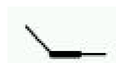
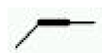
Spatial Patterns of Roadkill

To identify roadkill hot spots within the study area, the researchers divided the length of the US 93 study area into 117 sequentially numbered 525-ft (160 m) segments, corresponding to highway units designated by ADOT for tracking wildlife-vehicle collisions and highway maintenance (Dodd et al. 2007). They then evaluated the frequency of roadkill within each highway segment (Malo et al. 2004; Langen et al. 2009). Roadkill "hot spots" for each taxonomic group were defined as segments of highway where the frequency of roadkill exceeded the median roadkill frequency across the study area. The hot spots were presented graphically for each taxonomic group.

Factors Related to Roadkill Hot Spots

The research team used logistic regression (Hosmer and Lemeshow 2000) to identify predictive variables associated with taxa-specific roadkill hot spots by comparing a series of hypotheses (i.e., statistical models) based on a priori variables thought to influence the spatial pattern of roadkill accumulation under a model selection framework (Burnham and Anderson 2002). First, each 525-ft (160 m) highway segment was classified as a hot-spot segment or a non-hot-spot segment. The team then modeled this binary response variable as a function of landscape and road-specific variables chosen to describe roadkill segments (Table 2). Indicator, or dummy, variables were created for categorical variables with one reference variable (e.g., RTOPO1= level roadside topography). The researchers did not include the binary variable CROSSING, which represented the presence or absence of a highway crossing structure, in analyses for birds or bats (Clevenger et al. 2003).

Table 2. Variables Used in the Analysis of Factors Influencing the Spatial Pattern of Roadkill Hot Spots on US 93.

Variable Name	Definition
CROSSING	0 = underpass not present in highway segment, 1 = underpass present
RTOPO	Roadside topography (bold line represents pavement):
	(1) Level (4) Buried-Raised 
	(2) Partially Buried  (5) Buried 
	(3) Partially Raised  (6) Raised 
CURVE	0 = straight segment of highway, 1 = curved
ELEV	Elevation (meters above mean sea level) at segment centroid
DWASH	Distance (meters) from highway segment centroid to nearest wash
PROPHAB	Proportion of ReGAP (Regional Gap Analysis Project) landcover classes within highway segment:
	Apacherian-Chihuahuan Mesquite Upland Scrub
	Sonoran Paloverde-Mixed Cacti Desertscrub
	Sonora-Mojave Creosotebush-White Bursage Desertscrub
	North American Warm Desert Riparian Mesquite Bosque
	Madrean Pinyon-Juniper Woodland
	Sonoran Mid-Elevation Desertscrub

The researchers assessed overall fit for the global model using the Hosmer and Lemeshow (2000) goodness-of-fit test. They evaluated overdispersion for the global model (i.e., a model including all the parameters of interest) based on the variance inflation factor ($\hat{c}$), which was calculated by dividing the residual deviance of the global model by its degrees of freedom (df) (Burnham and Anderson 2002; Crawley 2007). The team used the small sample correction for Akaike's information criterion (AIC_c) (Hurvich and Tsai 1989; Burnham and Anderson 2001; Vaida and Blanchard 2005) to rank candidate models. The quasi-likelihood Akaike's information criterion ($QAIC_c$) was used when $\hat{c} > 1$ (Burnham and Anderson 2002). The inclusion of $\hat{c}$ added an additional parameter to AIC calculation (Burnham and Anderson 2002). The researchers calculated AIC_c difference (ΔAIC_c or $\Delta QAIC_c$) and Akaike weight (w_i) (Buckland et al. 1997) for each model to assess model uncertainty and the likelihood of each candidate model given the data. They considered models with ΔAIC_c or $\Delta QAIC_c \leq 2$ to be well supported by the data (Burnham and Anderson 2002). The researchers then examined the classification rates for the supported models (ΔAIC_c or $\Delta QAIC_c \leq 2$) to determine the relative predictive ability of the models. Finally, they examined the Nagelkerke R^2, which is a likelihood-based analogy to the coefficient of determination (R^2) used in ordinary least-squares regression analyses (Nagelkerke 1991), for models with ΔAIC_c or $\Delta QAIC_c \leq 2$ (Burnham and Anderson 2002).

Desert Tortoise Movement Patterns and Space Use Relative to the US 93 Alignment

Determining the Location of Highway Crossing Locations

The research team plotted desert tortoise locations obtained with the GPS tracking units using ArcGIS 9.3™, a geographic information system (GIS), in order to identify whether any of the monitored tortoises crossed the highway. The team also used the Hawth's Analysis Tools ArcGIS extension (Beyer 2004) to estimate the path between successive locations and to examine the resulting pathway to determine whether the tortoises crossed the alignment and, if so, where the crossings occurred.

Identifying Space Use Relative to the US 93 Alignment

The team used the Brownian bridge movement model (BBMM) defined by Horne et al. (2007) to assess desert tortoise space use adjacent to the US 93 alignment. The BBMM is a continuous-time stochastic movement model that quantifies the probability of space use along a movement pathway defined by consecutive location estimates obtained using frequent location data, such as that obtained using GPS tracking technologies (Horne et al. 2007). The BBMM is estimated using the location estimates for consecutive GPS fixes, the variance related to the error of the location estimates, the time elapsed between consecutive locations, and a likelihood-based estimate of the animal's mobility (Horne et al. 2007).

The researchers used the BBMM to estimate tortoise home ranges adjacent to US 93 based on location data collected using GPS tracking units programmed to collect a GPS fix every 30 minutes. GPS tracking units obtained location estimates with an estimated location error of ± 50 ft (15 m). The team used the software program Animal Space Use (Horne and Garton 2009) to estimate the Brownian movement variance parameter using maximum likelihood estimation techniques and output the resulting probability distribution of desert tortoise space use within the study area. They then plotted the resulting home-range estimates using ArcGIS 9.3 to examine the location relative to the US 93 alignment. The researchers calculated the mean (±SE) home-range size and core area for both males and females. Core areas were defined by the upper quintile of the probability distribution (i.e., where the probability of space use generally exceeded 0.98) estimated by the BBMM.

The research team also examined the complete set of tortoise locations using the entire location dataset across all individuals to determine the distribution of tortoise locations along a distance gradient from the US 93 alignment. They presented these results as a histogram of the frequency of tortoise locations within 82-ft (25 m) segments perpendicular to the highway's alignment.

3.3 RESULTS

3.3.1 Identifying Deficiencies in the Mitigation Fencing and Crossing Structures

The research team identified 561 structural and biological fence deficiencies distributed across the entire study area, which have rendered approximately 0.49 mi (0.8 km) of the desert tortoise barrier fencing ineffective. Most of the deficiencies noted were structural (n = 506; 90 percent), and the remainder (n = 55) were biological (i.e., deficiencies caused by animal burrowing). Structural deficiencies included 464 breaches under the fence resulting from erosion or ineffective fencing placement across washes that caused undercutting. The mean length of breaches under the fencing was 3.31 ft (1 m; SE = 5.64 ft [1.72 m]; range = 0.33 to 53.48 ft [0.1 to 16.3 m]). Another 42 structural deficiencies were associated with breaches over the fencing resulting from siltation that buried the fencing. These breaches were greater in length than breaches under the fencing; the mean length of breaches over the fencing was 23.75 ft (7.2 m; SE = 31.72 ft [9.7 m]; range = 1.96 to 177.16 ft [0.6 to 54.0 m]). Most of the biological breaches were too small to allow adult desert tortoises to access the highway (mean length = 0.66 ft [0.2 m]; SE = 0.36 ft [0.1 m]; range = 0.32 to 1.64 ft [0.1 to 0.5 m]) but were large enough to possibly facilitate hatchling or juvenile tortoise movement onto the pavement.

The team inventoried 25 culverts within the study area. Of the culverts inventoried, 9 structures (36 percent) were nonfunctional based on the presence of a perched opening ≥0.33 ft (0.1 m) off the ground, and 16 structures (64 percent) were accessible to desert tortoises and could conceivably have facilitated movement under the highway (Figure 13).

3.3.2 Evaluating Crossing-Structure Permeability on US 93

The research team deployed eight camera systems in 2008 and 2009, monitoring a total of 12 crossing structures over the course of the two-year study. Of the 12 culverts, 4 were monitored during both years. In total, the team documented 651 wildlife approaches during the monitoring period, although no tortoises were documented using the culverts (Table 3). The team documented greater than 10 approaches for bobcats (*Lynx rufus*), desert cottontails (*Sylvilagus audubonii*), and javelinas (*Tayassu tajacu*) at multiple culverts (Table 4). The mean passage rate was highest for javelinas (0.883 ± 0.083), followed by bobcats (0.821 ± 0.151) and desert cottontails (0.465 ± 0.141).

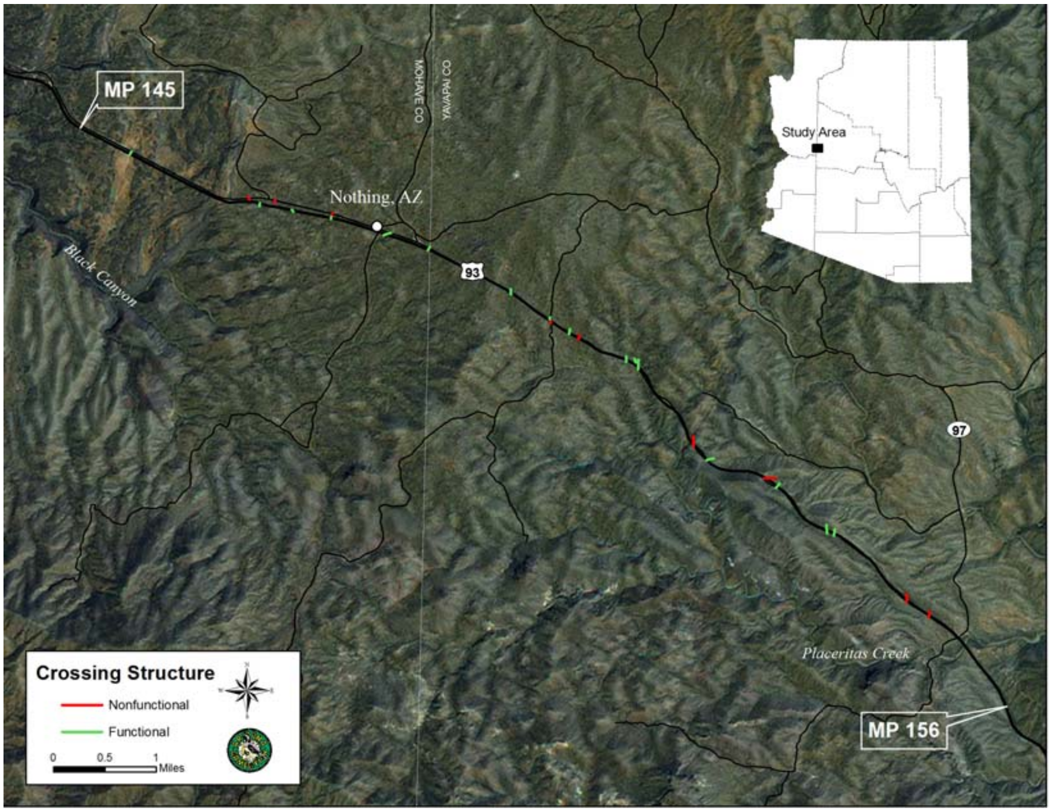


Figure 13. Culvert Locations within the US 93 Study Area.

3.3.3 Temporal, Spatial, and Habitat Characteristics of Roadkill Hot Spots on US 93

Species Composition and Temporal Patterns of Roadkill

Weekly roadkill surveys yielded 3276 and 2403 detections in 2008 and 2009, respectively (a tabular summary of all roadkill detections is included in Appendix B). The biologists found five desert tortoise carcasses in 2008 but did not detect any tortoise carcasses in 2009. The frequency of roadkill occurrence varied among years for amphibians (χ^2 = 184.5, df = 1, P < 0.001), lizards (χ^2 = 317.1, df = 1, P < 0.001), and small mammals (χ^2 = 10.8, df = 1, P = 0.001) but not for snakes (χ^2 = 1.1, df = 1, P = 0.301). Herpetofaunal roadkill frequency was higher in 2008 than 2009, while small-mammal roadkill frequency was lower in 2008 than in 2009 (Figure 14). Roadkill occurrence varied by month for amphibians (χ^2 = 315.4, df = 5, P < 0.001), lizards (χ^2 = 618.6, df = 7, P < 0.001), snakes (χ^2 = 269.3, df = 7, P < 0.001), and small mammals (χ^2 = 397.4, df = 7, P < 0.001).

Table 3. Observations of Wildlife at 12 Culverts along US 93 in 2008 and 2009.

Guild	Common Name	Scientific Name	No. of Observations
Lizard	Spiny lizard	*Sceloporus* spp.	2
	Whiptail lizard	*Aspidoscelis* spp.	2
	Unknown lizard	N/A	4
Avian	Cactus wren	*Campylorhynchus brunneicapillus*	5
	Greater roadrunner	*Geococcyx californianus*	41
	Mourning dove	*Zenaida macroura*	13
	Northern mocking bird	*Mimus polyglottos*	1
	Lesser nighthawk	*Chordeiles acutipennis*	3
	Gambel's quail	*Callipepla gambelii*	76
	Western meadowlark	*Sturnella neglecta*	1
	Unknown bird	N/A	10
Bat	Unknown bat	N/A	7
Small mammal	Black-tailed jackrabbit	*Lepus californicus*	6
	Desert cottontail	*Sylvilagus audubonii*	132
	Harris's ground squirrel	*Ammospermophilus harrisii*	14
	Hog-nosed skunk	*Conepatus leuconotus*	13
	Spotted skunk	*Spilogale gracilis*	3
	Striped skunk	*Mephitis mephitis*	6
	Unknown skunk	N/A	3
	Rock squirrel	*Spermophilus variegatus*	45
	White-throated woodrat	*Neotoma albigula*	1
	Unknown rodent	N/A	1
Ungulate	Javelina	*Tayassu tajacu*	90
	Mule deer	*Odocoileus hemionus*	4
Livestock	Domestic cattle	*Bos primigenius*	13
	Domestic sheep	*Ovis aries*	3
Carnivore	Badger	*Taxidea taxus*	2
	Black bear	*Ursus americanus*	1
	Bobcat	*Lynx rufus*	103
	Coyote	*Canis latrans*	19
	Gray fox	*Urocyon cinereoargenteus*	23
	Unknown carnivore	N/A	3

Table 4. Passage Rates for Wildlife Species with Greater Than 10 Observed Approaches.

CUL_ID	Stype[a]	Species	Guild	Attempts	Success	Passage Rate[b]
CUL01	CMP	Bobcat	Carnivore	24	21	0.875
CUL03	CBC	Bobcat	Carnivore	17	11	0.647
CUL09	CMP	Bobcat	Carnivore	21	16	0.762
CUL11	CBC	Bobcat	Carnivore	10	10	1.000
CUL01	CMP	Desert cottontail	Small mammal	10	3	0.300
CUL03	CBC	Desert cottontail	Small mammal	20	8	0.400
CUL06	CMP	Desert cottontail	Small mammal	23	14	0.609
CUL09	CMP	Desert cottontail	Small mammal	20	11	0.550
CUL01	CMP	Domestic cow	Livestock	12	0	0.000
CUL01	CMP	Gambel's quail	Avian	21	4	0.190
CUL03	CBC	Gambel's quail	Avian	19	0	0.000
CUL11	CBC	Gambel's quail	Avian	12	7	0.583
CUL01	CMP	Gray fox	Carnivore	17	16	0.941
CUL01	CMP	Javelina	Ungulate	21	17	0.810
CUL03	CBC	Javelina	Ungulate	36	35	0.972
CUL09	CMP	Javelina	Ungulate	15	13	0.867
CUL03	CBC	Rock squirrel	Small mammal	11	4	0.364

[a] Structure type: CMP = corrugated metal pipe; CBC = concrete box culvert.
[b] Ratio of successful crossings to total number of approaches.

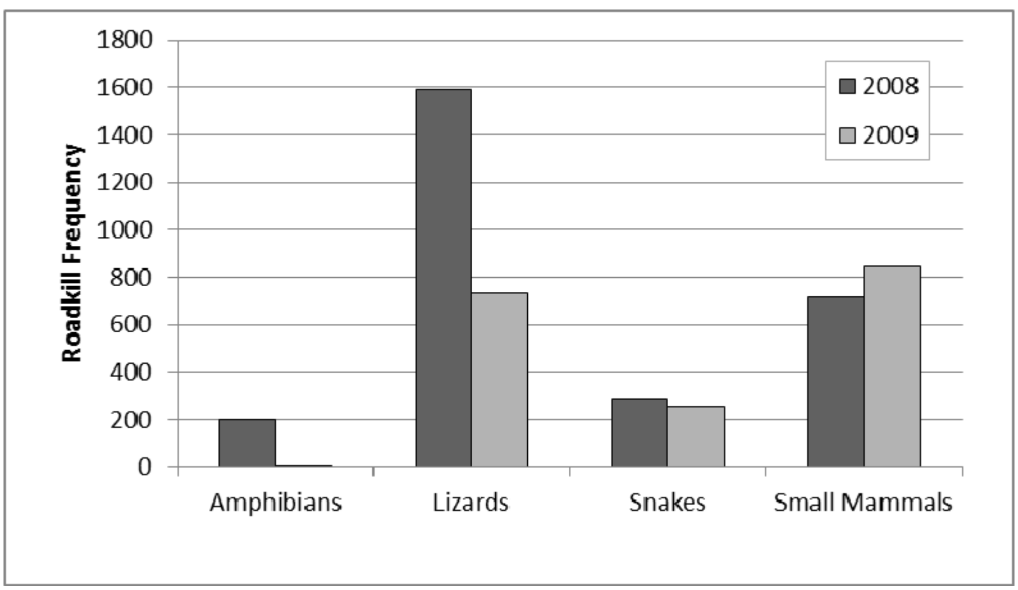


Figure 14. Annual Roadkill Frequency on US 93.

Amphibian roadkill (Figure 15) accumulated primarily during July (49 percent) and August (43 percent). Lizard roadkill occurred throughout the survey period, with the highest levels of accumulation in May (23 percent), June (17 percent), and July (19 percent), whereas snake roadkill primarily occurred in August (23 percent) and September (25 percent) and October (22 percent). Small-mammal roadkill was highest in May (20 percent), June (19 percent), and July (21 percent). Monthly small-mammal roadkill accumulation was correlated with monthly precipitation ($r_s = 226.1$, $P = 0.02$). There was no statistically significant correlation between precipitation and the accumulation of amphibian, lizard, or snake roadkill. Likewise, there was no detectable correlation between monthly traffic volume and roadkill accumulation for any of the four taxonomic groups. Roadkill detections for carnivores ($n = 34$), ungulates ($n = 16$), bats ($n = 17$), and avian species ($n = 131$) were also documented within the study area (Appendix B).

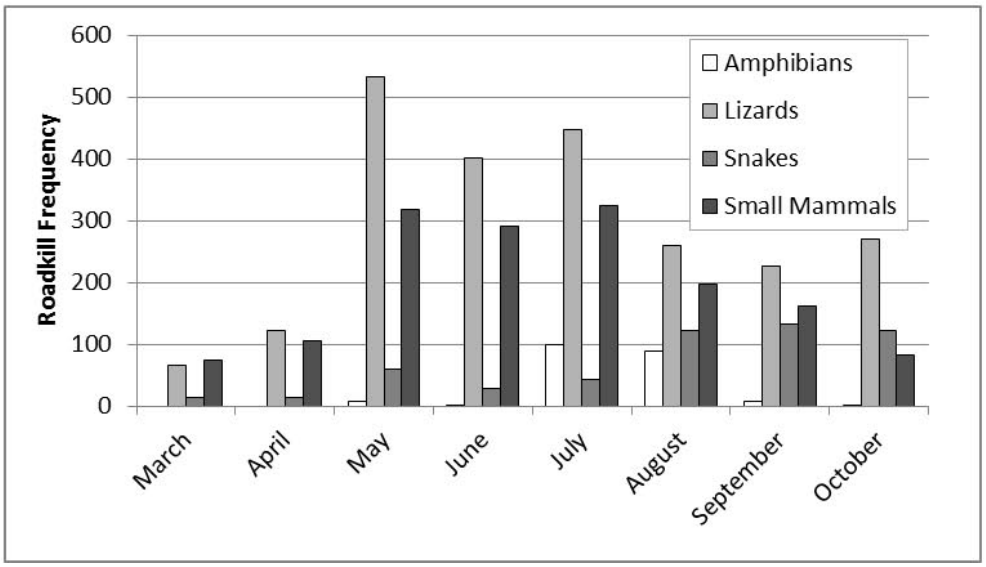


Figure 15. Monthly Roadkill Frequency on US 93.

Spatial Patterns of Roadkill

Tortoise roadkill, although low over all ($n = 5$), appeared to cluster between MPs 150 and 153 (Figure 16). The researchers identified 68 highway segments where lizard roadkill exceeded the median lizard roadkill frequency within the study area. On average, lizard roadkill hot spots were 0.61 mi (1.0 km) long. The longest lizard hot spot was located between MPs 153 and 155 (Figure 17). Hot-spot length and roadkill frequency declined along a northwest gradient. Amphibian hot-spot locations followed a similar pattern as lizard hot spots, although the overall number of amphibian roadkill was lower. The researchers identified 18 amphibian hot spots, with an average hot-spot length of 0.43 mi (0.7 km). The majority of amphibian hot spots were located between MPs 150 and 155 (Figure 18). In total, 22 snake hot spots were identified in the analysis. The average snake hot spot was 0.34 mi (0.5 km) long. Similar to lizard and amphibian hot spots, the largest contiguous snake hot spot was located between MPs 153 and 155 (Figure 19).

The analysis identified a similar hot-spot pattern for small mammals (Figure 20). Most of the small-mammal roadkill was located between MPs 153 and 155. The research team found 17 small-mammal hot spots, with an average hot-spot length of 0.36 mi (0.6 km). There were 10 ungulate hot spots within the study area (Figure 21), although the number of ungulate roadkill was low overall (Appendix B). Given the low frequency of ungulate roadkill, there was no distinct pattern in the location of ungulate hot spots, which were mostly evenly distributed across the study area between MPs 148 and 156. The researchers found the same results with their examination of carnivore roadkill patterns (Figure 22). Sixteen carnivore hot spots were evenly distributed across the entire length of the study area between MPs 145 and 156. Carnivore hot spots averaged 0.10 mi (0.2 km) long. Avian (n = 28) and bat (n = 13) hot spots also were evenly distributed across the study area, averaging 0.22 and 0.11 mi (0.3 and 0.2 km) long, respectively.

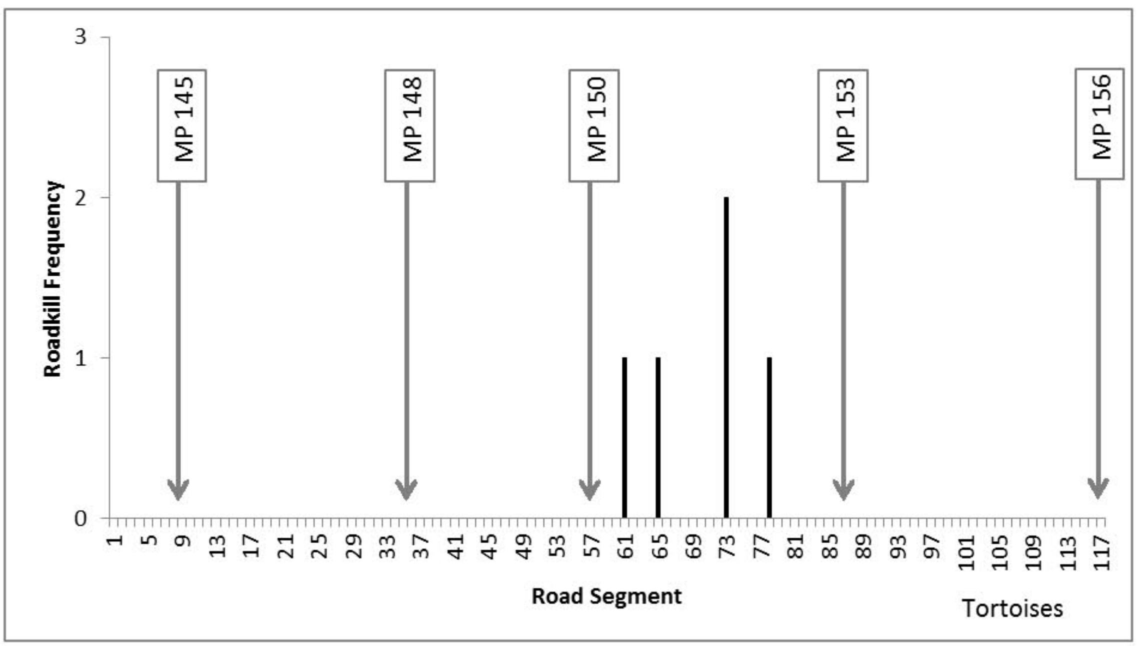


Figure 16. Location of Desert Tortoise Roadkill Hot Spots on US 93.

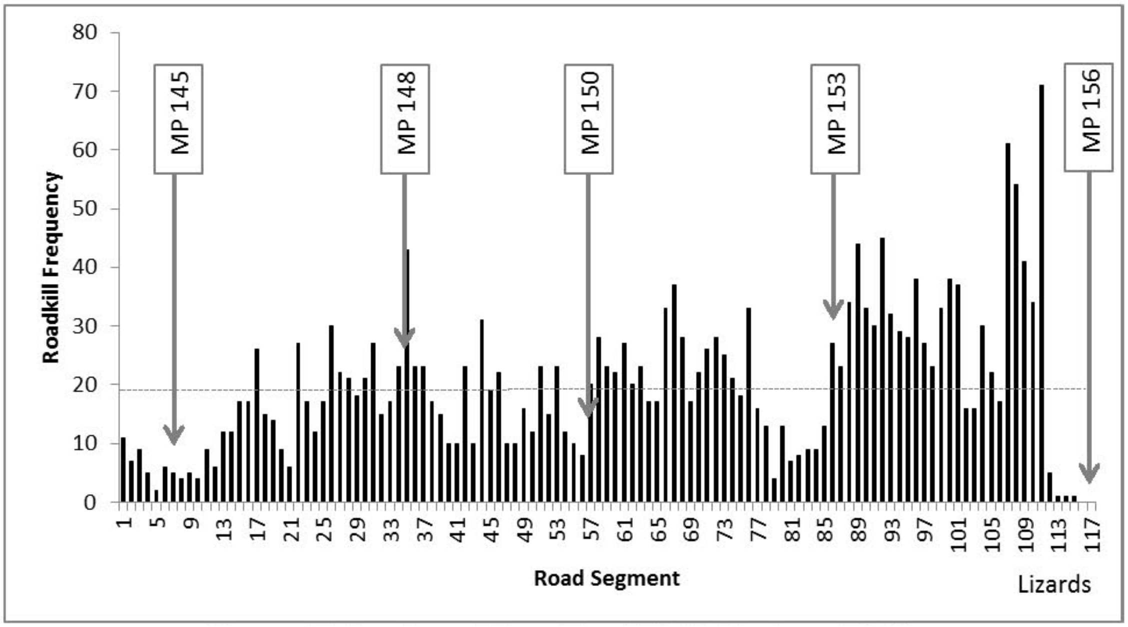


Figure 17. Location of Lizard Roadkill Hot Spots on US 93.

(The horizontal dashed line indicates the median roadkill frequency, 17, across the entire study area.)

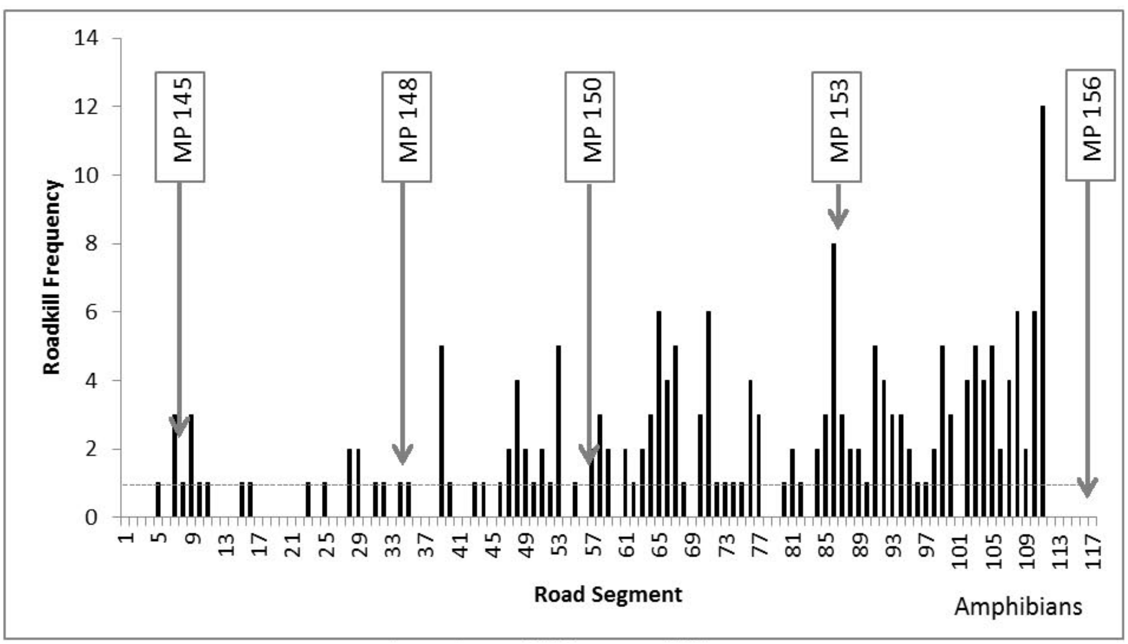


Figure 18. Location of Amphibian Roadkill Hot Spots on US 93.

(The horizontal dashed line indicates the median roadkill frequency, 1, across the entire study area.)

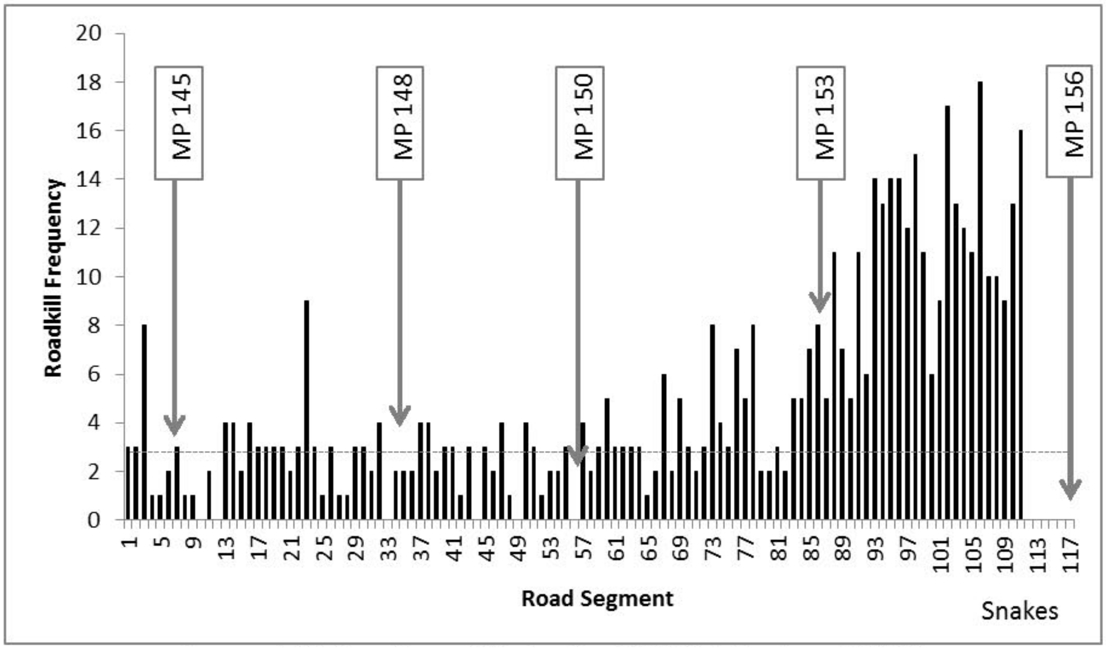


Figure 19. Location of Snake Roadkill Hot Spots on US 93.

(The horizontal dashed line indicates the median roadkill frequency, 3, across the entire study area.)

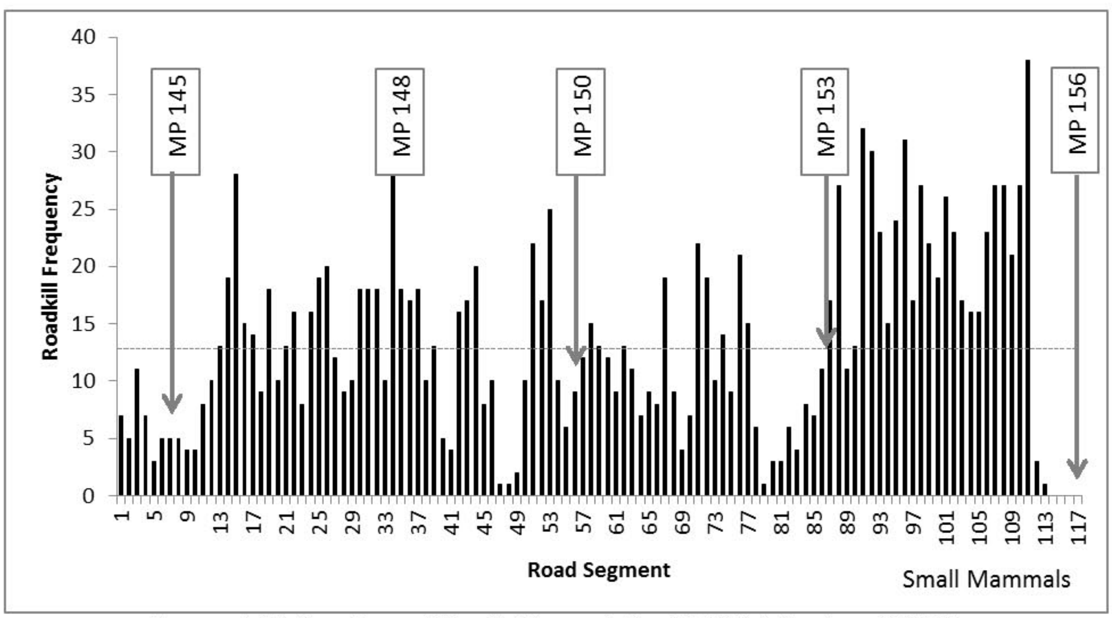


Figure 20. Location of Small-Mammal Roadkill Hot Spots on US 93.

(The horizontal dashed line indicates the median roadkill frequency, 12, across the entire study area.)

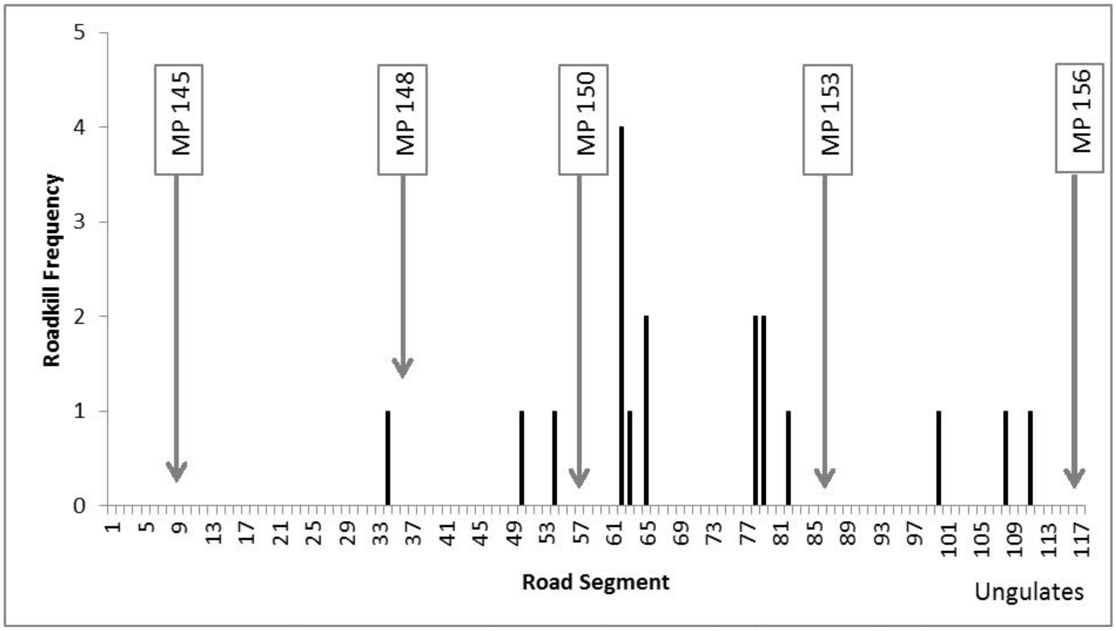


Figure 21. Location of Ungulate Roadkill Hot Spots on US 93.

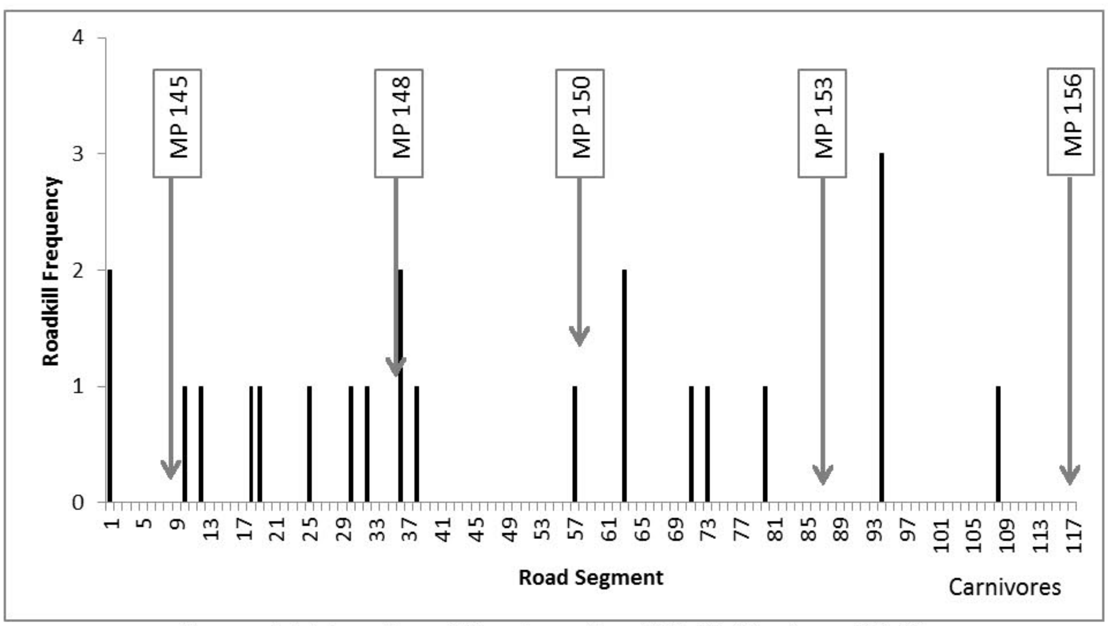


Figure 22. Location of Carnivore Roadkill Hot Spots on US 93.

Factors Related to Roadkill Hot Spots

The global models for taxa-specific hot spots provided an adequate fit to the data (Table 5). Overdispersion was detected for lizard, small-mammal, amphibian, and avian hot-spot models. As a result, the QAIC was used in model comparison for these taxa (Burnham and Anderson 2002). Overall, the supported models provided a limited ability to predict the spatial pattern of roadkill hot spots based on correct classification rates and the Nagelkerke R^2 (Table 6). Increasing the distance to a wash reduced the odds of a highway segment being considered a roadkill hot spot for lizards, amphibians, snakes, small mammals, bats, and birds. However, the odds ratio for distance to a wash was close to 1 for all taxa-specific models, indicating that the magnitude of the variable's influence was small (Table 6).

Table 5. Overdispersion Parameters ($\hat{c}$) and *P* Values for the Hosmer-Lemeshow Goodness-of-Fit Test for Global Hot-Spot Models Developed for Each Taxonomic Guild.

Guild	$\hat{c}$	*P*
Lizard	1.221	0.589
Small mammal	1.302	0.915
Amphibian	1.236	0.546
Snake	1.317	0.429
Tortoise	0.249	0.762
Carnivore	0.828	0.517
Ungulate	0.640	0.826
Bat	0.661	0.870
Avian	1.340	0.615

Four univariate models were supported for predicting desert tortoise hot spots based on ΔAIC_c and w_i (Table 6). Curved highway segments were five times as likely to support a tortoise roadkill hot spot; however, the presence of a crossing structure decreased the likelihood of tortoise roadkill hot spots within the segment. Likewise, as elevation increased and distance to a wash increased, so too did the likelihood of a highway hot-spot segment. However, while the correct classification of all cases was high (96.6 percent), the models failed to classify highway segments as tortoise roadkill hot spots. In addition, the confidence interval for the odds ratios for all of the variables in the supported models included 1 (Table 6). Furthermore, the power of these models to predict the spatial pattern of desert tortoise hot spots was limited.

Two models appeared to meet the prediction of lizard hot spots ($\Delta QAIC_c \leq 2$; Table 6), although there was substantial weight of evidence for consideration of the third model as well ($\Delta QAIC_c = 3.2978$, $w_i = 0.1202$). Distance to a wash was included in all three models, with the addition of elevation to the second-best model and roadside topography to the third. Distance to a wash and elevation were negatively related to lizard hot spots. However, the addition of elevation to the model did not substantially increase the log-likelihood and $QAIC_c \approx 2$, suggesting that elevation was a noninformative variable (Anderson 2008). Adding the categorical variable roadside topography provided additional information, since it increased the correct classification for all cases to 70.9 percent compared to 66.7 percent for the model containing distance to a wash only. Examining the odds ratios for elevation and roadside topography indicated that the confidence interval included 1. These results suggest that distance to a wash was the main factor influencing the spatial pattern of lizard roadkill hot spots relative to the candidate model set. Distance to a wash was negatively related to lizard hot spots, although based on the magnitude of the odds ratio, the influence of distance to a wash was small. The remaining models had substantially less support based on $\Delta QAIC_c$ and w_i.

The research team's results indicated that distance to a wash and elevation influenced amphibian hot spots based on $\Delta QAIC_c$ and w_i. The distance to a wash model was the best model, providing a 58.1 percent correct classification for all cases compared to 55.6 percent for the distance to a wash and elevation model. As in the lizard analysis, distance to a wash had a negative relationship to the spatial pattern of amphibian roadkill hot spots, whereas the confidence interval for the elevation odds ratio included 1 (Table 6).

Distance to a wash and elevation were also identified as important for identifying snake hot spots, with habitat adjacent to the roadway also supported based on $\Delta QAIC_c$ and w_i. The distance to a wash model was the best model and was included in the top three models. Combining distance to a wash and elevation provided a 66.7 percent correct classification rate for all cases compared to 64.1 percent for the model involving distance to a wash only. However, the confidence intervals for the elevation odds ratio included 1. Parameter estimates and SEs for the ReGAP (Regional Gap Analysis Project) landcover classes were extremely large, and the odds ratios for each class were zero. As in the lizard and amphibian analyses, increasing the distance to a wash reduced the odds of a highway segment being a snake hot spot (Table 6).

Model selection for small-mammal hot spots followed a similar pattern, with two models including distance to a wash and elevation supported by the data based on $\Delta QAIC_c$ and w_i. The distance to a wash model was identified as the best model and provided an overall correct classification of 58.1 percent for all cases. The odds ratio confidence intervals for elevation included 1, indicating that elevation was not an effective predictor of small-mammal roadkill hot spots. However, increasing the distance to a wash reduced the odds of a highway segment being a small-mammal hot spot (Table 6).

Roadkill hot spots for bats were best modeled as a function of distance to a wash and roadside topography based on ΔAIC_c and w_i. However, the confidence intervals for the distance to a wash odds ratios in both models included 1 and therefore had little influence on the spatial pattern of bat hot spots (Table 6). The parameter estimates and SEs for the roadside topography parameters were large, and the odds ratios were estimated as zero with the exception of RTOPO4, which had an odds ratio confidence interval that overlapped 1 (Table 6).

Avian hot-spot models that included distance to wash and elevation were best supported by the data based on ΔAIC_c and w_i. Following the observed patterns of other taxa models, the confidence interval for the elevation odds ratio included 1, and the odds ratio for distance to a wash was close to 1 (Table 6), suggesting a limited influence on the spatial pattern of avian hot spots.

Three models were supported for predicting ungulate roadkill hot spots based on ΔAIC_c and w_i. However, the confidence intervals for the odds ratios in each of the three models included 1, indicating that road alignment, distance to a wash, and the presence of a crossing structure did not have substantial influence on the spatial pattern of ungulate roadkill hot spots (Table 6).

Six models were supported for predicting carnivore roadkill hot spots based on ΔAIC_c and w_i. However, the confidence interval for the odds ratios for all of the variables in the supported models was either 0 or included 1 (Table 6). As a result, the predictive power of these models was limited.

Table 6. Taxa-Specific Hot-Spot Model Results.

Taxonomic Group:Model	Parameter[a]	Odds Ratio	LCI[b]	UCI[c]	R^2	% Correct Classification
Tortoise:Model5	CURVE	5.071	0.511	50.338	0.075	96.6
Tortoise:Model7	CROSSING	0.643	0.171	2.422	0.044	96.6
Tortoise:Model6	ELEV	1.007	0.993	1.021	0.039	96.6
Tortoise:Model2	DWASH	0.997	0.990	1.006	0.013	96.6
Lizard:Model2	DWASH	0.994	0.990	0.997	0.233	66.7
Lizard:Model14	DWASH	0.994	0.990	0.997	0.235	68.4
	ELEV	1.001	0.996	1.005		
Lizard:Model9	DWASH	0.993	0.990	0.997	0.310	70.9
	RTOPO2	0.239	0.036	1.584		
	RTOPO3	2.272	0.371	13.908		
	RTOPO4	0.682	0.270	1.720		
	RTOPO5	1884634990.304				
	RTOPO6	480818299.026				
Amphibian:Model2	DWASH	0.997	0.994	0.999	0.082	58.1
Amphibian:Model14	DWASH	0.997	0.994	0.999	0.095	55.6
	ELEV	1.001	0.997	1.006	0.005	
Snake:Model2	DWASH	0.997	0.995	0.999	0.055	64.1
Snake:Model14	DWASH	0.997	0.995	0.999	0.085	66.7
	ELEV	0.996	0.991	1.001		
Snake:Model8	DWASH	0.996	0.993	0.999	0.116	63.2
	HAB52	0.000				
	HAB57	0.000				
	HAB60	0.000				
	HAB84	3.45E+45				
	HAB92	0.000				
	HAB105	0.000				

Table 6. Taxa-Specific Hot-Spot Model Results. (Continued)

Taxonomic Group:Model	Parameter[a]	Odds Ratio	LCI[b]	UCI[c]	R^2	% Correct Classification
Small Mammal:Model2	DWASH	0.997	0.994	0.999	0.082	58.1
Small Mammal:Model14	DWASH	0.996	0.994	0.999	0.095	55.6
	ELEV	0.998	0.993	1.002		
Bat:Model8	DWASH	0.995	0.989	1.000	0.215	88.0
	RTOPO2	0.000				
	RTOPO3	0.000				
	RTOPO4	0.857	0.268	2.740		
	RTOPO5	0.000				
	RTOPO6	0.000				
Bat:Model2	DWASH	0.996	0.991	1.001	0.046	87.2
Avian:Model2	DWASH	0.996	0.994	0.999	0.098	63.2
Avian:Model13	DWASH	0.996	0.994	0.999	0.111	62.4
	ELEV	1.002	0.998	1.006		
Ungulate:Model5	CURVE	2.468	0.732	8.317	0.038	89.7
Ungulate:Model2	DWASH	0.997	0.992	1.002	0.026	89.7
Ungulate:Model7	CROSSING	0.607	0.125	2.950	0.007	89.7
Carnivore:Model2	DWASH	1.002	0.999	1.004	0.018	85.5
Carnivore:Model7	CROSSING	0.643	0.171	2.422	0.007	85.5
Carnivore:Model6	ELEV	1.002	0.996	1.008	0.006	85.5
Carnivore:Model5	CURVE	0.853	0.292	2.490	0.001	85.5
Carnivore:Model14	DWASH	1.002	0.999	1.005	0.029	85.5
	ELEV	1.003	0.996	1.009		
Carnivore:Model4	RTOPO2	0.000				
	RTOPO3	0.656	0.072	5.995		
	RTOPO4	0.943	0.312	2.842		
	RTOPO5	0.000				
	RTOPO6	0.000				

[a] See Table 2 for parameter descriptions.
[b] LCI = lower 95% confidence interval for the odds ratio estimate.
[c] UCI = upper 95% confidence interval for the odds ratio estimate.

3.3.4 Desert Tortoise Movement Patterns and Space Use Relative to the US 93 Alignment

Desert Tortoise Surveys

The researchers, along with volunteers, logged 1260 survey hours in 2008, covering approximately 700 ha (1,730 ac) within 0.31 mi (0.5 km) of the US 93 alignment. Seven desert tortoises were detected during this effort, along with one tortoise carcass.

An additional 15 tortoises were detected during subsequent VHF radio-telemetry efforts in 2008 (Table 7). During the 2009 field season, seven additional desert tortoises were marked. Overall, 16 adult females, 10 adult males, and 3 juveniles were marked during the study (Table 7). One hatchling was also detected but not marked.

Table 7. Capture Information for Desert Tortoises Marked within the US 93 Study Area in 2008 and 2009.

Capture Date	Tortoise ID	Gender	Age Class	Capture Date	Tortoise ID	Gender	Age Class
4/5/2008	1	Unknown	Hatchling	8/21/2008	29	Male	Adult
4/5/2008	2	Female	Adult	9/5/2008	30	Male	Adult
4/5/2008	3	Male	Adult	9/17/2008	31	Male	Adult
4/6/2008	7	Female	Adult	9/25/2008	32	Female	Adult
4/6/2008	8	Male	Adult	9/25/2008	33	Male	Adult
4/24/2008	9	Male	Adult	10/9/2008	38	Female	Adult
4/26/2008	10	Female	Adult	10/9/2008	33a	Unknown	Juvenile
5/7/2008	11	Female	Adult	3/17/2009	80	Female	Adult
5/31/2008	12	Female	Adult	3/28/2009	90	Female	Adult
6/1/2008	13	Male	Adult	3/28/2009	91	Female	Adult
6/9/2008	18	Male	Adult	7/28/2009	92	Female	Adult
7/31/2008	19	Unknown	Juvenile	8/11/2009	31a	Female	Adult
7/31/2008	20	Female	Adult	8/26/2009	100	Female	Adult
8/1/2008	21	Female	Adult	9/2/2009	109	Female	Adult
8/18/2008	28	Male	Adult	4/5/2008	N/A	Unknown	Juvenile

Desert Tortoise Telemetry

The research team instrumented 11adult desert tortoises (6 females and 5 males)with VHF radio transmitters and deployed GPS tracking units on all of these tortoises during both field seasons. In total, the team obtained 770 VHF locations (mean = 70 ± 11 SE locations per individual) and 5610 GPS locations (mean = 510 ± 429 SE locations per individual) during the 2008 and 2009 field seasons. The number of GPS locations per individual varied given the ability to access tortoises for collecting the tracking units and deploying replacement units and the variation in tortoise activity (e.g., if a tortoise was in a shelter site, the GPS unit was unable to communicate with satellites to obtain locations).

Determining the Location of Highway Crossing Locations

None of the desert tortoises monitored with VHF radio-telemetry and GPS tracking units crossed the US 93 alignment (Figure 23).

Identifying Space Use Relative to the US 93 Alignment

The mean BBMM home-range estimates for females and males were 16.5 ha (± 2.4 SE) and 21.4 ha (± 1.1 SE), respectively (females: 40.8 ac ± 5.9 SE; males: 52.9 ac ± 2.7 SE). Only one of the BBMM space-use estimates intersected with US 93 (Figure 24), although none of the location estimates for that tortoise were closer than 242 ft (73.8 m) from the highway. Females averaged 3.6 (± 0.8 SE) core areas per individual, whereas males averaged 10 (± 3.0 SE) per individual. Mean core-area estimates for females and males were 3.1 ha (± 0.4 SE) and 4.0 ha (± 0.2), respectively (females: 7.7 ac ± 1.0 SE; males: 9.9 ac ± 0.5 SE). The mean distance between the center of desert tortoise core areas and the highway was 0.33 mi (± 0.17 SE [0.53 km ± 27 SE]).

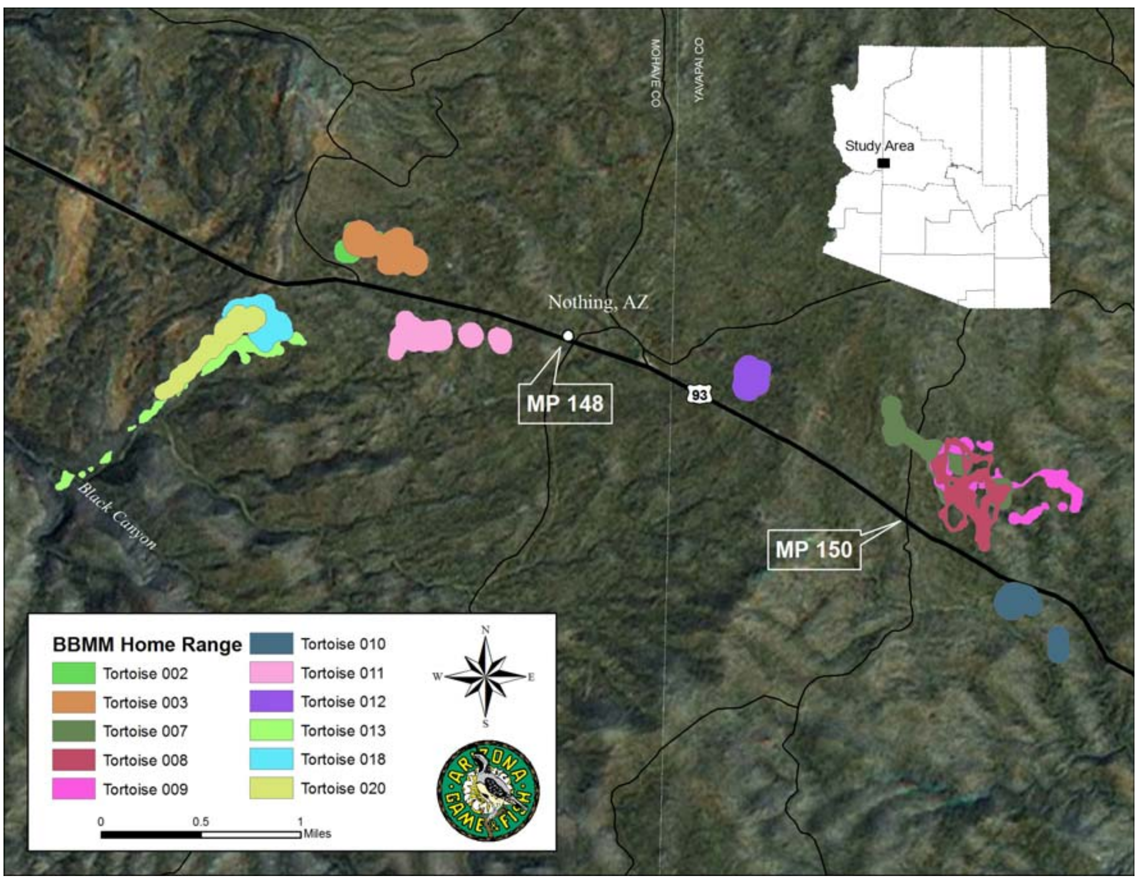


Figure 23. Home-Range Estimates for 11 Desert Tortoises Tracked within the US 93 Study Area (Brownian Bridge Movement Model).

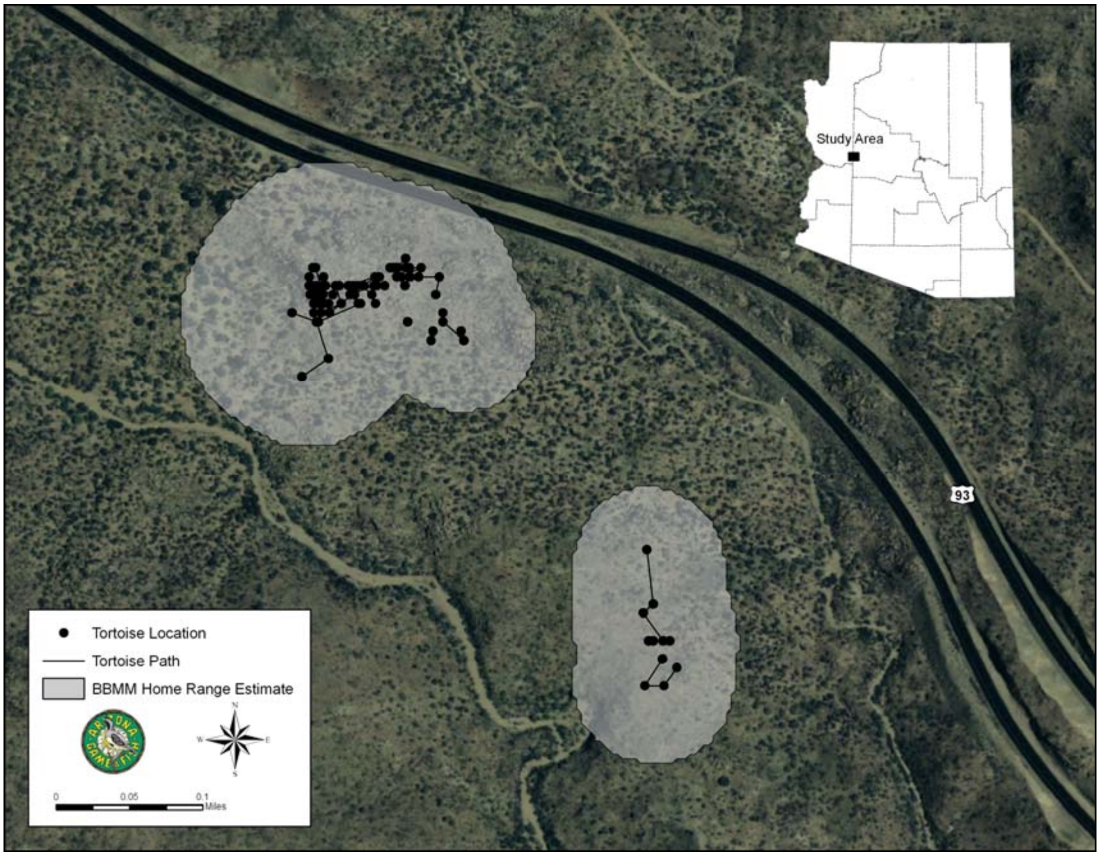


Figure 24. Home-Range Estimate for Tortoise T010 (Brownian bridge movement model).

The overall distribution of desert tortoise locations indicated that there was very little tortoise activity adjacent to the highway and that the number of locations increased as distance from US 93 increased (Figure 25). Based on the location data collected on the 11 monitored tortoises, there was a peak in tortoise locations approximately 0.23 mi (0.37 km) from the highway. A secondary peak existed at 0.34 mi (0.55 km), and a tertiary peak at 0.56 mi (0.90 km). The number of locations tapered off beyond 0.56 mi (0.90 km), as would be expected given the spatial extent of the home ranges mapped during the study and the focus on tracking tortoise movements close to the US 93 alignment.

3.4 DISCUSSION

3.4.1 Status of Highway Mitigation for Desert Tortoises on US 93

The results indicate that the desert tortoise mitigation installed on US 93 has deteriorated to the point of limited functionality. While a number of the underpass crossing structures remain accessible to desert tortoises and provide effective crossing opportunities for various wildlife species, a significant proportion of the structures are nonfunctional. The study did not detect any tortoise passages through functional crossing structures, which supports the research team's assertion that the existing crossing structures in their current condition are not effective in facilitating desert tortoise permeability across the highway.

Regardless of underpass condition, numerous fencing breaches along the extent of the study area create ample opportunity for tortoises to access the highway at grade. The occurrence of long-distance tortoise movement, albeit infrequent, is supported by genetic data (Edwards 2003; Edwards et al. 2004) and observational data (Woodbury and Hardy 1948). These movements involve seasonal migration, mate-seeking movements by males, avoidance of unfavorable habitat conditions, juvenile dispersal, and seasonal movements to hibernacula (Gibbons 1986). When encountering a barrier, tortoises are known to pace great distances to find a way around it (Fusari 1982, Ruby et al. 1994). This suggests that underpasses can be successful (Ruby et al. 1994), but it also indicates that tortoises will find breaches in the fence, if present, and access the road surface. As a result, tortoises attempting to cross the highway are in danger of being hit by passing vehicles.

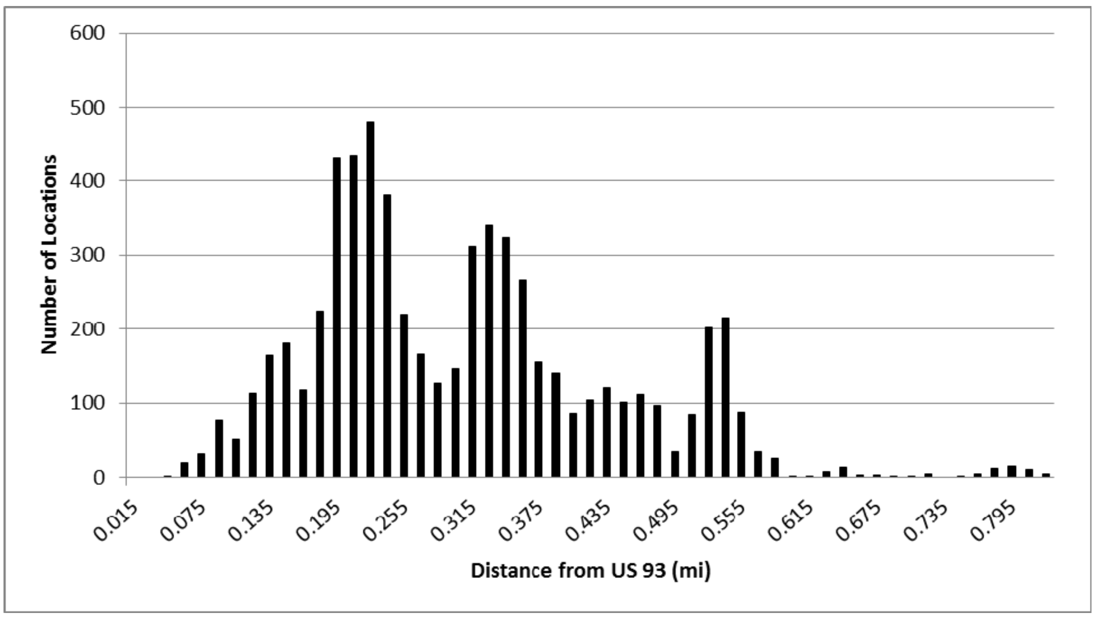


Figure 25. Distribution of Tortoise Locations Relative to the US 93 Alignment.

Given the wealth of information regarding the impact of roads on tortoises at both the individual and population level, failure of the existing mitigation fencing should be addressed, and repairs and modifications should be implemented. The original objective of the desert tortoise mitigation was to reduce the impact of the highway on the adjacent tortoise population. As such, maintenance of fencing and culvert functionality should be conducted on a regular basis to ensure this objective is met.

Ensuring structural integrity at locations where the fencing is susceptible to damage from erosion is the greatest challenge for repairing and modifying the existing mitigation fencing. Fencing that crosses desert washes will require regular maintenance and may need to be moved altogether. Likewise, engineering solutions that reduce the likelihood of undercutting entrances at the outflow end of culverts will need to be implemented to maintain access by desert tortoises. Recent efforts to create permanent "tortoise paths" (i.e., concrete ramps) at outflow entrances have been implemented on various ADOT projects and should be considered as solutions to the perched entrances documented on US 93. However, none of the existing ramps have been monitored to determine their effectiveness. This lack of information limits the ability to make reliable recommendations on the specific design of these paths to meet mitigation objectives.

While fencing and culvert modifications are likely to yield positive results relative to survival of individual desert tortoises that occupy home ranges adjacent to the roadway, population-level benefits of desert tortoise fencing and crossing structures have yet to be demonstrated. While this study was not designed to examine population-level benefits of desert tortoise mitigation, the researchers believe that these results can provide a baseline for future efforts to assess the effects of improvements along this stretch of US 93. The current baseline is indicative of an unfenced scenario—especially given the sheer number of fencing breaches and the length and distribution of nonfunctional fencing within the study area.

3.4.2 Patterns of Roadkill along US 93

Although the research team detected only five desert tortoise carcasses on US 93 during the two-year study, it is evident that tortoises are still being hit by passing vehicles. The data indicate that road-related tortoise mortality is most likely to occur within the study area between MPs 150 and 153. However, the team monitored tortoise activity as far west as MP 146.5. These data can be used to prioritize maintenance and modification efforts along this stretch of highway (see Section 7.0, Recommendations).

The team also found that roadkill hot spots for other taxa, specifically lizards, amphibians, snakes and small mammals, appear to align with the hot spot for desert tortoises between MPs 150 and 153. This suggests that the spatial pattern of roadkill for other small vertebrates could be used to predict desert tortoise mortality hot spots. This warrants further research using detailed roadkill datasets to identify the correlation between tortoise mortality locations and the mortality locations for other taxa.

3.4.3 Predicting Wildlife Hot Spots

For some taxa (e.g., desert tortoises, ungulates, and carnivores), small sample sizes hampered the ability to specify adequate predictive models for identifying roadkill hot spots. However, a low percentage of correct classification was consistent for all taxa, and the Nagelkerke R^2 was generally low even when sample sizes were high. Low R^2 values indicated that there was a substantial amount of unmodeled variability in the system and that additional covariates and spatial scales should be considered in future analyses.

The inability to effectively model roadkill hot spots using landcover and structural variables associated with highway segments suggests that site-specific surveys remain the most effective approach for identifying priority roadway segments for roadkill mitigation efforts. However, additional modeling efforts should be conducted to define the appropriate scale for covariate data collection and hot-spot identification. Despite the lack of strong predictive abilities of the models, there is some evidence that desert washes play a role for lizards, amphibians, snakes, small mammals, and birds. The results from this study provide some support for the importance of proximity to desert washes, but these results are preliminary. While the importance of desert washes as desert tortoise habitat is well documented (Barrett 1990; Jennings 1997; Riedle et al. 2008; Grandmaison et al. 2010), their relationship to roadkill hot spots needs further clarification. One must be cautious when using desert washes as the sole predictor of roadkill hot spots until further evaluations can be conducted; however, in the absence of site-specific data, desert washes provide a first approximation to predicting roadkill hot spots and identifying mitigation priorities to reduce roadkill on Arizona's highways.

Until reliable predictive models can be developed and validated, the research team recommends that site-specific surveys continue to be implemented to determine the important roadkill hot spots within project areas (Boarman et al. 1993; Ruby et al. 1994). Implementing a modeling approach in the absence of site-specific data could lead to spurious decisions regarding placement of mitigation fencing and underpass or overpass structures for wildlife. Appropriate highway mitigation for desert tortoises should be founded on data-driven decisions. As an example, ADOT is implementing a desert tortoise mitigation strategy on SR 87 in Maricopa County that will examine the impact of fencing for reducing tortoise roadkill. This project involves pre- and postconstruction roadkill surveys within the mitigation segment and adjacent control segments where fencing will not be installed. The results of these surveys will provide quantitative data on the effectiveness of mitigation fencing for reducing desert tortoise roadkill.

3.4.4 Space Use by Desert Tortoises

Radio-telemetry and GPS tracking data did not document desert tortoise movement onto or across US 93, although researchers found tortoise carcasses on the highway during surveys. Reports provided by Department of Public Safety personnel indicate that tortoises have attempted to cross the highway in nearby locations (near MPs 123 and 142; B. Wohlenhaus, Department of Public Safety, personal communication). Based on the radio-telemetry and GPS tracking data adjacent to US 93, the majority of tortoise home ranges do not overlap the highway. However, the highway is close enough to existing home ranges to allow for the possibility of transhighway movements.

Examination of the spatial distribution of desert tortoise locations relative to the US 93 alignment suggests that there is a road-effect zone extending up to 0.22 mi (0.35 km). Road-effect zones are an indication of the overall population-level impact of roadways on desert tortoises (Nicholson 1979; Karl 1989; von Seckendorff Hoff and Marlow 2002; Boarman and Sazaki 2006). The road-effect zone increases as the impact of the roadway increases. Conversely, it would be expected that as the impact of a roadway declines, the road-effect zone would also decrease. The extent of the road-effect zone can be used as a metric to evaluate the success of roadway mitigation for desert tortoises. For example, successful mitigation would ideally reduce road mortality and facilitate the successful reoccupation of habitat adjacent to the roadway (Boarman 2010). In this case, success would be defined as a reduction in the extent of the road-effect zone. As these roadside habitats become reoccupied, the expectation is that tortoises will be more likely to encounter, and ultimately use, the underpass crossing structures.

Otherwise suitable tortoise habitat adjacent to US 93 is not currently occupied, which suggests that the highway itself is preventing successful reoccupation of this roadside habitat. Given the current condition of mitigation fencing along this section of US 93, tortoises whose home ranges include portions of the US 93 alignment or whose dispersal movements cross the alignment will continue to be at risk of road-related mortality until the fencing is repaired and nonfunctional culverts are modified to facilitate safe road crossing.

3.5 CONCLUSIONS

US 93 continues to be a challenging barrier for desert tortoises. The current condition of the barrier fencing is inadequate. However, more effective placement of barrier fencing and modifications to culvert entrances may have a positive effect toward reducing the road-effect zone documented in this research study. Successful transhighway movements by desert tortoises are infrequent, and tortoises are still accessing the road surface. Without effectively funneling tortoises to underpass structures, the likelihood of underpass use will remain low.

Maintenance of barrier fencing and underpass structures is time consuming and requires resources that may not be available to transportation agencies. However, effective fencing installation that considers the impacts of erosion and siltation will increase maintenance efficiency and reduce overall maintenance costs. Barrier fencing should avoid washes and steep slopes. When unavoidable, fencing placed in suboptimal locations should be regularly monitored to identify the need for maintenance.

The road-effect zone has serious implications for the success of roadway mitigation for desert tortoises. If the habitat adjacent to the roadway is unoccupied due to the hazards associated with direct mortality from vehicle collisions, tortoises will not find the underpass structures and connectivity will not be maintained. As the road-effect zone attenuates through recolonization of suitable roadside habitat, permeability is likely to increase given that tortoises will follow barrier fencing to the underpass structures and subsequently pass underneath the roadway.

4.0 PREDICTIVE LANDSCAPE-SCALE HABITAT MODELING FOR DESERT TORTOISES IN THE BLACK MOUNTAINS ECOSYSTEM, MOHAVE COUNTY, ARIZONA

4.1 INTRODUCTION

The desert tortoise is listed as federally threatened across the northern third of its geographic range (Figure 26; U.S. Fish and Wildlife Service [USFWS] 1990). Declines in Mojave Desert populations (located in southern California, southern Nevada, the southwestern tip of Utah, and Arizona north of the Colorado River) have been attributed to direct and indirect human-caused mortality and inadequate regulatory mechanisms to protect desert tortoises and their habitat. Specific stressors identified in the listing include destruction, degradation, and fragmentation of habitat from urbanization, agricultural development, livestock grazing, mining, and roads. This situation has been exacerbated by continuing drought, disease transmission, accidental or intentional removal, and direct mortality related to other human activities (USFWS 1990).

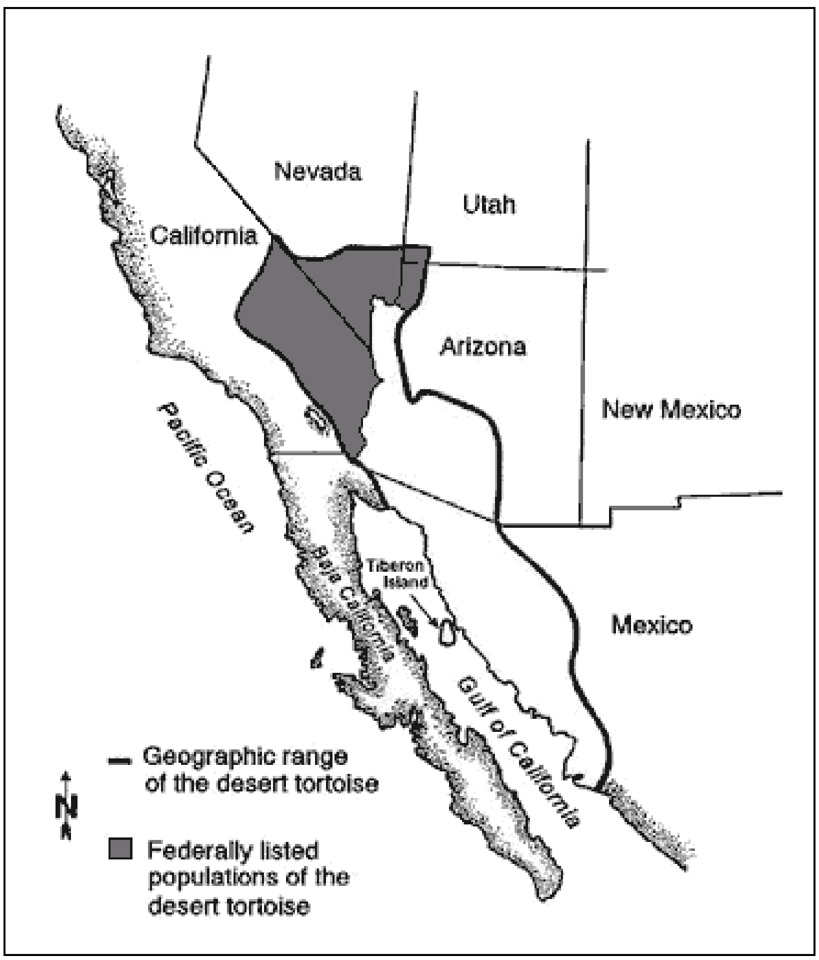


Figure 26. Geographic Distribution of the Desert Tortoise. (Source: Stebbins 1985; Berry 1997)

The Mojave and Sonoran desert tortoise populations likely experience similar threats despite differences in habitat use across a broad geographic distribution (see Figure 26; Germano et al. 1994). While the intensity and magnitude of these threats vary geographically, they represent reoccurring themes for desert tortoise conservation and management (Boarman 2002). The desert tortoise shares evolutionary traits (i.e., longevity, delayed sexual maturity, low fecundity, and low survivorship of juveniles) with other chelonian species that make it highly susceptible to environmental and anthropogenic stressors (Wilbur and Morin 1988; Congdon and Gibbons 1990; Germano et al. 1994). Doak et al. (1994) found that desert tortoise population growth rates are most sensitive to survival rates of adult females and that improving survival rates for this population segment could reverse population declines (see also Reed et al. 2009). Congdon et al. (1993) pointed out that incremental increases in adult mortality rates require a concomitant increase in pre-reproductive survival to maintain a stable population, a response that is not likely (Brooks et al. 1991; Congdon et al. 1993). As a result, cumulative increases in adult mortality can have significant impacts on desert tortoise population persistence.

Given the perceived pervasiveness of landscape-scale threats and the challenges of autecological characteristics that increase the susceptibility of desert tortoise populations to sources of additive mortality, the status of the desert tortoise in the Sonoran Desert is under review by the USFWS. In December 2010, the USFWS issued a 12-month finding indicating that the desert tortoise in the Sonoran Desert warranted protection as a distinct population segment under the Endangered Species Act of 1973 but that this species was precluded from listing by the need to address higher-priority species (USFWS 2010). Regardless of its federal status under the Endangered Species Act, the desert tortoise is a species of concern in Arizona, and efforts are under way to monitor populations and identify and mitigate the impacts of manageable threats such as roads (http://www.azgfd.gov/w_c/deserttortoisemanagement.shtml). An important tool for managing desert tortoises is the development of habitat models that can be used for predicting desert tortoise occupancy in areas where site-specific data may not exist (Schamberger and Turner 1986; Andersen et al. 2000).

In the Sonoran Desert, tortoise habitat generally occurs in distinct geographic units characterized by volcanic outcrops, boulder-strewn hillsides, and mountain bajadas with large, deeply incised washes (Barrett 1990; Germano et al. 1994; Riedle et al. 2008). Desert tortoises also occur within lowland intermountain desert valleys at lower densities (Edwards et al. 2004; Averill-Murray and Averill-Murray 2005). A recent summary of desert tortoise habitat in the Mojave Desert describes the importance of alluvial fans with vegetation communities consisting of creosotebush, blackbrush, Joshua tree (*Yucca brevifolia*), saltbushes (*Atriplex* spp.) and even junipers at higher elevations (USFWS 2008).

At the local level, tortoise density is largely associated with the availability of shelter sites (Fritts and Jennings 1994; Averill-Murray et al. 2002; Riedle et al. 2008). Desert tortoises spend approximately 98 percent of their life inactive in subterranean shelter sites (soil burrows, caliche burrows, boulder piles, woodrat nests, etc.) (Woodbury and Hardy 1948; Nagy and Medica 1986; Bailey et al. 1995). Shelter sites provide nest sites, protection from predators, and refuge from extreme temperatures (Bury et al. 1994; Germano et al. 1994; Bailey et al. 1995). Individual tortoises will use multiple shelter sites during a given season but prefer shelters that are frequently reused (Woodbury and Hardy 1948). In addition, desert tortoises often occupy habitat with a high percentage of canopy cover and near desert washes within their home ranges (Andersen et al. 2000; Grandmaison et al. 2010). Areas with sufficient canopy cover are likely to provide adequate shade for escaping the desert heat (Burge 1978). Woodbury and Hardy (1948: 170) also described the importance of soil composition as it relates to the creation of permanent shelter sites, calling soil a "critical factor in tortoise distribution within their range, more or less restricting them to suitable soil types." Andersen et al. (2000) determined that tortoise density was positively related to soil characteristics, namely loamy soils and granitic conglomerate soil substrates. In general, soil substrate characteristics are thought to influence the distribution of burrowing animals (Hardy 1945).

Studies within the Black Mountains of northwestern Arizona have shown a possible link between tortoise occurrence and soil type, specifically the Aridisol soil order (AGFD, unpublished data). Aridisol soils generally occur on older landscapes where soil stability has occurred over a sufficient period for the development of diagnostic soil horizons (Soil Survey Staff 1975; Hendricks 1985). The Aridisol order is characterized by soils with low amounts of organic matter and well-developed subsurface soil horizons. Calcium dissolved in rainwater is continuously deposited on the soil surface where it leaches into the soil and combines with carbon dioxide in soil water to form calcium carbonate (Breazeale and Smith 1930). Calcium carbonate accumulates and cements soil particles together to form a hardened calcareous deposit often referred to as the "caliche layer." In Aridisols, calcium carbonate is present in some or all parts of the soil (Soil Survey Staff 1975). When caliche is exposed by erosional processes, such as wind or the flow of water, desert tortoises are able to take advantage of the stability of the caliche layer and create deep, permanent shelters beneath it (Germano et al. 1994; Riedle et al. 2008). Conversely, the Entisol soil order is characterized by soils of a more recent origin that do not have diagnostic horizons and that generally lack the soil structure required for the creation of permanent burrows (Soil Survey Staff 1975; Hendricks 1985). The research team hypothesized that desert tortoise occupancy would vary among soil designations at the landscape scale. Specifically, the team predicted that tortoise occupancy would be higher in Aridisol soil subgroups than Entisol subgroups and that the presence of washes would influence occupancy.

The primary objective of this study was to test a landscape-level habitat model based on existing knowledge of desert tortoise habitat requirements (e.g., the importance of shelter sites and desert washes) and soil classifications. The usefulness of such a model, if validated with empirical data, could be extremely valuable given the importance of regionwide planning for desert tortoise conservation (Schamberger and Turner 1986; Krzysik 2002). Landscape planning tools for desert tortoise conservation and management are critical for informing landscape planning efforts for human infrastructure within tortoise habitat. Current evaluations regarding the realignment of SR 95 in Mohave County, Arizona, led to the development of this study, whose goal was to provide a landscape tool for estimating the impacts of various alignment options on desert tortoise habitat on the western bajadas of the Black Mountains.

4.2 METHODS

4.2.1 Sampling Design

Landscape-scale inference regarding desert tortoise distribution and habitat use is a key component for developing management strategies that can be implemented at large spatial scales (Andersen et al. 2000). Given the need for occurrence and habitat association data to reflect a spatial scale that matches the spatial extent of the potential impact of the SR 95 realignment, a probabilistic sampling approach was required to select sampling units across the entire Black Mountains ecosystem. The research team implemented a stratified random sampling design (Cochran 1977) in which random samples were taken from soil strata (i.e., soil subgroups) defined by the National Cooperative Soil Survey (NCSS) division of the Natural Resources Conservation Service, a branch of the U.S. Department of Agriculture. Using a stratified random sampling approach improves the precision of the parameter of interest when sampling units are heterogeneous across strata but homogenous within strata (Cochran 1977).

Given the geographic scope of the study area and the study objectives regarding the spatial distribution of desert tortoises relative to the SR 95 realignment study, the researchers chose tortoise occupancy (presence/absence) as the population parameter of interest. However, unlike traditional occupancy estimation studies in which defined sampling units are visited on multiple occasions and the species of interest is either detected or not detected, the study substituted spatial replicates for temporal replicates (Kendall and White 2009). Under this sampling methodology, “sites” were defined as distinct soil subgroup patches with survey locations representing spatial subunits within sites.

The stratification for the probabilistic sampling design reflected the hypothesis that desert tortoise occupancy varies among soil designations at the landscape scale. Specifically, the study predicted that tortoise occupancy would be higher in Aridisol soils (i.e., soils with subsurface horizon development containing clays, calcium carbonate, silica, salts, and/or gypsum) than in Entisol soils (i.e., soils of recent origin with no diagnostic horizons), given the ability of Aridisol soils to support deeper, more long-lasting burrows for desert tortoises (AGFD, unpublished data). To test this hypothesis, the study compared desert tortoise occupancy among soil subgroups.

The research team used an occupancy modeling approach (MacKenzie et al. 2002) to obtain an estimate of the PAO for desert tortoises and tortoise detection probability within each soil subgroup patch. Desert tortoises can be difficult to detect because they are cryptic, occur at low density, have limited activity periods, and spend a majority of their lives concealed in subsurface shelters (Nagy and Medica 1986). Detection rates of <1 are problematic when trying to determine whether tortoises are present or absent on a survey plot and result in an underestimate of the true PAO (MacKenzie 2006). The estimation of detection probability inherent in the occupancy modeling approach (MacKenzie et al. 2002) accounts for tortoises not being detected on a survey plot even when they may be present and provides a more robust estimate of the true PAO.

In addition, previous research has shown that occupancy estimation methods for desert tortoises provide a higher level of precision of the PAO estimate than more traditional distance-sampling techniques used to estimate tortoise density in the Sonoran Desert (Zylstra et al. 2010). While distance sampling has proved effective for estimating tortoise density in the Mojave Desert, differences in tortoise habitat use in the Sonoran Desert, namely steep topography and dense vegetation (Swann et al. 2002; Averill-Murray and Averill-Murray 2005; Zylstra and Steidl 2009), make occupancy modeling methods more efficient (Zylstra et al. 2010). For rare species such as the desert tortoise, estimates of state variables such as density and abundance are difficult to obtain at desired levels of precision (Inman et al. 2009). Occupancy can be considered a surrogate for abundance and will often require less effort than sampling programs designed specifically to estimate abundance or density (Tyre et al. 2001; MacKenzie et al. 2002; Zylstra et al. 2010).

4.2.2 Desert Tortoise Surveys

Eleven soil subgroups occur within the study area. The research team did not conduct desert tortoise surveys in areas identified as exposed bedrock due to its minimal presence within the SR 95 realignment zone and the low likelihood for tortoise occupancy in such areas. The team used the Hawth's Analysis Tools ArcGIS extension (Beyer 2004) to select 60 random survey locations within each soil subgroup. Survey plots were distributed throughout the study area in an effort to allow inference to the entire Black Mountains ecosystem (Figure 27).

Using an area search methodology for complete coverage within the plot boundaries (Zylstra and Steidl 2009), the researchers conducted standardized surveys for tortoises and their sign (e.g., carcasses, scat, tracks, shell) within each 3 ha (7.4 ac) survey plot. They classified a plot as occupied if a live tortoise or tortoise sign was detected. MacKenzie et al. (2005) suggested that the assumption that survey plots are closed to changes in occupancy during the duration of repeat surveys (i.e., within a "season") can be relaxed provided changes in occupancy occur at random. Under this scenario, occupancy is interpreted as use. All shelter sites detected during these surveys were examined for tortoises and their sign. In addition, the research team collected survey-specific data regarding habitat features, temperature, and timing (year and season) of each survey. Surveys were conducted in a manner that minimized the potential effects of heterogeneity in detection (MacKenzie and Royle 2005). Specifically, field protocols ensured that surveyors rotated among soil subgroups to avoid bias and that the order of subgroup surveying changed each day to avoid biases related to survey timing. Field protocols also ensured that an approximately equal number of survey plots were visited within each of the soil subgroups each week during the survey season. The surveyors used GPS units to record geographic coordinates of all tortoise sign and live individual tortoises encountered.

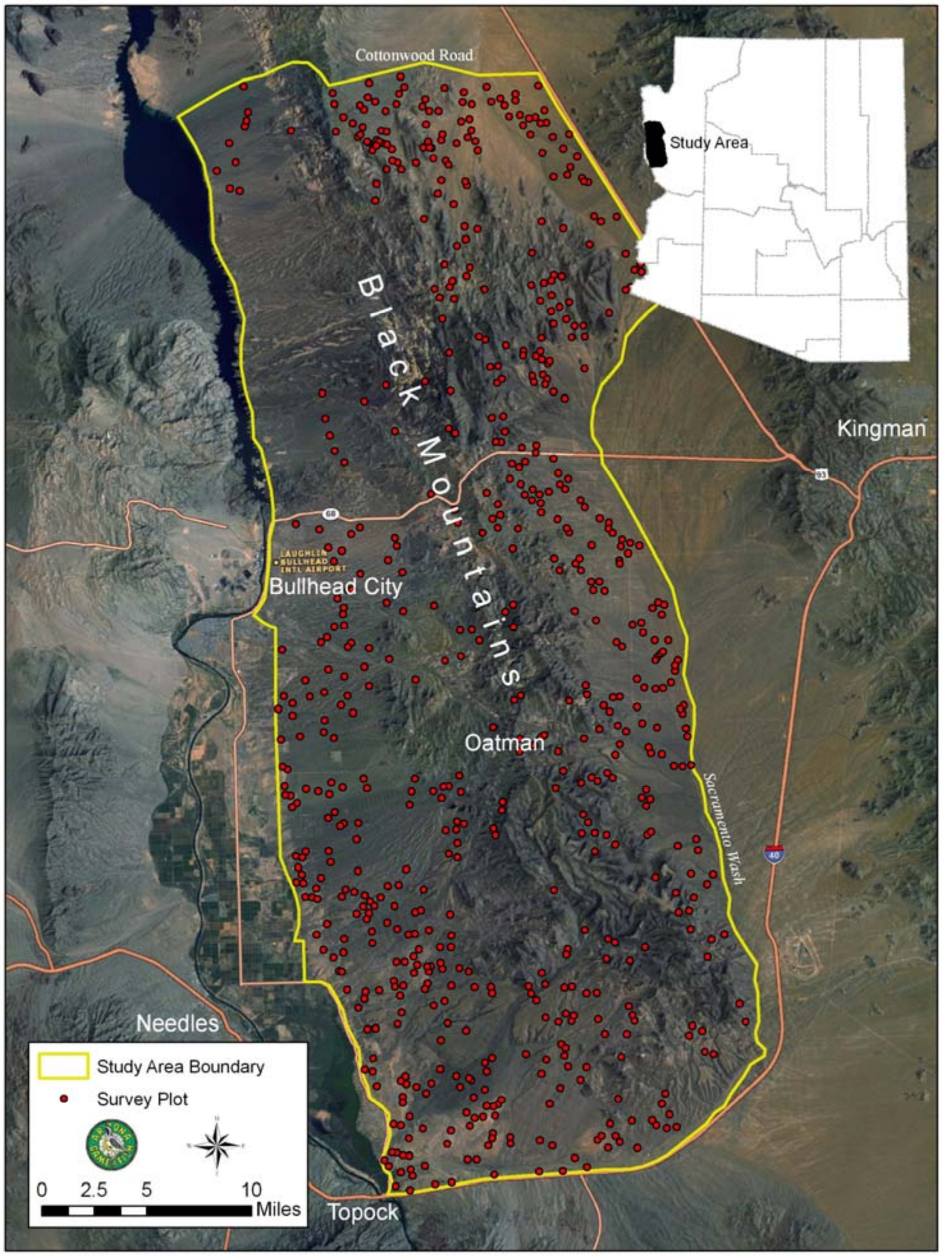


Figure 27. Location of Desert Tortoise Survey Plots in the Black Mountains Ecosystem.

The surveyors followed established guidelines to prevent unnecessary stress and potential disease transmission (Berry and Christopher 2001) for all detected tortoises. Tortoises were weighed, measured, sexed, and marked as specified in Section 3.2.4.

In addition to recording the presence of tortoises and tortoise sign and survey-specific data for each survey, the surveyors collected additional information related to the survey plot location. These data included the number and location of permanent shelter sites (i.e., burrows ≥3.28 ft [1.0 m] deep), distance to the nearest wash, and distance to the nearest road.

4.2.3 Data Analysis

Survey Plots

The researchers compared means of continuous covariates between occupied and unoccupied survey plots using nonparametric Wilcoxon signed-ranked tests (Zar 1999). Comparisons of categorical variables between occupied and unoccupied plots were conducted using Pearson chi-square tests. Before developing occupancy models, the team evaluated multicollinearity among covariates by examining pairwise Pearson correlation coefficients (Zar 1999). Predictor variables with statistically significant correlation coefficient values $|r| \geq 0.50$ ($P < 0.05$) were not included in the same model to avoid multicollinearity (Glanz and Slinker 1990; Graham 2003). The team used SPSS 11.5.1™ to conduct plot-level comparisons.

Soil-Patch Occupancy

Occupancy analyses were conducted at the soil group and soil subgroup levels. The team used the single-season occupancy model in Program PRESENCE (version 3.0; Hines 2006) to obtain detection probabilities and an estimate of PAO for desert tortoises at the soil group level (i.e., Aridisol and Entisol) and soil subgroup level. The year was included as a covariate in detection model comparisons to determine whether an annual pattern in detection probability existed. PAO and detection probability were estimated using maximum likelihood methods developed by MacKenzie et al. (2005) and were based on the spatially replicated detection/nondetection data from sampling sites within soil patches (Kendall and White 2009).

The research team examined hypotheses regarding the influence of various covariates (Table 8) on detection and occupancy probabilities. The spatially replicated nature of the occupancy analysis (Kendall and White 2009) required that modeled covariates be treated as sample-specific covariates rather than site-specific covariates. For example, under a repeat-visit sampling design, distance to a wash is considered a site-specific covariate. However, under the spatially replicated design, each survey plot is visited once, with spatial replication occurring within soil patches. As a result, habitat covariates are treated as sample specific (L. Bailey, Colorado State University, personal communication).

The researchers used a two-step approach to this model-based analysis. First, they determined which factors best explained variation in detection probability. Detection and occupancy models were based on a priori hypotheses that detection was influenced by season, year, and temperature (Table 8). They also examined how the number of permanent shelter sites on each survey plot influenced detection probability, since previous studies had suggested that tortoises are more likely to be detected in subterranean shelters than aboveground (AGFD, unpublished data).

Following the methodology suggested by MacKenzie and Bailey (2004), the research team used a parametric bootstrap procedure to assess the fit of the global detection model (Burnham and Anderson 2002). They evaluated overdispersion for the global model based on $\hat{c}$, which was calculated by dividing the residual deviance of the global model by its degrees of freedom (Burnham and Anderson 2002; Crawley 2007). The small sample correction for AIC_c (Hurvich and Tsai 1989; Burnham and Anderson 2001; Vaida and Blanchard 2005) was used to rank candidate models. The QAICc was used when $\hat{c} > 1$ (Burnham and Anderson 2002). The inclusion of $\hat{c}$ added an additional parameter to AIC calculation (Burnham and Anderson 2002). The team calculated ΔAIC_c or $\Delta QAIC_c$ as well as w_i (Buckland et al. 1997) for each model to assess model uncertainty and the likelihood of each candidate model given the data. They considered models with ΔAIC_c or $\Delta QAICc \leq 2$ to be well supported by the data (Burnham and Anderson 2002). The team further evaluated the top-ranked detection models by examining parameter estimates and SEs for the regression coefficients.

The best detection model was then used in the second step of the analysis. The research team modeled occupancy as a function of various combinations of habitat-related covariates (Table 8). Proximity to roads has an influence on tortoise habitat selection (Lovich and Daniels 2000; Grandmaison et al. 2010) and space use (Nicholson 1979; Karl 1989; von Seckendorff Hoff and Marlow 2002; Boarman and Sazaki 2006). Similarly, desert washes are an important component of desert tortoise habitat because they provide access to forage and shelter sites and are used as travel routes (Barrett 1990, Jennings 1997, Riedle et al. 2008; Grandmaison et al. 2010). The importance of shelter sites for desert tortoises is well documented (Bury et al. 1994; Fritts and Jennings 1994; Averill-Murray et al. 2002; Duda et al. 2002; Riedle et al. 2008), and as such, the researchers predicted that the number of permanent shelter sites would influence tortoise occupancy. Finally, studies have shown that geomorphic landforms serve as an effective surrogate variable for habitat because they affect the spatial and temporal distributions of plants and animals (McAuliffe 1994; Shenbrot et al. 1991; Shepherd and Kelt 1999; Heaton et al. 2006). At the level of soil order, the team also included models in which occupancy varied by soil subgroup.

The study compared occupancy models using the information-theoretic approach by calculating AIC_c values and comparing AIC_c weights (Burnham and Anderson 2002) and used model-averaging techniques where appropriate. The researchers reported detection and occupancy estimates for comparison among soil orders and subgroups (±SE) and compared the naïve occupancy estimate with those obtained using the program PRESENCE. For models in which detection varied as a function of survey-specific covariates, the team calculated the mean detection probability estimate across sample sites to obtain an overall estimate of detection probability and associated SE for the top-ranked model.

Table 8. Description of Covariates Used in Detection and Occupancy Modeling.

Parameter	Covariate	Abbreviation	Description
Detection	Year	*year*	Temporal covariate indicating the year in which the survey was conducted (2008, 2009)
	Season	*season*	Temporal covariate indicating the season in which the survey was conducted (spring, summer, winter)
	Survey	*survey*	Temporal covariate representing variation in detection based on the timing of each survey
	Temperature	*temp*	Covariate derived from the average temperature during each survey
	Permanent shelter	*pshelt*	Number of permanent shelter sites (>3.28 ft [1.0 m] deep) on a survey plot
Occupancy	Soil subgroup	*subgroup*	Soil subgroup category based on National Cooperative Soil Survey (NCSS) survey data
	Permanent shelter	*pshelt*	Number of permanent shelter sites (>3.28 ft [1.0 m] deep) on a survey plot
	Distance to road	*droad*	Distance (meters) from plot center to the nearest gravel or two-track road
	Distance to wash	*dwash*	Distance (meters) from plot center to the nearest desert wash
	Landform	*landform*	Landform category based on NCSS survey data

4.3 RESULTS

4.3.1 Desert Tortoise Surveys

The research team detected a total of 57 individual desert tortoises within the study area (Table 9). Including recaptures of marked individuals, the team accumulated 69 detections over a two-year period. Eleven of the individual tortoises (19 percent) were detected during standardized surveys on 660 survey plots that were each 3 ha (7.4 ac) in size. The remaining detections occurred during radio-telemetry tracking efforts or while en route to survey plots. The surveyors detected 47 tortoises in 2008 and 22 tortoises in 2009. Detections in soil subgroup patches were few (Table 10). The highest proportion of patches with ≥1 detection of a live tortoise or tortoise sign (i.e., the naïve occupancy estimate) was attributed to the Typic Calciargid subgroup. Only four soil subgroups—all of them Aridisols—had ≥5 patches with detections of tortoises or tortoise sign (Table 10).

4.3.2 Landscape-Scale Habitat Model Evaluation

Survey Plots

Tortoises, tortoise sign, or both were detected on 52 of the 660 total survey plots (7.9 percent). Overall, 8.3 percent of the Aridisol survey plots and 6.7 percent of the Entisol survey plots showed signs of tortoise use—a difference that was not statistically significant ($Z = 0.55$, $P > 0.05$). The number of permanent shelter sites was greater for occupied plots than unoccupied plots ($P < 0.001$; Table 11). The differences between distance to a road, distance to a wash, and temperature on occupied and unoccupied plots were not statistically significant (Table 11). There was a statistically significant difference in the frequency of occupied and unoccupied survey plots among soil subgroups ($P < 0.001$) but not for landform, year, or season (Table 12).

Table 9. Capture Information for Desert Tortoises Marked within the SR 95 Study Area in 2008 and 2009.

Capture Date	Tortoise ID	Gender	Age Class	Survey Detection	Capture Date	Tortoise ID	Gender	Age Class	Survey Detection
10/5/2008	201	Female	Adult		5/28/2008	719	Female	Adult	
8/20/2008	300	Female	Adult		7/11/2008	720	Male	Adult	
9/11/2008	301	Male	Adult		7/17/2008	721	Male	Adult	
9/11/2008	401	Male	Adult		7/17/2008	730	Female	Adult	
4/4/2008	500	Female	Adult		8/12/2008	731	Male	Adult	X
10/2/2008	501	Male	Adult		8/21/2008	732	Male	Adult	
3/25/2009	530	Male	Adult		9/4/2008	780	Female	Adult	X
7/6/2009	532	Female	Adult		9/18/2008	781	Male	Adult	
7/9/2009	533	Female	Adult		10/2/2008	782	Male	Adult	
3/4/2009	540	Male	Adult	X	4/4/2008	801	Female	Adult	
4/21/2009	541	Female	Adult		4/7/2008	802	Male	Adult	
4/21/2009	542	Male	Adult		4/16/2008	803	Female	Adult	
4/21/2009	543	Female	Adult		4/16/2008	810	Male	Adult	
5/11/2009	544	Male	Adult		4/22/2008	811	Male	Adult	
8/7/2009	548	Male	Adult	X	7/25/2008	812	Male	Adult	
3/30/2009	550	Female	Adult		9/18/2008	813	Male	Adult	
8/28/2009	562	Male	Adult	X	10/2/2008	821	Male	Adult	
8/28/2009	580	Female	Adult	X	7/30/2008	900	Male	Adult	
9/13/2009	598	Male	Adult		7/30/2008	901	Male	Adult	
9/14/2009	599	Female	Adult		8/12/2008	902	Male	Adult	
2/29/2008	700	Female	Adult		9/4/2008	903	Male	Adult	
3/6/2008	702	Female	Adult		8/13/2008	908	Female	Adult	
3/6/2008	708	Male	Adult		8/20/2008	909	Male	Adult	
3/25/2008	709	Female	Adult	X	10/5/2008	911	Male	Adult	
4/3/2008	710	Male	Adult	X	9/22/2008	913	Male	Adult	X
4/15/2008	711	Unknown	Hatchling		10/17/2008	918	Female	Adult	X
4/28/2008	712	Female	Adult		5/12/2008	N/A	Unknown	Hatchling	X
4/28/2008	713	Male	Adult		10/29/2008	N/A	Unknown	Hatchling	
5/15/2008	718	Male	Adult						

Table 10. Distribution of Patch-Level Detections and Naïve Occupancy Estimates.

Soil Subgroup	Survey Plot	No. of Soil Patches Surveyed	No. of Detections	Naïve Patch Occupancy
Aridisols				
Durinodic Haplocalcid	60	26	10	0.3846
Lithic Haplargid	60	21	0	0.0000
Typic Argidurid	60	13	1	0.0769
Typic Calciargids	60	14	6	0.4286
Typic Haplargid	60	12	0	0.0000
Typic Haplocalcid	60	17	5	0.2941
Typic Haplocambid	60	8	1	0.1250
Typic Haplodurid	60	28	5	0.1786
Entisols				
Lithic Torriorthent	60	8	2	0.2500
Typic Torriorthent	60	21	1	0.0476
Typic Torripsamment	60	21	0	0.0000

Table 11. Comparison of Continuous Covariates on Survey Plots where Tortoise Presence was Detected and Not Detected.

	Tortoise Presence Detected				Tortoise Presence Not Detected					
Covariate[a]	**Min.**	**Max.**	**Mean**	**SD[b]**	**Min.**	**Max.**	**Mean**	**SD[b]**	***Z***	***P***
droad	10.58	3950.6	825.17	811.58	2.91	4962.81	734.38	805.16	-0.19	0.848
dwash	11.08	899.15	315.49	203.77	0.11	1074.12	300.49	203.23	-0.47	0.636
pshelt	0	19	2.08	3.85	0	10	0.39	1.02	-3.47	<0.001
temp	16.8	41.1	29.354	6.28	7.8	54.2	28.2	7.44	-0.33	0.739

[a] See Table 8 for covariate descriptions.
[b] SD = standard deviation.

Soil-Patch Occupancy: Soil Order

Desert tortoises, tortoise sign, or both were detected in 28 of the 139 Aridisol soil patches surveyed (20.1 percent). The global detection model for Aridisol soils provided an adequate fit to the data ($P = 0.941$), and overdispersion was not detected. Modeling results indicated that year and the number of permanent shelter sites had an influence on detection probability in Aridisol soils (Table 13). There was little indication that temperature or season influenced detection probabilities, given the low weight of evidence for models that contained these covariates. There was no evidence to support variation in occupancy relative to the soil subgroup, distance to a road, distance to a wash, or landform (Table 14). The weight of evidence unequivocally supported constant occupancy within Aridisol soils.

Table 12. Comparison of Categorical Covariates on the Number of Survey Plots Where Tortoise Presence Was Detected and Not Detected.

Covariate	Tortoise Presence Detected	Tortoise Presence Not Detected	Pearson χ^2	*P*
Soil Subgroup			57.45	<0.001
Durinodic Haplocalcid	13	47		
Lithic Haplargid	0	60		
Typic Argidurid	1	59		
Typic Calciargids	11	49		
Typic Haplargid	0	60		
Typic Haplocalcid	6	54		
Typic Haplocambid	1	59		
Typic Haplodurid	8	52		
Lithic Torriorthent	10	50		
Typic Torriorthent	2	58		
Typic Torripsamment	0	60		
Landform			9.96	0.126
Alluvial Fan	0	13		
Dune	0	53		
Floodplain	2	41		
Hill	10	117		
Mesa	0	7		
Pediment	6	36		
Terrace	34	341		
Year			3.01	0.083
2008	32	298		
2009	20	310		
Season			2.363	0.307
Spring	17	251		
Summer	35	349		
Winter	0	8		

The global detection model for Entisol soils did not provide an adequate fit to the data ($P = 0.020$), and overdispersion was high ($\hat{c} = 43.50$). The overall number of desert tortoise detections in Entisol soil patches was low, with only 3 of the 50 Entisol soil patches (6.0 percent) showing signs of tortoise presence. The low number of detections hampered the ability to derive reliable detection and PAO estimates for Entisol soils. Furthermore, due to the low number of tortoise detections, none of the models that included covariates for occupancy performed better than the null model (i.e., constant occupancy across soil patches). Therefore, the researchers estimated detection and occupancy probabilities from the null detection model for Entisol soils, that is, the model in which detection and occupancy are constant across soil patches.

Soil-patch-occupancy modeling results indicated that the probability of desert tortoise detection was higher for Entisol soils than Aridisol soils (Figure 28). However, the low number of tortoise detections limited the ability to obtain reliable estimates of detection or occupancy for Entisol soils. Comparison of PAO estimates at the level of soil order indicated that tortoise occupancy was higher in Aridisols than Entisols (Figure 29).

Table 13. Comparison of Detection Models for Aridisol Soil Patches.

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*year,pshelt*)	3	-90.150	0.0000	0.9507
psi(.),p(*pshelt,temp*)	3	-93.110	5.9200	0.0493
psi(.),p(.)	2	-104.000	25.6405	0.0000
psi(.),p(*year*)	2	-104.000	25.6405	0.0000
psi(.),p(*year,temp*)	3	-103.840	27.3800	0.0000
psi(.),p(*temp*)	2	-105.035	27.7105	0.0000
psi(.),p(*global*)	5	-103.720	31.3519	0.0000
psi(.),p(*pshelt*)	2	-107.585	32.8105	0.0000
psi(.),p(*pshelt,season*)	3	-107.585	34.8700	0.0000
psi(.),p(*season*)	2	-109.880	37.4005	0.0000
psi(.),p(*survey*)	19	-98.330	54.0190	0.0000

[a] See Table 8 for covariate descriptions.

Table 14. Occupancy Models for Aridisol Soil Patches.

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*year,pshelt*)	3	-90.150	0.0000	1.0000
psi(*pshelt*),p(*year,pshelt*)	3	-696.270	1212.2400	0.0000
psi(*droad,pshelt*),p(*year,pshelt*)	4	-695.875	1213.5402	0.0000
psi(*dwash,pshelt*),p(*year,pshelt*)	4	-695.965	1213.7202	0.0000
psi(*pshelt,landform*),p(*year,pshelt*)	4	-696.270	1214.3302	0.0000
psi(*droad*),p(*year,pshelt*)	3	-697.575	1214.8500	0.0000
psi(*landform*),p(*year,pshelt*)	3	-697.655	1215.0100	0.0000
psi(*dwash*),p(*year,pshelt*)	3	-697.655	1215.0100	0.0000
psi(*droad,dwash*),p(*year,pshelt*)	4	-697.550	1216.8902	0.0000
psi(*droad,landform*),p(*year,pshelt*)	4	-697.575	1216.9402	0.0000
psi(*dwash,landform*),p(*year,pshelt*)	4	-697.655	1217.1002	0.0000
psi(*subgroup*),p(*year,pshelt*)	3	-763.060	1345.8200	0.0000

[a] See Table 8 for covariate descriptions.

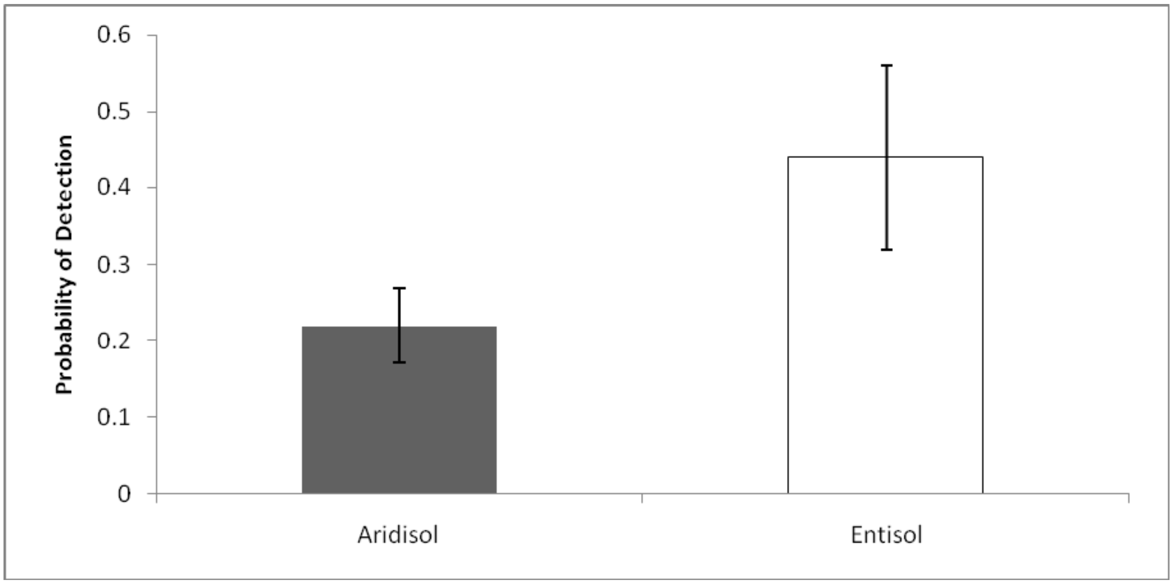


Figure 28. Probability(±SE) of Desert Tortoise Detection for Soil Groups within the SR 95 Realignment Zone Project Area.

(The open box indicates that the global detection model for Entisol soils did not fit the data.)

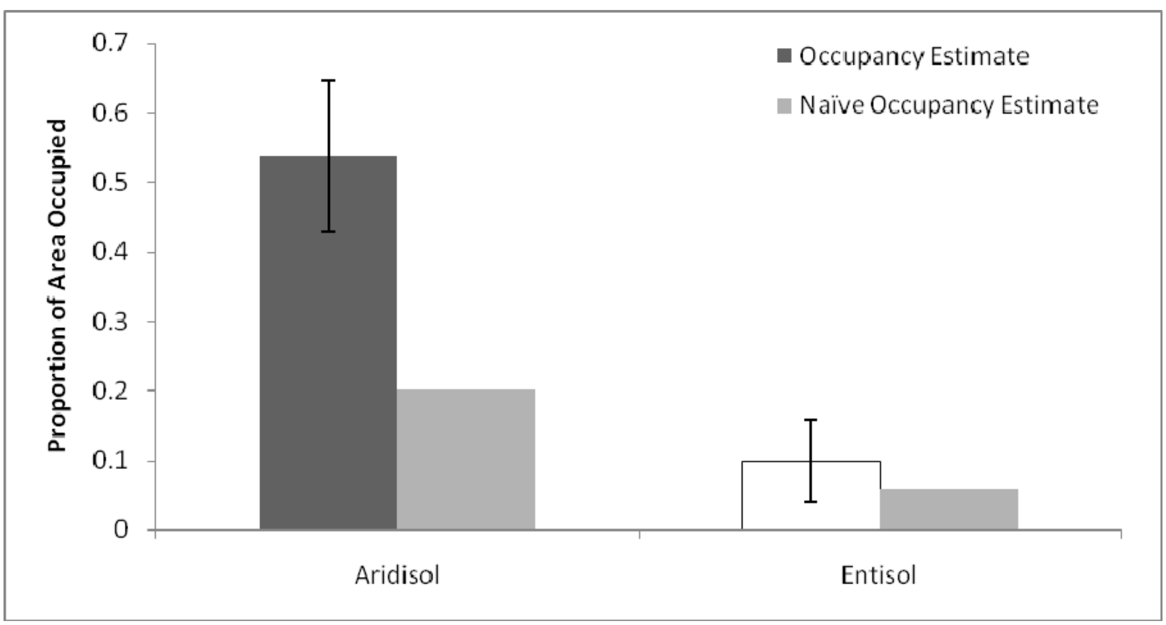


Figure 29. Proportion of Area Occupied (±SE) by Desert Tortoises for Soil Groups within the SR 95 Realignment Zone Project Area.

(The open box indicates that the global detection model for Entisol soils did not fit the data.)

Soil-Patch Occupancy: Soil Subgroup

Analyses at the level of soil order indicated that there was no evidence to support variation in occupancy among soil subgroups. However, sign of desert tortoise occupancy was only detected within 8 of the 11 soil subgroups within the study area (see Table 10). The lack of positive data points (i.e., lack of detected occupancy) in the detection histories for 3 soil subgroups comprising 54 soil patches (39 percent) posed a problem for analysis with the entire dataset. Therefore, the research team examined patterns in detection and occupancy within the 8 soil subgroups where tortoise presence was detected in ≥1 soil patch.

With the exception of the Lithic Torriorthent soil subgroup, all of the global detection models provided an adequate fit to the data. However, the most well-supported model did not necessarily include biologically meaningful detection or PAO estimates. For example, the two top-ranked detection models for Durinodic Haplocalcids identified the number of permanent shelter sites, year, and temperature as important covariates for modeling detection probability (Table 15). However, model evaluation indicted that the SEs for the occupancy parameter estimates were very large compared to the parameter estimates. PAO estimates were noninformative, with confidence intervals from 0 to 1. The null model, which ranked third, provided an informative estimate of both detection probability and PAO for Durinodic Haplocalcid soils. For each soil subgroup analysis, the study examined detection models in order of increasing ΔAIC_c until informative estimates were obtained for detection probability and PAO. The researchers report the estimates (±SE) from the highest-ranked informative model for comparison among soil subgroups.

Entisol soil subgroups proved problematic in the estimation of detection probability and PAO. As stated previously, goodness-of-fit assessment of the global detection model for Lithic Torriorthents indicated substantial lack of fit ($P = 0.0297$), rendering estimates of detection and PAO unreliable. Similarly, all of the Typic Torriorthent models failed to provide a meaningful estimate of detection and its associated SE. Both soils had a low number of detections (see Table 10).

Table 15. Model Comparison for Durinodic Haplocalcid Soil Patches.

Model	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*year,pshelt*)	3	-24.735	0.0000	0.4870
psi(.),p(*pshelt,temp*)	3	-25.280	1.0900	0.2824
psi(.),p(.)	2	-28.030	4.5305	0.0505
psi(.),p(*year*)	2	-28.030	4.5305	0.0505
psi(.),p(*global*)	5	-25.280	5.3019	0.0344
psi(.),p(*temp*)	2	-28.415	5.3005	0.0344
psi(.),p(*year,temp*)	3	-27.915	6.3600	0.0203
psi(.),p(*pshelt*)	2	-28.995	6.4605	0.0193
psi(.),p(*season*)	2	-29.285	7.0405	0.0144
psi(.),p(*pshelt,season*)	3	-28.995	8.5200	0.0069
psi(.),p(*survey*)	19	-19.115	26.4190	0.0000

[a] See Table 8 for covariate descriptions.

Despite the difficulties in estimating detection and PAO for Entisol soil subgroups resulting from the low overall number of detections, the researchers were able to obtain estimates for five of the six Aridisol soil subgroups in which tortoise detections occurred. For each analysis conducted at the soil subgroup level, the constant occupancy model was unequivocally supported over models that included habitat-related covariates (i.e., soil subgroup, landform, distance to a road, distance to a wash; occupancy model comparisons are included in Appendix C). These estimates generally came from models with one or fewer covariates for detection and were simpler in structure than the top-ranked models.

At the soil subgroup level the research team observed a considerable amount of variability in estimates of both detection (Figure 30) and PAO (Figure 31). The mean detection probability ranged from 0.20 to 0.42. Reliable estimates of detection probability were not obtained for Entisols. Model-derived estimates of PAO exceeded the naïve occupancy estimates for all soil categories except Typic Torriorthents in which the modeled PAO was equal to the naïve estimate (Figure 31).

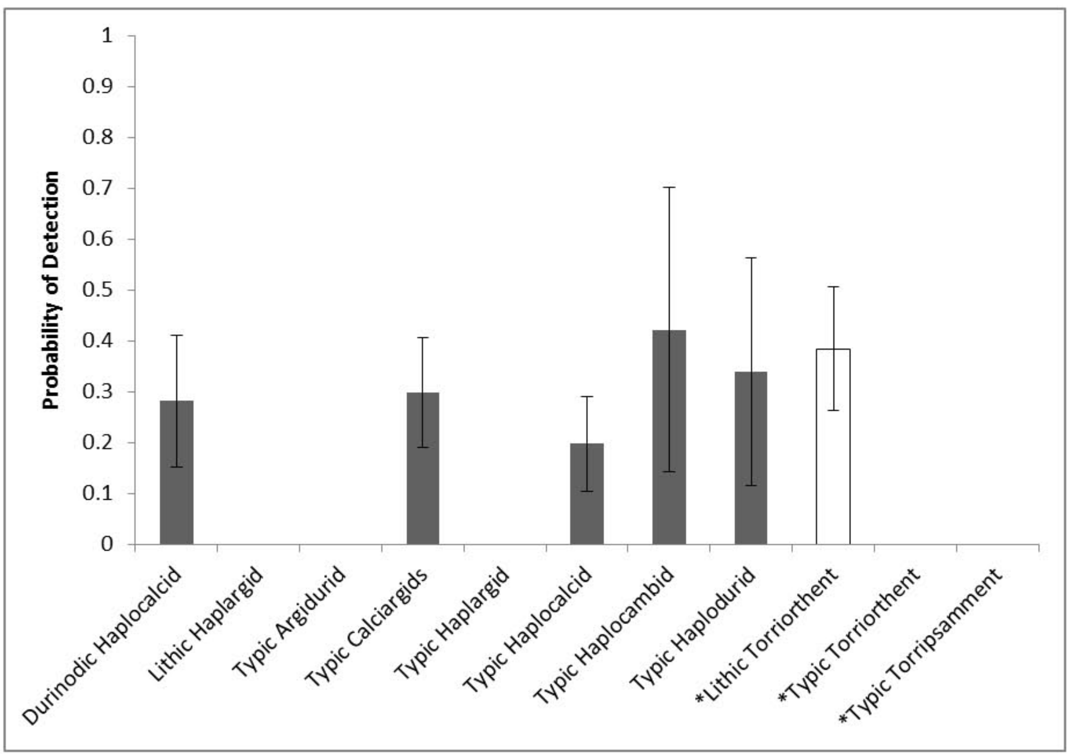


Figure 30. Probability of Desert Tortoise Detection for Soil Subgroups within the SR 95 Realignment Zone Project Area.

(The open box indicates that the global detection model for Lithic Torriorthent soil patches did not fit the data. Asterisks identify Entisol soil subgroups. No estimate was obtained for detection in Typic Argidurid or Typic Torriorthent soil patches.)

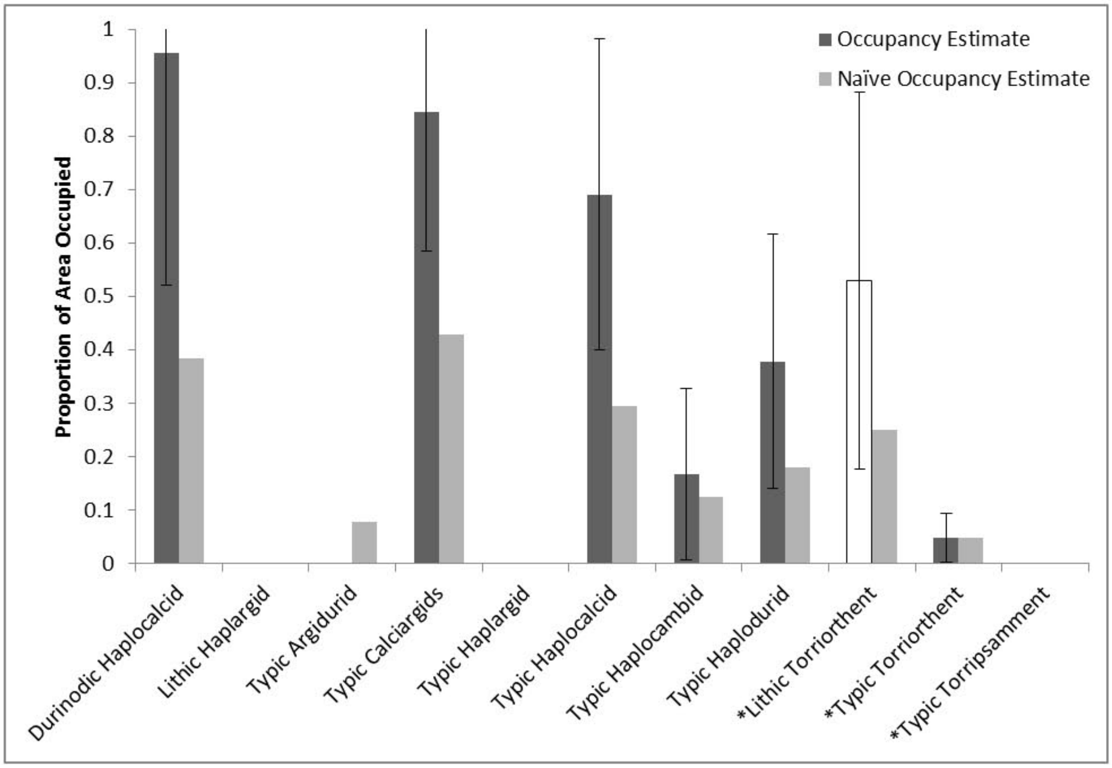


Figure 31. Proportion of Area Occupied (±SE) by Desert Tortoises for Soil Subgroups within the SR 95 Realignment Zone Project Area.

(The open box indicates that the global detection model for Lithic Torriorthent soil patches did not fit the data. Asterisks identify Entisol soil subgroups. No estimate was obtained for detection in Lithic Haplargid, Typic Argidurid, Typic Haplargid or Typic Torriorthent soil patches.)

4.4 DISCUSSION

Overall, the ability to identify landscape-scale patterns in desert tortoise occupancy was limited by a low number of detections. Inferences to desert tortoise habitat associations at the landscape level were difficult to obtain, largely the result of ecological and behavioral characteristics that make tortoises difficult to detect. Given desert tortoises' cryptic nature, low density, limited activity periods, and subterranean behaviors (Nagy and Medica 1986) desert tortoise encounter rates are low and the probability of desert tortoise detection is <1 (Freilich and LaRue 1998; Anderson et al. 2001; Zylstra et al. 2010). However, estimated detection probabilities at the soil subgroup level approximated the estimated detection probabilities reported for other desert tortoise occupancy studies in Arizona. For example, Zylstra et al. (2010) obtained detection probability estimates in Saguaro National Park at 0.43, and unpublished data from an AGFD study on the Florence Military Reservation in Pinal County obtained estimates of 0.33 (AGFD, unpublished data). Given reasonable detection rates in Aridisol soil subgroups, the research team believes that failure to estimate occupancy in Entisol soils and limited inference regarding the influence of covariates on detection and PAO were due to low occupancy by desert tortoises within the study area.

Low detections in the Entisol soil subgroups contributed to goodness-of-fit issues; the inability of maximum likelihood estimation to converge on meaningful detection and occupancy parameters; and, at the soil-order level, failure to detect variation in occupancy when modeled as a function of soil subgroup. An alternative interpretation for this last result is that soil subgroups did not influence tortoise occupancy. However, the analyses at the subgroup level did not support this conclusion.

Detection and PAO estimates were obtained for Aridisol soil subgroups, although model selection results indicated that the low number of tortoise detections limited the team's ability to adequately model the influence of temporal and habitat-related covariates. Top-ranked models consistently failed to provide meaningful PAO estimates, whereas lower-ranked, simpler models did. While the resulting estimates of detection probability and PAO are useful for comparing soil subgroups, interpretation of the importance of covariates on detection and occupancy is problematic.

This analysis suggests that desert tortoise occupancy was higher for soil subgroups with defined horizons (i.e., Aridisols) compared to soils lacking horizons (i.e., Entisols). PAO estimates for five Aridisol subgroups were made at >0.15. This relationship may be the result of the ability of Aridisol soils to maintain shelter structure and support deeper, more permanent shelter sites. PAO varied among soil subgroups within the Aridisol soil order, suggesting that diagnostic characteristics at the subgroup level may be correlated with tortoise occupancy. However, complex models that included habitat covariates for PAO estimation were not supported in the model selection analysis. These results do not necessarily indicate a lack of influence of habitat features within soil subgroups; rather, the research team cautions that the data were insufficient for evaluating more complex hypotheses related to the interplay between soil classification and site-specific habitat features.

Three soil subgroups had no tortoise detections during the surveys. Two of the three were Haplargid soils, which are relatively noncalcareous with respect to other Aridisols and do not generally have an appreciable cementation of soil particles by silica (Soil Survey Staff 1975). The third subgroup was Torripsamment, which belongs to the Entisol soil order. Torripsamments are sandy soils with no horizons. They are characteristic of dunes in arid climates (Soil Survey Staff 1975). The characteristics of these three soil types—specifically the lack of significant particle cementation and/or calcium carbonate in Haplargids and the sandy structure of the Torripsamments—do not readily facilitate the creation of deep, permanent burrows by desert tortoises. These factors may have accounted for the lack of tortoise detections within the three soil subgroups.

Four Aridisol soil subgroups had high estimates for PAO. Based on the analysis, the team was unable to identify the characteristics within these subgroups that contribute to variation in occupancy. However, the team can use the occupancy estimates obtained in this study to make recommendations regarding the proposed SR 95 realignment routes and to assess the impacts of the selected route on tortoise habitat. Likewise, the occupancy analyses can guide mitigation efforts once a specific alignment is chosen.

4.5 CONCLUSIONS

The results suggest that desert tortoise occupancy varies among soil subgroups. The highest PAO estimates were found in Durinodic Haplocalcid, Typic Calciargid, Typic Haplocalcid, and Typic Haplodurid soil subgroups. Despite the low number of detections and difficulty in modeling habitat covariates such as proximity to roads and washes at the landscape scale, other studies have shown that these characteristics influence tortoise habitat use (Barrett 1990; Germano et al. 1994; Lovich and Daniels 2000; Riedle et al. 2008; Grandmaison et al. 2010). PAO estimates for soil subgroups found within the SR 95 realignment route can be used to evaluate alignment impacts and prioritize locations for desert tortoise mitigation. At the scale of desert tortoise home ranges, desert washes should be identified for the installation of crossing structures and directional fencing, and road redundancy should be minimized.

5.0 DESERT TORTOISE MOVEMENT PATTERNS WITHIN THE PROPOSED SR 95 REALIGNMENT ZONE

5.1 INTRODUCTION

Transportation networks impose significant challenges to wildlife populations through habitat loss (Forman 2000) and their pervasive barrier effects on the landscape (Forman et al. 2003). As barriers to wildlife movement, roadways fragment and isolate habitat and reduce gene flow, thereby increasing the susceptibility of wildlife populations to demographic and environmental stochasticity (Forman and Alexander 1998; Trombulak and Frissell 2000).

Desert tortoises are particularly sensitive to the effects of road-induced habitat loss because tortoises occur at low density, have low reproductive rates, and have low mobility (Trombulak and Frissell 2000). Gene flow among desert tortoise populations is important for long-term population persistence. Although infrequent, long-distance movements have been documented in the Sonoran Desert (Edwards 2003), and gene-flow estimates from southern Arizona indicate that tortoise populations historically exchanged individuals at a rate greater than one migrant per generation. Anthropogenic barriers to dispersal, such as roads, reduce the likelihood of gene flow between desert tortoise populations (Edwards et al. 2004) unless successful mitigation, such as crossing structures and exclusion fencing, is implemented. However, population-level benefits of these types of mitigation strategies have not been effectively demonstrated for desert tortoises in the Sonoran Desert.

Research on wildlife-crossing structures has generally taken two approaches: (1) identifying the species using the crossing structure and their frequency of use and (2) using crossing data as an independent variable to identify factors that influence the use of crossing structures. Few studies have measured the performance of mitigation measures in meeting conservation goals (but see Dodd et al. 2007). Given the conservation goal inherent in the use of tortoise crossing structures and exclusion fencing as a mitigation measure, it is essential to obtain quantitative data regarding tortoise movements in an experimental (e.g., pre- and postconstruction) context, as Dodd et al. (2007) did for elk along SR 260 in central Arizona.

In 2005, ADOT conducted a feasibility study to identify the need for realigning SR 95 to reduce traffic congestion within the existing alignment and enhance motorist safety (ADOT 2005). The feasibility study indicated that the existing SR 95 corridor experiences high traffic volume and congestion during peak traffic periods, therefore making regional through-traffic difficult. Furthermore, the existing alignment fails to provide a contiguous north-south highway connection in northwestern Arizona (ADOT 2005). The proposed realignment identified in the 2005 study bisects known desert tortoise habitat east of the Colorado River and west of the Black Mountains in Mohave County, Arizona.

The tortoise population in the Black Mountains ecosystem is currently designated as a part of the Sonoran assemblage (USFWS 1990), although most of the tortoises in this population exhibit ecological (USFWS 1994) and genetic (Glenn et al. 1990; McLuckie et al. 1999) similarities to tortoises in the Mojave Desert. Desert tortoise habitat in the Sonoran Desert is generally characterized by volcanic outcrops, boulder-strewn hillsides, and mountain bajadas with large, deeply incised washes (Barrett 1990; Germano et al. 1994; Riedle et al. 2008; Grandmaison et al. 2010) and lowland intermountain desert valleys, albeit at lower densities (Edwards et al. 2004; Averill-Murray and Averill-Murray 2005). However, desert tortoises in the Black Mountains occupy bajadas dominated by creosotebush and white bursage and deeply incised washes more akin to tortoise habitat in the Mojave Desert (USFWS 1994). Furthermore, tortoise habitat use on the western bajadas of the Black Mountains coincides with the proposed realignment of SR 95. Because this tortoise population may be more closely related to the federally threatened Mojave assemblage, and there are growing concerns regarding cumulative impacts on the Sonoran assemblage, the desert tortoise has been elevated as a species of concern for the SR 95 realignment proposal.

The objective of this component of the study was to identify desert tortoise movement patterns within and adjacent to the SR 95 realignment zone to identify the most effective geographic location for tortoise crossing structures and exclusion fencing within the highway's proposed footprint. The study also sought to establish a baseline dataset identifying existing desert tortoise movement patterns relative to existing roads within the project area against which to compare future postconstruction evaluations of impacts on landscape permeability. Finally, the study examined habitat characteristics within desert tortoise home ranges, with special emphasis on soil subgroups, to provide further insight on the importance of soil characteristics.

5.2 METHODS

5.2.1 Desert Tortoise Surveys

The research team conducted desert tortoise surveys within a 1.24-mi (2.0 km) buffer centered on the proposed SR 95 realignment route (Figure 32). The SR 95 project area was divided into four segments (Segment 1: SR 68 south to Silver Creek Road.; Segment 2: Silver Creek Road to Boundary Cone Road; Segment 3: Boundary Cone Road southeast to Historic Route 66; and Segment 4: Historic Route 66 to I-40). The team located desert tortoises by segment and deployed VHF radio transmitters on three tortoises within each segment. Researchers and volunteers conducted tortoise surveys in areas with the highest probability of supporting desert tortoises based on known tortoise habitat characteristics (Barrett 1990; Germano et al. 1994; Averill-Murray and Averill-Murray 2005; Riedle et al. 2008). All shelter sites detected during these surveys were examined for tortoises and their sign.

Tortoise handling followed guidelines established by Berry and Christopher (2001) to prevent unnecessary stress and potential disease transmission. Tortoises were weighed, measured, sexed, and marked as specified in Section 3.2.4.

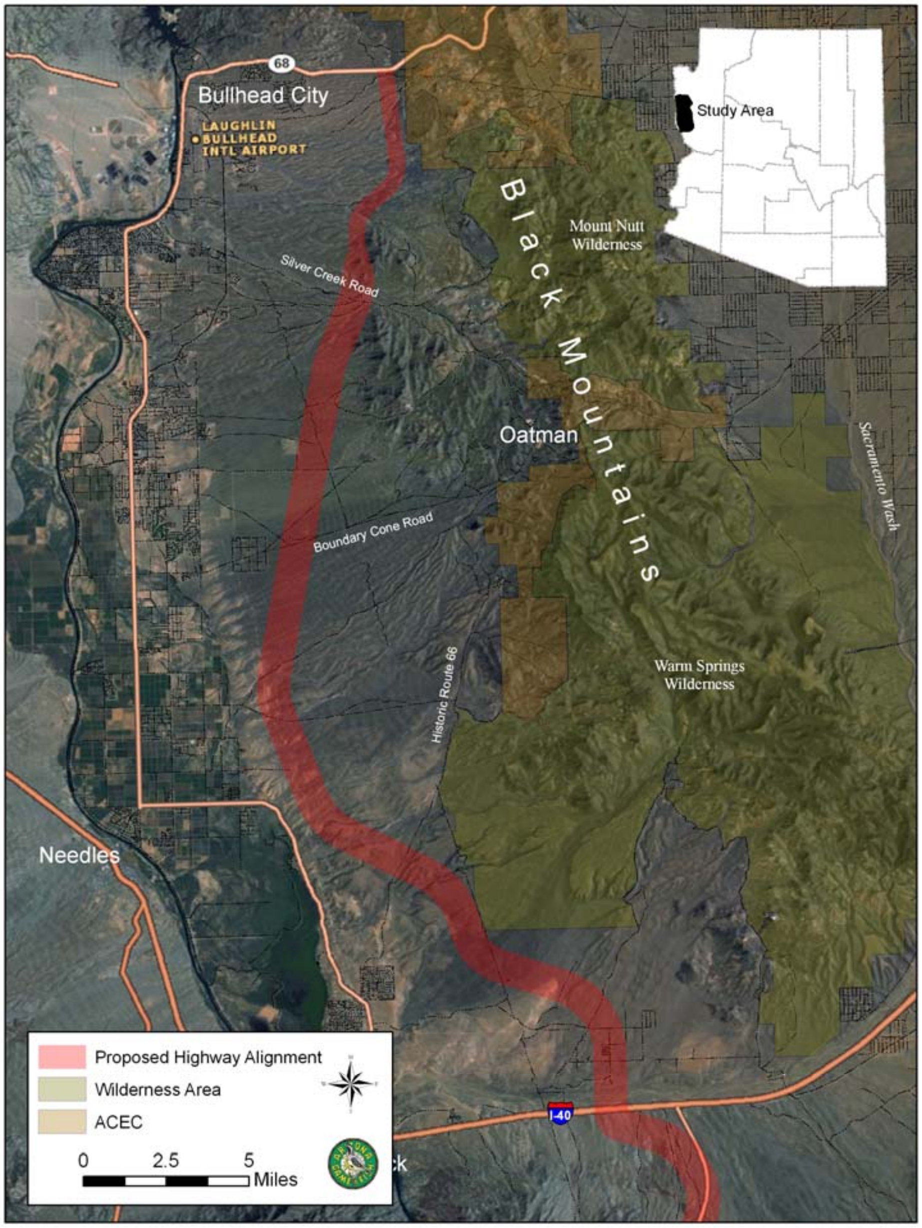


Figure 32. Proposed SR 95 Realignment Route in Mohave County, Arizona.

5.2.2 Desert Tortoise Telemetry

Telonics radio transmitters were glued with epoxy to the first left costal scute of 12 tortoises, and the device was positioned below the highest point on the carapace (Boarman et al. 1998). The transmitter antenna was inserted into 0.25-inch (6.3 mm) segments of shrink tubing that were glued to the marginal scutes. The epoxy was not applied to the seams between scutes. In addition, 11 adult desert tortoises were instrumented with Sirtrack MicroGPS (mean weight = 1.89 oz [53.5 g]) tracking units. The GPS tracking units were glued to the top of the carapace to ensure adequate communication with satellites. Short pieces of electrical tape were placed over the scute margins to ensure that epoxy was not applied to the seams between scutes.

GPS tracking units collected detailed location data (≤ 50-ft [15 m] resolution) once every 30 minutes from 5 am to 10 am and 5 pm to 9 pm, coinciding with peaks in daily activity (AGFD, unpublished data). GPS tracking units were deployed for a minimum of two weeks and then retrieved for data download and battery charging before being redeployed. The use of GPS tracking units allowed the research team to collect fine-scale movement pattern information for identifying tortoise activity areas, evaluating tortoise space use relative to the proposed SR 95 alignment, and identifying habitat characteristics within tortoise home ranges.

The researcher team monitored radio-tagged tortoises weekly during 2008 and biweekly during 2009 until the tortoises entered hibernacula in mid-November. During hibernation, the team located tortoises monthly until the tortoises resumed activity in the spring.

5.2.3 Movement Pattern Analysis

Desert Tortoise Home-Range Estimation

To assess desert tortoise space use within the SR 95 realignment project area, the researchers estimated tortoise home ranges using location data collected with GPS tracking units and then analyzed this data using the BBMM approach (Horne et al. 2007). GPS tracking units, programmed to record tortoise locations every 30 minutes, obtained location estimates with an estimated location error of ±50 ft (15 m). The researchers used the program Animal Space Use (Horne and Garton 2009) to estimate the Brownian movement variance parameter using maximum likelihood estimation techniques and output the resulting probability distribution of desert tortoise space use within the study area. They calculated the mean (±SE) home-range size and core area for both males and females. Core areas were defined by the upper quintile of the probability distribution (i.e., where the probability of space use generally exceeded 0.98) estimated by the BBMM. The team compared home-range size, core area size, and the number of core areas between males and females with ANOVA (Zar 1999).

Tortoise Movement Patterns and Permeability

The study used GIS analysis to map desert tortoise movement patterns relative to the proposed SR 95 realignment project area and to assess permeability within the project area corridor. The research team used the Animal Movement extension for ArcGIS 9.3 (Beyer 2004) to estimate movement pathways between successive GPS locations and to measure the distance between successive locations. The study defined "movement pathways" as successive GPS locations where the time between successive locations did not exceed 120 minutes. When the time between successive locations exceeded 120 minutes, a new pathway was started. The team calculated the mean pathway length for each individual tortoise by summing the distance between successive locations for each pathway.

The research team examined landscape permeability for desert tortoises using the existing road network within the SR 95 realignment project area. The team used the 2008 MAF/TIGER road database (http://www.land.state.az.us/alris/metadata/streets.htm) as the baseline road dataset. However, many roads within the study area were not part of this baseline dataset. Therefore, the team digitized missing roads identified from field surveys and ESRI's world imagery layer (http://downloads2.esri.com/resources/arcgisdesktop/layers/World_Imagery.lyr), which provides 3.3-ft (1 m) or better resolution imagery for the contiguous United States. The team then determined the frequency of road crossings for each tortoise, defined as successive GPS fixes occurring on each side of the alignment (Dodd et al. 2007), and estimated permeability, a quantitative measure of the ability of an organism to move across the landscape (Cramer and Bissonette 2005), as the ratio of road crossings to approaches (Dodd et al. 2007). The study defined an "approach" as tortoise movement into buffer zones surrounding roads without a road-crossing movement to the opposite side of the road. Through a post hoc determination, the team identified the width of the buffer zone as the maximum mean pathway length calculated from the tortoise movement path dataset. The team then estimated permeability for each individual tortoise to examine the existing level of permeability within the project area.

Soil Subgroup Composition and Tortoise Home Ranges

The study examined habitat characteristics associated with desert tortoise home ranges at two levels. The research team began by comparing soil subgroup categories within desert tortoise home ranges to the proportions of subgroups within the proposed SR 95 realignment route. The researchers used BBMM home-range estimates to define home ranges for tortoises that were monitored with GPS tracking units. An additional nine desert tortoises were not monitored with GPS tracking units; therefore, their home ranges could not be estimated using the BBMM approach (Horne et al. 2007). For those individual tortoises, the researchers estimated home ranges using minimum convex polygons (MCP). Despite differences in home-range estimation techniques, the team included these nine tortoises in the analysis to increase sample size and to avoid overlooking any potential contributions to clarifying habitat characteristics within the study area. The team compared the mean proportion of each soil subgroup found within tortoise home ranges (BBMM and MCP estimates combined) with the proportion of soil subgroups found within the proposed SR 95 realignment buffer using the Z test (Zar 1999).

The study then examined habitat characteristics within tortoise home ranges. The researchers used the BBMM-estimated home range to define habitat availability for each tortoise. They began by examining the difference in available and used soil subgroups using compositional analysis (Aebischer et al. 1993) to determine whether selection was occurring for soil subgroups found within tortoise home ranges. Availability of soil subgroups was calculated as the percentage of each soil subgroup category within each BBMM home-range estimate ($n = 11$). Used resources were calculated as the percentage of locations for each individual within each soil subgroup. The study addressed habitat type values of 0 percent (corresponding to an unutilized but available habitat category) by replacing them with 0.001 percent, an order of magnitude less than the smallest recorded nonzero percentage (Aebischer et al. 1993). Utilized and available resource compositions were transformed to log ratios using Durinodic Haplargid soils as the denominator and the difference in log ratios between used and available proportions were then calculated for each tortoise (Leban 1999). The research team calculated means and SEs for each of the elements in the resulting matrix over all the tortoises and created ranking matrices (Aebischer et al. 1993) to assess relative habitat preferences relative to soil subgroups.

5.3 RESULTS

5.3.1 Desert Tortoise Surveys

In total, the surveyors captured 57 individual desert tortoises within the study area (Table 16; Figure 33). Including recaptures of marked individual tortoises, the study accumulated 69 detections over a two-year period. Twenty-eight detections occurred within the 1.24-mi (2.0 km) survey buffer. The remaining detections occurred during occupancy surveys and radio-telemetry tracking efforts or while en route to survey plots. The surveyors detected 47 desert tortoises in 2008 and 22 in 2009.

5.3.2 Desert Tortoise Telemetry

The research team instrumented 12 adult desert tortoises with VHF radio transmitters (6 females and 6 males) and deployed GPS tracking units on 11 of the 12 tortoises during both field seasons. The study gathered 560 VHF locations (mean = 46 ± 2.5 SE locations per individual) and 7888 GPS locations (mean = 657 ± 196.5 SE locations per individual) during the 2008 and 2009 field seasons. The number of GPS locations per individual tortoise varied based on the ability to access tortoises for collecting the tracking units and deploying replacement units and on the variation in tortoise activity (i.e., if a tortoise was in a shelter site, the GPS unit was unable to communicate with satellites to obtain locations).

5.3.3 Movement-Pattern Analysis

Desert Tortoise Home-Range Estimation

The mean BBMM home-range estimates for females and males were 20.6 ha (± 7.2 SE) and 24.6 ha (± 1.3), respectively (females: 50.9 ac ± 17.8 SE; males: 60.8 ac ± 3.2 SE). Home-range size did not differ between sexes ($F_{1,9} = 0.238$, $P = 0.637$). Females averaged 6.0 (± 2.9 SE) core areas per individual, whereas males averaged 7.8 (± 1.8 SE). The number of core areas did not differ between sexes ($F_{1,9} = 0.248$, $P = 0.630$). Mean core-area estimates for females and males were 3.7 ha (± 1.1 SE) and 3.6 ha (± 0.7 SE), respectively (females: 9.1 ac ± 2.7 SE; males: 8.9 ac ± 1.7 SE). The size of core areas within tortoise home ranges did not differ between sexes ($F_{1,9} = 0.005$, $P = 0.945$).

Table 16. Capture Information for Desert Tortoises Marked within the SR 95 Study Area in 2008 and 2009.

Capture Date	Tortoise ID	Gender	Age Class	Radio-Tagged	Capture Date	Tortoise ID	Gender	Age Class	Radio-Tagged
10/5/2008	201	Female	Adult		5/28/2008	719	Female	Adult	
8/20/2008	300	Female	Adult		7/11/2008	720	Male	Adult	
9/11/2008	301	Male	Adult		7/17/2008	721	Male	Adult	
9/11/2008	401	Male	Adult		7/17/2008	730	Female	Adult	
4/4/2008	500	Female	Adult	X	8/12/2008	731	Male	Adult	
10/2/2008	501	Male	Adult		8/21/2008	732	Male	Adult	
3/25/2009	530	Male	Adult		9/4/2008	780	Female	Adult	
7/6/2009	532	Female	Adult		9/18/2008	781	Male	Adult	
7/9/2009	533	Female	Adult		10/2/2008	782	Male	Adult	
3/4/2009	540	Male	Adult		4/4/2008	801	Female	Adult	X
4/21/2009	541	Female	Adult		4/7/2008	802	Male	Adult	X
4/21/2009	542	Male	Adult		4/16/2008	803	Female	Adult	X
4/21/2009	543	Female	Adult		4/16/2008	810	Male	Adult	X
5/11/2009	544	Male	Adult		4/22/2008	811	Male	Adult	X
8/7/2009	548	Male	Adult		7/25/2008	812	Male	Adult	
3/30/2009	550	Female	Adult		9/18/2008	813	Male	Adult	
8/28/2009	562	Male	Adult		10/2/2008	821	Male	Adult	
8/28/2009	580	Female	Adult		7/30/2008	900	Male	Adult	
9/13/2009	598	Male	Adult		7/30/2008	901	Male	Adult	
9/14/2009	599	Female	Adult		8/12/2008	902	Male	Adult	X
2/29/2008	700	Female	Adult	X	9/4/2008	903	Male	Adult	
3/6/2008	702	Female	Adult	X	8/13/2008	908	Female	Adult	
3/6/2008	708	Male	Adult	X	8/20/2008	909	Male	Adult	
3/25/2008	709	Female	Adult	X	10/5/2008	911	Male	Adult	
4/3/2008	710	Male	Adult	X	9/22/2008	913	Male	Adult	
4/15/2008	711	Unknown	Hatchling		10/17/2008	918	Female	Adult	
4/28/2008	712	Female	Adult		5/12/2008	N/A	Unknown	Hatchling	
4/28/2008	713	Male	Adult		10/29/2008	N/A	Unknown	Hatchling	
5/15/2008	718	Male	Adult						

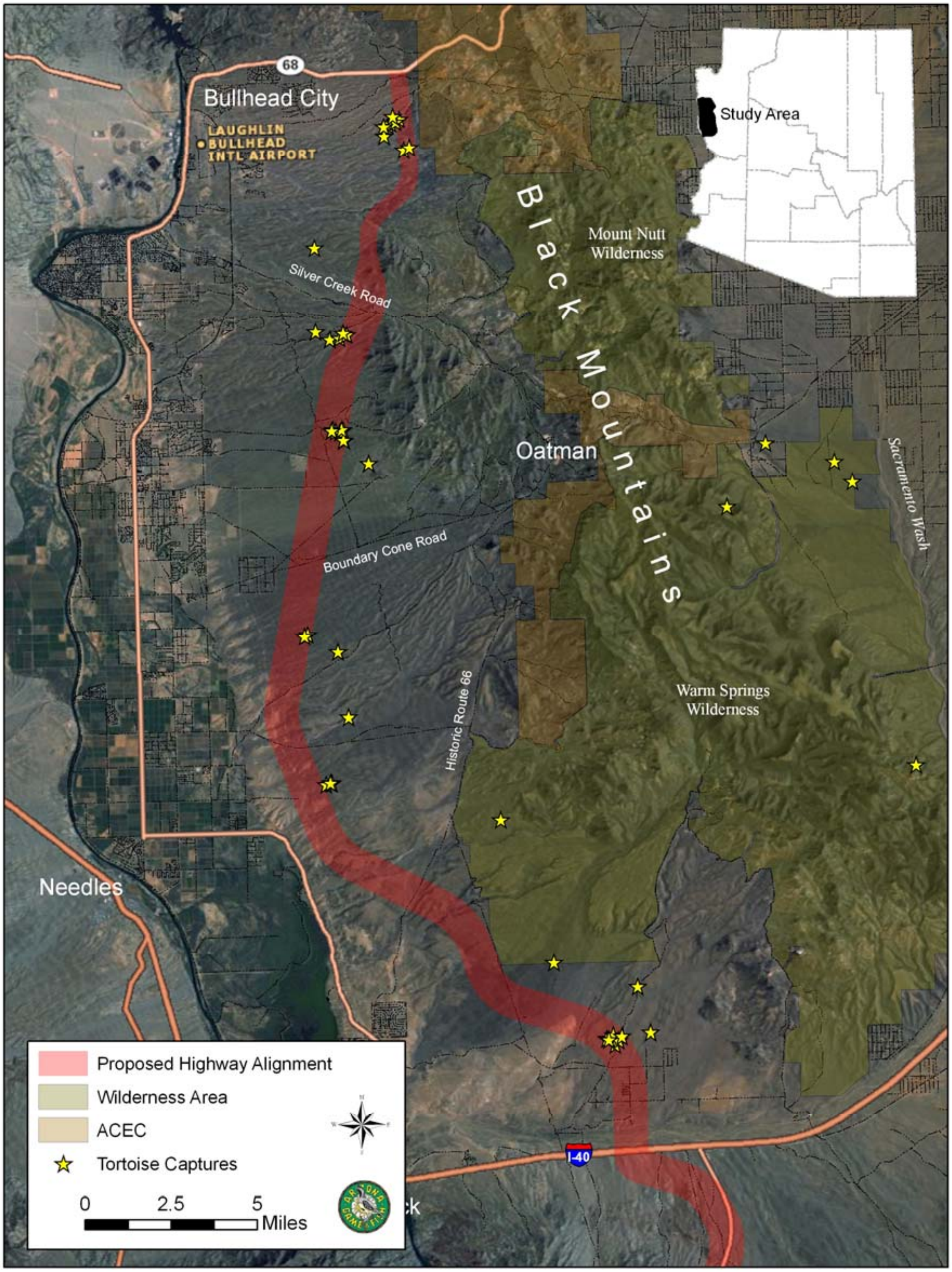


Figure 33. Desert Tortoise Captures within the Black Mountains Ecosystem.

Tortoise Movement Patterns and Permeability

Five desert tortoise BBMM-estimated home ranges overlapped existing gravel roads within the study area. Two tortoise core areas were bisected by roads. The mean length of desert tortoise movement paths for all tortoises was 319.5 ft (± 25.6 SE; 97.4 m ± 7.8 SE), although the mean path length varied among individuals (Table 17). The maximum mean path length was approximately 415.0 ft (126.5 m). Therefore, the team used a 415.0-ft (126.5 m) roadway buffer within the study area to define tortoise roadway approaches.

Of the 11 tortoises monitored with GPS tracking units, 6 moved into the 415.0-ft (126.5 m) roadway buffer, although only 3 tortoises made more than 10 approaches. Permeability estimates for these 3 individuals ranged from 0 to 0.136 (Table 17). Overall, roads appeared to serve as boundaries for desert home ranges within the study area (Figure 34).

Table 17. Length and Permeability Estimates for Tortoise Paths within the SR 95 Realignment Study Area.

Tortoise	Sex	No. of Documented Paths	Maximum Path Length (ft)	Mean Path Length (ft)	No. of Road Crossings	No. of Approaches	Permeability Estimate
500	Female	70	1362.78	198.04	9	66	0.136
700	Female	38	955.36	328.99	0	0	N/A
702	Female	11	792.38	342.13	1	1	1.000
709	Female	38	1015.93	169.68	0	0	N/A
801	Female	196	4022.33	387.95	2	5	0.400
803	Female	25	1387.05	255.12	0	0	N/A
710	Male	205	2389.07	343.13	0	13	0.000
802	Male	80	998.28	267.80	0	2	0.000
810	Male	158	1185.49	407.62	1	32	0.031
811	Male	54	2156.03	398.36	0	0	N/A
902	Male	93	1184.73	414.76	0	0	N/A

Home-Range Habitat Characteristics

Desert tortoise home ranges were located within three soil subgroups (Table 18). Typic Calciargid and Durinodic Haplocalcid soil subgroups composed most, and in some cases all, of the soil within desert tortoise home ranges. Typic Torriorthent soils represented wide washes with sandy substrates. The mean proportion of Typic Calciargid and Durinodic Haplocalcid soils was higher in tortoise home ranges than in the SR 95 realignment buffer (Figure 35), although the difference was not statistically significant (Table 19). Compositional analysis results examining resource use within desert tortoise home ranges indicated that soil subgroups were used in proportion to their availability ($\chi^2 = 2.207$, $P = 0.33$).

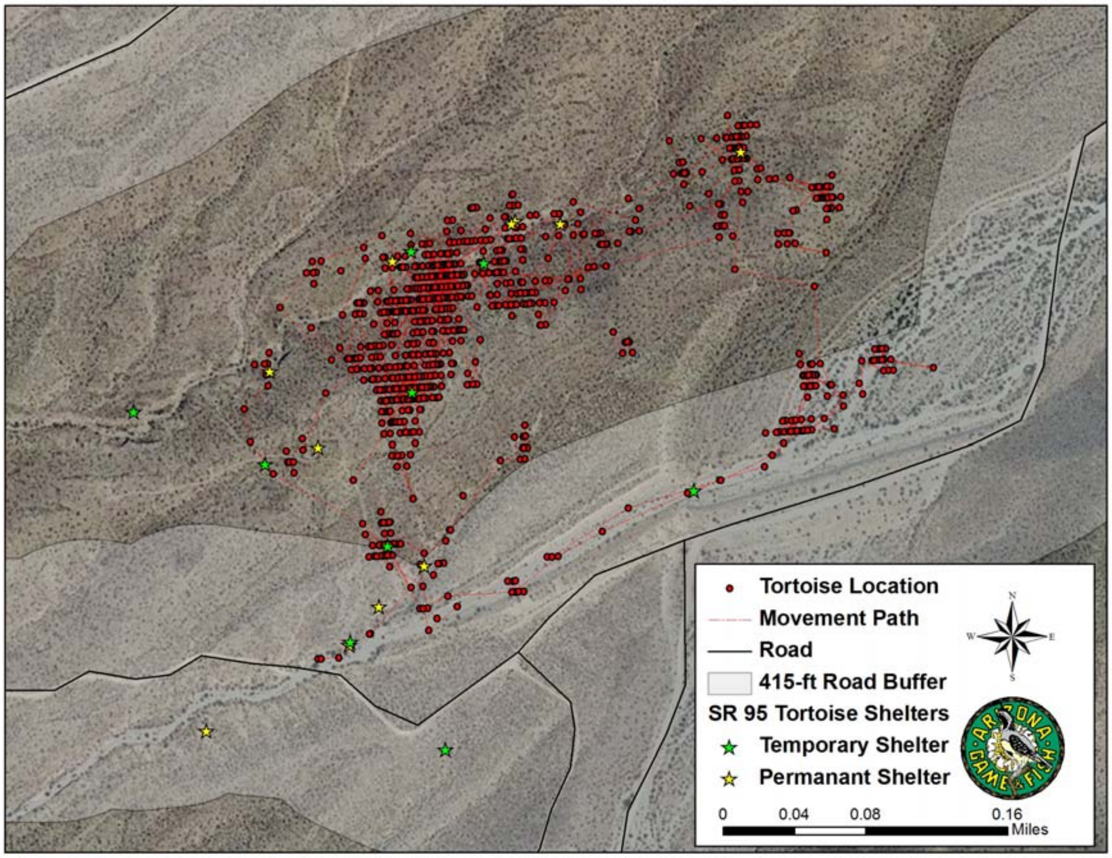


Figure 34. Example of a Road Serving as a Desert Tortoise Home-Range Boundary.

Table 18. Proportions of Soil Types within Desert Tortoise Home Ranges.

Tortoise	Typic Calciargid	Durinodic Haplocalcid	Typic Torriorthent	Tortoise	Typic Calciargid	Durinodic Haplocalcid	Typic Torriorthent
T500	0.00	0.46	0.54	T902	1.00	0.00	0.00
T700	1.00	0.00	0.00	T708	0.00	0.72	0.28
T702	0.00	1.00	0.00	T491	0.00	1.00	0.00
T709	0.00	1.00	0.00	T420	1.00	0.00	0.00
T710	0.00	1.00	0.00	T421	1.00	0.00	0.00
T801	0.00	0.99	0.01	T422	1.00	0.00	0.00
T802	0.00	1.00	0.00	T423	1.00	0.00	0.00
T803	1.00	0.00	0.00	T432	1.00	0.00	0.00
T810	1.00	0.00	0.00	T433	0.03	0.97	0.00
T811	0.82	0.18	0.00	T490	0.00	1.00	0.00

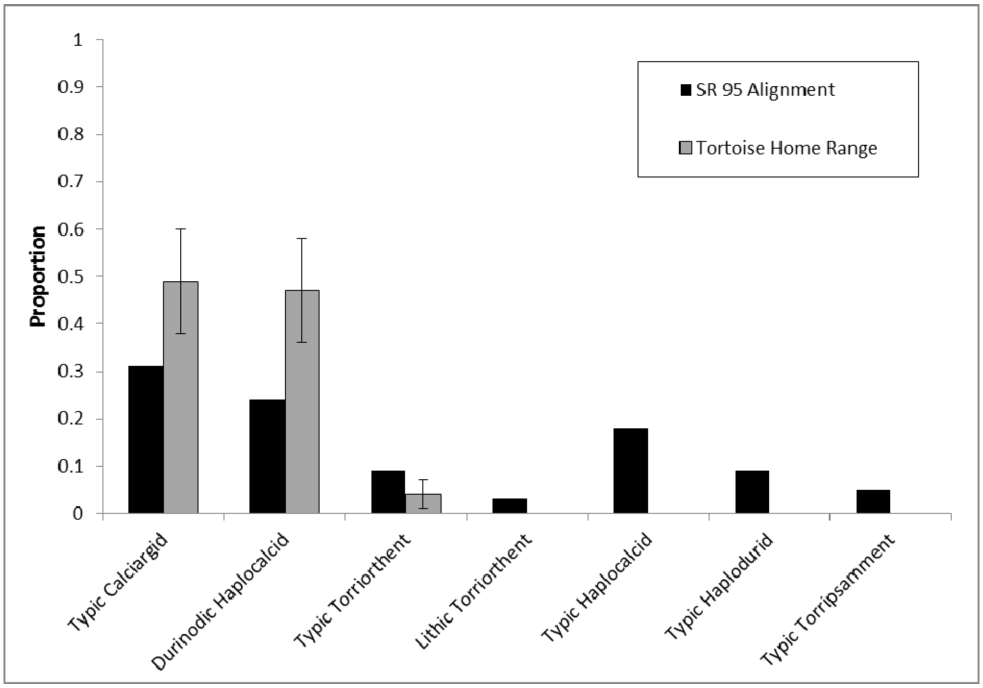


Figure 35. Comparison of Soil Subgroup Proportions in Tortoise Home Ranges and the SR 95 Realignment Buffer.

Table 19. Statistical Analysis of Proportional Soil Characteristics within Tortoise Home Ranges.

	SR 95 Realignment Buffer	Tortoise Home Range			
Soil	**Mean**	**Mean**	**SE[a]**	**Z**	***P***
Typic Calciargid	0.31	0.49	0.11	1.63	0.202
Durinodic Haplocalcid	0.24	0.47	0.11	1.30	0.254
Typic Torriorthent	0.09	0.04	0.03	0.20	0.655
Lithic Torriorthent	0.03	0	N/A	0.41	0.524
Typic Haplocalcid	0.18	0	N/A	0.25	0.617
Typic Haplodurid	0.09	0	N/A	0.41	0.524
Typic Torripsamment	0.05	0	N/A	0.25	0.617

[a] SE = standard error.

5.4 DISCUSSION

Desert tortoises currently occupy habitat within the proposed SR 95 realignment route. Nearly 50 percent of the tortoises captured in 2008 and 2009 were found within a buffer zone that encompassed the alternative highway routes currently under consideration by ADOT (ADOT 2010). The proximity of tortoise home ranges to the final alignment will determine the level of the highway's impact (Nicholson 1979; Karl 1989; von Seckendorff Hoff and Marlow 2002; Boarman and Sazaki 2006). The extent of the resulting road-effect zone, which is thought to be largely influenced by traffic volume (von Seckendorff Hoff and Marlow 2002), could be substantial given the projected traffic levels for the new highway (ADOT 2010). A conservative estimate, taken from the research on US 93, would predict a road-effect zone extending a minimum of 0.22 mi (0.35 km) from the highway's physical footprint. However, others have estimated road-effect zones greater than 2.5 mi (4.0 km) (von Seckendorff Hoff and Marlow 2002).

BBMM home-range estimates for the SR 95 study area were similar to estimated home ranges from other studies in the Mojave and Sonoran deserts using MCP estimation (Barrett 1990; O'Connor et al. 1994; Duda et al. 2002; Riedle et al. 2008; Harless et al. 2009). However, an added advantage of using the BBMM method for estimating home ranges was the ability to identify core areas within tortoise home ranges that were based on probabilities of space use rather than more subjective approaches, such as reduced MCP estimation (i.e., 50 percent MCP; Harless et al. 2009). While previous research has shown that kernel density estimators for estimating animal home ranges (Worton 1989) produce similar results to BBMM estimators, certain assumptions inherent in the kernel approach suggest that BBMM methods are more appropriate when serially correlated movement data derived from GPS tracking are used to define home ranges (Horne et al. 2007). GPS tracking applications are just beginning to be available for desert tortoise studies. The current study demonstrated the utility of tracking applications in identifying fine-scale movement patterns that are useful for evaluating habitat use and identifying management considerations related to the impacts of roads.

The data suggest that existing roads within the study area are limiting desert tortoise movement, thereby impacting landscape permeability. Desert tortoise movements across gravel roads within their home range were infrequent, and examination of desert tortoise locations suggested that roads served as de facto boundaries for tortoise home ranges. The barrier effect of roads has been well documented for desert tortoises (Berry 1986a, 1986b; Boarman et al. 1993; von Seckendorff Hoff and Marlow 2002; Boarman and Sazaki 2006). However, some studies have found that on unpaved roads with limited vehicle access and low traffic volume, tortoise activity occurs closer to roads than expected (Lovich and Daniels 2000; Grandmaison et al. 2010). In fact, some studies have documented tortoises using roads as travel pathways (Grandmaison et al. 2010), which may put them at risk of direct mortality or illegal collection as access to these roads is improved and traffic volume increases. Depending on traffic control along the final SR 95 alignment (i.e., location of traffic interchanges and connectivity to adjacent gravel roads), the barrier effect of existing roads may increase further.

Seven soil subgroups are present within the proposed SR 95 realignment route. However, the study found that tortoise home ranges were within only three soil subgroups. Analysis of soil subgroups at the level of tortoise home ranges corroborated, in part, the results of the soil modeling within the Black Mountains ecosystem.

Typic Calciargid and Durinodic Haplocalcid soil subgroups were dominant soil components within home ranges. These soil subgroups are both within the Aridisol soil order, which is characterized by soils with low amounts of organic matter and well-developed subsurface soil horizons, some of which contain calcium carbonate

(Soil Survey Staff 1975). When calcium carbonate accumulates and cements soil particles together, it forms a hardened calcareous deposit often referred to as the caliche layer. When caliche is exposed by erosional processes, such as wind or the flow of water, desert tortoises are able to take advantage of the stability of the caliche layer and create deep, permanent shelters beneath it (Germano et al. 1994; Riedle et al. 2008).

Typic Torriorthent was the third soil subgroup found within tortoise home ranges. These soils reflected the sandy substrate found within large desert washes within, and adjacent to, tortoise home ranges. Washes are an important component of desert tortoise habitat because they provide access to forage and shelter sites and are used as travel routes (Barrett 1990; Jennings 1997; Riedle et al. 2008). Washes provide access to friable caliche soils as the erosional processes of flowing water cut through adjacent Aridisol soils. Subsequently, the exposed horizons in Aridisol soils allow for the construction of permanent shelter sites.

5.5 CONCLUSIONS

The proposed alignments for the new SR 95 route along the western bajadas of the Black Mountains will impact tortoises that occupy habitat within the final route's physical footprint. In addition, the final alignment has a high likelihood of creating a significant barrier to tortoise movements unless effective mitigation strategies are incorporated into the final highway design. Efforts should be made to minimize an alignment route through Typic Calciargid and Durinodic Haplocalcid soil subgroups (Figure 36). If unavoidable, crossing structures and exclusion fencing should be placed where the roadway intersects washes within these subgroups to facilitate movements underneath the highway. Access to the existing network of gravel roads also should be considered in the final highway design. Limited access (i.e., few traffic interchanges) to gravel roads within Typic Calciargid and Durinodic Haplocalcid soils should be evaluated, and where possible, traffic patterns should be directed to areas where impacts on important habitat features could be minimized.

Finally, the research team recommends that monitoring be conducted before and after construction to identify changes in the road-effect zone in order to evaluate the overall impact on the local desert tortoise population. This monitoring should commence upon selection of the final alignment route with the extent of the road-effect zone serving as the metric by which successful mitigation is evaluated. Successful mitigation should minimize road mortality and maintain existing levels of desert tortoise occupancy in habitat adjacent to the roadway. If the road-effect zone is not minimized, mitigation structures for maintaining landscape permeability for desert tortoises will ultimately fail because unoccupied habitat adjacent to the highway will limit the ability of tortoises to encounter underpass structures and successfully cross the highway.

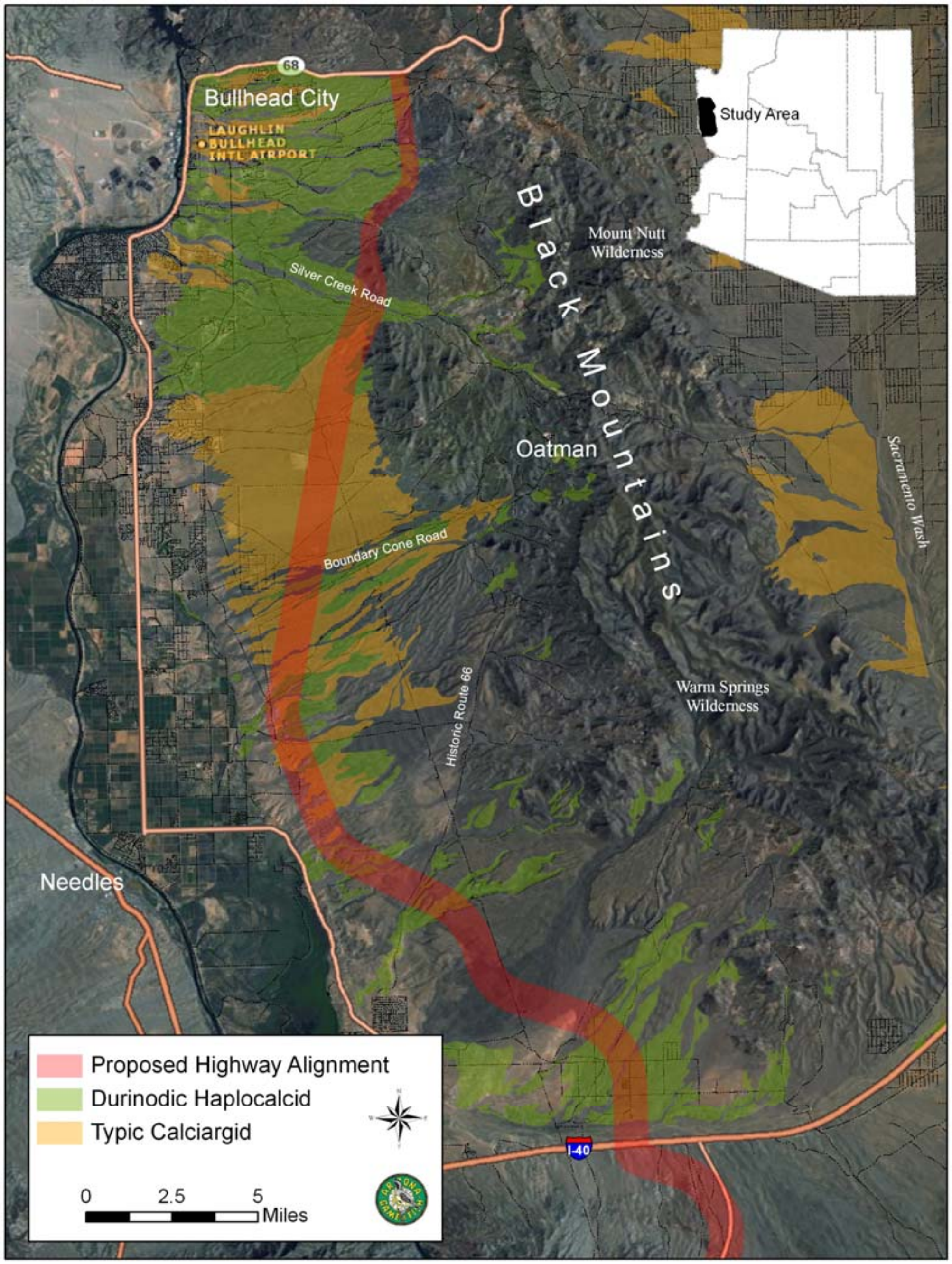


Figure 36. Juxtaposition of the Proposed SR 95 Realignment Route and Soil Subgroups Identified as Important for Desert Tortoise Habitat.

6.0 RESEARCH SYNTHESIS

6.1 MITIGATION FENCING

6.1.1 Prioritizing Maintenance, Repairs, and Modifications to Mitigation on US 93

The study of the ongoing mitigation measures along US 93 indicates that repairs and modifications to existing tortoise exclusion fencing should be focused between MPs 150 and 153. A secondary priority is the stretch of highway between MPs 146.5 and 150, where the study documented tortoise activity adjacent to the highway. Likewise, annual maintenance should be conducted between MPs 146.5 and 153 to reduce the probability of road-related tortoise mortality. To be effective, the annual maintenance should be timed to coincide with the summer monsoon so that damage to the fencing caused by erosion and siltation can be repaired quickly.

6.1.2 Modifications for Increasing the Effectiveness of Existing Mitigation on US 93

The surveyors consistently found fencing failures where the fence was installed across or at the edge of desert washes (Figure 37). The team recommends that fencing be rerouted so it does not cross desert washes, thereby reducing the likelihood of fencing failure. Instead, fencing should be placed outside the washes, even if this means that fencing cannot be directly tied into culvert wing walls. In fact, the connection between the fencing and wing walls was often identified as the location of mitigation failure (Figure 38). Installing effective fencing is more important than maintaining a direct connection between fencing and culvert wing walls. Direct connection is preferable when possible, but not at the expense of effective mitigation. Where a direct connection to culvert wing walls is inhibited by hydrology or topography, the fencing should be placed above the culvert to maintain continuity (Figure 39). Secondary directional fencing segments could be tied into the wing walls, with the expectation that they will need periodic repair or replacement.

Another consideration for the placement of fencing is slope. Fencing installed on the sides of roadbeds is susceptible to siltation damage where water flows off the roadway and down the slope into the adjacent habitat. Moving the barrier fencing to the top of the slope where the velocity of flowing water is lower should reduce erosion damage. For example, a section of US 93 south of the study area (i.e., south of MP 156) has tortoise exclusion fencing installed just off the pavement outside the guardrail (Figure 40). This setup should increase the longevity of the fencing and reduce maintenance costs due to erosion and siltation damage.

Figure 37. Example of Desert Wash Damage to Fencing.

(*note*: fencing disappeared over time)

Figure 38. Example of Erosion Damage to Connection between Fencing and Culvert Wing Wall.

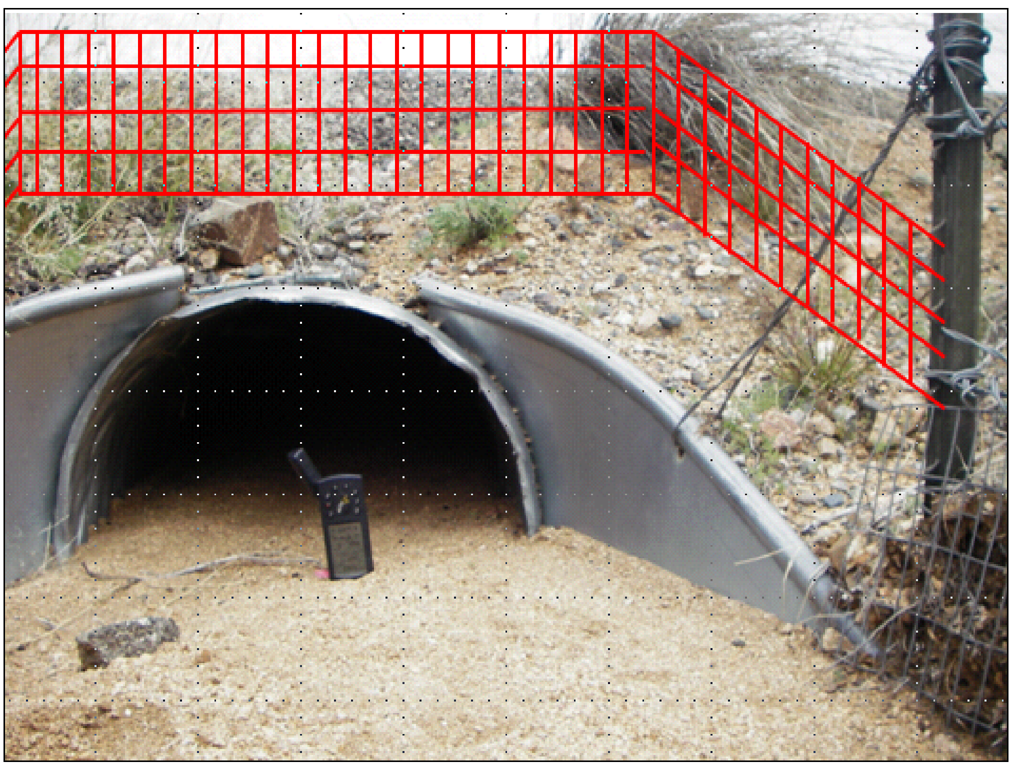


Figure 39. Example of Alternative Fencing Placement Where Hydrology and Topography Are Likely to Damage Fencing (see Figure 38).

Figure 40. Desert Tortoise Exclusion Fencing Installed Directly Adjacent to Guardrail on US 93. (Source: J. Alpert, ADOT)

6.1.3 Gates and Access Roads

Two additional challenges are associated with the implementation of effective mitigation fencing—gates and cattle guards. The gap between the bottom of a gate and the ground should be no greater than 0.5 inch. Larger gaps will allow tortoise hatchlings access to the road surface. In addition, the footer below the gate should be constructed of concrete. Wooden footers will warp or degrade over time and may create large gaps that could be breached by tortoises.

On US 93, and in other areas where mitigation fencing has been installed, access roads connect with the main highway and require that fencing be opened to allow unobstructed travel by vehicles. Cattle guards with escape ramps (to prevent tortoises falling through the bars and becoming trapped) or other guard structures (Figure 41) can be installed to inhibit tortoise movement onto the main highway through the fence openings. Mitigation fencing should terminate at the guard structure so that tortoises cannot bypass the structures to access the road. In some cases, it might be preferable to install fencing along access roads to funnel tortoises to crossing structures that allow tortoises to move across the access road while inhibiting movement onto the main highway.

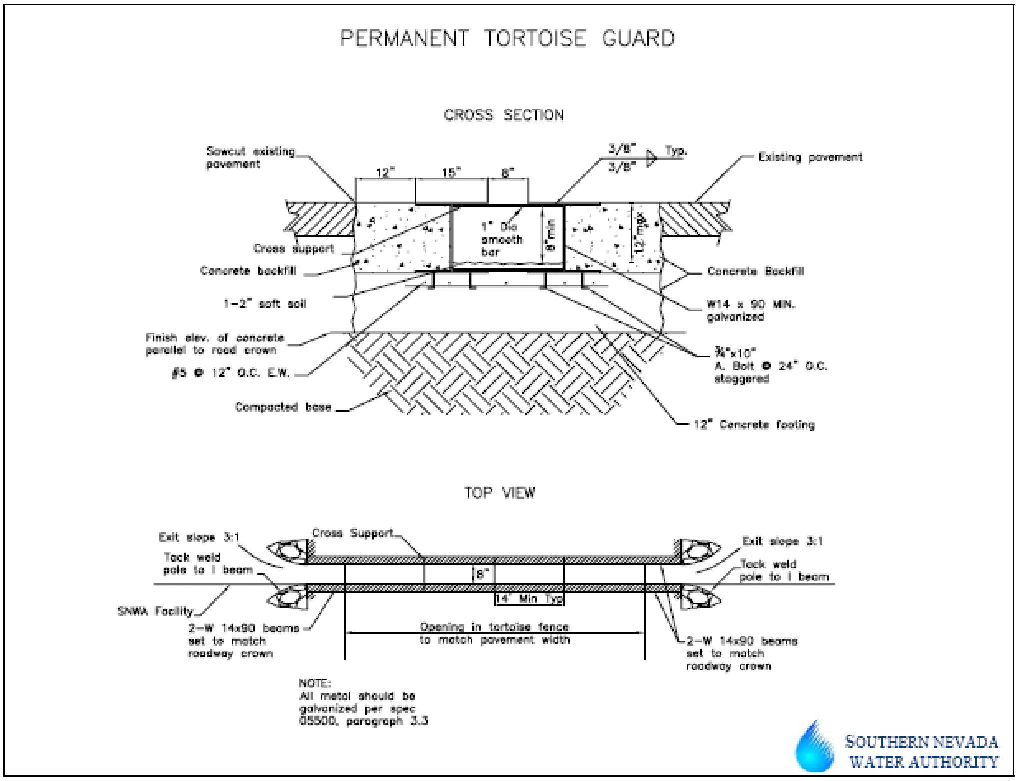


Figure 41. Tortoise-Guard Specifications.
(Source: Southern Nevada Water Authority)

6.1.4 General Tortoise-Fence Installation Considerations

While the Sonoran Desert's varied terrain makes installing tortoise barrier fencing difficult, efforts should be made to follow the fencing guidelines established by the USFWS (Appendix A). The assessment of the existing barrier fencing along US 93 identified numerous locations where fencing was not buried and not anchored according to the USFWS's barrier-fencing installation recommendations:

> In situations where burying the fence is not practical because of rocky or undigable substrate, the fence material should be bent at a 90-degree angle to produce a lower section approximately 14 inches wide which will be placed parallel to, and in direct contact with, the ground surface; the remaining 22-inch wide upper section should be placed vertically against the existing fence, perpendicular to the ground and attached to the existing fence with hog rings at 12 to18-inch intervals. The lower section in contact with the ground should be placed within the enclosure in the direction of potential desert tortoise encounters and level with the ground surface. Soil and cobble (approximately 2 to 4 inches in diameter; can use larger rocks where soil is shallow) should be placed on top of all of the lower section of fence material on the ground to a height 4 inches, leaving a minimum of 18 inches of open space between the top of the cobble surface and the top of the vertical portion of the desert tortoise-exclusion fence.

The study found that simply burying the folded barrier fencing with soil and cobble was not sufficient for maintaining the barrier effectiveness. In many cases, the soil and cobble did not maintain an effective anchor. Alternatively, using larger boulders could provide tortoises with unintended "steps" for climbing over the fence. Rather, the research team recommends that bolts be driven through the fencing into the ground to ensure that the folded fencing remains flush with the ground. This technique was applied in some locations along the US 93 study area with mixed results. The main factor leading to its effectiveness was fencing placement in areas where siltation and erosion were not sufficient to pull the fencing and anchors from the ground. Appropriate fencing placement would likely increase the effectiveness of anchoring folded barrier fencing.

Additional recommendations from the AGFD for mitigating the impacts of construction activities on desert tortoises are available online at http://www.azgfd.gov/pdfs/w_c/tortoise/MitigationMeasures.pdf.

6.2 CROSSING STRUCTURES

Engineering solutions to the issue of perched culvert entrances (Figure 42) may include structures that reduce water velocity at the culvert outflow or tortoise ramps that maintain a stable path for tortoise movement in the event of undercutting (Figures 43 and 44). In California, Caltrans has annually backfilled the outflow entrances to maintain access by desert tortoises (B. Boarman, Conservation Science Research and Consulting, personal communication). This approach, while potentially effective, does not create a lasting solution given the challenges for funding highway maintenance in Arizona. A preferred solution is the installation of concrete tortoise ramps that will provide reliable access and require less maintenance. However, it should be noted that none of the existing tortoise ramps in Arizona have been monitored for effectiveness. Therefore, the research team recommends that the installation of tortoise ramps should be conducted in an experimental manner with sufficient monitoring to determine their utility in facilitating tortoise movement. Before the realignment of SR 95, monitoring and research could be conducted on existing roadways where tortoise ramps have been installed (e.g., US 93 near Hoover Dam, US 60). Other research questions regarding the optimal underpass design for facilitating tortoise passage could include the importance of light wells and short underpasses that open into the median before connecting to a second underpass under the opposite lanes of traffic.

Figure 42. Tortoise Use of Underpass Structure Inhibited by Perched Culvert Entrance. (Source: S. Blair, U.S. Forest Service)

Figure 43. Desert Tortoise Path Installed along US 93 near the Hoover Dam.

Figure 44. Desert Tortoise Path Installed along US 60 near Gonzales Pass. (Source: S. Blair, U.S. Forest Service)

6.3 MONITORING MITIGATION EFFECTIVENESS

6.3.1 Identify the Population-Level Benefits of Road Mitigation for Desert Tortoises

While fencing and culvert modifications are likely to yield positive results relative to the survival of individual desert tortoises that occupy home ranges adjacent to the roadway, population-level benefits of desert tortoise fencing and crossing structures have yet to be demonstrated. The research team recommends that a systematic survey be implemented on US 93 and SR 95 to provide baseline data on the distribution of desert tortoises relative to transportation infrastructure before implementing or, in the case of US 93, repairing desert tortoise mitigation fencing and crossing structures. These surveys should be repeated after the installation or repair of desert tortoise mitigation fencing to identify changes in the extent of the road-effect zone over time (von Seckendorff Hoff and Marlow 2002) and to provide an objective metric for evaluating the population-level benefits of the mitigation efforts. Likewise, as repairs and modifications to fencing and crossing structures are made along US 93, continued efforts should be made to determine whether tortoises will use the crossing structures. Design and construction phases for new or existing highway projects should explicitly include tortoise monitoring to obtain additional datasets by which to evaluate mitigation for roadway impacts.

6.3.2 Monitor the Effectiveness of Tortoise Paths and Other Mitigation Structures

Evaluating crossing-structure use by tortoises is key to developing reliable mitigation recommendations for future highway construction and enhancement. Effectiveness monitoring both improves the understanding of how various treatments influence parameters of interest and provides insight regarding treatment characteristics that could be manipulated for improving effectiveness. For example, crossing-structure monitoring could identify supplemental mitigation measures (fencing or culvert design modifications) to increase the use of the structures or to reduce the frequency of desert tortoise roadkill. Determining whether additional modifications are needed to achieve the goals set forth by the mitigation objectives can only be achieved by monitoring crossing-structure use. As such, monitoring is a critical component in the development of successful crossing structures, especially in Arizona where management decisions regarding roadway mitigation have been based on limited monitoring.

6.4 PROPOSED SR 95 ALIGNMENT

These recommendations have been developed in the context of desert tortoise management in the Black Mountains ecosystem and do not include evaluation of other important resources or land management designations found within the region. Similarly, these recommendations do not include other existing or predicted impacts (e.g., development) to the landscape encompassed within the proposed transportation development area.

6.4.1 Considerations for the Alignment of SR 95

The study analyses indicated that the realignment of SR 95 along the western bajadas of the Black Mountains will impact desert tortoise habitat. When considering alignment alternatives, the results of the study can be used to identify relative impacts based on PAO estimates for soil subgroups. Tortoise occupancy was highest in Durinodic Haplocalcids, Typic Calciargids, Typic Haplocalcids, and Typic Haplodurids. Furthermore, tortoise home ranges were found within Durinodic Haplocalcids, Typic Calciargids, and Typic Torriorthents. Alignment routes that intersect these soil types will have the greatest impact on desert tortoises in the Black Mountains ecosystem.

The following recommendations are based on occupancy analyses and soil subgroup components within desert tortoise home ranges:

- Alternatives analyses should identify the extent of the highway's physical footprint within soil subgroups and include the impact on soil subgroups with high tortoise occupancy as a decision factor for the final alignment (see Section 6.4.2).

- The final alignment should minimize impacts on Durinodic Haplocalcid and Typic Calciargid soils, given their prevalence in tortoise home ranges and their high levels of tortoise occupancy relative to other soil subgroups within the proposed alignment zone.
- The final alignment should be moved as far west as possible to reduce fragmentation of suitable desert tortoise habitat.
- Typic Torriorthent soils, also found within tortoise home ranges, are located in large washes that cross the proposed alignment zone. These areas should be identified for large underpass structures to facilitate movement by desert tortoises and other wildlife.
- Resources for highway mitigation should be focused within Durinodic Haplocalcid and Typic Calciargid soils. Mitigation should include installation of fencing and underpass structures specifically designed to facilitate desert tortoise movement where the alignment crosses desert washes and upland areas.
- Access to the existing network of gravel roads also should be considered in the final highway design. Limited access (i.e., few traffic interchanges) to gravel roads within Typic Calciargid and Durinodic Haplocalcid soils should be considered, and where possible, traffic patterns should be directed to areas where impacts on important habitat features would be minimal. Increased access to adjacent habitat may inadvertently increase the probability of desert tortoise roadkill on gravel roads and could result in elevated levels of tortoise collection.
- Where crossing structures serve the dual purpose of directing water flow and providing crossing opportunities, the downflow end should be treated with erosion abatement structures or tortoise ramps that maintain structure functionality for desert tortoise movement in the event that undercutting results in perched entrances. If riprap is installed to reduce undercutting, interstitial spaces should be grouted to provide tortoises with a pathway to and from the underpass structure.

6.4.2 Route Alternatives Analysis

The research team performed a GIS evaluation of each alignment route provided by the predesign team Jacobs Engineering, Inc., by overlaying the alternative routes on regional soil survey data collected by the NCSS. Each alignment was intersected with NCSS data depicting soil subgroups for which PAO estimates were obtained (see Figure 31) and calculations were made regarding the linear distance over which each alignment bisected those soil subgroups (Table 20).

The researchers then weighted the linear impact of each route by the PAO estimates obtained in the analysis to reflect tortoise habitat relationships within soil subgroups. In this sense, PAO served as an index of habitat value for soil subgroups. This weighting system accounted for the variation in tortoise occupancy among soil subgroups under the assumption that observed variation reflected differences in habitat quality for desert tortoises. In other words, impacts on soil subgroups with high PAO estimates were less desirable than impacts on subgroups with low PAO estimates. The team used the resulting weighted distance, while not an absolute measure of the impact of the alignment, to compare alignments regarding their impact on desert tortoise habitat in the project area. The weighted distances served as an index of the relative measure of the impact for each alignment (Table 21).

This analysis indicated that Alternatives B-2a, C-2a, and A-3 would have the lowest impact on desert tortoises within the SR 95 realignment zone. However, it should be noted that this analysis only represents the direct impacts on tortoise habitat (i.e., soils) within the physical footprint. It does not include indirect impacts on adjacent habitat represented by the road-effect zone.

Table 20. Linear Distance (miles) of Soil Subgroups Impacted by Each Alternative Alignment Route for the Proposed SR 95 Realignment between I-40 and SR 68, Mohave County, Arizona.

	Alternative Alignment Route									
Soil Subgroup	**A-3**	**B-2**	**B-2a**	**C-2**	**C-2a**	**C-4**	**D-2**	**D-4**	**E-2**	**E-3**
Durinodic Haplocalcid	2.57	4.01	0.70	1.93	1.05	0.75	1.00	0.68	3.46	2.84
Typic Calciargid	0.00	0.00	0.00	5.27	0.00	3.19	7.05	7.63	0.00	0.00
Lithic Torriorthent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	2.72
Typic Haplodurid	0.00	2.70	1.26	0.00	0.00	0.00	0.00	0.00	0.45	0.21
Typic Haplocalcid	0.20	3.10	0.11	1.55	1.76	0.00	0.00	0.00	0.00	0.00
Typic Torriorthent	0.63	1.31	0.00	1.16	0.20	0.82	0.00	0.00	0.72	0.69
Typic Haplocambid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.40	11.12	2.06	9.91	3.01	4.77	8.05	8.31	5.64	6.47

Table 21. Weighted Impact for Each Alternative Alignment Route for the Proposed SR 95 Realignment between I-40 and SR 68, Mohave County, Arizona.

	Alternative Alignment Routes									
Soil Subgroup	**A-3**	**B-2**	**B-2a**	**C-2**	**C-2a**	**C-4**	**D-2**	**D-4**	**E-2**	**E-3**
Durinodic Haplocalcid	2.46	3.84	0.67	1.85	1.00	0.72	0.95	0.66	3.31	2.72
Typic Calciargid	0.00	0.00	0.00	4.46	0.00	2.70	5.97	6.45	0.00	0.00
Lithic Torriorthent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	1.44
Typic Haplodurid	0.00	1.02	0.48	0.00	0.00	0.00	0.00	0.00	0.17	0.08
Typic Haplocalcid	0.14	2.14	0.07	1.07	1.22	0.00	0.00	0.00	0.00	0.00
Typic Torriorthent	0.03	0.06	0.00	0.06	0.01	0.04	0.00	0.00	0.03	0.03
Typic Haplocambid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weighted Impact[a]	2.62	7.06	1.22	7.43	2.23	3.46	6.92	7.11	4.05	4.27

[a] The weighted impact is a relative measure of the impact of each alignment on desert tortoise habitat.

6.4.3 Estimated Road-Effect Zone

Traditionally, alternatives selection as it relates to wildlife resources has focused on habitat lost within the physical footprint of the road. However, a road's true impact extends beyond the right-of-way. Roads have been shown to exert a road-effect zone up to (and beyond) 2.5 mi (4.0 km) from highway rights-of-way (von Seckendorff Hoff and Marlow 2002). Seemingly suitable tortoise habitat remains unoccupied or occupied at lower rates in the road-effect zone than in more distant habitat (Nicholson 1979; Karl 1989; von Seckendorff Hoff and Marlow 2002; Boarman and Sazaki 2006). Traffic volume is the main influence on the magnitude of the impact. As traffic levels increase, so too does the distance to which the road-effect zone extends into the surrounding landscape (von Seckendorff Hoff and Marlow 2002).

Given the estimated traffic volume for all alignment routes (as presented in the Alternatives Selection Report [ADOT 2010]) of approximately 10,000 vehicles per day, the road-effect zone for desert tortoises will likely be substantial, especially if effective mitigation is not incorporated into the design of the new highway. Based on a road-effect zone of 0.22 mi (0.35 km) estimated from the evaluation of tortoise space use on US 93, the research team estimated approximately 4208 ha (10,398 ac) of habitat will be impacted by the new SR 95 route. This is a conservative estimate, and the actual impact could be larger.

6.4.4 Monitoring Impacts of SR 95 and Mitigation Efforts

Regardless of the alternative selected for the SR 95 realignment, the research team's recommendation remains the same—ADOT and AGFD should collaborate in monitoring the new alignment's impact on desert tortoises (i.e., demographics, movement patterns, and roadkill mortality) and tortoise habitat (i.e., extent of the road-effect zone). The existing dataset on desert tortoise distribution and habitat associations in the Black Mountains ecosystem can be used to guide placement of the alignment, mitigation fencing, and underpass structures. However, evaluating the impacts will entail a well-designed monitoring program that places special emphasis on evaluating the extent of the highway's road-effect zone. This monitoring should commence upon selection of the final alignment route, with the extent of the road-effect zone serving as the metric by which successful mitigation is evaluated. Successful mitigation should minimize road mortality and maintain existing levels of desert tortoise occupancy in habitat adjacent to the roadway. If the road-effect zone is not minimized, mitigation structures for maintaining landscape permeability for desert tortoises will ultimately fail because unoccupied habitat adjacent to the highway will limit the ability of tortoises to encounter underpass structures and successfully cross the highway.

7.0 RECOMMENDATIONS

Prioritizing Maintenance, Repairs, and Modifications to Mitigation on US 93

- Repairs and modifications to existing tortoise exclusion fencing should be focused between MPs 146.5 and 153.
- Annual maintenance should be conducted between MPs 146.5 and 153 to reduce the probability of road-related tortoise mortality.
- Maintenance should be timed to coincide with the summer monsoon so that damage to the fencing due to erosion and siltation can be repaired quickly.

Modifications for Increasing the Effectiveness of Existing Mitigation on US 93

- To reduce the likelihood of fencing failure, tortoise fencing should be rerouted so that it does not cross desert washes.
- Where a direct connection between tortoise fencing and culvert wing walls is inhibited by hydrology or topography, the fencing should be placed above the culvert to maintain continuity.

Gates and Access Roads

- The gap between the bottom of a gate and the ground should be no greater than 0.5 inch.
- The footer below the gate should be constructed of concrete. Wooden footers will warp or degrade over time and may create large gaps that could be breached by tortoises.
- Mitigation fencing should terminate at cattle-guard structures so that tortoises cannot bypass the structures to access the road. In some cases, it might be preferable to install fencing along access roads to funnel tortoises to crossing structures that allow tortoises to move across the access road while inhibiting movement onto the main highway.

General Tortoise-Fence Installation Considerations

- Efforts should be made to follow the guidelines established by the USFWS (Appendix A).
- Folding the tortoise fencing in areas where burying the fencing is not possible should be minimized by rerouting fencing to areas where it can be buried.
- In areas where folding fencing is unavoidable, bolts should be driven through the fencing and into the ground to ensure that the folded fencing remains flush with the ground.

Crossing Structures

- Engineering solutions to the issue of perched culvert entrances may include structures that reduce water velocity at the culvert outflow or tortoise ramps that maintain a stable path for tortoise movement in the event of undercutting.
- Concrete tortoise ramps may provide reliable access and require less maintenance than other options. However, the research team recommends that the installation of tortoise ramps should be conducted in an experimental manner with sufficient monitoring to determine their utility in facilitating tortoise movement.

Identifying the Population-Level Benefits of Road Mitigation for Desert Tortoises

- The research team recommends implementing a systematic survey on US 93 and SR 95 to provide baseline data on the distribution of desert tortoises. This would be relative to transportation infrastructure before implementing or, in the case of US 93, repairing desert tortoise mitigation fencing and crossing structures.
- Surveys should be repeated after the installation or repair of desert tortoise mitigation fencing to identify changes in the extent of the road-effect zone over time and to provide an objective metric for evaluating the population-level benefits of the mitigation efforts.
- Design and construction phases for new or existing highway projects should explicitly include tortoise monitoring to obtain additional datasets by which to evaluate mitigation for roadway impacts.

Considerations for the Alignment of SR 95

- Alternatives analyses should identify the extent of the highway's physical footprint within soil subgroups and include the impact on soil subgroups with high tortoise occupancy as a decision factor for the final alignment (see Section 6.4.2).
- The final alignment should minimize impacts on Durinodic Haplocalcid and Typic Calciargid soils, given their prevalence in tortoise home ranges and their high levels of tortoise occupancy relative to other soil subgroups within the proposed alignment zone.
- The final alignment should be moved as far west as possible to reduce fragmentation of suitable desert tortoise habitat.
- Typic Torriorthent soils, also found within tortoise home ranges, are located in large washes that cross the proposed alignment zone. These areas should be identified for large underpass structures to facilitate movement by desert tortoises and other wildlife.

- Resources for highway mitigation should be focused within Durinodic Haplocalcid and Typic Calciargid soils. Mitigation should include installation of fencing and underpass structures specifically designed to facilitate desert tortoise movement where the alignment crosses desert washes and upland areas.
- Access to the existing network of gravel roads also should be considered in the final highway design. Limited access (i.e., few traffic interchanges) to gravel roads within Typic Calciargid and Durinodic Haplocalcid soils should be considered, and where possible, traffic patterns should be directed to areas where impacts on important habitat features would be minimal. Increased access to adjacent habitat may inadvertently increase the probability of desert tortoise roadkill on gravel roads.
- Where crossing structures serve the dual purpose of directing water flow and providing crossing opportunities, the downflow end should be treated with erosion abatement structures or tortoise ramps. These will maintain structure functionality for desert tortoise movement in the event that undercutting results in perched entrances. If riprap is installed to reduce undercutting, interstitial spaces should be grouted to provide tortoises with a pathway to and from the underpass structure.

Monitoring Impacts of SR 95 and Mitigation Efforts

- Regardless of the alternative selected for the SR 95 realignment, ADOT and AGFD should collaborate in monitoring the new alignment's impact on desert tortoises (i.e., demographics, movement patterns, and roadkill mortality) and tortoise habitat (i.e., extent of the road-effect zone).
- Monitoring should commence upon selection of the final alignment route, with the extent of the road-effect zone serving as the metric by which successful mitigation is evaluated.

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APPENDIX A.
U.S. FISH AND WILDLIFE SERVICE
DESERT TORTOISE FENCING SPECIFICATIONS

RECOMMENDED SPECIFICATIONS FOR DESERT TORTOISE EXCLUSION FENCING
September 2005

These specifications were developed to standardize fence materials and construction procedures to confine desert tortoises or exclude them from harmful situations, primarily roads and highways. Prior to commencing any field work, all field workers should comply with all stipulations and measures developed by the jurisdictional land manager, the U.S. Fish and Wildlife Service, and state wildlife resource agency for conducting such activities in desert tortoise habitat, which will include, at a minimum, completing a desert tortoise education program.

FENCE CONSTRUCTION

Materials
Fences should be constructed with durable materials (*i.e.,* 16 gauge or heavier) suitable to resist desert environments, alkaline and acidic soils, wind, and erosion. Fence material should consist of 1-inch horizontal by 2-inch vertical, galvanized welded wire, 36 inches in width. Other materials include: Hog rings, steel T-posts, and smooth or barbed livestock wire. Hog rings should be used to attach the fence material to existing strand fence. Steel T-posts (5 to 6-foot) are used for new fence construction. If a fence is constructed within the range of bighorn sheep, 6-foot T-posts should be used (see New Fence Construction below). Standard smooth livestock wire fencing should be used for new fence construction, on which desert tortoise-exclusion fencing would be attached.

Retrofitting Existing Livestock Fence

Option 1 (see enclosed drawing). Fence material should be buried a minimum of 12 inches below the ground surface, leaving 22-24 inches above ground. A trench should be dug or a cut made with a heavy equipment blade to allow 12 inches of fence to be buried below the natural level of the ground. The top end of the desert tortoise fence should be secured to the livestock wire with hog rings at 12- to 18-inch intervals. Distances between T-posts should not exceed 10 ft, unless the desert tortoise fence is being attached to an existing right-of-way fence that has larger interspaces between posts. The fence must be perpendicular to the ground surface, or slightly angled away from the road, toward the side encountered by desert tortoises. After the fence has been installed and secured to the top wire and T-posts, excavated soil will be replaced and compacted to minimize soil erosion.

Option 2 (see enclosed drawing). In situations where burying the fence is not practical because of rocky or undigable substrate, the fence material should be bent at a 90-degree angle to produce a lower section approximately 14 inches wide which will be placed parallel to, and in direct contact with, the ground surface; the remaining 22-inch wide upper section should be placed vertically against the existing fence, perpendicular to the ground and attached to the existing fence with hog rings at 12- to18-inch intervals. The lower section in contact with the ground should be placed within the enclosure in the direction of potential desert tortoise encounters and level with the ground surface. Soil and cobble (approximately 2 to 4 inches in diameter; can use larger rocks where soil is shallow) should be placed on top of all of the lower section of fence material on the ground to a height of 4 inches, leaving a minimum of 18 inches of open space between the top of the cobble surface and the top of the vertical portion of the desert tortoise-exclusion fence. Care should be taken to ensure that the fence material parallel to the ground surface is adequately covered and is flush with the ground surface.

New Fence Construction

Options 1 or 2 should be followed except in areas that require special construction and engineering such as wash-out sections (*see below*). T-posts should be driven approximately 24 inches below the ground surface and spaced approximately 10 feet apart. Livestock wire should be stretched between the T-posts, 18 to 24 inches above the ground to match the top edge of the fence material; desert tortoise-exclusion fencing should be attached to this wire with hog rings placed at 12- to 18-inch intervals. Smooth (barb-less) livestock wire should be used except where grazing occurs.

If the fence is constructed within the range of bighorn sheep, two smooth-strand wires are required at the top of the T-post, approximately 4 inches apart, to make the wire(s) more visible to sheep. A 20- to 24-inch gap must exist between the top of the desert tortoise exclusion fence material and the lowest smooth-strand wire at the top of the T-post. The lower of the top two smooth-strand wires must be at least 43 inches above the ground surface (i.e., 72-inch T-posts: 24 inches below ground + 18 inches of desert tortoise exclusion fence above ground + 20- to 24- inch gap to lower top wire + 4 inches to upper top wire = 66 to 70 inches).

INSPECTION OF DESERT TORTOISE BARRIERS

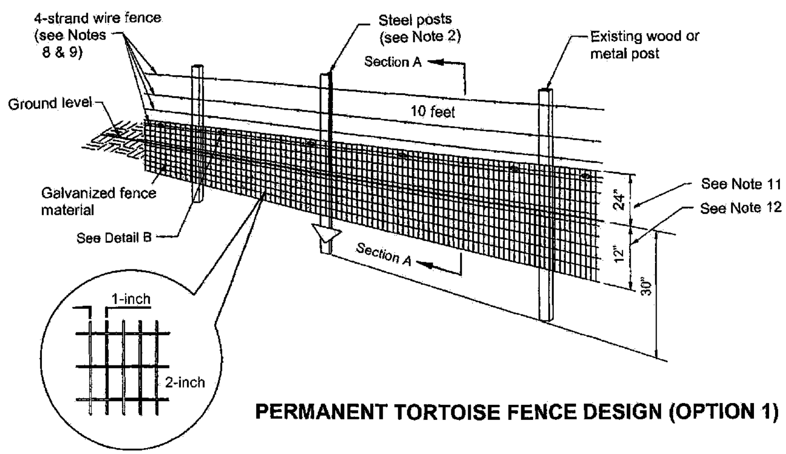
The risk level for a desert tortoise encountering a breach in the fence is greatest in the spring and fall, particularly around the time of precipitation including the period during which precipitation occurs and at least several days afterward. All desert tortoise fences and cattle guards should be inspected on a regular basis sufficient to maintain an effective barrier to tortoise movement. Inspections should be documented in writing and include any observations of entrapped animals; repairs needed, including bent T-posts, leaning or non-perpendicular fencing, cuts, breaks, and gaps; cattle guards without escape paths for tortoises or that need maintenance; tortoises and tortoise burrows, including carcasses; and recommendations for supplies and equipment needed to complete repairs and maintenance.

All fence and cattle guard inventories should be inspected at least twice per year. However, during the first two to three years all inspections will be conducted quarterly at a minimum, to identify and document breaches and problem areas such as washouts, vandalism, and cattle guards that fill in with soil or gravel. GPS coordinates and mileages from existing highway markers should be recorded in order to pinpoint problem locations and build a database of problem locations that may require more frequent checking. Following two to three years of initial inspection, subsequent inspections should focus on known problem areas which will be inspected more frequently than twice per year. In addition to semi-annual inspections, problem areas prone to washouts should be inspected following precipitation that produces potentially fence-damaging water flow. A database of problem areas will be established whereby checking fences in such areas can be done efficiently.

REPAIR AND MAINTENANCE OF DESERT TORTOISE BARRIERS

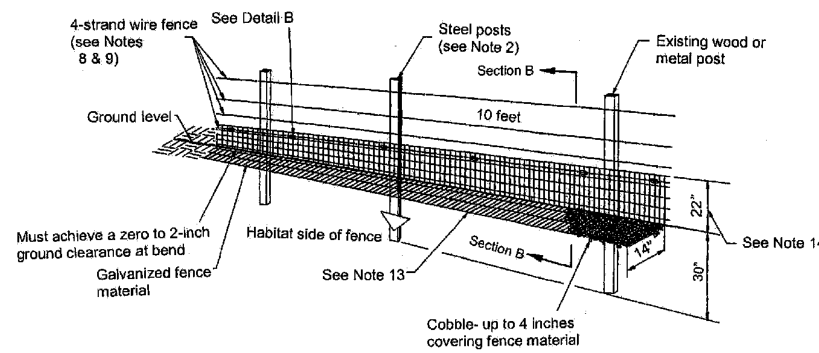
Repairs of fence washouts: (1) realign the fence out of the wash if possible to avoid the problem area, or (2) re-construct tortoise-proof fencing using techniques that will ensure that an effective desert tortoise barrier is established that will not require frequent repairs and maintenance. Gaps and breaks will require either: (a) repairs to the existing fence in place, with similar diameter and composition of original material, (b) replacement of the damaged section to the nearest T-post, with new fence material that meets original fence standards, (c) burying fence, and/or (d) restoring zero ground clearance by filling in gaps or holes under the fence and replacing cobble over fence constructed under Option 2. Tortoise-proof fencing should be constructed and maintained at cattle guards to ensure that a desert tortoise barrier exists at all times.

All fence damage should be repaired in a timely manner to ensure that tortoises do not travel through damaged sections. Similarly, cattle guards will be cleaned out of deposited material underneath them in a timely manner. In addition to periodic inspections, debris should be removed that accumulates along the fence. All cattle guards that serve as tortoise barriers should be installed and maintained to ensure that any tortoise that falls underneath has a path of escape without crossing the intended barrier.

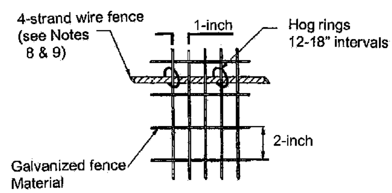


DETAIL A

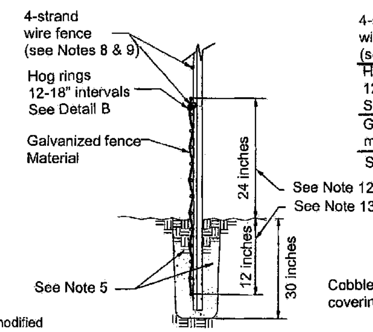
PERMANENT TORTOISE FENCE DESIGN (OPTION 1)



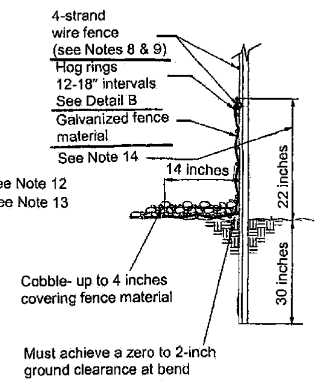
PERMANENT TORTOISE FENCE DESIGN (OPTION 2)



DETAIL B



SECTION A



SECTION B

GENERAL NOTES:

1. Use Option 2 when fence material cannot be placed 6 inches below existing ground level due to rock or caliche substrate
2. Install steel posts when span between existing fence posts exceed 10 feet.
3. Fence posts and materials shall conform with the standards approved by the U.S. Fish and Wildlife Service.
4. Fence material shall be attached to existing fence or wire using hog rings at 12 to 18-inch intervals.
5. Backfill trench with excavated material and compact.
6. Fence material shall be fastened to posts with 3 tie wires with a wire near the top, bottom, and center of the fence material.
7. Attach fence material to all gates. Clearance at base of gate should achieve zero ground clearance.
8. Substitute smooth wire for barbed wire if additional support wires are necessary.
9. The number and placement of support wires may be modified to allow sheep and deer to pass safely through.
10. Fence should tie into existing culverts and cattleguards when determined necessary to allow tortoise passage underneath roadways.
11. Option 1: height above ground level should be no less than 18 inches and no higher than 24 inches.
12. Option 1: depth of fence material below ground level should be no less than 6 inches.
13. Erosion at the edge of the fence material where the fence crosses washes may occur and require appropriate monitoring and repair.
14. Option 2: height above ground level should be no less than 22 inches.

APPENDIX B.
SUMMARY OF ALL ROADKILL DETECTED ON US 93 IN 2008 AND 2009

Table B.1. All Roadkill Detected on US 93 in 2008 and 2009.

Class	Scientific Name	Common Name	Class Subtype	2008 Total	2009 Total	Grand Total
Avian	*Amphispiza bilineata*	Black-throated sparrow	Avian	0	1	1
	Campylorhynchus brunneicapillus	Cactus wren	Avian	1	0	1
	Chordeiles acutipennis	Lesser nighthawk	Avian	0	1	1
	Corvus corax	Common raven	Avian	1	1	2
	Cynanthus latirostris	Broad-billed hummingbird	Avian	1	0	1
	Geococcyx californianus	Greater roadrunner	Avian	4	3	7
	Phalaenoptilus nuttallii	Common poorwill	Avian	0	2	2
	Pipilo chlorurus	Green-tailed towhee	Avian	2	0	2
	Polioptila spp.	Gnatcatcher	Avian	0	1	1
	Sturnella neglecta	Western meadowlark	Avian	0	1	1
	Toxostoma curvirostre	Curve-billed thrasher	Avian	0	1	1
	Zenaida macroura	Mourning dove	Avian	5	3	8
	Vermivora celata	Orange-crowned warbler	Avian	0	3	3
	Callipepla gambelii	Gambel's quail	Avian	3	1	4
		Unidentified avian	Avian	31	65	96
			Total Avian	48	83	131
Mammal	*Canis latrans*	Coyote	Carnivore	8	11	19
	Felis concolor	Mountain lion	Carnivore	1	0	1
	Urocyon cinereoargenteus	Common gray fox	Carnivore	5	9	14
	Odocoileus hemionus	Mule deer	Ungulate	7	3	10
	Tayassu tajacu	Javelina	Ungulate	1	5	6
		Unidentified large mammal	Large mammal	2	2	4
	Conepatus mesoleucus	Common hog-nosed skunk	Small mammal	1	0	1
	Lepus californicus	Black-tailed jackrabbit	Small mammal	23	10	33
	Mephitis mephitis	Striped skunk	Small mammal	2	1	3
	Spilogale gracilis	Spotted skunk	Small mammal	0	1	1
	Sylvilagus audubonii	Desert cottontail	Small mammal	32	27	59
	Ammospermophilus harrisii	Harris's antelope squirrel	Small mammal	0	1	1
	Dipodomys spp.	Kangaroo rat	Small mammal	21	31	52
	Neotoma spp.	Unidentified woodrat	Small mammal	59	48	107
	Peromyscus spp.	Unidentified mouse	Small mammal	17	50	67

Table B.1. All Roadkill Detected on US 93 in 2008 and 2009. (Continued)

Class	Scientific Name	Common Name	Class Subtype	2008 Total	2009 Total	Grand Total
	Spermophilus spp.	Ground squirrel	Small mammal	1	1	2
	Spermophilus variegatus	Rock squirrel	Small mammal	0	1	1
		Unidentified small mammal	Small mammal	567	654	1,221
	Eptesicus fuscus	Big brown bat	Bat	1	0	1
	Parastrellus hesperus	Canyon bat	Bat	3	0	3
	Tadarida brasiliensis	Mexican free-tailed bat	Bat	0	1	1
		Unidentified bat	Bat	9	3	12
		Unidentified mammal	Mammal	1	263	264
			Total Mammal	761	1122	1883
Tortoise	*Gopherus morafkai* (formerly, *G. agassizii)*	Morafka's desert tortoise	Tortoise	5	0	5
			Total Tortoise	5	0	5
Amphibian	*Bufo cognatus*	Great plains toad	Amphibian	0	1	1
	Bufo punctatus	Red-spotted toad	Amphibian	194	7	201
	Spea multiplicata	Mexican spadefoot toad	Amphibian	2	0	2
		Unidentified toad	Amphibian	3	0	3
			Total Amphibian	199	8	207
Lizard	*Aspidoscelis flagellicauda*	Gila spotted whiptail	Lizard	11	3	14
	Aspidoscelis tigris	Tiger whiptail	Lizard	283	86	369
	Aspidoscelis velox	Plateau striped whiptail	Lizard	0	2	2
	Aspidoscelis spp.	Whiptail	Lizard	74	32	106
	Callisaurus draconoides	Zebra-tailed lizard	Lizard	6	54	60
	Coleonyx variegatus	Western banded gecko	Lizard	25	18	43
	Cophosaurus texanus	Greater earless lizard	Lizard	118	24	142
	Phrynosoma hernandesi	Greater short-horned lizard	Lizard	1	0	1
	Phrynosoma solare	Regal horned lizard	Lizard	69	5	74
	Phrynosoma spp.	Horned lizard	Lizard	0	11	11
	Sceloporus clarkii	Clark's spiny lizard	Lizard	10	1	11
	Sceloporus magister	Desert spiny lizard	Lizard	7	16	23
	Sceloporus spp.	Spiny lizard	Lizard	9	1	10

Table B.1. All Roadkill Detected on US 93 in 2008 and 2009. (Continued)

Class	Scientific Name	Common Name	Class Subtype	2008 Total	2009 Total	Grand Total
	Urosaurus ornatus	Ornate tree lizard	Lizard	32	28	60
	Uta stansburiana	Common side-blotched lizard	Lizard	194	56	250
	Xantusia vigilis	Desert night lizard	Lizard	1	0	1
		Unidentified lizard	Lizard	773	397	1170
			Total Lizard	1613	734	2347
Snake	*Arizona elegans*	Glossy snake	Snake	0	5	5
	Crotalus atrox	Western diamond-backed rattlesnake	Snake	20	12	32
	Crotalus mitchellii	Speckled rattlesnake	Snake	1	1	2
	Crotalus molossus	Black-tailed rattlesnake	Snake	2	2	4
	Diadophis punctatus	Ring-necked snake	Snake	1	2	3
	Hypsiglena torquata	Nightsnake	Snake	27	17	44
	Lampropeltis getula	Common kingsnake	Snake	3	7	10
	Coluber bilineatus	Sonoran whipsnake	Snake	7	26	33
	Coluber flagellum	Coachwhip	Snake	2	1	3
	Coluber taeniatus	Striped whipsnake	Snake	12	15	27
	Crotalus spp.	Unidentified rattlesnake	Snake	0	1	1
	Phyllorhynchus decurtatus	Spotted leaf-nosed snake	Snake	1	1	2
	Pituophis catenifer	Gophersnake	Snake	17	19	36
	Rhinocheilus lecontei	Long-nosed snake	Snake	21	19	40
	Salvadora hexalepis	Western patch-nosed snake	Snake	76	27	103
	Sonora semiannulata	Groundsnake	Snake	34	15	49
	Tantilla hobartsmithi	Smith's black-headed snake	Snake	17	4	21
	Thamnophis spp.	Gartersnake	Snake	1	0	1
	Trimorphodon biscutatus	Western lyresnake	Snake	4	9	13
		Unidentified snake	Snake	35	74	109
			Total Snake	281	257	538
Unidentified		Unidentified roadkill	N/A	369	199	568
			Total Unidentified Roadkill	369	199	568
All classes			**Grand Total**	3276	2403	5679

APPENDIX C.
OCCUPANCY-MODEL COMPARISONS FOR SOIL SUBGROUPS

Table C.1. Durinodic Haplocalcid

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*year,pshelt*)	3	-24.735	0.0000	0.4870
psi(.),p(*pshelt,temp*)	3	-25.280	1.0900	0.2824
psi(.),p(.)	2	-28.030	4.5305	0.0505
psi(.),p(*year*)	2	-28.030	4.5305	0.0505
psi(.),p(*global*)	5	-25.280	5.3019	0.0344
psi(.),p(*temp*)	2	-28.415	5.3005	0.0344
psi(.),p(*year,temp*)	3	-27.915	6.3600	0.0203
psi(.),p(*pshelt*)	2	-28.995	6.4605	0.0193
psi(.),p(*season*)	2	-29.285	7.0405	0.0144
psi(.),p(*pshelt,season*)	3	-28.995	8.5200	0.0069
psi(.),p(*survey*)	19	-19.115	26.4190	0.0000
psi(*pshelt*),p(*year,pshelt*)	3	-260.295	526.6789	0.0000
psi(*droad,pshelt*),p(*year,pshelt*)	4	-259.605	527.3891	0.0000
psi(*dwash,pshelt*),p(*year,pshelt*)	4	-259.605	527.3891	0.0000
psi(*droad,dwash*),p(*year,pshelt*)	4	-259.605	527.3891	0.0000
psi(*droad*),p(*year,pshelt*)	3	-260.860	527.8089	0.0000
psi(*dwash*),p(*year,pshelt*)	3	-260.970	528.0289	0.0000
psi(*landform*),p(*year,pshelt*)	3	-260.990	528.0689	0.0000
psi(*pshelt,landform*),p(*year,pshelt*)	4	-260.295	528.7691	0.0000
psi(*dwash,pshelt,landform*),p(*year,pshelt*)	5	-259.605	529.5108	0.0000
psi(*droad,pshelt,landform*),p(*year,pshelt*)	5	-259.605	529.5108	0.0000
psi(*droad,dwash,landform*),p(*year,pshelt*)	5	-259.605	529.5108	0.0000
psi(*droad,dwash,pshelt*),p(*year,pshelt*)	5	-259.605	529.5108	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.2. Typic Calciargid

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*year,pshelt*)	3	-12.640	0.0000	0.6533
psi(.),p(*pshelt,temp*)	3	-14.060	2.8400	0.1579
psi(.),p(*global*)	5	-12.640	4.2119	0.0795
psi(.),p(*year*)	2	-16.810	6.2805	0.0283
psi(.),p(.)	2	-16.810	6.2805	0.0283
psi(.),p(*year,temp*)	3	-15.830	6.3800	0.0269
psi(.),p(*temp*)	2	-17.845	8.3505	0.0100
psi(.),p(*pshelt*)	2	-18.160	8.9805	0.0073
psi(.),p(*pshelt,season*)	3	-18.160	11.0400	0.0026
psi(.),p(*season*)	2	-19.355	11.3705	0.0022
psi(.),p(*survey*)	19	-10.480	33.3390	0.0000
psi(*droad*),p(*year,pshelt*)	3	-175.150	325.0200	0.0000
psi(*dwash*),p(*year,pshelt*)	3	-175.150	325.0200	0.0000
psi(*pshelt*),p(*year,pshelt*)	3	-175.840	326.4000	0.0000
psi(*landform*),p(*year,pshelt*)	3	-175.840	326.4000	0.0000
psi(*pshelt,droad*),p(*year,pshelt*)	4	-175.150	327.1102	0.0000
psi(*pshelt,dwash*),p(*year,pshelt*)	4	-175.150	327.1102	0.0000
psi(*droad,dwash*),p(*year,pshelt*)	4	-175.150	327.1102	0.0000
psi(*pshelt,landform*),p(*year,pshelt*)	4	-175.840	328.4902	0.0000
psi(*pshelt,dwash,landform*),p(*year,pshelt*)	5	-175.150	329.2319	0.0000
psi(*pshelt,droad,landform*),p(*year,pshelt*)	5	-175.150	329.2319	0.0000
psi(*dwash,droad,landform*),p(*year,pshelt*)	5	-175.150	329.2319	0.0000
psi(*dwash,droad,pshelt*),p(*year,pshelt*)	5	-175.150	329.2319	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.3. Typic Haplocalcid

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(*pshelt,temp*)	3	-11.725	0.0000	0.6844
psi(.),p(*year,pshelt*)	3	-12.900	2.3500	0.2114
psi(.),p(*global*)	5	-11.725	4.2119	0.0833
psi(.),p(*temp*)	2	-17.220	8.9305	0.0079
psi(.),p(*year*)	2	-17.770	10.0305	0.0045
psi(.),p(.)	2	-17.770	10.0305	0.0045
psi(.),p(*year,temp*)	3	-17.040	10.6300	0.0034
psi(.),p(*pshelt*)	2	-20.665	15.8205	0.0003
psi(.),p(*season*)	2	-20.905	16.3005	0.0002
psi(.),p(*pshelt,season*)	3	-20.665	17.8800	0.0001
psi(.),p(*survey*)	19	-8.840	31.8890	0.0000
psi(*droad*),p(*pshelt,temp*)	3	-89.885	156.3200	0.0000
psi(*dwash*),p(*pshelt,temp*)	3	-89.885	156.3200	0.0000
psi(*pshelt*),p(*pshelt,temp*)	3	-90.580	157.7100	0.0000
psi(*pshelt,droad*),p(*pshelt,temp*)	4	-89.885	158.4102	0.0000
psi(*pshelt,dwash*),p(*pshelt,temp*)	4	-89.885	158.4102	0.0000
psi(*droad,dwash*),p(*pshelt,temp*)	4	-89.885	158.4102	0.0000
psi(*landform*),p(*pshelt,temp*)	3	-91.270	159.0900	0.0000
psi(*pshelt,landform*),p(*pshelt,temp*)	4	-90.580	159.8002	0.0000
psi(*pshelt,dwash,landform*),p(*pshelt,temp*)	5	-89.885	160.5319	0.0000
psi(*pshelt,droad,landform*),p(*pshelt,temp*)	5	-89.885	160.5319	0.0000
psi(*droad,dwash,landform*),p(*pshelt,temp*)	5	-89.885	160.5319	0.0000
psi(*droad,dwash,pshelt*),p(*pshelt,temp*)	5	-89.885	160.5319	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.4. Typic Haplocambid

Model[a]	No. of Parameters	log-likelihood	ΔAIC$_c$	*w*
psi(.),p(*year,pshelt*)	3	-1.385	0.0000	0.3552
psi(.),p(*pshelt,temp*)	3	-2.250	1.7300	0.1496
psi(.),p(*pshelt*)	2	-3.515	2.2600	0.1147
psi(.),p(*year*)	2	-4.115	3.4600	0.0630
psi(.),p(.)	2	-4.115	3.4600	0.0630
psi(.),p(*temp*)	2	-4.135	3.5000	0.0617
psi(.),p(*season*)	2	-4.175	3.5800	0.0593
psi(.),p(*global*)	5	-1.385	4.0000	0.0481
psi(.),p(*year,temp*)	3	-3.490	4.2100	0.0433
psi(.),p(*season,pshelt*)	3	-3.515	4.2600	0.0422
psi(.),p(*survey*)	19	-1.385	32.0000	0.0000
psi(*dwash*),p(*year,pshelt*)	3	-25.150	47.5300	0.0000
psi(*droad*),p(*year,pshelt*)	3	-25.150	47.5300	0.0000
psi(*pshelt*),p(*year,pshelt*)	3	-25.150	47.5300	0.0000
psi(*landform*),p(*year,pshelt*)	3	-25.150	47.5300	0.0000
psi(*pshelt,droad*),p(*year,pshelt*)	4	-25.150	49.5300	0.0000
psi(*pshelt,dwash*),p(*year,pshelt*)	4	-25.150	49.5300	0.0000
psi(*droad,dwash*),p(*year,pshelt*)	4	-25.150	49.5300	0.0000
psi(*pshelt,landform*),p(*year,pshelt*)	4	-25.855	50.9400	0.0000
psi(*dwash,pshelt,landform*),p(*year,pshelt*)	5	-25.855	52.9400	0.0000
psi(*droad,pshelt,landform*),p(*year,pshelt*)	5	-25.855	52.9400	0.0000
psi(*droad,dwash,landform*),p(*year,pshelt*)	5	-25.855	52.9400	0.0000
psi(*droad,dwash,pshelt*),p(*year,pshelt*)	5	-25.855	52.9400	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.5. Typic Haplodurid

Model[a]	No. of Parameters	log-likelihood	ΔAIC$_c$	*w*
psi(.),p(*pshelt,temp*)	3	-13.190	0.0000	0.4619
psi(.),p(*year,pshelt*)	3	-14.225	2.0700	0.1641
psi(.),p(*pshelt*)	2	-15.295	2.1505	0.1576
psi(.),p(*global*)	5	-13.115	4.0619	0.0606
psi(.),p(*temp*)	2	-16.775	5.1105	0.0359
psi(.),p(.)	2	-16.970	5.5005	0.0295
psi(.),p(*year*)	2	-16.970	5.5005	0.0295
psi(.),p(*season*)	2	-17.010	5.5805	0.0284
psi(.),p(*year,temp*)	3	-16.235	6.0900	0.0220
psi(.),p(*year,season*)	3	-16.970	7.5600	0.0105
psi(.),p(*survey*)	19	-9.550	30.3790	0.0000
psi(*droad*),p(*pshelt,temp*)	3	-134.750	243.1200	0.0000
psi(*dwash*),p(*pshelt,temp*)	3	-134.750	243.1200	0.0000
psi(*pshelt*),p(*pshelt,temp*)	3	-135.445	244.5100	0.0000
psi(*landform*),p(*pshelt,temp*)	3	-135.445	244.5100	0.0000
psi(*pshelt,droad*),p(*pshelt,temp*)	4	-134.750	245.2102	0.0000
psi(*pshelt,dwash*),p(*pshelt,temp*)	4	-134.750	245.2102	0.0000
psi(*droad,dwash*),p(*pshelt,temp*)	4	-134.750	245.2102	0.0000
psi(*pshelt,landform*),p(*pshelt,temp*)	4	-135.445	246.6002	0.0000
psi(*dwash,pshelt,landform*),p(*pshelt,temp*)	5	-134.750	247.3319	0.0000
psi(*droad,pshelt,landform*),p(*pshelt,temp*)	5	-134.750	247.3319	0.0000
psi(*droad,dwash,landform*),p(*pshelt,temp*)	5	-134.750	247.3319	0.0000
psi(*droad,dwash,pshelt*),p(*pshelt,temp*)	5	-134.750	247.3319	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.6. Lithic Torriorthent

Model[a]	No. of Parameters	log-likelihood	$\Delta QAIC_c$	*w*
psi(.),p(*pshelt*)	3	-15.405	0.0000	0.1535
psi(.),p(.)	3	-15.480	0.1500	0.1424
psi(.),p(*year*)	3	-15.480	0.1500	0.1424
psi(.),p(*year,pshelt*)	4	-14.680	0.6402	0.1114
psi(.),p(*temp*)	3	-15.755	0.7000	0.1082
psi(.),p(*season*)	3	-15.910	1.0100	0.0926
psi(.),p(*pshelt,temp*)	4	-15.050	1.3802	0.0770
psi(.),p(*year,temp*)	4	-15.075	1.4302	0.0751
psi(.),p(*pshelt,season*)	4	-15.405	2.0902	0.0540
psi(.),p(*global*)	5	-14.560	2.5219	0.0435
psi(.),p(*survey*)	20	-4.160	17.8618	0.0000
psi(*landform*),p(*pshelt*)	3	-56.840	82.8700	0.0000
psi(*droad*),p(*pshelt*)	3	-56.840	82.8700	0.0000
psi(*dwash*),p(*pshelt*)	3	-56.840	82.8700	0.0000
psi(*pshelt*),p(*pshelt*)	3	-56.840	82.8700	0.0000
psi(*droad,dwash*),p(*pshelt*)	4	-56.840	84.9602	0.0000
psi(*pshelt,droad*),p(*pshelt*)	4	-56.840	84.9602	0.0000
psi(*pshelt,dwash*),p(*pshelt*)	4	-56.840	84.9602	0.0000
psi(*pshelt,landform*),p(*pshelt*)	4	-56.840	84.9602	0.0000
psi(*pshelt,dwash,landform*),p(*pshelt*)	5	-56.840	87.0819	0.0000
psi(*pshelt,droad,landform*),p(*pshelt*)	5	-56.840	87.0819	0.0000
psi(*dwash,droad,landform*),p(*pshelt*)	5	-56.840	87.0819	0.0000
psi(*dwash,droad,pshelt*),p(*pshelt*)	5	-56.840	87.0819	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.

Table C.7. Typic Torriorthent

Model[a]	No. of Parameters	log-likelihood	ΔAIC_c	*w*
psi(.),p(.)	2	-4.020	0.0000	0.1808
psi(.),p(*temp*)	2	-4.020	0.0000	0.1808
psi(.),p(*year*)	2	-4.020	0.0000	0.1808
psi(.),p(*pshelt*)	2	-4.460	0.8800	0.1164
psi(.),p(*year,temp*)	3	-3.740	1.4995	0.0854
psi(.),p(*year,pshelt*)	3	-3.970	1.9595	0.0679
psi(.),p(*season*)	2	-5.005	1.9700	0.0675
psi(.),p(*pshelt,temp*)	3	-4.015	2.0495	0.0649
psi(.),p(*pshelt,season*)	3	-4.460	2.9395	0.0416
psi(.),p(*global*)	5	-3.440	5.1113	0.0140
psi(*droad*),p(.)	2	-18.215	28.3900	0.0000
psi(*dwash*),p(.)	2	-18.215	28.3900	0.0000
psi(*droad,dwash*),p(.)	3	-18.215	30.4495	0.0000
psi(*pshelt,droad*),p(.)	3	-18.215	30.4495	0.0000
psi(*pshelt,dwash*),p(.)	3	-18.215	30.4495	0.0000
psi(*pshelt*),p(.)	2	-19.605	31.1700	0.0000
psi(.),p(*survey*)	19	-2.705	37.0885	0.0000
psi(*dwash,pshelt,landform*),p(.)	4	-18.215	32.5397	0.0000
psi(*droad,pshelt,landform*),p(.)	4	-18.215	32.5397	0.0000
psi(*droad,dwash,landform*),p(.)	4	-18.215	32.5397	0.0000
psi(*droad,dwash,pshelt*),p(.)	4	-18.215	32.5397	0.0000
psi(*landform*),p(.)	2	-20.295	32.5500	0.0000
psi(*pshelt,landform*),p(.)	3	-19.605	33.2295	0.0000

[a] *temp* = temperature; *pshelt* = permanent shelter; *droad* = distance to road; *dwash* = distance to wash.