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Development of Dual-Purpose Desert Tortoise Crossing Culverts: Literature Review Report

August 2021

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16. Abstract

As the maintenance entity of hundreds of miles of highway roadway that exist within desert tortoise range, the Nevada Department of Transportation is interested in finding solutions that balance Mojave Desert tortoise and roadways associated needs. This report presents the results of the literature review of published and unpublished information for wildlife crossing structures to determine potential applicability to the mitigation of road impacts on desert tortoise. This exercise also compiled wildlife crossing characteristics that make or would potentially make an underpass available and attractive to the Mojave Desert tortoise.

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LITERATURE REVIEW REPORT
DESERT TORTOISE DUAL PURPOSE CROSSINGS PROJECT

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ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degrees Celsius
AMSL	Above Mean Sea Level
BACI	Before-After-Control-Impact
cm	Centimeters
GPS	Global Positioning System
ha	Hectares
km	Kilometers
m	Meters
MCP	Minimum Convex Polygons
NDOT	Nevada Department of Transportation
Project	Desert Tortoise Crossings Project
Stantec	Stantec Consulting Services Inc.
USFWS	United States Fish and Wildlife Service

1.0 INTRODUCTION

1.1 PURPOSE

As the maintenance entity of hundreds of miles of highway roadway that exist within desert tortoise range, the Nevada Department of Transportation (NDOT) is interested in finding solutions that balance Mojave Desert tortoise (*Gopherus agassizii*) and roadways associated needs. Accordingly, NDOT contracted with Stantec Consulting Services Inc. (Stantec) in a multi-phase project with the end goal of developing designs for dual-purpose structures that are accessible to tortoises while maintaining full hydraulic function and withstanding carried sediment and abrasion, and resisting erosion and scour. As summarized by NDOT's Research Problem Statement:

> *Due to topographical restraints and variation in flow patterns throughout southern Nevada, there are limited sites where single-purpose tortoise crossings may be installed without becoming, by default, a drainage structure during flood events. Without erosion control measures (such as riprap) in place, the single-purpose tortoise crossings may succumb to erosion very quickly in some areas. Therefore, there is a need to design and monitor dual-purpose structures for their ability to withstand large hydraulic events while also being easily navigated by desert tortoises.*

This report presents the results of the first phase of the Desert Tortoise Crossings Project (Project), which consisted of conducting a literature review of published and unpublished information for wildlife crossing structures to determine potential applicability to the mitigation of road impacts on desert tortoise. Sources used within this report have been provided electronically within **Appendix A**. This exercise also compiled wildlife crossing characteristics that make or would potentially make an underpass available and attractive to the Mojave Desert tortoise.

1.1.1 Wildlife Crossings

Re-establishing or maintaining movement corridors across highways, using engineered animal crossings and other methods, is vital to the conservation of wildlife (Corlatti et al., 2009). Current practices for the development of single-purpose animal crossings on roadways often relate to populations that migrate seasonally and that have documented movement patterns via some type of telemetry device (e.g., radio, Global Positioning System [GPS], etc.) installed on animals within the population. Several studies note that probabilities of vehicle collisions with wildlife are dependent on patterns of animal movement, physical features of landscapes, traffic volume, and the placement of roads (Dussault et al., 2007; Lewis et al., 2011; Neumann et al., 2012; Simpson et al., 2016). Vehicle collision and animal roadway mortality data are often used during the process of determining ideal locations for placement of wildlife crossings.

Typical design considerations for wildlife crossings relate to ratios between height and width of openings, and relationships between opening size and total length (known as the openness ratio or openness factor). Large ungulate species are often the focus of research and mitigation efforts due to the higher likelihood of human fatalities during vehicle collisions. Crossings are often located within flowing creek or river bottoms or dry washes as these features have shown a natural affinity for use as travel corridors in certain species of wildlife (Peaden et al., 2017).

1.1.1.1 Hydraulic Culverts

Hydraulic culverts are constructed to convey surface runoff underneath an engineered structure such as a road, parking lot, or building. Culverts are typically associated with river, creek, or channel flows; floodwater; or a combination thereof. Numerous factors are considered during the development and design of hydraulic culverts including:

- Geography – location, climate, floodplain, and geotechnical/soil conditions.
- Capacity – the amount of flow the culvert will convey. Flow rates are obtained from hydrologic analyses and/or measurements taken along a flowing river or channel for a particular storm or flood recurrence interval.
- Geometry – alignment, shape, length, and slope of the drainage way and culvert along the flow line.
- Structure – culvert material, headwalls, wingwalls, end sections, inlet and outlet aprons, energy dissipation, and abutments.
- Conveyance – incoming and outgoing flow velocities and depths, freeboard, ponding, sediment transport, and sediment deposition.
- Construction complexity and feasibility.
- Construction cost.
- Maintenance requirements.
- Permitting Requirements – Local agency requirements outlined in agency specific guidance including drainage and roadway design manuals. City, County, State, and Federal requirements may apply depending on location and jurisdiction. Typically, projects for NDOT refer to the NDOT Drainage Manual dated December 2006. This manual outlines NDOT's required methods for hydrologic and hydraulic analyses for proposed improvements within their right-of-way. Culvert-specific design guidance is located within Section 3.3.4.

The process of designing a culvert begins with establishing initial design factors, completing calculations, and evaluating the conceptual design based on jurisdictional requirements. The culvert is then hydraulically designed based on the initial factors to ensure conveyance and capacity factors.

The local hydrology and geography determine the hydraulic culvert's required capacity based on regulatory requirements (e.g., 10-year, 25-year, 50-year, 100-year storm event). The required capacity drives the culvert geometry and structure design to achieve the desired conveyance, while minimizing adverse effects to the upstream and downstream hydraulic conditions.

In practice, two types of culverts are generally used within tortoise habitat, box culverts (concrete) and pipe (concrete or metal). The type of culvert is a function of the specific peak flow rate within each drainage and each location. Pipe culverts are normally used for smaller peak flows; whereas box culverts are used for higher peak flows. The cost of pipe culverts is considerably less than box culverts to install. Another advantage of pipe culverts are that they can withstand heavy traffic loads; however, pipe culverts become limited in capacity if the location requires a culvert to traverse long distances under traffic due to their large height-length ratio (i.e., height to cross-sectional area ratio). When it is critical to meet specific grade lines, large pipe culverts may not be practical. In these instances, box culverts may be more practical because they have a lower height-length ratio and provide more flexibility in meeting specific site conditions.

Culvert inlets sometimes require the incoming flow be directed or "funneled" to the culvert. This can be accomplished with concrete wingwalls and headwalls, with grading, or with flared inlets. In some instances, this funneling action may result in scouring near the entrance of the culvert. As such, armoring around the inlet may be necessary to prevent erosion and/or undercutting.

When the velocity of water exiting a culvert is expected to exceed a certain threshold, it may be necessary to provide energy dissipation and armoring at the outlet to prevent erosion and undercutting. Riprap is often placed at the outlet and can provide protection from erosion. High exit velocities can also cause erosion in the downstream channel. Thus, it may be necessary to install energy dissipaters at the outlet of the culvert to slow the water and prevent erosion. In addition to armoring, riprap can also provide energy dissipation. There are many other erosion and energy dissipation devices, in addition to riprap, that can be used. These include rock gabions, concrete aprons, concrete pillows, articulating concrete blocks, and geotextiles (e.g., fabrics and mats). The selection of the appropriate armoring method is dependent on the site conditions; however, riprap is commonly used because of its low cost, availability, and dual armoring/energy dissipation function. Regardless of the method used, careful hydraulic analysis is required for each culvert to determine the entrance and exit velocities and select the appropriate armoring and energy dissipation features.

A properly functioning culvert will accumulate sediments during periods of low flow, but have those sediment scoured out and transported downstream during higher flows. This minimizes the need to have maintenance crews remove sediment accumulations to prevent plugging of the culvert. To understand the sediment occurring at a culvert, it is important to consider the conditions of the drainage's watershed. The size of the watershed, precipitation rates, slopes, soils, and other aspects. Rocky and steep watershed will have sediments with a wide size distribution, while flat sandy watersheds will have sediments with a smaller size distribution shifted to the smaller particle size. Fine sediments are scoured by relatively low water velocities, while greater water velocities are needed to scour coarser sediments. Designing a properly functioning culvert is often a balancing act between promoting adequate scouring velocities versus preventing erosion and undercutting.

Culvert capacity is generally controlled by the conditions at the inlet (known as inlet control) or at the outlet (outlet control). The specific conditions of the site will dictate whether inlet or outlet control dominates. Understanding inlet and outlet control conditions at a culvert is important, as it dictates the velocity of the water entering and leaving the culvert.

Specific hydraulic design requirements for culverts are provided in various reference and design guidance documents presented below. Specific design requirements can be summarized by the following key points:

- Able to pass peak design flows (e.g.,100-year storm event).
- Designed to accommodate debris, as appropriate.
- Designed to avoid sediment accumulation.
- Include erosion protection where erosive velocities occur.
- Culvert flow line is between 45 and 90 degrees to the roadway.
- Maximum allowable ponding is at the edge of pavement.

Reference Manuals and Guidance Documents for the Development of Hydraulic Culverts

Numerous reference manuals and guidance documents are used in the development and design of hydraulic culverts. For NDOT projects, typically the following documents are preferred:

- Nevada Department of Transportation Drainage Manual, 2nd Edition, prepared by the Hydraulics Section, dated December 2006. (https://www.nevadadot.com/home/showpublisheddocument?id=1663)
- Nevada Department of Transportation Standard Plans for Road and Bridge Construction 2020. (https://www.nevadadot.com/home/showpublisheddocument?id=17276)
- Nevada Department of Transportation Standard Specifications for Road and Bridge Construction 2014. (https://www.nevadadot.com/home/showpublisheddocument?id=6916)
- Nevada Department of Transportation Road Design Guide, 2019 Edition. (https://www.nevadadot.com/home/showpublisheddocument?id=16066)
- Nevada Department of Transportation Plan Preparation Guide 2020. (https://www.nevadadot.com/home/showpublisheddocument?id=18896)
- Nevada Department of Transportation Stormwater Quality Manuals Planning and Design Guide, September 2017. (https://www.nevadadot.com/home/showpublisheddocument?id=3704)
- Nevada Department of Transportation Stormwater Quality Manuals Construction Site Best Management Practices (BMPs) Manual, December 2017. (https://www.nevadadot.com/home/showpublisheddocument?id=9417)

Depending on location within the state, drainage design manuals for local jurisdictions also apply. For example, NDOT projects performed within Clark County also reference the Clark County Regional Flood Control District Hydrologic Criteria and Drainage Design Manual, dated August 12, 1999.
(https://gustfront.ccrfcd.org/pdf_arch1/hcddm/Current%20Manual%20(Complete)/hcddm.pdf)
In addition to the NDOT and local agency-specific documents, supplemental guidance can also be obtained from the United States Department of Transportation Federal Highway Administration (FHWA) (https://highways.dot.gov/federal-lands/tech-resources) and the American Association of State Highway and Transportation Officials (AASHTO) (https://www.fhwa.dot.gov/programadmin/standards.cfm) publications.

Target Highways and Project Area

In broad terms, the Project areas are in the southern portion of Nevada along two highways north of Las Vegas. Both target highways (i.e., United States (US) 93 and US 95) are in the Northeastern and Eastern Mojave Recovery Unit of the desert tortoise in Clark and Nye counties. The habitat is typical Mojave Desert Scrub vegetation. The section of US 93 of interest is in Coyote Springs Critical Habitat Unit, whereas the section of US 95 of interest is on Bureau of Land Management-managed habitats. Within both sections, multiple culverts exist, and United States Fish and Wildlife Service (USFWS) began monitoring these structures for wildlife usage, in particular desert tortoises, between 2015 and 2017. Though these two sections of highway are included within the scope of this Project, the overarching goal of this Project is to provide tools and information for NDOT's future use throughout all roadways within desert tortoise habitat.

Culvert Conflicts with Desert Tortoise

In desert systems, hydraulic culverts are usually constructed at dry washes along roads and highways. Mojave Desert tortoises utilize dry washes for multiple reasons, and the species prefers moving along these features (Peaden et al., 2017). Often hydraulic culverts in association with exclusionary roadside fencing are an effective strategy mitigating road mortality in Mojave Desert tortoises (Boarman and Sazaki, 1996). The ultimate goals of this strategy are to funnel individuals away from road risks (i.e., reducing mortality) and towards culverts to allow for passage underneath the road (i.e., decrease fragmentation). For example, due to the installation of roadside fencing near hydraulic culverts, Boarman and Sazaki (1996) found 93 percent (%) less dead on the road tortoises when compared to unfenced roadsides. After one year of monitoring, four tortoises "used" (i.e., entered or passed) the culverts 60 times (Boarman et al., 1998). However, any wildlife interactions with anthropogenic structures potentially have their own associated risks. In the following report, we summarize the literature on the wildlife-culvert interactions and largely focus on design features (e.g., dimensions and materials) and characteristics (e.g., surrounding habitat and anthropogenic disturbances) predicting the success of a wildlife crossing. We expanded our literature search to include underpasses, ecopassages, and other anthropogenic features utilized by wildlife to cross roadways.

1.2 DESERT TORTOISE

In the United States, desert tortoise habitat occurs in two desert ecosystems – the Mojave Desert, which is dominated by desert scrub (e.g., creosotebush-bursage scrub vegetation) and few cacti

(Nussear and Tuberville, 2012), and the Sonoran Desert, which supports subtropical desert scrub, as well as a large diversity of cacti and perennial plants (Vasek and Barbour, 1977). In 2011, the desert tortoise was split into two distinct species: *Gopherus agassizii* (Mojave Desert tortoise) located primarily to the west of the Colorado River *and Gopherus morafkai* (Morafka's desert tortoise) located to the east of the Colorado River (Murphy et al., 2011).

The Mojave Desert tortoise distribution includes the Mojave and the western portion of the Sonoran Deserts (Murphy et al., 2011). The species largely inhabits valleys and alluvial fans (i.e., bajadas) at moderate elevations (generally 300-920 meters [m] above mean seal level [AMSL]; (Luckenbach, 1982) from southern Nevada and southwest Utah through southeast California, and a small portion of southwestern Arizona (Hulse and Middendorf, 1979; Luckenbach, 1982; Murphy et al., 2011). This species is absent at extremely low elevations (e.g., Coachella, Cadiz, Eureka, Saline, and Death valleys), due to inhospitable temperatures, and at high elevations greater than 2000 m AMSL (reviewed in Lovich et al., 2020). The diet of the Mojave Desert tortoise is diverse and consisted of 52.9% annual forbs, 12.6% annual or perennial grass, 19.5% perennial forbs, 11.5% woody plants, and 3.4% succulents in one report (Esque et al., 2012).

The Mojave Desert tortoise is a conservation-reliant species, and one of the largest terrestrial turtle species (maximum reported carapace length = 38.1 centimeters (cm); reported by Stebbins, 2003) in the United States (Ernst and Lovich, 2009; Bramble and Hutchison, 2014). Like other tortoise species within the genus *Gopherus*, this species exhibits a suite of co-evolved life-history traits, such as long lifespan (>30 years of age, Germano, 1992; Ernst and Lovich, 2009) accompanied by > 90% annual survivorship for adults, slow maturation (15 to 20 years for females; Ernst and Lovich, 2009), and relatively low annual fecundity (4 to 12 eggs; Lovich et al., 2015). Because of this suite of traits, desert tortoise populations are sensitive to human perturbations, especially any perturbation that lowers adult female survivorship, and are slow to recover afterwards (Doak et al., 1994).

The desert tortoise is considered an environmental engineer due to the multiple burrows, pads, and shelters it excavates into the desert soils (Ernst and Lovich, 2009; Lovich et al., 2018). These structures are critical for the survival of tortoises. In fact, desert tortoises spend upwards of 98% of their annual cycle sheltering in these structures (Nagy and Medica, 1986), thus linking the placement of these structures within the landscape to individual fitness (Lovich and Daniels, 2000). Structures provide refugia from predators, fires, and flood events, but also play a vital role in thermoregulation and water regulation throughout the year (Bulova, 2002; Spotila et al., 2012; Mack et al., 2015). Tortoise burrows are a key feature in the desert landscape and are utilized by a wide variety of other organisms (Agha et al., 2017).

The Mojave Desert tortoise's daily activity is determined by season and largely dictated by temperature and precipitation events (Woodbury and Hardy, 1948; Luckenbach, 1982; Zimmerman et al., 1994; Berish and Medica, 2012). The species is diurnal but displays nocturnal activity associated with rain events (Berish and Medica, 2012). Although the Mojave Desert tortoise can be active (depending on geography and weather) in all months, activity pattens are usually predictable by season. For example, activity patterns shift from a unimodal pattern in the spring and fall to a more bimodal pattern in the summer and winter (Woodbury and Hardy, 1948;

Luckenbach 1982; Zimmerman et al., 1994). During the spring and fall, individuals typically forage after sunrise into the late afternoon when temperatures are amenable. Above ground activities are restricted during the summer months to the relatively cooler portions of the day. Individuals are active in the mornings but retreat into burrows when temperatures near their zenith (e.g., 40-45 degrees Celsius [°C]) and reemerge in the late afternoon to early evening (Luckenbach, 1982; Zimmermann et al., 1994).

A wide range of body temperatures from active individuals have been reported in the literature and vary by geography and season (Brattstrom, 1965; McGinnis and Voigt, 1971; Zimmerman et al., 1994). These values are generally between 19-38°C with the upper limit near reported critical thermal maximums (43°C, Hutchison et al., 1966; Ernst and Lovich, 2009). In the late fall, the Mojave Desert tortoise hibernates, and the timing and length of hibernation depends on latitude, elevation, and precipitation. The onset of hibernation occurs between October and November, and tortoises will emerge between February and April (Rautenstrauch et al., 1998; Nussear et al., 2007).

The Mojave Desert tortoise nesting season occurs from mid-April to August, during which females typically lay clutches of 4 to 6 eggs (extreme range of 1 to 15 eggs) in nest cavities excavated within or at the entrances of an existing burrows, but more rarely beneath vegetation (Murray et al., 1996; Rostal et al., 1994; Wallis et al., 1999, Averill-Murray et al., 2012; Ennen et al., 2012; Lovich et al., 2015; Jackson et al., 2015). The species can produce three clutches annually, especially following an El Nino (Lovich et al., 2015); however, clutch frequency is typically 1 or 2 clutches per year (reviewed by Averill-Murray et al., 2012). Hatchlings emerge from the nest cavity from mid-August to October (Lewis-Winokur and Winokur, 1995; Ernst and Lovich, 2009) and depends upon when the clutch of eggs were laid.

Tortoise densities declined considerably before the turn of the century, which led to the species being listed under the Endangered Species Act in 1990 (USFWS, 1990). In many locations, these declines have continued into more recent times (Allison and Mcluckie, 2018). Population declines are associated with a myriad of anthropogenic factors, such as habitat loss and fragmentation, disease, subsidized predators, vehicle kills, fire, invasive plants, and climate change (reviewed by Berry and Aresco, 2012). The greatest threat to biodiversity, including desert tortoises, is habitat loss, fragmentation, and degradation. For the Mojave Desert tortoise, this threat comes in several forms (e.g., urbanization, roads and other linear features, military maneuvers, energy developments, invasive species, fire, livestock, and climate change), which Berry and Aresco (2012) consider serious threats to tortoise populations.

Due to their slow movement, turtles and tortoises are highly susceptible to road mortality (Gibbs and Steen, 2005; Fahrig and Rytwinski, 2009; Andrews et al., 2015), and the Mojave Desert tortoise is no exception. Furthermore, their long life, delayed onset of maturity, and relatively low reproductive output make desert tortoise populations highly sensitive to road mortalities (Rytwinski and Fahrig, 2012). Although Hromada et al. (2020) reported that desert tortoises generally avoided road surfaces, over 80% of individuals crossed roads, and typically, desert tortoises crossed roads near washes (Peaden et al., 2017). It has been documented that road mortalities reduce tortoise densities considerably in habitats nearest the road (200-400 m from road; Boarman and Sazaki, 2006; Hughson and Darby, 2013; Nafus et al., 2013; Peaden et al., 2015); however, von Seckendorff Hoff and Marlow (2002) suggest the impact can extend further (e.g., 1-4 kilometers (km) from the road). Additionally, some mortalities are directly associated with road infrastructure, such as hydraulic culverts for Mojave Desert tortoises (Lovich et al., 2011) and fencing in desert and leopard tortoises (Peaden et al., 2017; Lee et al., 2021).

A mitigation strategy to curb road mortalities for desert tortoises is roadside fencing (USFWS, 2011; Peaden et al., 2015). Studies report a reduction in road-related mortalities for Mojave Desert tortoises after fence installations (up to 93%; Boarman and Sazaki, 2006). Little was known about individual- or population-level impacts associated with roadside fencing until recently. Desert tortoises moved linearly along fences (Peaden et al., 2017; Hromada et al., 2020), and Peaden et al. (2017) reported individuals spent longer durations and moved faster (i.e., meter per hour) near roads and fencing relative to other portions of their home ranges. Peaden et al. (2017) suggested that roads may be attractants to Mojave Desert tortoises because they mimic washes by possessing increased food and water resources.

Culverts are associated with some roads in desert environments and allow for streams and stormwater passage underneath roadways and prevent erosion of the road's integrity. These structures can be dual purpose and function as wildlife crossings, thus reducing road mortalities (Andrews et al., 2008). Mojave Desert tortoises are known to utilize culverts as crossings and surrogate dens for thermal refugia and hibernation (Boarman 1995; Boarman and Sazaki, 1996; Boarman et al., 1998; Lovich et al., 2011). As pointed out by Lovich et al. (2011), very little is known about the effectiveness of hydraulic culverts as a wildlife passage for Mojave Desert tortoises. The following sections discuss the literature search methodology, results, and interpretation we completed to describe morphological, behavioral, and ecological aspects of desert tortoise use of culverts as wildlife corridors.

2.0 METHODOLOGY

We conducted a literature review using available resources and databases (Google Scholar [https://scholar.google.com] and JSTOR [https://www.jstor.com]), as well as the literature search engine Scopus (https://www.scopus.com) and Web of Science (https://login.webofknowledge.com). We recorded search strings for transparency and repeatability. These included various combinations of the following terms: tortoise, *Gopherus,* predator, turtle, reptile, wildlife passage, ecopassage, desert, home range, dispersal, Nevada, burrow, culvert, crossing, fence, road, climb, barrier, slope, passage, arid, and road mortality.

This literature review focused on how desert tortoise biology relates to two main themes:

1. The design of wildlife crossings, and
2. The placement of wildlife crossings.

Research questions pertaining to the design of wildlife crossings concentrated on Mojave Desert tortoise behavior, design and success of crossing structures with specific consideration for tortoises and terrestrial turtles, general design and success of crossing structures with consideration for use by other vertebrate species, and the negative effects of specific design elements. Research questions regarding crossing placement investigated the general characteristics of wildlife crossings that make them successful for tortoises and terrestrial turtles, characteristics of wildlife crossings that make them successful for general vertebrate populations, characteristics of surrounding habitat and surrounding wildlife populations that make crossings more likely to be successful, and features that were used more often or were shown to affect the studies' target populations.

2.1 DESIGN OF WILDLIFE CROSSING STRUCTURES

For design of wildlife crossing structures, we investigated the following topics:

- What is the maximum vertical obstruction that tortoises can climb?
- What is the maximum slope that tortoises are known to traverse?
- What are the typical dimensions of an adult tortoise burrow?
- What is the typical home range size and what are typical dispersal distances for desert tortoise?
- What types of crossings have been designed and/or implemented for tortoises and/or terrestrial turtles?
- Which, if any, design features have been shown to either deter tortoises or attract them but be detrimental?
- What types of crossings have been designed and/or implemented in arid or semiarid environments?

- What types of culvert/underpass crossings have been designed and/or implemented?

- What are the common characteristics of entrapment (age of animals killed, locations, etc.)?

- Are there any similarities noted in the literature regarding entrapment?

- Is there evidence of increased predation at crossing locations or fences? Do predators congregate there because it is a bottleneck for tortoises and other wildlife?

- What other wildlife use crossings in desert environments?

- Are there characteristics of other reptile species crossings that may be applicable to desert tortoise?

- What does the available research show specific to reproduction rate in desert tortoise populations fragmented by a fenced road? Is there information on the rate of dispersal required to maintain genetic diversity and avoid inbreeding depression?

2.2 PLACEMENT OF CROSSINGS

- What locational aspects of wildlife crossings make them most successful (generally and specifically for tortoises/turtles)?

- What characteristics of the surrounding habitat and surrounding populations of wildlife make the crossings most successful (i.e. used more often or shown to positively affect the target populations)?

- What is known about the tortoise populations surrounding the target highways (i.e., US 93 and US 95)? Are there any similarities or key differences between these populations and those found in other studies?

- What is known about the tortoise habitat surrounding the target highways? Are there any similarities or key differences between this habitat and habitats found in other studies?

While the purpose of the literature review is to inform the design and placement of dual-purpose culverts within the Project area, applicable information from research conducted in similar habitats and/or on similar species (sometimes outside of the United States) are also presented in the findings.

3.0 RESULTS

3.1 DESIGN OF CROSSINGS

3.1.1 Biology

We researched four main questions pertaining to the biology of tortoises and the desert tortoise: (1) the maximum vertical obstruction that adult and juvenile tortoises of both sexes can climb, (2) the maximum slope that adult and juvenile tortoises of both sexes are known to traverse, (3) the typical dimensions of tortoise's burrow, and (4) the typical home range size and dispersal distance for desert tortoise.

3.1.1.1 Maximum Vertical Climbing Height

There is a paucity of literature regarding Mojave Desert tortoise's ability to climb vertical surfaces. We found only one experimental study (Ruby et al., 1994), which tested a variety of fencing materials and heights, reporting the climbing ability of desert tortoises over vertical surfaces. Other reports did not explicitly test climbing ability of Mojave Desert tortoises; however, these reports provide valuable insights on this ability or lack thereof. Additionally, we found a study on a closely-related tortoise species (*Gopherus polyphemus*) reporting climbing ability of vertical surfaces, which may provide insight to the ability of desert tortoises.

Mojave Desert tortoises attempted to climb anthropogenic structures; however, the success of scaling vertical structures was rare or rarely observed at installed roadside fences (Boarman et al., 1997). In the only peer-reviewed publication explicitly testing climbing ability of Mojave Desert tortoise, Ruby et al. (1994) tested a variety of fencing materials, which varied in height. These included redwood landscaping timbers (height = 30-34 cm), railroad ties (31-52 cm), chain link (70-100 cm), chicken wire (76-80 cm), open slat fencing (44-50 cm), aluminum flashing (62-66 cm), silverized insulation (45-50 cm), buried mesh (60-75 cm), unburied mesh (70-75 cm), trench with mesh (40-45 cm), trench with PVC pipe (27-28 cm), cement block (46-50 cm), and telephone poles (20-35 cm). Adult tortoises (maximum carapace length > 180 cm) attempted to climb out of all barrier pens constructed of the various materials. Many of these unsuccessful attempts were made at 90-degree corners of the pens, suggesting that corners may be more attractive for climbing. Ruby et al. (1994) reported successful escapes in pens constructed from horizontally-laid telephone poles. These successful escapes were in areas where the height was less than 30 cm in diameter. It should be noted that Ruby et al. (1994) did not truly test vertical climbing ability because height was confounded by the various materials. For example, many of the materials posed a true vertical height unlike telephone poles, which are rounded and might be easier for tortoises to gain purchase on. Furthermore, materials have different surfaces and provide varying traction for climbing (e.g., smooth [flashing] versus textured [wood]).

Hoover (1995) studied desert tortoise mortality in fiberglass and concrete upland game watering devices (a.k.a. guzzlers). Mortalities were recorded in both fiberglass and concrete tanks that had vertical faces up to 10 cm (average of 6.1 cm). Hoover (1995) reported that vertical height differences among guzzlers did not affect mortality counts. In other words, a greater mortality count did not occur in guzzlers with larger vertical faces. Mortality counts were, however, associated with construction material. Hoover (1995) reported greater mortality counts in fiberglass tanks relative to concrete tanks and suggested that the roughness of the concrete tanks gave the tortoises enough traction to escape. Unfortunately, Hoover (1995) did not provide body sizes or age classes (e.g., adult, sub-adults, juveniles, or hatchlings) for any tortoise mortalities, so we cannot infer any size-specific mortality effects. He did report an additional 173 mortalities that included coyotes, birds, rabbits, rodents, lizards, badgers, and snakes. Many of these species, in particular coyotes and badgers, likely possessed better climbing abilities than tortoises but still perished.

Two other studies that investigated desert tortoise climbing behavior reported differences among materials. In pens using three types of construction materials - 2-inch mesh chicken wire, 0.25-inch hardware cloth, and aluminum flashing - Mojave Desert tortoises displayed climbing behaviors more often at the chicken wire fencing than the more solid fencing types (hardware cloth and solid metal) (Fusari, 1982; Spotila et al., 1992). In both studies, escape via climbing from the pens was not reported.

Although not a desert tortoise study, Rautsaw et al. (2018) tested the ability of gopher tortoises (*Gopherus polyphemus*) to escape railroad entrapment (i.e., in between the parallel rails) and thus vertical climbing ability. They placed 24 adult gopher tortoises (average carapace length = 28.44 cm, minimum = 24 cm) between the rails of an inactive railroad and recorded behaviors. No tortoises were able to successfully climb over the 15-cm rail, despite being able to stand on their hind limbs with forelimbs reaching the top of the rail. Additionally, this experiment had a control group, which consisted of 12 adult tortoises. Rautsaw et al. (2018) constructed an arena with wooden barriers (height = 2.5 cm) that mimicked a railroad (i.e., parallel beams). All 12 tortoises easily crossed the barriers. Hromada et al. (2020) reported linear movements of Mojave Desert tortoises along railroads, which suggested an inability or avoidance of climbing railroad rails.

For additional perspective, we reviewed studies reporting vertical climbing ability of other turtle species. An experimental study from Woltz et al. (2008) constructed circular experimental pens created from opaque, corrugated plastic at three heights (i.e., 30 cm, 60 cm, and 90 cm). Woltz et al. (2008) reported the inability of painted turtles (*Chrysemys picta*) to escape the pen regardless of height. At a height of 0.3 m, approximately 16% of snapping turtles *(Chelydra serpentina)* could escape the pens, but the higher barriers (i.e., 0.6 m and 0.9 m height) effectively blocked passage of snapping turtles. At one Florida site, Aresco (2005) reported that several freshwater turtle species "are exceptional climbers". It should be noted that these species of freshwater turtles routinely bask and possess sharp claws that assist in climbing onto basking structures.

3.1.1.2 Maximum Slope Traversal

We searched literature related to terrain slope, slope at which burrows were located within the landscape, and the declination angle of burrow tunnels. Slope is an important determination in habitat suitability and movement for Mojave Desert tortoises. In general, the Mojave Desert tortoise inhabits valleys and alluvial fans (i.e., bajadas) with gentle slopes (i.e., 3-5 %; Bury et al., 1994; Ernst and Lovich, 2009; Hagerty et al., 2010). In general, slope had a negative association with movement (Hromada et al., 2020), and many habitat connectivity models assume desert tortoises avoid steep slopes (Nussear et al., 2009; Dickson et al., 2017; Gray et al., 2019). For example, the Mojave Desert tortoise rarely traversed areas of 30-degree (58 %) slope or greater (Hromada et al., 2020). Berry et al. (2013), however, found that tortoise sign in the northwestern Mojave Desert was positively related to degree of slope and that tortoises spend more time in the hills and away from low bare areas. This suggests that in the absence of shade structures and appropriate soil conditions at lower slopes, tortoises will traverse steeper slopes to find necessary resources. However, Berry et al. (2013) does not provide slope values were individuals (living or signs) were found, instead providing a range (0 – 66 %) for slope of the site. An account from Woodbury and Hardy (1948) claimed individuals traversed 40-45 degree slopes (83.91–100%) to enter hibernacula, which is the highest values reported.

Burrow placement within the landscape depends upon available habitat characteristics. The greatest reported value of slope for a burrow location was 31.9% (17.69 degrees; Lovich and Daniels, 2000) for a site located in the foothills of the San Bernardino Mountains, near Palm Springs, California. At the same location, other studies reported average slope values for burrows locations with nests as 24.4% (13.71 degrees) in 2000 and 26.4% (14.79 degrees) in 2001 (Lovich et al., 2014). Near Boulder City, Nevada – a relatively flat region, Young et al. (2017) only found burrow locations on slopes less than 4.6% (2.63 degrees). Desert tortoise burrows were assessed at two field sites in the Sonoran Desert of California (Cummings et al., 2020). At the Cottonwood site, a steeper-sloped site, burrow locations occurred on slopes up to 33.4% (18.47 degrees, average = 10.7% [6.11 degrees], minimum = 1.9% [1.09 degrees]). Burrow locations at the Orocopia site – a gentler-sloped site– occurred on slopes up to 2.4% (1.37 degrees, average = 1.6% [0.96 degrees], minimum = 0.6% [0.34 degrees]; Cummings et al., 2020).

Burrow declination angles were more difficult to find in the peer-reviewed literature for Mojave Desert tortoises. One account provided a broad range (20-40 degrees [36.4-83.91%]; Woodbury and Hardy, 1948) for declination angles, which were generally steeper than traversed terrain and burrow location slopes (see above). In two studies conducted by Bulova (1994 and 2002), declination of angle ranged from 16-27 degrees (28.67-50.95%). Finally, Luckenbach (1982) reports declination angles of 10-30 degrees (17.63-57.73%) in California. Excluding Woodbury and Hard (1948), the upper limit of declination angle reported in the literature neared the 30-degree terrain slope limitation reported by Hromada et al. (2020).

3.1.1.3 Tortoise Burrow Dimensions

Several studies have investigated the dimensions of desert tortoise burrows including length of a burrow (i.e., distance of the tunnel from burrow mouth to chamber [end of the tunnel]), entrance width (side wall to side wall measurement), and entrance height (floor to ceiling measurement). Occasionally, studies report declination angles (see above). As expected, burrow dimensions could vary with geography, soil type, and temperature extremes. Burrow dimensions varied among the sexes, especially when considering season, and age classes. For example, several studies reported that males utilize longer burrows than females in winter (Bailey et al.,1995; Rautenstrauch et al., 2002). Luckenbach (1982) reported an overall seasonal influence in burrow length, where individuals–both male and female–utilize longer burrows in winter relative to other portions the year. Additionally, burrow dimensions were intrinsically associated with individual carapace shape and size (Luckenbach, 1982).

Overall, desert tortoise burrows have a wide range of length from 5 cm to 1000 cm. The latter value was reported by Woodbury and Hardy (1948) and burrows of this length are rare. The former value was reported for neonates (Wilson et al., 1999). Near Twentynine Palms, the average length of active burrows was 110 cm (Duda et al., 2002) with 75% of burrows being less than 66 cm and 98% being less than 2 m in length (Krzysik, 2002). Lovich et al. (2014) observed an average burrow length of 55.4 cm at the western edge of the Sonoran Desert near Palm Springs, California; whereas Jackson et al. (2015) reported lengths of 70 cm, on average, at a site near Barstow, California. In southern Nevada, burrow length ranged from 52 cm-130 cm (Bulova, 1994). In the western Mojave Desert, average length of neonate and juvenile burrows was 52.7 cm (range 5-130 cm; Wilson et al., 1999).

The dimensions of burrow entrances (i.e., width and height) were reported far less than burrow length. We found several published studies focusing on adults, and collectively burrow entrance widths (30-76 cm) were larger than heights (13-17 cm). Near Palm Springs, Lovich et al. (2014) observed an average burrow width of 32.4 cm and height of 13.8 cm, and Bulova (1994) observed slightly larger values (width: 30-76 cm, height: 15.5-17 cm) in southern Nevada. Jackson et al. (2015) measured a “representative” burrow near Barstow that was 40 cm wide and 15.5 cm high. Dimensions of juvenile and neonate burrows were considerably narrower and shorter (Hazard and Morafka, 2004) than mature tortoise. On average, neonate burrow entrances were 7.79 cm and 4.2 cm in width and height, respectively (Hazard and Morafka, 2004). The average dimensions of juvenile burrow entrances were slightly larger (width 11.49 cm, height 5.87 cm; Hazard and Moraka, 2004).

3.1.2 Home Range and Dispersal Distance

Berish and Medica (2012) provided a comprehensive review home range and movement ecology of the Mojave Desert tortoise and North American tortoises. We used their summary to characterize home range and dispersal distance but also provided overlooked and more recent research quantifying movement behavior. In their review, Berish and Medica (2012) compared only studies using minimum convex polygons (MCP). Home range results varied, and other authors noted that this variation was influenced by the sampling protocols (number of individuals tracked, duration, and number of relocation points), geography, individual body size, climate and weather (Baily, 1992; Duda et al., 1999; Franks et al., 2011; Ennen et al., 2012), and investigators’ statistical approaches (Harless et al., 2010). In general, home range and dispersal distance were larger for males compared to females (Berry, 1974; Holt and Rautenstrauch, 1995; Harless et al., 2009; Berish and Medica, 2012; Farnsworth et al., 2015); however, there are exceptions to this rule for Mojave Desert tortoises. Another generalization was that there was considerable variability of home range among individuals within a population, which is likely due to individual behavioral and genetic differences.

Average home ranges varied from 1-33 hectares (ha) (reviewed by Berish and Medica, 2012; Woodbury and Hardy, 1948; Hohman and Ohmart, 1980; Berry, 1986; Barrett, 1990; Bailey, 1992), but the maximum home range for an individual can exceed 200 ha (Harless et al., 2009). More recent studies reported that average home ranges vary from 29-87 ha (Harless et al., 2009; Franks et al., 2011; Farnsworth et al., 2015; Peaden et al., 2017). Peaden et al. (2017) used GPS loggers, which allowed for more relocation points, and reported an average home range of 87 ha (range 24-181 ha). Another movement study using GPS loggers, Hromada et al. (2020), reported home ranges ranging from 2-100 ha. However, Hromada et al. (2020) used kernel density approach, which consistently estimated home range smaller than MCP. In both studies and in general, tortoises had a proclivity for natural washes. Additionally, roads and their associated infrastructure influenced the movement behavior of the Mojave Desert tortoise. For example, Peaden et al. (2017) reported a reduction of home range size for individuals near and around roads and their associated infrastructure, and Hromada et al. (2020) reported that individuals selected areas away from roads at another site. Although there was a general avoidance of roads, Hromada et al. (2020) reported that individuals selected to move along anthropogenic linear features, such as fences, flood control berms, and railroads, and Sadoti et al. (2017) reported that tortoises moved more frequently near fences. Both of these findings were likely because these structures where impassible (see Rautsaw et al., 2018).

The Mojave Desert tortoise can traverse long distances, and males usually disperse further, on average, than females (Berry, 1974; Coombs, 1977; Burge, 1977; Berish and Medica, 2012). Adult tortoises moved on average 437 to 656 m per day. During the nesting season, female tortoises can move on average 632 m between the first and second clutches (Lovich et al., 2014); whereas in the spring, some males were reported dispersing greater than 1441 m leaving their home range in search of mates (Berry, 1974; Coombs, 1977; Burge, 1977). Franks et al. (2011) reported a maximum-distance traveled was 589 m, and Berry (1986) reported these types of movements could range between 1.4-7.3 km; relocated tortoises dispersed approximately 6.6 km from their original release site in some instances. However, O'Connor et al. (1994) suggested that movements of less than 200 m were most common.

In general, non-penned, relocated individuals often displayed long-distance dispersal and habitat can influence the dispersal distance (Nafus et al., 2017). The dispersal of juveniles and hatchlings was far more limited. These smaller size-classes dispersed at shorter distances relative to adults, and hatchlings moved less than 50 m per day (Berry, 1974; Coombs, 1977). Hazard and Morafka (2002) reported that hatchery-reared neonate and juvenile desert tortoise traveled a mean distance of 116 m and 107 m from release site after release, respectively, and travelled a total distance of 144 m and 203 m, respectively.

3.1.3 Tortoise and Terrestrial Turtle-Specific Crossing Design and Implementation

We searched the literature for the types of crossings that have been designed and/or implemented for use by tortoises or terrestrial turtles, which specific design criteria have shown to be more successful, and if any design features have been shown to either deter tortoises or terrestrial turtles or attract them but be detrimental.

3.1.3.1 Tortoise and Terrestrial Turtle-Specific Crossing Structure Design

There are several reports that Mojave Desert tortoises utilized existing drainage culverts with fencing (Boarman and Sazaki, 1996; Boarman et al., 1997; Boarman et al., 1998; Boarman and Kristan, 2006). However, we found no literature of crossings designed specifically for Mojave Desert tortoises. Desert tortoises were reported to use various crossing structure types, such as corrugated metal pipe culverts, reinforced concrete pipe culverts, reinforced concrete box culverts (Boarman et al., 1992; Boarman, et al., 1997; Cavallaro et al., 2005; Lovich et al., 2011), and potentially bridges (Cavallaro et al., 2005). In most cases, culverts were designed for the purposes of transporting stormwater runoff beneath roads and were adapted (e.g., fencing was added) to funnel tortoises or other vertebrate species to the crossing (Boarman et al., 1997). For example, in San Bernardino County, California along Highway 58, 24 culverts designed for stormwater runoff diversion were retrofitted with road-side fences as a Mojave Desert tortoise road mortality mitigation strategy. The culverts were constructed from corrugated steel pipes or reinforced concrete conduits and varied in size (i.e., 48-63 m in length, 1-3.6 m in diameter; Boarman and Sazaki, 1996; Boarman et al., 1997).

Although there were no examples of culverts specifically engineered for Mojave Desert tortoises, there was literature about fence design for tortoises and freshwater turtles. Boarman et al. (1997) constructed tortoise-barrier fences consisting of galvanized steel wire (10 gauge) and hardware cloth (1.3 cm mesh). The fence was 45 cm in height. In another tortoise species in France, fences were constructed of sheep wire and fine wire mesh and were installed in association with under passages (i.e., culverts and tunnels) alongside a highway route to minimize road mortalities of Hermann's tortoise (*Testudo hermanni*; Guyot and Clobert, 1997). This fence was 40 cm in height and 10 cm of fencing was buried. Studies focusing on freshwater turtles recommended fencing to be at least 60 cm in height (Woltz et al., 2008) and slanting fencing inwards with an accompany lip at the top of the fence to decrease escape (Aresco, 2005). In all these studies (i.e., Boarman et al. [1997]; Guyot and Clobert [1997]; Aresco [2005]), turtles and tortoises successfully crossed roadways by utilizing hydraulic culverts, tunnels, and dual-purpose culverts.

3.1.3.2 Design Criteria Showing Success

There is little experimental research focusing on Mojave Desert tortoises and the various designs of under passages. Tortoises successfully crossed a variety of culverts constructed from different materials (corrugated steel, concrete pipe, and concrete box culverts) and different dimensions (33-66 m length, 0.9-1.5 m diameter pipe, and 3-3.6 m by 1.8 - 3.0 m diameter for box culverts, see Boarman and Sazaki, 1996; Boarman et al., 1997; Boarman et al., 1998). In a study being conducted in southern Nevada, preliminary data suggested that culvert usage by Mojave Desert tortoises was not influenced by culvert dimensions (BLM and USFWS, unpublished data). For example, tortoises successfully crossed under roadways via culverts with small openness ratios (i.e., 0.06, 0.17, and 0.20; BLM and USFWS, 2020). There is evidence that upland reptiles, including desert tortoises, may prefer easily accessible box culverts for protection from predators and overheating in the sun, and incorporate extended tunnels at those locations (AGFD, 2006; Cavallaro et al., 2005). In a small study, desert tortoises entered concrete culverts (2.44 X 1.22 m) under large highways (Ruby et al., 1994); however, these tortoises (*N* = 5) were placed at the culvert entrance before the experimental trial began. Unfortunately, the published literature pertaining to hydraulic culvert use by Mojave Desert Tortoise lacks specific design details about the culvert, such as plunge pool depth, erosion, vegetation and debris blockage, apron slope, and presence of riprap. All of these design features could influence tortoise usage.

Culverts alone were not effective mitigation strategies against road mortality (Cunnington et al., 2014); however, culverts in association with fencing were highly effective for desert tortoises (Boarman and Sazaki, 1996; Boarman et al. 1997). As a mitigation strategy for road mortalities, fencing was installed along various roadways throughout desert tortoise range (USFWS, 2011). Boarman et al. (1997) suggested without empirical data that visibility through fencing material might encourage tortoise through structures beneath roads. He based this suggestion on results from Ruby et al. (1994), where tortoises interacted (e.g., nose and foot touches) with solid fencing materials more often than non-solid materials. Fences have also resulted in reduced traffic mortality by Hermann's tortoise in France (Guyot and Clobert, 1997), and other freshwater turtles (Aresco, 2005).

3.1.3.3 Deterrents, Detrimental Attractants, and other Dangers

There was very little published about deterrents and detrimental attractants of culverts for the Mojave Desert tortoise. We found one study specifically investigating deterrents in culvert usage by Mojave Desert tortoises. Ruby et al. (1994) reported observations after placing tortoises in front of concrete barriers along a busy highway, and suggested vibrations and noise from traffic impacted movement behavior. For general wildlife, there was a plethora of reported deterrents (e.g., light, vibrations and noise, habitat quality, topography, human activities, high water level, humidity and temperature) in the literature (e.g., Yanes et al., 1995; Ng et al., 2004; Dickson et al., 2005; van der Grift et al., 2015; Craveiro et al., 2019; Brunen et al., 2020; Testud et al., 2020), however, most of studies focus on mammal communities (Taylor and Goldingay, 2010).

Unlike deterrents, there were several detrimental attractants identified in the literature. Any holes in the road-side fencing might be perceived as a burrow. These holes allowed access to the road, but then made exit from the road way difficult (Baxter-Gilbert et al., 2015; Ruby et al., 1994). Another maintenance-related detriment was unmaintained culverts. Mojave Desert tortoises, in an industrial landscape, utilized anthropogenic structures as surrogate burrows (e.g., wind turbine pads and drainage culverts; Lovich and Daniels, 2000; Lovich et al., 2011). This attraction for anthropogenic burrow surrogates was also reported in western burrowing owls (*Athene cunicularia hypugaea*) in southern Nevada (Greger and Hall, 2009). In one instance, a corrugated steel culvert (i.e., 60 cm diameter) installed for stormwater runoff partially filled with sediment, and a male desert tortoise utilizing the culvert as a burrow was entrapped after an erosion event completely filled the structure (Lovich et al., 2011). This entrapment threat might extend beyond industrial landscapes and include drainage culverts throughout the range of the desert tortoise, especially sites with steep slopes and narrow culverts. Although there is no existing published literature about plunge pools associated with culverts attracting Mojave Desert tortoises due to water storage, any anthropogenic structure with the ability to hold water for extended periods could attract and be detrimental to desert tortoises. As an example of an attractant, Medica et al. (1980) reported several Mojave Desert tortoises likely ingesting water from a roadway after a thunderstorm event. In an industrially-altered landscape in southern California, wind-turbine pads often collect rain water after rain events and potentially attracted desert tortoises to construct and use burrows near these anthropogenic structures (Lovich and Daniels, 2000). In general, tortoises are poor swimmers but possess the ability to float (Patterson, 1973; Strong and Walde, 2006). Deep, standing water might be a detriment to Mojave Desert tortoises, if individuals are trapped. For example, in swimming pools, desert tortoises will float for extend periods, but over time, they will sink and drown from drinking copious amounts of water (Jarchow et al., 2002). Also, see Section 3.1.1.1 and the discussion about guzzlers. Given the above literature, plunge pools associated with culverts, which hold water for extend periods of time, have the potential to cause drowning of desert tortoises if individuals cannot climb.

Entrapment of Mojave Desert tortoises was observed in other studies, including sites in southern Nevada. These entrapment events were from rock falls and riprap, a culvert design feature to reduce erosion and scour, consisting of cobble-sized rocks or larger. Near Yucca Mountain, an adult desert tortoise was trapped within a burrow by sections of a fragmented boulder for 11 months (Christopher, 1999); therefore, any culvert using cobble or larger rocks might pose a risk to tortoises. This adult tortoise survived but suffered severe physiological imbalances. Additionally, riprap was reported to have entrapped and killed one tortoise, likely through thermal exposure (BLM and USFWS, unpublished data). It is unknown how widespread or common entrapment by riprap is for Mojave Desert tortoises. USGS scientists (e.g., Boarman et al., 1992, 1997, 1998; Boarman, 1995; Boarman and Sazaki, 1996, 2006) monitored culverts over multiple years and did not report entrapment within riprap. Likewise, Stantec and USFWS biologists have monitored culverts in southern Nevada over several years without any instance of entrapment as well.

Wildlife passages, including culverts, potentially influence the predator-prey relationship by spatially condensing prey and increasing predation events (i.e., prey-trap hypothesis; see Hunt et al., 1987; Foster and Humphrey, 1995). For example, Alcott et al. (2020) reported that eastern snapping turtles utilized wet culverts (i.e., permanent lotic system) for foraging and specifically targeted migrating river herring as they pass through the structures. Mata et al. (2020) suggested that predators targeted wildlife passages and crossings in search of prey, while small mammals avoided crossings in the presence of predators. Similarly, Harris et al. (2010) reported a decline in southern brown bandicoot crossings at an underpass after foxes began utilizing the area (Harris et al., 2010). However, much of the research supporting the prey-trap hypothesis at wildlife underpasses (mostly non-permanent wet or fully terrestrial) was anecdotal (reviewed by Little et al., 2002), and most research found no support for the prey-trap hypothesis at terrestrial wildlife under passages (Little et al., 2002; Little, 2003; Dickson et al., 2005; Ford and Clevenger, 2010; Dupuis-Desormeaux et al., 2015; Martinig et al., 2020). Furthermore, Martinig et al. (2020) even suggested the temporal clustering of prey at under passages might dilute predation risk (i.e., predator swamping)- the exact opposite of the prey-trap hypothesis. In the Mojave Desert, numerous species utilize culverts as passages and these include predators, such as domesticated dogs and cats, coyotes, bobcats, raccoons, and humans (Ng et al., 2004; Boarman and Kristan, 2006). Undoubtedly, there is likely many more species, including mesopredators, that utilize culverts as crossing structures in the Mojave Desert, but the research is lacking at small- to medium-sized culverts (see Murphy-Marsical et al., 2015 for large underpasses). Although the presence of predators could potentially increase predation risk and support the prey-trap hypothesis, there was no evidence found in the literature that Mojave Desert tortoise densities increased or predation events increased at wildlife under passages. In general, tortoises displayed avoidance behaviors to roads and infrastructure (Peaden et al., 2017; Hromada et al., 2020), and their densities were lower near roads (see above citations).

Although roads are usually avoided by Mojave Desert tortoises, individuals still cross and use these linear structures (Peaden et al., 2017; Hromada et al., 2020), and sometimes to their detriment. Peaden et al. (2017) reported an increase in the time spent along fencing and roads relative to moving away from them. They postulated several reasons for their findings. One explanation was that tortoises were reluctant to crossroads. Another explanation was that roads were often attractants to Mojave Desert tortoises because roads mimic washes that usually possess bountiful food and water resources. Rainwater can collect on roads allowing individuals access to a very limited resource–water (Johnson et al., 1975). Because of the increase in water availability along roadside edges, vegetation is more robust providing wildlife, in particular herbivores like desert tortoises, ample and consistent foraging even in drought years (Johnson et al., 1975). Peaden et al. (2017) suggested individuals would spend more time along roads and fences foraging. This affinity toward road-side forage was mirrored in another tortoise species (Chaco tortoise [*Chelonoidis chilensis*]; Boarman et al., 1997). Finally, several authors reported a pacing behavior by Mojave Desert tortoises along fences (Fusari, 1982; Ruby et al., 1994; Boarman et al., 1997; Peaden et al., 2017), which would increase duration along roads. This increased duration along fencing could increase heat exposure risk, and Peaden et al. (2017) reported one death.

3.1.4 General Wildlife Use and Crossing Design and Implementation

We examined the use of crossings by other species of wildlife, looking at aspects of those structures that were successful and applicable to the design of desert tortoise crossing structures. For this, we focused on reptiles similar to desert tortoises when the literature was available. When literature was not available, we investigated the general types of wildlife crossings and underpasses designed and/or implemented with a focus on arid or semiarid environments in addition to those specific design criteria that were successful. We also looked at the reproduction rates of wildlife populations fragmented by fenced roads and their ability to maintain genetic diversity and avoid inbreeding depression.

3.1.4.1 General Crossing Design/Implementation in Arid or Semiarid Environments

Other than Mojave Desert tortoise examples (e.g., Boarman et al., 1992; Boarman, et al., 1997; Cavallaro et al., 2005; Lovich et al., 2011), we found several other studies within arid environments. Ng et al. (2004) reported mammalian wildlife use of wildlife passages (i.e., culverts and large underpasses) along three highways (i.e., US 101, State Route 23, and US 118) in the San Fernando Valley, and these underpasses varied in size considerably (square culverts–97 m X 4.2 X 3.7 m [length X width X height]; pipe culverts – 176 m X 2.6 m X 2.9 m; underpasses – 44 m X 42 m X 5.2 m). In southern California's Coachella Valley and San Gorgonio Pass, a study focusing largely on mammalian usage of underpasses reported the dimensions of seven underpasses range as follows: 11.5-150 m wide, 12.2-112 m long, and 2.5-9.0 m high (Murphy-Mariscal et al., 2015). The openness factor of these large underpasses ranged from 0.46-28.0 (Murphy-Mariscal et al., 2015).

The construction materials were not characterized by authors, but these underpasses were large and associated with interstates, highways, and state routes and likely not designed initially for wildlife in mind. Along Route 14 near Red Rock Canyon State Park, California, Bremner-Harrison (2007) reported bobcats and coyotes successfully cross the road using pipe culverts. At these sites, bobcats utilized smaller culverts (38-61 cm height, 47-71 cm width, 34-205 m length, 0.001-0.006 openness factor) than coyotes (95 cm height, 175 cm width, 116 m length, 0.014 openness factor). This pattern was repeated other pipe culverts along Highway 58 near Kramer Junction, California (bobcat: 92-159 cm height, 93-149 cm width, 181-204 m length, 0.004-0.01 openness factor; coyote: 141-180 cm height, 130-170 cm width, 172-220 m length, 0.01 openness factor). Interestingly, domestic cats and dogs utilized a wider range of sizes (i.e., height, length, widths, and openness factors) in pipe culverts than bobcats and coyotes.

Numerous species of desert wildlife were reported utilizing drainage culverts and other underpasses; however, the published literature was mammal-biased for arid environments. In southern California, large predator species, such as mountain lions, were observed using wildlife underpasses (Ng et al., 2004). Several species of mesocarnivores species, including coyotes, bobcats, foxes, raccoons, skunks, opossums, and ringtails, were reported using drainage culverts, underpasses, and wildlife crossings in southern California and Nevada. Lagomorphs (e.g., jackrabbits and cottontails) and other small mammal species (e.g., ground squirrels, kangaroo rats, wood rats, mice, shrews, and voles) were documented utilizing these structures (Boarman and Sazaki, 1996; Bremner-Harrison et al., 2007; Ng et al., 2004; Tracey et al., 2014; Murphy-Mariscal 2015; and Stricker, 2015). Finally, some studies reported humans, as well as domestic dogs and cats using crossings (Boarman and Sazaki, 1996; Bremner-Harrison, 2007; Murphy-Mariscal et al., 2015; and Ng et al., 2004).

3.1.4.2 Arid or Semiarid Environment Design Criteria Showing Success

Culverts with accompanying fencing were very successful reducing road mortalities in arid environments. For example, studies reported a 93% reduction in road mortality for desert tortoises post-installation of fencing and verified tortoises utilized culverts to cross the road (Boarman and Sazaki, 1996; Boarman et al., 1997). Additionally, these studies reported other small to medium-sized vertebrates utilizing the culverts, which reduced road mortality of these species as well. Ng et al. (2004) reported that the surrounding habitat was the best predictor of culvert use in for mammalian species in an arid environment, but they also reported that passage length was an important predictor for mid-sized mammalian species. For example, Ng et al. (2004) reported that bobcats and coyotes avoided passages surrounded by developed habitats. Racoon passage usage was positively correlated with developed habitat and length of passage. No significant relationship was found between mule deer passage use and habitat type, but mule deer were likely to use passages with shorter lengths and more human activity. For highway underpasses, structural design factors were not important for most species except for bobcats and lagomorphs (Murphy-Mariscal et al., 2015). Bobcats preferred wider and lagomorphs preferred narrower underpasses (Murphy-Mariscal et al., 2015). Recall, Murphy-Mariscal et al. (2015) studied large, highway/interstate underpasses, which were larger than culverts. Giving no dimensions, construction design or material details, Manteca-Rodríguez et al. (2021) reported underpass usage by javelina, gray fox, Coues white-tail deer, white-nosed coati, raccoon, hooded and striped skunks, opossum, coyote, ringtail, and mountain lion in the Sonoran Desert near the Mexico-Unites States broader.

3.1.4.3 General Culvert and Underpass Design/Implementation

Box culvert underpasses can be retrofitted with fencing to benefit a target species. Utilization of a lipped wall alongside highways may prevent road access by amphibians and may encourage movement toward installations like culverts that lead underneath roadways (Puky, 2003; Cavallaro et al., 2005). Box culverts have been modified with a ledge to allow for passage of small mammals, and stumps and vegetation have been shown to provide protective cover for small mammals beneath an underpass designed for the passage of large mammals beneath a highway (FHWA/US DOT, 2011). Trenches dug underneath the rails and between the ties of railroad tracks facilitate the passage of gopher tortoises across the railway and create an escape route for individual tortoises trapped between the rails while maintaining full rail functionality (Rautsaw et al., 2018).

3.1.4.4 General Culvert and Underpass Design Criteria Showing Success

There were mixed results within the literature about the importance of structure design and landscape characteristics of under passages with wildlife usage metrics (see Clevenger and Waltho, 2005). This lack of generalization about how organisms respond to crossing structures was undoubtedly related to species-specific and habitat-specific factors of each study. There was a plethora of reported factors (e.g., light, vibrations and noise, habitat quality, topography, human activities, high water level, humidity and temperature) predicting success and failure of culverts and ecopassages (e.g., Yanes et al., 1995; Ng et al., 2004; Dickson et al., 2005; van der Grift et al., 2015; Craveiro et al., 2019; Brunen et al., 2020; Testud et al., 2020), however, most studies focused on mammal and amphibian communities.

Preferred culvert size varies depending upon the animal of concern. A study from Smith (2003) reported that meso-mammals in Florida were observed to select culverts approximately 3.1 m wide and larger carnivores selected 2.4 m wide culverts for passage. In contrast, Herpetofauna selected culverts 1.5 m or wider and 60-150 cm high. Small mammals selected for a range of culvert width of 0.6-3.1 m. In the Smith (2003) study, culverts consisted of pipes or boxes made of corrugated steel or concrete with varying dimensions and lengths. These structures were single- or multi-celled structures, where a single-celled structure consisted of one pipe or box culvert and a multi-celled structure consisted of two or more pipes or box culverts. Passage rates of small mammals and herpetofauna were higher for multi-celled structures, while carnivores passage rates were higher for structures with less cells (Smith, 2003). Herpetofauna passage rates were highest in two- and three-celled culverts. For amphibians and reptiles, Woltz et al. (2008) suggested roadway crossing structures be made of round PVC pipe and be a diameter of >0.5 m, and also suggested that a substrate like soil or gravel be used to line the passage. Fencing that guides wildlife to a specific crossing area or structure is also suggested to aid in successful roadway crossing and mitigating road mortalities in a variety of locations with amphibians and reptiles (Puky, 2003; Smith, 2003; Woltz et al., 2008). Reptile species preferred shorter culverts (Ascensão and Mira, 2007), and avoided culverts with detritus pits near the entrances and below the level of culvert structures (Yanes et al., 1995; Woltz et al., 2008). Other species of reptiles, in particular freshwater turtles, utilized culverts after fencing was retrofitted (Aresco, 2005); however, these culverts were fully aquatic. In another aquatic example, eastern snapping turtles foraged around culverts taking advantage the naivety of migrating river herring (Alcott et al., 2020).

3.1.4.5 Effect on Reproduction Rates of Populations Fragmented by Fenced Road

In general, roads and their infrastructure negatively impacted turtle populations. We were unable to identify any published literature quantifying the effects of fragmentation by road fencing on Mojave Desert tortoise reproductive rates. Roads, in general, were shown to lower adult Mojave Desert tortoise densities (Boarman and Sazaki, 2006; Nafus et al., 2013), cause avoidance behaviors (Peaden et al., 2017; Hromada et al., 2020), expose individuals to extreme temperatures (Peaden et al., 2017), and cause genetic structuring at a fine scale (Latch et al., 2011). All these effects could indirectly influence reproductive rate within tortoise populations adjacent to roads and their infrastructure.

Lower genetic diversity can cause inbreeding depression, which can cause well-documented detriments to numerous fitness parameters (see Reed and Frankham, 2003), specifically reproduction. Roads and their associated infrastructure, through direct morality (e.g., vehicle collisions and temperature exposure), could reduce the effective population size via genetic drift (i.e., the loss of genetic diversity; Holderegger and Di Giulio, 2010). Another mechanism for reducing genetic diversity within a population is through isolation (i.e., impeding of gene flow). Roads and railways reduced genetic connectivity within Mojave Desert tortoise (Dutcher et al., 2020), and roads were even shown to impede gene flow enough to create fine-scale genetic differentiation at one site (Latch et al., 2011). This road effect pattern was not replicated among two other populations of Mojave Desert tortoises separated by an interstate in California (Lovich et al., 2020). In another turtle species (*Chrysemys picta*), maternal genetic diversity (i.e., mtDNA) was lowered in populations adjacent to roads compared to natural populations, and these populations had less females contributing to recruitment (i.e., genetic contribution to next generation; Laporte et al., 2013). Given enough time, any anthropogenic factor impeding gene flow could create inbreeding depression and adversely impact reproduction of tortoises. This trend is especially true when it is compounded by natural barriers that impede gene flow. There was a wealth of knowledge related to genetic structuring and landscape features associated with the impediment of gene flow for Mojave Desert tortoises. For example, Hagerty et al. (2011) reported that mountain ranges and low-lying valleys impeded gene flow among populations, highlighting the importance of elevation in genetic structuring of the species. Gene flow was further impeded by distance among the populations – a phenomenon termed isolation by distance (Murphy et al., 2007; Hagerty and Tracy, 2010; Averill-Murrary and Hagerty, 2014; Sánchez-Ramírez et al., 2018; Lovich et al., 2020; Dutcher et al., 2020).

In tortoises, lower genetic diversity at the population and individual levels was shown to reduce fitness, reproduction and survival. For example, Ennen et al. (2010) linked lower genetic diversity (i.e., lower genetic heterozygosity, allelic diversity, and percentage of polymorphic loci) and poor reproduction and recruitment in populations of gopher tortoises (*Gopherus polyphemus*) – a close relative to the Mojave Desert tortoise. These populations experienced dramatic population declines and likely suffered from reduced gene flow due in part to the patchy distribution of suitable soils and fragmentation caused by habitat destruction and degradation. The importance of genetic diversity for the Mojave Desert tortoise has implications for conservation mitigation beyond the discussion above. Recently, individual heterozygosity – a measure of genetic diversity of an individual tortoise – was linked to translocation success (Scott et al., 2020). Individuals with greater heterozygosity had higher survival rates post translocation.

3.2 PLACEMENT OF CROSSINGS

3.2.1 Criteria for Crossing Success

We investigated the general characteristics of wildlife crossings that make them successful specifically for tortoises and terrestrial turtles and generally for vertebrate populations at large. We also reviewed studies that assessed which characteristics of surrounding habitat and surrounding wildlife populations make crossings more likely to be successful, focusing on features that were used more often or were shown to affect the studies' target populations. For Mojave Desert tortoises, the best placement of crossings were dry desert washes because tortoises use these features regularly and culverts already exist in many of the locations to divert stormwater.

3.2.1.1 Characteristics of Successful Crossings

3.2.2 Tortoises and Terrestrial Turtles

Most research documenting successful wildlife crossings for chelonians (order Testudinidae) were for freshwater species and not terrestrial species. Located in Paynes Prairie, Florida, one of the most successful crossings consisted of 8 concrete culverts (box culverts – 2.4 m X 2.4 m X 44 m and 1.8 m X 1.8 X 44 m; cylindrical culvert – 0.9 m diameter X 44 m) along a 2.8 km stretch of US Highway 441 (Dodd et al., 2004). These culverts could collect natural sedimentation or were partially buried, and two of the culverts constructed in locations along this section of road were dry culvert crossings. Natural substrate was considered a preferred crossing characteristic for amphibians and reptiles (Kintsch and Cramer, 2011), and a combination of wet and dry culverts will likely increase the numbers of unique species using the crossings (see Brunen et al., 2020). Accompanying the 8 culverts at Paynes Prairie was a concrete barrier (i.e., 1 m concrete wall with inward facing lip at the top) extending the full length of the site on both sides of the road (Dodd et al., 2004). In another example from Florida, Aresco (2005) installed erosion control fencing (i.e., woven vinyl of 0.6 m height) in association with a wet culvert and significantly reduced turtle road mortality. Fencing appears to be the key feature predicting success of turtle and tortoise crossings or retrofitting culverts (see citations above). Other attributes reported as successful for turtles include structure/cover objects, accessibility, entrance dimensions, excluding detritus pits, and strategic placement considering target species ecology (Yanes et al., 1995; Jochimsen, et al., 2004; Cavallaro et al., 2005; AGFD, 2006).

3.2.3 General Vertebrate Populations

Like previously stated, characteristics that make crossings successful for the general vertebrate population likely mirror those that make them successful for tortoise populations. There was a plethora of reported factors (e.g., light, vibrations and noise, habitat quality, topography, human activities, high water level, natural vegetation, humidity and temperature) predicting success and failure of culverts and ecopassages in the literature for vertebrates (e.g., Yanes et al., 1995; Cavallaro et al., 2005; Clevenger et al., 2001; Clevenger et al., 2003; Smith, 2003; Ng et al., 2004; Dickson et al., 2005; van der Grift et al., 2015; Craveiro et al., 2019; Brunen et al., 2020; Testud et al., 2020), however, most of these studies focused on mammal and amphibian communities. The reoccurring theme for successful wildlife crossing via culvert is the need for fencing (Jochimsen et al., 2004).

3.2.3.1 Characteristics of Surrounding Habitat and Wildlife Populations

Habitat quality, but also human disturbances and development, might impact the success of the wildlife crossing (Yanes et al., 1995; Ng et al., 2004). Connectivity of local vegetation and other habitat characteristics near the entrance of a culvert is recommended (Smith, 2003; Ng et al., 2004; Clevenger et al., 2001; Clevenger et al., 2003) and major alteration to areas where passage structures are placed may reduce the success of new structures (Cavallaro et al., 2005). Smith (2003) recommended placement of crossing structures between 3.7 and 5.1 m from habitat and careful consideration of vegetation height (> 30 cm) leading towards the entrance because this feature was important to herpetofauna usage.

3.2.4 Desert Tortoise Population and Habitat at the Project

We reviewed the available peer-reviewed literature for information about desert tortoise populations and habitat surrounding the Project's two "target" highways, US 95 and US 93. From these studies, Stantec gathered information about known similarities and key differences between the desert tortoise populations and habitat surrounding the "target" highways and other desert tortoise populations and habitat observed in similar studies.

3.2.4.1 Desert Tortoise Population at Target Highways

The Mojave Desert tortoise population along US 95 and US 93 in Nevada occurs within the Eastern Mojave and Northeastern Mojave Recovery Units, and population densities were generally low in these units (USFWS, 2011), especially the Northeastern Mojave Recovery Unit. Two studies (Garcia et al., 1985; USFWS, 2020) in Coyote Spring Valley (near and along US 93) reported variable densities in Coyote Spring Valley (i.e., Northeastern Mojave Recovery Unit), but this area was largely characterized as low-density. However, within the Northeastern Mojave Recovery Unit, long-term monitoring since 2004 suggested positive trends in density making it the only unit with such trends (Allison and McLuckie, 2018).

Both the Northeastern Mojave and Eastern Mojave Recovery Units are genetically distinct and possessed genetic structure within each recovery unit (Hagerty and Tracy, 2010). The populations in the Northeastern Mojave Recovery Unit were genetically similar to the Upper Virgin River Recovery Unit to the northeast (i.e., both within the northern Mojave cluster) but remained genetically distinct based on substructure (Hagerty and Tracy 2010). In general, genetic structuring across the desert landscape was largely influenced by distance (i.e., isolation by distance) and barriers (i.e., valleys and mountains; Hagerty and Tracey, 2010; Hagerty et al., 2011; Lovich et al., 2020; Dutcher et al., 2020). Along US 95 and US 93 in Nevada, these populations cluster within Amargosa Desert and Muddy Mountain subunits (Hagerty and Tracy, 2010).

3.2.4.2 Desert Tortoise Habitat Surrounding Target Highways

The area around the target highways is mostly Mojave Desert scrub vegetation, dominated by creosote bush/white bursage (*Larrea tridentata/Ambrosia dumosa*) (Turner, 1982; Drake et al., 2013).

In 2005, lightning fires near the area of concern in the northeast Mojave Desert, (called the Southern Nevada Fire Complex) impacted over 24,254 ha of desert tortoise critical habitat (Nussear et al., 2009; USFWS, 2011; Drake et al., 2015). This wildfire complex resulted in direct impacts (injury and death) to desert tortoise individuals as well as indirect impacts (altered plant community) (Drake et al., 2015). As a result, perennial vegetation cover was reduced by >90% (Drake et al., 2015). Drake et al. (2015) found different habitat selection patterns by desert tortoises between unburned and burned habitats when based on the use of open and vegetated microhabitats. In contrast, burrow selection was not found to be different between burned and unburned areas. Interestingly, Drake et al. (2015) found that the desert tortoise was not deterred from using areas impacted by wildfire. Desert tortoises that occupied unburned area selected *A. dumosa* a short shrub, *L. tridentata* a tall evergreen shrub, and *Yucca schidigera* a tall succulent for cover. Desert tortoises within burned habitat continued to use remaining *A. dumosa*, and *L. tridentata*, and years after the fire relied more on *Sphaeralcea ambigua* an herbaceous perennial as cover (Drake et al., 2015).

4.0 DISCUSSION

4.1 DESIGN OF CROSSINGS

4.1.1 Desert Tortoise Maximum Vertical Climbing Height

Adult Mojave Desert tortoises were limited in their ability to climb vertical barriers, in general. They possessed, however, the ability to climb barriers of less than 30 cm. This reported ability was likely linked to barrier materials and shape. For example, tortoises were able to climb horizontally laid telephone poles (i.e., not a perfect vertical barrier) of less than 30 cm in height and likely lacked the ability to climb a gentle slope of a fiber-glass guzzler due to the lack of traction. Gopher tortoises, a related tortoise species to the Mojave Desert tortoise, were unable to climb vertical obstructions of 15 cm (i.e., railroad rails) without a bolster such as vegetation or debris. This inability to climb a much smaller vertical barrier might be species-specific, but movement studies reported linear movements of Mojave Desert tortoises along railways suggesting that individuals rarely crossing railroad rails and disperse along the rails in a parallel fashion. One study, which focused on freshwater turtles – a group possessing a greater proclivity to climb, recommended barriers slanted inwards with overhanging, inward facing lip could potentially decrease the ability of turtles to climb barrier fencing. These additional precautions could potentially reduce the needed height of the barrier fencing; however, more research is needed to assess the effectiveness of these features on Mojave Desert tortoises. Our literature review highlights the lack of information of the vertical climbing ability of Mojave Desert tortoise. For example, we found no study investigating age- or size-specific climbing ability; therefore, there was a knowledge gap on this ability for sub-adults, juveniles, and hatchlings. All reports in the published literature focused on adults. We would not expect the climbing ability to hold constant across size and age classes. For example, tire ruts on sandy roads influenced the movement behavior and patterns of juvenile gopher tortoise. Although no published literature exists about the ability of desert tortoise to climb and traverse vertical barriers associated with hydraulic culverts, such as riprap, plunge pools, debris, or vegetation (e.g., Russian thistle), the literature did demonstrate that any vertical barrier of 30 cm or greater associated with an existing culvert could impeded adult tortoises from using the culvert as a wildlife crossing.

4.1.2 Desert Tortoise Maximum Slope Traversal

We assessed maximum slope traversal using three criteria: above ground terrain, burrow location, and declination of the subterranean burrows. Individuals were reported traversing slopes between 3-100%, 4.6-33.4%, and 17.63-83.91% for above ground terrain, burrow locations, and declination of subterranean burrows, respectively. Although the Mojave Desert tortoise could traverse steep slopes up to 100% (i.e., climbing to a winter burrow; Woodbury and Hardy, 1948), there was more information suggesting individuals typically avoid slopes nearing 60% aboveground and rarely excavated burrows with declination at that slope. Like previously mentioned, a tortoises' ability to traverse slope will undoubtedly be linked to construction material. Even at negligible slopes, tortoises were likely unable to traverse slopes constructed of fiberglass; therefore, the traction of materials should be considered.

4.1.3 Desert Tortoise Burrow Dimensions

We found that burrows had a wide range of lengths (5-1000 cm), entrance widths (30-76 cm) and heights (13-17 cm). Burrow measurements may be informative to the design and dimensions of road crossings because of the risk of entombment due to erosion in unmaintained culverts. Culverts, however, were much larger than burrows constructed by Mojave Desert tortoise. There was little experimental research focusing on Mojave Desert tortoises and the various designs of under passages. Tortoises successfully crossed culverts constructed from corrugated steel and concrete (i.e., pipe and box culverts), and these culverts had different dimensions (e.g., 33-66 m length, 0.9-1.5 m diameter, and 3-3.6 m by 1.8-3.0 m for box culverts). To our knowledge, there exists no study investigating the relationship between culvert design (material and dimension) and desert tortoise usage. Preliminary data suggested that tortoises successfully crossed under roadways via culverts with small openness ratios (i.e., 0.06, 0.17, and 0.20).

4.1.4 Desert Tortoises Home Range size and Dispersal distance

The average home range of Mojave Desert tortoises can vary between 1-33 ha among populations, and home range size was extremely variable among individuals within populations. Individual home range values can exceed 200 ha. The Mojave Desert tortoise can disperse long-distances (i.e., 1.4-7.3 km, normally) on occasion. The movement ecology (i.e., home range size, dispersal, and movement patterns) will be related to geography, climate and weather patterns, season, slope, and other landscape features. Linear features, such as roads and railways, impede tortoise movements, lower home range sizes, and might restrict gene flow throughout the landscape. Home range, individual movement, and population densities, especially of local populations, will be informative to the placement and prioritization of road crossings for desert tortoise and may aid in reducing roadway mortality, promoting habitat connectivity of habitat, facilitating individual movement, and genetic flow.

4.1.5 Types and Characteristics of Crossing Implemented for Desert Tortoises and other Wildlife

Although we did not find single-purpose desert tortoise crossing structures in the literature, tortoises and terrestrial turtles were found to use metal and reinforced concrete pipe culverts, and reinforced concrete box culverts designed for transporting stormwater runoff under physical barriers such as roads. To our knowledge, there were no studies quantifying the relationship between culverts or crossings characteristics (i.e., design and landscape features) and desert tortoise usage. In most cases, wildlife crossings utilized by turtles/tortoises were not specifically designed to facilitate wildlife movement, but retrofitted to increase use (i.e., installation of road-side fencing). Culverts varied in size, construction, and location. Even in arid and semiarid environments, design features were variable, but authors suggested habitat quality and passage length were key features for success for mammals. Within the desert, culverts were used by medium-sized vertebrates, bobcats, coyotes, racoons, mountain lions, and deer (to name a few). There was some evidence for a positive relationship between design features (e.g., number of cells and dimensions) for wildlife use; however, these varied depending on taxonomic group and trophic position. Herpetofauna and small mammals preferred multiple-celled culverts, whereas carnivores preferred single-celled culverts. The only generalization to be made was culverts alone, regardless of location, climate (e.g., arid, semiarid, or temperate), or taxonomy, were not enough to mitigate road mortality on wildlife, including desert tortoises, reptiles, amphibians, and other mammal species. Culverts needed roadside fencing to be effective mitigation to road mortality.

Most studies investigated culvert usage by desert tortoise post-installation (i.e., usually decades after construction) and usually compared vehicle mortality rates before and after the construction of roadside fences associated with these culverts. The fencing of roads near culverts significantly reduced wildlife mortality, including desert tortoises and turtles. However, fencing was linked to one mortality due to heat exposure. To our knowledge, there exists no published literature describing a mortality event related to plunge pool (i.e., entrapment or drowning) or standing water within plunge pool or culvert. However, one study reported a significant number of mortality (i.e., drowning) events for desert tortoises within wildlife guzzlers, especially those constructed from fiberglass. Additionally, there exists no published literature about movement impediments of desert tortoises through culverts or wildlife crossings due to plunge pools height, the presence of riprap and erosion, and surrounding vegetation. Overall, there is a dearth of before-after-control-impact (BACI) studies isolating the impacts (both positive and negative) of culverts pre- and postconstruction. BACI studies would specifically address (i.e., causation relationship) the influence of culverts and their associated features (i.e., fences, plunge pools, riprap, etc.), collectively, on desert tortoises. This finding was not unexpected because culverts, especially culverts in desert tortoise habitat, were installed or designed for stormwater when these roads were constructed decades ago. What we do know is that structures allow for relatively safe passage (i.e., no evidence of prey-trap) for desert tortoises and may provide a location to overnight in and refugia from overheating. Detriments may have lower population consequences compared to the unmitigated road mortalities of the past. Long-term studies on culvert usage by desert tortoises is required to better understand frequency of usage, and its interaction with abiotic and biotic variables.

4.1.6 Design Features Associated with Deterrents, Attractants, and Detriments to Desert Tortoises

More rigorous investigations are needed to identify attractants and detriments of culvert use by Mojave Desert tortoises. Culverts can attract many species for variety of reasons, but habitat quality was a common landscape feature reported as an attractant in the literature for wildlife. However, there were numerous factors shown to either to deter or attract wildlife, and these factors were highly variable depending on location and focus taxon. Again, we found no study that quantified tortoise preference or avoidance for a specific design or landscape features associated with culverts. This finding was largely due to the lack of published research on the subject. However, we potentially identified two detriments associated with culverts. Unmaintained culverts (i.e., partially filled with sedimentation) were found to be utilized by desert tortoises and burrowing owls. In the case of burrowing owls, these unmaintained culverts increased occupancy of the species at sites in Nevada. However, for desert tortoises, unmaintained culverts had the potential of entrapment leading to death, which occurred at a hilly, altered industrial landscape with erosion issues. When desert tortoises traversed in areas with linear features (e.g., roads and fences), individuals spent more time in these areas compared to natural areas, and more often experienced extreme temperatures near the thermal maximum. In one instance, an adult tortoise was found dead along a road-side fence.

Wildlife passages, including culverts, rarely influenced the predator-prey relationship by spatially condensing prey and increasing predation events. Most research found no support for the prey-trap hypothesis at terrestrial wildlife under passages, and this finding included turtles. We found literature reported known predators (e.g., dogs and coyotes) of the Mojave Desert tortoises utilizing culverts as wildlife passages. In arid environments, most other culvert-use studies focused on mammals, especially large carnivores (e.g., mountain lions and bobcats) and game species (e.g., deer). Although the presence of predators could potentially increase predation risk and support the prey-trap hypothesis, there was no evidence, to our knowledge, that Mojave Desert tortoise densities increase above natural values and that predation events increased at wildlife under passages. The prey-trap hypothesis has mixed support in the literature with more studies rejecting the premise. From our findings, tortoises, in general, displayed avoidance behaviors towards roads and infrastructure, and their densities are usually lower near roads. Again, long-term monitoring of culverts would be needed to assess the prey-trap hypothesis in the desert ecosystem and identify additional usage of culverts by predators.

4.1.7 Impacts of Fenced Roads on Genetic Diversity and Inbreeding Depression

To our knowledge, there exists no study on the Mojave Desert tortoise quantifying the effects of fragmentation by road fencing on reproductive rates. From the literature, roads and their associated infrastructure were shown to impact adult Mojave Desert tortoise densities, movements, and genetic structuring at a fine scale. All these adverse effects could indirectly influence reproductive rate with tortoise populations adjacent to roads and their infrastructure. Roads and their associated infrastructure could reduce genetic diversity through direct morality (e.g., genetic drift; the random loss of genetic diversity) and reduce gene flow and connectivity to create fine-scale genetic differentiation for Mojave Desert tortoises. Lower genetic diversity can cause inbreeding depression and lower reproductive rates. For example, lower genetic diversity at the population and individual levels were shown to reduce fitness, reproduction and survival in tortoises with *Gopherus*.

4.2 PLACEMENT OF CROSSINGS

4.2.1 Landscape and Habitat Characteristics of Successful Wildlife Crossings

There were mixed results within the literature about the importance of structure design (i.e., materials, dimensions, etc.) and landscape characteristics of under passages with wildlife usage metrics. This lack of generalization about how organisms respond to these anthropogenic structures was undoubtedly related to species-specific and habitat-specific factors of each study. There was a plethora of reported factors (e.g., light, vibrations and noise, habitat quality, topography, human activities, high water level, humidity and temperature – to name a few) predicting success and failure of culverts and ecopassages in the literature; however, most of these studies focused on mammal and amphibian communities not in arid ecosystems. Although published literature exists about Mojave Desert utilization of existing culvert, these studies usually only provide dimensions and construction material of the culverts and failed to full describe the characteristics of the culverts, such as plunge pools height, the presence of riprap and erosion, and surrounding vegetation. From the literature, we can conclude that culverts in Mojave Desert tortoise habitat were likely constructed in the best location (i.e., dry desert washes) for use by tortoises. Desert tortoises have an affinity for washes for movement, foraging, and burrow placement. In one study, many road crossings occurred in areas near washes. Outside of intersections between linear features (i.e., roads and railways) and natural washes, placement of future wildlife crossings for desert tortoises should consider areas with high road mortality rates, important dispersal corridors, and low gene flow. According to USWFS (2011), there exists 186 km and 142 km of roads and railways in need of fencing in the North-East Mojave Recovery Unit, and they specifically identify US 93 as an area in need of fencing. Based on goals and strategic planning for this species set by the USFWS and Nevada officials, the placement of new and the retrofitting of existing crossings can be identified through interagency coordination and placed at sites with high road mortalities, and lack of connectivity and gene flow.

4.2.2 Desert Tortoise Populations and Habitat Characteristics surround the Target Highways

The Mojave Desert tortoise population along US 95 and US 93 in Nevada occurs within the Eastern Mojave and Northeastern Mojave Recovery Units. In general, population densities were relatively low compared to other portions of the range, but long-term data suggested positive trends in density. These two populations are likely genetically distinct from each other due to isolation by distances and significant geographic barriers. Near the Yucca Mountains, tortoise reproductive output was very similar to other populations throughout the rest of the distribution, except for extreme western populations near Palm Springs. It is reasonable to suspect the life and natural history of these populations are very similar to other populations within their recovery units.

The area around the target highways consisted of Mojave Desert scrub vegetation with a gentle slope – typical for this region. The northeast Mojave Desert has experienced wildfires that impacted habitat for the desert tortoise. This wildfire complex dramatically changed plant biodiversity (i.e., species richness, composition, and structure), which will likely take years for the desert communities to fully recover.

5.0 SUMMARY

There is a dearth of rigorous research on specific characteristics, designs, and placement creating a successful crossing for desert tortoises or retrofitting of existing culverts to facilitate desert tortoise usage. However, useful information applicable to the design and placement of dual-purpose crossings does exist.

5.1 DESIGN

From a design aspect, the literature infers that all features associated with the dual-purpose culvert should be less than a 60% slope to facilitate movement. Due to issues related to fiberglass guzzlers and traction discussed above, any surface designed to facilitate tortoise movement should be constructed from materials that provide adequate traction; this includes the sides of plunge pools to allow for a safe egress. Vertical barriers associated with the dual-purpose culvert should be less than 30 cm (12 inches) to allow the movement of adult tortoises, and shorter vertical barriers should be considered to facilitate subadult, juvenile, and hatchlings movements. If riprap or blocks are used for energy dissipation and erosion control, it may be necessary to maximize interstitial space to exceed the length of an adult tortoise (38.1 cm) to minimize risk of entrapment. The culvert dimensions should meet or exceed those of a typical desert tortoise burrow entrance (i.e., entrance minimum widths: 76 cm and minimum height: 17 cm). There is no literature pertaining to the behavior of desert tortoises and debris within or blocking an opening of the dual-purpose culvert; however, any debris impeding movement would likely decrease the probability of a desert tortoise unitizing a dual-purpose culvert, particularly if the debris causes issues with the maximum slope, height, interstitial space, or culvert metrics noted above.

5.2 PLACEMENT

The literature infers that culverts in Mojave Desert tortoise habitat were likely constructed in the best location (i.e., dry desert washes) for use by tortoises. Desert tortoises have an affinity for washes for movement, foraging, and burrow placement. Placement of new dual-purpose culverts or retrofitting existing culverts within the distribution of desert tortoise should be prioritized in critical habitat, as defined by the USFWS. If not in critical habitat, prioritization of dual-purpose culvert placement should next incorporate known occupied habitat, followed by the highest habitat potential index value from habitat model of Nussear et al. (2009).

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APPENDIX A

Literature Review PDFs

(provided in separate electronic file)

files intentionally excluded

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