Mojave Desert Tortoise Conservation and Recovery Measures Along Roads; A Practical Guide

by

Marcel P. Huijser[1], PhD

Elizabeth R. Fairbank[2], MSc

FINAL REPORT

[1]Western Transportation Institute - Montana State University,
PO Box 174250, Bozeman, MT 59717-4250, USA
[2] Center for Large Landscape Conservation, P.O. Box 1587, Bozeman, MT 59771, USA

A report prepared for the
U.S. Fish & Wildlife Service, Headquarters Office,
Transportation Branch, 5275 Leesburg Pike, Falls Church, VA 22041

June, 2023

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Western Transportation Institute (WTI) or Montana State University (MSU) or the Center for Large Landscape Conservation or the U.S. Fish & Wildlife Service. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

The authors of this report would like to thank the U.S. Fish & Wildlife Service (USFWS) for funding this project.

Many of the images in this report show a Mojave desert tortoise. This is a dead freeze-dried tortoise named “Frieda”. This animal is not alive, there was no handling of any live animals for the creation of these images. Frieda lived as a captive tortoise in Las Vegas, Nevada. When she passed away from natural causes, her custodian had her preserved through freeze-drying and donated her to the Tortoise Group to be used for educational purposes. The Tortoise Group graciously allowed the U.S. Fish and Wildlife Service to take her into the field to serve as a model for filming a documentary regarding Mojave desert tortoise road ecology and for demonstration purposes while collecting data and photographing field sites. Frieda is featured as a demonstration model in many of the photos in this publication. For further information regarding captive Mojave desert tortoise issues, please visit: www.tortoisegroup.org.

Special thanks are due to Florence “Flo” Deffner, Desert Tortoise Recovery Biologist, U.S. Fish and Wildlife Service (USFWS). She had the vision and organized the site visits and interviews with researchers and practitioners that formed the foundation of this report. The site visits took place between 8 and 12 February 2021. Thanks also to Florence “Flo” Deffner, Kelly Douglas, Karla (Kristina) Drake, and Kerry Holcomb (USFWS) for reviewing an earlier version of this document.

The following individuals graciously received us at the field sites and shared their expertise:

- William “Bill” Boarman, Conservation Science Research & Consulting / Hardshell Labs, California.
- Michael Burchett, Mojave National Preserve, California.
- Kristi Holcomb, Nevada Department of Transportation, Nevada.
- Kevin Killian, Nevada Department of Transportation, Nevada.
- Jordan Perez, Snow Canyon State Park, Utah.
- Cameron Rognan, Washington County Habitat Conservation Plan (HCP) Department, Red Cliffs Desert Reserve, Utah.
- Mahmoud Sadeghi, Caltrans, California.
- Michael Vamstad, Joshua Tree National Park, National Park Service, California.

Thanks are also due to the 130 participants of the workshop held on 22, 23 and 26 March 2021 (Fairbank et al. 2021). The presentations and discussions contributed to this report. Lastly, we want to thank the members of the Mojave desert tortoise technical working group for their contributions.

TECHNICAL DOCUMENTATION

1. Report No. 4W8966	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A

4. Title and Subtitle
Mojave desert tortoise conservation and recovery measures along roads; a practical guide

5. Report Date June 2023

6. Performing Organization Code

7. Author(s)
Marcel P. Huijser & Elizabeth R. Fairbank

8. Performing Organization Report No.

9. Performing Organization Name and Address
Western Transportation Institute
P.O. Box 174250
Montana State University
Bozeman, MT 59717-4250

10. Work Unit No. (TRAIS)

11. Contract or Grant No. 4W8966

12. Sponsoring Agency Name and Address
U.S. Fish & Wildlife Service, Headquarters Office,
Transportation Branch, 5275 Leesburg Pike, Falls Church, VA 22041

13. Type of Report and Period Covered
Report 1 January 2021 – 1 June 2023

14. Sponsoring Agency Code

15. Supplementary Notes
A PDF version of this report is available from WTI's website at www.westerntransportationinstitute.org

16. Abstract
This is a practical guide for Mojave desert tortoise conservation and recovery measures along roads. It contains design, implementation, and maintenance considerations for measures aimed at reducing direct road mortality and maintaining connectivity for Mojave desert tortoises. The most effective combination of mitigation measures is fences, or other barriers, in combination with crossing structures under or over the road. However, when Mojave desert tortoise populations have been depleted already, these mitigation measures may have to be supplemented through population augmentation or reintroduction. Additional measures such as the control of predator species (e.g., ravens and coyotes) may be needed as these species have unnaturally high population densities in the Mojave desert because of human disturbance and associated food sources, and unnatural perching, roosting and nesting habitat, including along roads. Parks roads may allow for other measures, including night-time or seasonal road closures, and speed reduction. While not the focus of this report, additional measures may be required for unpaved roads and off-road vehicles. Finally, this report contains suggestions for the public on how to be involved with Mojave desert tortoise conservation in relation to roads.

17. Key Words barrier, collisions, connectivity, conservation, corridors, crashes, crossing structures, culverts, desert, fences, *Gopherus agassizii*, habitat, highway, hotspot, mitigation measures, Mojave, plan, prioritization, procedures, ranking, recovery, strategy, strategies, tools, tortoise, tunnels, underpasses, wildlife, wildlife–vehicle collisions

18. Distribution Statement Unrestricted. This document is available through U.S. Fish & Wildlife Service and WTI-MSU.

19. Security Classification (of this report) Unclassified	**20. Security Classification. (of this page)** Unclassified	**21. No. of Pages** 106	**22. Price**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Background

This report focuses on documenting the experiences and knowledge of practitioners, researchers, and managers with the funding, planning, design, implementation, and the investigation of the effectiveness of measures taken to avoid, mitigate or compensate for the effects of roads and traffic (Cuperus et al. 1999) on the federally threatened Mojave desert tortoise (*Gopherus agassizii*) (US Fish and Wildlife Service 1990, 1994, 2011). The terms "avoid, mitigate or compensate" in this report are consistent with the common use and meaning in the field of road ecology (e.g., Cuperus et al. 1999), and they do not necessarily relate to the policy of any agency or other organization, nor are they used in a legal context. Most measures are focused on limiting habitat loss due to roads, reducing direct road mortality, reducing the barrier effect of roads and traffic, improving habitat quality, and enable recolonization of zones adjacent to roads, and restoring habitat. Note that the order of these actions is not necessarily based on the importance to Mojave desert tortoise conservation, but they are based on general impact of roads as described by others (e.g., van der Ree et al. 2015). By making this information available to stakeholders, more successful road mitigation measures may be implemented.

1.2. Objective and tasks

The objective is to make information available to stakeholders (practitioners, researchers, and managers) on the factors that contribute to the successful implementation of measures taken to avoid, mitigate or compensate for the effects of roads and traffic on Mojave desert tortoise populations.

The tasks included:

Task 1.
Conduct a literature review and synthesis to summarize the effects of roads and traffic on the Mojave desert tortoise.

Task 2.
Select road sites where measures associated with roads and traffic have been implemented for Mojave desert tortoises, successfully or unsuccessfully. Site selection occurred in close consultation with Flo Deffner (USFWS).

Task 3.
Identify policy makers, managers, researchers and/or practitioners that have experience and knowledge with funding, planning, design, implementation, and investigation of the effectiveness of measures taken to avoid, mitigate or compensate for the effects of roads and traffic on Mojave desert tortoise populations for the sites identified (see task 1). Specific attention was given to barrier designs, culvert designs, and hydrology and erosion issues along barriers and at crossing structures.

Task 4.
Conduct a field inspection of the sites identified in task 1. The field review included:

a. Describing, measuring, and photographing the mitigation measures at each of the sites.
b. Meet and interview subject matter experts, including researchers and practitioners at each of the sites. The questions or conversation covered the experience and knowledge of the stakeholders with the funding, planning, design, implementation, and the effectiveness of the road mitigation measures for sites identified (see task 1).

Task 5.
Summarize the information obtained during the field reviews centered around how to successfully implement measures associated with roads and traffic for the Mojave desert tortoise and how to avoid potential problems. The information is presented in this document.

Task 6.
Support the USFWS in conducting a workshop that reviewed examples of programmatic biological opinions (PBOs) for transportation projects. This included the reporting on the outcomes of the workshop (Fairbank et al., 2021).

Task 7.
Present the information from task 5 at a Mojave desert tortoise workshop that was held March 2021 (Fairbank et al., 2021).

2. EFFECTS OF ROADS AND TRAFFIC ON THE MOJAVE DESERT TORTOISE

Roads and vehicles can affect wildlife in several ways. In general, not specific for the Mojave desert tortoise, we distinguish five different categories of effects of roads and traffic on wildlife (Figure 1) (e.g., van der Ree et al. 2015):

- Habitat loss: e.g., the paved road surface and the heavily altered environment of the road-bed with a non-native substrate, altered hydrology, vegetation removal, seeded species, and regular mowing in the clear zone.
- Direct wildlife road mortality as a result of collisions with vehicles.
- Barrier to wildlife movements: e.g., animals do not cross the road as often as they cross natural terrain and only a portion of the crossing attempts is successful.
- Decrease in habitat quality in a zone adjacent to the road: e.g., noise and light disturbance, air and water pollution, increased access to the areas adjacent to the highways for humans and associated disturbance.
- Right-of-way habitat and corridor: Depending on the surrounding landscape the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refugium for native species (surrounding landscape heavily impacted by humans).

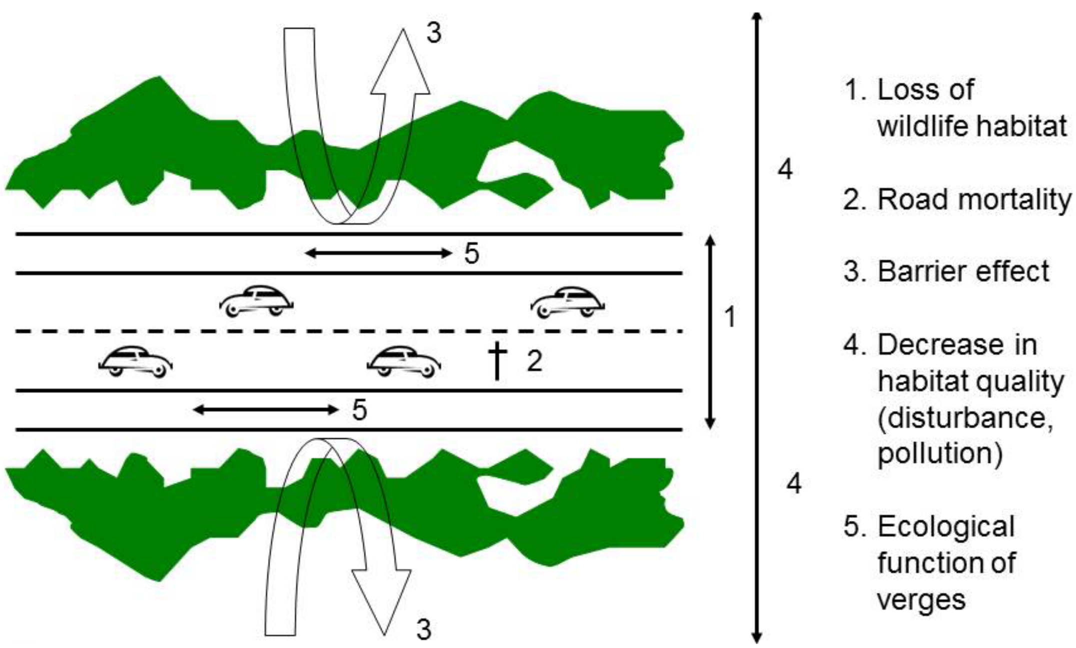


Figure 1: The effects of roads and traffic on wildlife.

This project focuses on the Mojave desert tortoise. The threats to this species include (US Fish and Wildlife Service 2011; 2022; Pers. com. Kerry Holcomb US Fish and Wildlife Service):

- Climate change (e.g., drought, temperature extremes, fire).
- General human presence and disturbance.
- Depredation by common raven (*Corvus corax*) and coyote (*Canis latrans*) which have increased their range and population size in the Mojave desert in response to human disturbance in the landscape. This includes the availability of non-natural food sources including road-killed animals (for ravens and coyotes) and unnatural nesting and perching sites, including along roads (e.g. bridges, billboards, fence posts) (for ravens).
- Habitat degradation including from soil disturbance (e.g. grazing by livestock, road building and right-of-way management, impact from vehicles driving off paved roads), the spread of non-native invasive plant species (e.g. by livestock and vehicles, especially along disturbed rights-of-ways and from there into the surrounding areas), and increased incidence and magnitude of fire.
- Pollutants.
- Direct road mortality on paved roads and by off road vehicles on or off unpaved roads.
- Habitat fragmentation and habitat loss from paved roads, off- highway vehicle use, other linear features in the landscape such as utility corridors, grazing, mining, military activities, and solar energy.
- Disease.

Note that this list is not necessarily complete, and that the order of the threats is not necessarily in order of importance.

Roads and vehicles cause direct road mortality, represent a barrier on the landscape, and result in reduced presence, or even complete absence (based on sign of Mojave desert tortoise or lack thereof), within a zone extending up to 230 or 800 meters from a road (Boarman et al. 1997, Boarman & Sazaki 2006, Hughson & Darby 2013, Peaden et al. 2015, Peaden 2017, Zylstra et al. 2023). Areas along highways with high traffic volume have fewer Mojave desert tortoises and higher (historic) numbers of road-killed tortoises than lower volume roads. Moreover, the body size (i.e., age class) of the animals decreases with increasing traffic volume, indicating that along high traffic roadways tortoises experience a shorter lifespan than is typical, which can contribute to extirpation due to this species' life history (Doak et al. 1994, Nafus et al. 2013, Peaden 2017). While direct road mortality is thought to be a primary driver of reduced population density close to roads, illegal collection and removal of animals by people, and direct predation of Mojave desert tortoises by common ravens and coyotes is also a concern along roads (Boarman et al. 1997, Grandmaison & Frary 2012, Nafus et al. 2013, Peaden et al. 2015).

Measures that have been implemented to reduce direct road mortality include desert tortoise warning signs. However, the presence of tortoise warning signs was not associated with a change in driver behavior when drivers were confronted with a tortoise model placed on the road by the researchers (Hughson & Darby 2013). The presence of tortoise warning signs was also not associated with more tortoise sign, and thus a higher population density, in a zone adjacent to roads (Hughson & Darby 2013). The most effective way to reduce road mortality is to erect barriers (fences) along roads for Mojave desert tortoises (Boarman et al. 1997, Peaden et al. 2015). Mesh and perforations in barriers allow for water permeability, but if animals in general, not necessarily specifically Mojave desert tortoise, can see through the barrier, it appears they try harder to breach the barrier, spend more time pacing back and forth along the barrier, and, as a result may be less likely to reach a crossing structure that provides safe passage to the other side of the highway (Ruby et al. 1994, Peaden et al. 2017). Walking along the fence in one direction (i.e., in contrast to pacing back and forth) may be beneficial as it allows animals to find a suitable crossing structure more quickly. However, since Mojave desert tortoises have elevated temperatures along fences and along unmitigated roads (Peaden et al. 2017), there may be a need to install shade structures and functional crossing opportunities at relatively short intervals, especially for displaced or translocated individuals. This is particularly important along newly installed tortoise exclusion fence as these animal's home range may now be split in two and the animals may be trying to access the other side of the fenced road corridor (Peaden et al. 2017).

While barrier fences along roads can substantially reduce direct road mortality of Mojave desert tortoises, they also contribute to further habitat fragmentation, both for Mojave desert tortoises and other species for which the fence acts as a barrier. To avoid these unintended negative side effects of fences, barriers are typically accompanied by suitable safe crossing opportunities for the species affected by the fence (Moore et al. 2021). However, since direct road mortality threatens the viability of Mojave desert tortoise populations (USFWS 2022), "immediate" fencing, with or without suitable crossing structures may be required (Nafus et al. 2013, Peaden 2017). Furthermore, the barrier effect of an unfenced major highway may be very substantial for Mojave desert tortoises already as successful crossings are unlikely and the fragmentation effect of an unfenced road is considered high (Pers. com. Kerry Holcomb, US Fish and Wildlife Service).

The function of wildlife crossing structures is to make a fenced road corridor more permeable to wildlife e.g., to allow for animals to have their home range on both sides of the road, to have one larger and more resilient population, to allow for seasonal migration, and to allow for dispersal. While the implementation of designated crossing structures for Mojave desert tortoises may be required, it is important to explore if, and under what conditions, existing drainage culverts under the road may also serve as a crossing structure for Mojave desert tortoises. This is especially relevant as Mojave desert tortoises are known to follow desert washes (Peaden 2017, Peaden et al. 2017). Many desert washes have culverts where they cross paved roads, which provides an opportunity for dual-purpose use; hydrology as well as a safe passage opportunity for Mojave desert tortoises. Since desert washes only carry water immediately after a rainstorm, they are available for wildlife most of the time. However, the amount of water and the velocity can be so substantial that erosion and sedimentation occur that may make a crossing structure inaccessible. In addition, if the only crossing opportunity is at desert washes through existing culverts for hydrology, then Mojave desert tortoises that follow the fence would have to travel as far as the nearest wash and suitable culvert, which may or may not be within reach. Moreover, other species that depend on higher and dryer habitat away from desert washes would be confronted with a fence, but not have access to suitable crossing structures within their typical habitat.

Departments of Transportation (DOTs) have installed fences for Mojave desert tortoises along some road sections and connected them to designated tortoise crossing structures or existing culverts originally designed for hydrology only. To reduce costs for hydraulic structures where desert washes cross the highway, the structures are often much narrower than the washes (e.g., a round corrugated metal culvert (or a Corrugated Metal Pipe (CMP)) of several feet wide for a wash that is many times that width). This increases water depth and water velocity in the structures, and may cause erosion, especially at the outflow. To reduce erosion, many culverts have large rocks ("riprap" or "rock slope protection") at the outflow, sometimes combined with a plunge pool to further reduce water velocity. The riprap can be a barrier to Mojave desert tortoises and it can prevent them from entering or leaving the culvert. In addition, the spaces between the rocks can cause mortality of Mojave desert tortoises through entrapment, overheating, or drowning in the pools that remain after a precipitation event (Gardipee et al. 2017). However, the frequency of these types of mortalities is unknown and potentially low. Filling the gaps in between the rocks with smaller rocks or soil may reduce the barrier effect, but the smaller material may simply erode after one or several rainstorms and associated flash floods in the desert environment. Replacing the finer aggregates or soil in between the larger rocks requires continuous maintenance and associated costs. Nonetheless, it is worthwhile exploring if and how culverts in desert washes can be retrofitted or designed to make them better accessible for the Mojave desert tortoise.

The wettest months in southern Nevada are usually November through March. April through June are the driest months, but precipitation increases again during the monsoon season (July through October). During the winter (mid-November until end-February) Mojave desert tortoises are mostly in inactive inside burrows (Woodbury & Hardy 1948, Nagy & Medica 1986, Zimmerman et al. 1994). Tortoises are generally most active between mid-March and mid-June and from mid-August to end-October depending on elevation, precipitation, and temperature (Mojave desert tortoises are mostly active between 60 and 95 °F (Personal communication Kelly Douglas, US Fish and Wildlife Service). This means that the most important period for the drainage structures to allow for safe passage for the Mojave desert tortoises is during these periods.

3. FENCES AND OTHER BARRIERS

3.1. Purpose

The purpose of fences and other barriers for Mojave desert tortoises along roads is to:

a. Reduce direct road mortality of Mojave desert tortoises by keeping them off the road. This helps stabilize population size in areas near roads, stabilize or increase population viability, and reduce the risk of extirpation or extinction.
b. Guide Mojave desert tortoises towards safe crossing opportunities so that they can safely access the habitat on the other side of the road.

3.2. Effectiveness

Fences designed to keep Mojave desert tortoises from accessing a highway reduced the number of road-killed Mojave desert tortoises by 93% (Boarman & Sazaki 1996). In addition, Mojave desert tortoises have been observed to walk along the safe side of a fenced highway for substantial distances (up to 6.5 km) or substantial time without having crossed the barrier (Boarman et al. 1997, Peaden et al. 2017). Based on modeling, fences and an associated reduction in direct road mortality can stop the decline in Mojave desert tortoise population density in areas adjacent to roads (Peaden 2017). However, even after direct road mortality is no longer a factor, Mojave desert tortoise populations may need additional measures to recover to their original population density (Peaden 2017). It is important that ongoing direct road mortality of Mojave desert tortoises is addressed quickly to prevent further depletion of populations close to roads (Peaden 2017).

3.3. Undesirable effects and possible solutions

- Fences and other barriers as a stand-alone measure can reduce direct road mortality but also make a road into an **absolute barrier** for the target species. This results in smaller and more isolated populations that have a greater risk of extirpation compared to larger and well-connected populations (e.g., Hanski & Thomas 1994, Hanski & Ovaskainen 2002). Therefore, **as a general rule, barriers should be combined with safe crossing opportunities** that are suitable for the target species. Safe crossing opportunities usually mean crossing structures (i.e., underpasses, overpasses) that physically separate the animals from vehicles (see separate section of safe crossing opportunities).
- Designated safe crossing opportunities for a target species, including the Mojave desert tortoise, typically take more effort, funding, and time to implement than fences or other barriers. Associated **delays in the implementation of a combination of barriers and crossing structures would affect the likelihood that Mojave desert tortoise populations near roads can be recovered.** Mojave desert tortoise populations are unable to recover on their own when population densities have been substantially reduced, e.g., through direct road mortality (Peaden 2017). **The longer major roads remain unfenced, the more tortoise mortality occurs, the more difficult it is for Mojave desert tortoise populations to recover after fencing would be implemented** (Peaden 2017). In areas where direct road mortality continues to reduce Mojave desert tortoise population density, implementation of

fences and other barriers as a stand-alone mitigation measure can be beneficial on the short term as it stops further depletion of the population (Jaeger & Fahrig 2004). In this context, **it would benefit Mojave desert tortoise conservation to implement fences or other barriers quickly, connect them to existing crossing structures originally designed for other purposes, and implement designated crossing structures at a later time**. However, this is not without risk and other undesirable side effects as: 1. Despite the best intentions, designated crossing structures may not be implemented after all and 2. Fences and other barriers do not only make the road corridor into a near absolute barrier for Mojave desert tortoises, but it may also be a barrier for other species for which habitat connectivity is essential for population persistence in the immediate future, and 3. Existing structures originally constructed for other purposes may or may not be suitable for use by Mojave desert tortoises. Therefore, **if at all possible, implement barriers in combination with suitable crossing structures as a package at the same time**. Suitable crossing structures may include designated crossing structures for Mojave desert tortoises, existing structures originally built for other purposes but that have been found suitable for Mojave desert tortoises, or a combination of these two types of crossing structures.

- Altered behavior and increased activity of Mojave desert tortoises along fences may lead to overheating as temperatures increase (Ruby et al. 1994, Peaden et al. 2017). Approaches to reduce the time that Mojave desert tortoises follow a fence or other barrier and potentially overheat include: 1. Providing safe crossing opportunities at short enough distances so that they can stop traveling along the barrier and cross to the other side of the road, or take advantage of the shade that an underpass provides (see separate document on crossing structures), 2. Placing "shade structures" along the barrier (see later in this document), and 3. Implement fence designs that keep Mojave desert tortoises moving rather than fence designs that encourage Mojave desert tortoises to explore whether they can breach the barrier (see later in this document).
- Fences and other barriers can affect **landscape aesthetics**, especially in flat and open areas. **Barriers may be integrated into the roadbed to reduce the visual impact of barriers**. This makes the barriers invisible from the road, and they do not stick out above the surrounding landscape any more than the roadbed itself (see section below).
- Fence posts and other structures may be used for **roosting by corvids or raptors that may prey on young Mojave desert tortoises**, especially individuals that may travel along the safe side of the fence (Campbell 1986, Boarman 1992). Minimizing the height and diameter of the posts may reduce its attractiveness to these predators. In addition, roosting may be reduced by placing spikes or other deterrents on top of posts, though success varies on the design, implementation, and species (Avery & Genchi 2004, Dwyer & Doloughan 2014, Dwyer et al. 2020).
- The standard mesh size for Mojave desert tortoise 1-inch horizontal by 2-inches vertical (U.S. Fish and Wildlife Service 2011). Smaller mesh sizes (e.g., 1 x 1 cm (0.25 x 0.25 inch) may pose a greater risk to small animal species (lizards, snakes) as they can get stuck in the meshes and die (Ruby et al. 1994; Pers. com. Kris Gade, Arizona Department of Transportation**;** Judy Hohman, Desert Tortoise Council and retired from US Fish and Wildlife Service; Brian Henen, Marine Corps Air Ground Combat Center, Twentynine Palms California). Small mesh sizes are also more likely to catch sediment.

A lizard that got stuck in a fence designed for Mojave desert tortoises, and later died. The mesh size of this fence (e.g., 1 x 1 cm (0.25 x 0.25 inch) is smaller than the recommended mesh size (1 inch horizontal, 2 inches vertical). Copyright Kristi Holcomb, Nevada Department of Transportation.

3.4. Planning

Selection of road sections

Fences or other barriers should typically be prioritized along road sections where direct road mortality of Mojave desert tortoises has substantially reduced population density and where reducing direct road mortality may increase the likelihood of Mojave desert tortoise population persistence or recovery within adjacent habitat. If the objective is to restore Mojave desert tortoise populations, e.g., through population augmentation or reintroduction, barriers that keep the animals off the road are an important tool too, regardless of recent road mortality and current population density. In this context, all roads that bisect important habitat for Mojave desert tortoises should be fenced, starting with the road sections where Mojave desert tortoises are still present in the surrounding landscape.

If road sections (fenced or unfenced) are identified where the barrier effect of the transportation corridor should be reduced, then wildlife crossing structures (see Chapter 4) should be implemented where connectivity is needed most and where a reduction in the barrier effect is likely to increase the likelihood of Mojave desert tortoise population persistence or recovery within adjacent habitat. If such crossing structures are connected to fences or other barriers, direct road mortality can be reduced as well. Barriers can also guide individual animals to the crossing structures and increase the use of the crossing structures, but this has not been investigated yet for Mojave desert tortoises (Dodd et al. 2007; Gagnon et al. 2010). The U.S. Fish and Wildlife Service conducted a modelling study to identify priority road segments for the installation of Mojave desert tortoise fencing (Pers. com. Kerry Holcomb and Florence “Flo” Deffner, USFWS). The GIS-based prioritization model incorporated a Recovery Importance Index (RII), a Feasibility Index (FI), and a composite Desert Tortoise Exclusionary Fence Installation Prioritization Index (DTEFIPI). The composite DTEFIPI (RII x FI) is intended to identify and prioritize 1-km segments of roads that most in need of Mojave desert tortoise fences from both a biological need and a feasibility perspective. In this approach, biological need (RII) is based on the road-effect zone area, average habitat potential value, and the number of overlapping buffered range-wide observations. Feasibility (FI) is based on landownership, road design (at grade or not), and the number of local roads or driveways that would perforate the fence. The DTEFIPI was then used to generate a map that identifies priority road segments (Pers. com. Kerry Holcomb and Florence “Flo” Deffner, USFWS).

Location of the barrier in relation to the right-of-way boundary
The main function of a right-of-way fence is to indicate the property boundary. In many cases, a right-of-way fence also serves as a barrier to keep livestock off the road. However, if a fence is placed on the property boundary, access for fence maintenance on the safe side of the fence may require the permission of the property owner or land managing agency of the parcel adjacent to the right-of-way. In this context, it may be advantageous to locate the fence or other barrier closer to the road and leave enough space for maintenance activities on the safe side of the barrier. Moving a wildlife fence or barrier closer to the travel lanes also reduces habitat loss for wildlife associated with fencing out the road corridor. If the property boundary still needs to be indicated, this could be achieved through a line of posts without fencing material between the posts, or through a livestock or right-of-way fence that is permeable to Mojave desert tortoises. Note that issues can arise if the fence is located within the right-of-way and when construction or maintenance of the Mojave desert tortoise barrier is not funded or executed by the transportation agency but by an adjacent land managing agency, e.g., the U.S. Bureau of Land Management (BLM). However, such bureaucratic problems may be solved through agreements of the agencies or other entities involved.

Functions of the barrier
Having right-of-way boundary indicators or fences that are separate from a barrier designed for Mojave desert tortoises or other wildlife species is less efficient than combining all these functions into one fence or barrier. It is commonplace to combine a barrier for Mojave desert tortoises with a property boundary or livestock fence. A taller and sturdier fence may also function as a barrier for large mammal species, but this is only advisable if there are also suitable crossing structures present for those other species in the appropriate locations.

3.5. Design

Most of the design specifications for Mojave desert tortoise fences listed below were originally published in 2005 and were later included in the 2011 revised recovery plan (U.S. Fish and Wildlife Service 2005, 2011).

Barrier types

Typical fences for tortoises consist of posts (e.g., metal fence posts) and fencing material (e.g., woven wire). Other barriers may consist of solid plastic or polymer or concrete barriers or walls. Polymer or concrete walls can be integrated in the roadbed so that they do not stick out above the surrounding area. These types of barriers are not visible from the road and may address landscape aesthetics, at least as experienced from the road. In addition, barriers that are integrated into the roadbed, may be exempt from surveys for cultural resources, and they may also help stabilize the roadbed by reducing erosion in the roadside ditch (Pers. com. Kerry Holcomb, USFWS). Note that solid barriers, or barriers with small mesh sizes compared to the size of the animal, are sometimes better than see-through barriers as the animals tend to spend more time investigating breaching see-through barriers and move quickly along solid barriers or barriers with small mesh sizes, allowing them to access a crossing structure sooner (Ruby et al. 1994, Brehme et al. 2021). However, solid barriers and barriers with small mesh sizes may result in erosion and sedimentation process, especially in highly erodible areas such as the Mojave Desert.

Mojave desert tortoise fencing, St. George, Utah. This fence has a mesh size that is 1 inch wide and 2 inch tall, the fence material is 20 inches above the ground, and it is attached with hog rings to three smooth strands of wire (at 4, 12, and 20 inches above the ground). There are two additional smooth wires above the fence material. Presumably, the fencing material is dug into the ground, about 16 inches deep.

Wildlife fence (8 ft tall (2.4 m)), primarily for desert bighorn sheep (*Ovis canadensis nelsoni*), I-11, near Boulder City, Nevada. Mojave desert tortoises and bighorn sheep are known to co-occur in this area. Therefore, tortoise exclusion fencing was installed at the bottom of the bighorn sheep fencing.


Plastic sheeting for amphibians attached to a Eurasian badger (*Meles meles*) fence, The Netherlands. Depending on the height, the sheeting may be suitable for Mojave desert tortoises. However, in arid ecosystems, erosion and sedimentation processes may be a substantial problem for this design as it is not permeable to water and fine sediments and solid barriers may also be more easily damaged by high winds.

Solid plastic fencing for small animal species attached to a chain-link fence designed for larger wildlife species, M79 motorway, south of Harcourt, Victoria, Australia. However, in arid ecosystems, erosion and sedimentation processes may be a substantial problem for this design as it is not permeable to water and fine sediments and solid barriers may also be more easily damaged by high winds.

Polymer wall for amphibians integrated into the roadbed, The Netherlands. This type of barrier does not affect landscape aesthetics as experienced from the road. The design also allows for tortoises to exit the road anywhere by tumbling down the barrier. The height may have to be adjusted to prevent large adult desert tortoises from climbing over the barrier while not posing any threat of injury to tortoises that may fall over the barrier.

Concrete barrier wall integrated into the roadbed, with overhang, designed and implemented to keep reptiles, amphibians and small mammals off a highway, U.S. 441, Paynes Prairie Ecopassage, south of Gainesville, Florida, USA. Depending on design and construction, this type of barrier might not affect landscape aesthetics as experienced from the road.

Barrier height and burrowing depth

Fences for Mojave desert tortoises should be about 22-24 inches (minimum 18 inches) above the ground, and at least an additional 12 inches (definitely no less than 6 inches) should be buried into the ground to prevent Mojave desert tortoises from digging under the fence (U.S. Fish and Wildlife Service 2011). A typical Mojave desert tortoise barrier is combined with a right-of-way or livestock fence that is taller than 22-24 inches; typically, about 4 ft in height. Attaching the fence to horizontal wires for the right-of-way or livestock fence gives the barrier additional strength and stability (U.S. Fish and Wildlife Service 2011). Hog rings (12 to 18-inches interval) are used to attach the top of the fence to the smooth wire that is at the height of the fence material. If the soil conditions do not allow for the fence to be buried into the soil, e.g., soil too rocky, bend the fence material at 14 inches from the bottom to 90°. The bottom 14 inches need to face the "safe side" (habitat side) of the fence (not the roadside) and, using rocks, debris, and soil, be as snug as possible to the ground level. The fence material is covered with up to 4 inches of material, leaving the effective height of the fence at 22 inches. However, some transportation agencies may be prohibited from bending the fence toward the habitat side because of right-of-way restrictions. In such cases, installing the fence closer to the road, set back from the property boundary, may be a workaround.

Mojave desert tortoise fence (height above ground 24 inches, presumably buried 12 inches below ground level, mesh size 1 inch wide, 2 inches tall), Hwy 58 near Kramer Junction, California. The fence material is attached to smooth wires at 10 and 22 inches above the ground.

Mojave desert tortoise fence (about 21.5 inches tall, mesh size about 1x1 cm), I-15 near Barstow, California. The small mesh size may pose a greater risk to small animal species (lizards, snakes) getting stuck and dying. Small mesh sizes are also more likely to catch sediment. Note that there is no smooth wire at the very top of the fence, making the fence less rigid.

Mojave desert tortoise fence (about 14 inches tall, mesh size about 1x1 cm), I-15 near Barstow, California. The small mesh size may pose a greater risk to small animal species (lizards, snakes) getting stuck and dying. Small mesh sizes are also more likely to catch sediment. Note that this fence is too low and there is no smooth wire at the very top of the fence, making the fence less rigid.

Mojave desert tortoise exclusion fence, USA Aerospace Highway (Hwy 14), near Inyokern, California. The small mesh size may pose a greater risk to small animal species (lizards, snakes) getting stuck and dying. Small mesh sizes are also more likely to catch sediment. Note that this fence is far too low (perhaps only a few inches) to be a functional barrier for Mojave desert tortoises.

Gap under Mojave desert tortoise exclusion fence, USA Aerospace Highway (Hwy 14), near Inyokern, California. The small mesh size may pose a greater risk to small animal species (lizards, snakes) getting stuck and dying. Small mesh sizes are also more likely to catch sediment. Note that this fence is not buried at all. Mojave desert tortoise fencing should be buried at least 12 inches deep.

Mojave desert tortoise exclusion fence, St. George, Utah. Normally, the fence should be buried, but here it is above ground, held down by rocks. Note: the section of the fence that lies on the soil should face the safe side (habitat side) of the fence (not the roadside). Also note that the section of the fence that lies on the ground should be buried up with to 4 inches of rocks and soil on top, leaving a barrier height of 22-24 inches above the ground level.

Mojave desert tortoise exclusion fence, Hwy 58 near Kramer Junction, California. Here the fence is angled towards the safe side of the fence (not the roadside), presumably because of rocky soil. Also note that the section of the fence that lies on the ground should be buried up with to 4 inches of rocks and soil on top, leaving a barrier height of 22-24 inches above the ground level.

Posts for fences

When combined with a right-of-way or livestock fence, use 72-inch (6 ft) t-posts and install them 24 inches (2 ft) below the ground (U.S. Fish and Wildlife Service 2011). This leaves 48 inches (4 ft) above ground. Posts should be spaced about 10 ft apart (U.S. Fish and Wildlife Service 2011).

Fence markers and bird spikes on t-posts, Montana. The markers are designed to reduce the likelihood that sage grouse (*Centrocercus urophasianus*) fly into the livestock fence. The bird spikes are designed to reduce the likelihood that corvids or raptors will use the fence posts to perch and prey on sage grouse, especially the chicks. Installation of bird spikes on fence posts attached to fences in desert tortoise habitat may help reduce predation on tortoises by birds within adjacent habitat.

Fencing material and mesh size

Galvanized welded wire (16 gauge or heavier) that is durable enough for desert environments, including exposure to alkaline and acidic soils, wind, and erosion and sedimentation processes is recommended. The mesh size should be 1-inch horizontal by 2-inches vertical (U.S. Fish and Wildlife Service 2011). The fencing material can be obtained in a 36-inch wide roll (22-24 inches above ground, at least 12 inches buried). When combined with a 4-strand right-of-way or livestock fence, smooth wires or combinations of smooth wire and barbed wire, are preferred to make the fence less of a hazard to large wild mammals (for specifications of wildlife friendly livestock fences see Arizona Game and Fish Department, Montana Department of Transportation, Paige 2008). Note that the lowest strand should be at the same level as the top of the fence material. While smaller mesh sizes or non-transparent fence material encourages wildlife species (in general) to continue moving along the barrier rather than attempting to breach the barrier, the suggested mesh size (1 inch wide, 2 inches high) is considered acceptable for Mojave desert tortoises.

Access roads

Access roads require a gap in the fence and some kind of measure to prevent Mojave desert tortoises from moving through this gap and accessing the main road. Low gates may simply be driven over and flattened and destroyed (see image below). Gates on a spring can allow vehicles to drive through without stopping, but such designs are a concern because of potential crushing of Mojave desert tortoises (Pers. com. Kerry Holcomb, US Fish and Wildlife Service). Gates that need to be opened by hand require a vehicle to stop and a person to open and close the gate. This often leads to gates being left open. Gates may also have permanent gaps under the gate allowing Mojave desert tortoises to enter the fenced road corridor (see images below). Gates that are effective in keeping Mojave desert tortoises from accessing the fenced road corridor have a concrete footer below the gate with a gap of less than 0.5 inches to the bottom of the gate (Hunt 2014). Larger openings will allow Mojave desert tortoise hatchlings to pass through (Hunt 2014). In addition, for a gate to be effective, it needs to be closed after use; a gate that is left open is equivalent to an opening in the fence. Currently, automatically closing gates with a concrete footer and a gap of at the most 0.5 inches, is recommended (Pers. com. Kerry Holcomb, USFWS). Sweeps may also be attached at the bottom of a gate to prevent gaps. Gates that close automatically based on gravity may also be considered.

Tortoise guards are similar to cattle guards and do not require drivers to stop or get out of the vehicle. A cattle guard may be modified to a tortoise guard, or a designated tortoise guard can be constructed. For a modified cattle guard, it is important that the slots are wide enough for a tortoise to not be able to walk across; the animal should fall into one of the slots. Similarly, structural elements between the slots should be sufficiently narrow so that a tortoise cannot cross the slot. In addition, there should not be any access to the top of the walls of the pit, as that would allow for tortoises to walk on top of the concrete walls and access the road corridor. Tortoises that have fallen into the pit below the guard should be able to escape from the pit. Designs in areas with tortoises should be combined with an escape opportunity; otherwise, it is a death trap. Escape opportunities may include openings at the bottom or escape ramps that allow tortoises to exit the pit and return to the safe side of the fence. While large openings on the side are likely to allow tortoises to escape from the pit, escape ramps from the pit may or may not be effective, and experiments are advised before relying on such escape ramps. Finally, maintenance of wildlife guards may require labor and associated expenses, especially if tumbleweeds get stuck in the pits.

Fence length

Wildlife fences are typically installed at locations where concentrations (“hotspots”) of wildlife-vehicle collisions occur, or road sections where we want to reduce direct road mortality, regardless of whether hotspots have been identified (e.g., fence the entire road length through habitat that is known to be occupied). To be effective in reducing wildlife-vehicle collisions, the fences need to cover the length of the entire road section where road mortality needs to be reduced. However, the fencing needs to extend further to prevent animals that approach the road at the edge of the identified road section from simply walking to the fence-end and crossing at grade (e.g., Bissonette & Rosa 2011, Huijser et al. 2015, Huijser et al. 2022). Therefore, a buffer zone should be added to the road section where mortality is to be reduced. There are several approaches for calculating what the length of the fenced buffer zone should be. One approach is to calculate the diameter of the home range for the target species in combination with the length of the “hotspot” can be used to decide on the appropriate length of the fence (Bissonette & Adair 2008, Huijser et al. 2008). For Mojave desert tortoises, the home range size depends on the sex, age, environmental conditions, and research methods (Berish & Medica 2014), but based on a minimum convex polygon, the average home range for resident males was 23-55 ha and 17-19 ha for resident females (Turner et al. 1980, Harless et al. 2010). Using the highest estimates of their home ranges, and assuming a circular home range, this translates in a diameter of the home range of 837 m for males and 492 m for females. Based on this approach, the minimum length of a road section that should be fenced for Mojave desert tortoises should be the length of the collision hotspot or priority road segment with a relatively high number of collisions, plus at least an additional 837 m on each side of those road segments. However, in reality, habitat suitability or quality is not uniform, and shape of the home ranges is almost never circular. In addition, when motivated, animals may travel for much longer distances than their average home range size suggests. Therefore, a more realistic approach is to measure how far individual tortoises have been observed walking along a fence. Distances of up to 6.5 km have been observed (Boarman et al. 1997). **Therefore, the minimum length of a road section that should be fenced for Mojave desert tortoises should be the length of the road section where road mortality is to be reduced, plus at least several kilometers (e.g., 3 km), potentially up to 5-10 kilometers, on each side of the road section that has a concentration of collisions (also known as a priority road segment for direct road mortality).**

Longer sections of wildlife fencing also reduce the potential of environmental leakage where roadkill is moved from a newly fenced road section to a nearby unfenced area rather than overall reduced (Huijser & Begley 2022**). If relatively short, unfenced sections would remain in between fenced road sections, consider extending the fence and making one longer fenced road section that is likely to be more effective in reducing collisions within the fenced road section and less likely to result in environmental leakage.**

Regardless of the length of a wildlife fence, there may still be a “fence-end run” as animals may cross more frequently in the immediate vicinity of fence-ends than at road sections that are not fenced (Clevenger et al. 2001, Cserkész et al. 2013). Fence-end runs occur because not all animals that approach the fenced road section may choose to use a safe wildlife crossing opportunity (e.g., wildlife underpass, wildlife overpass) that may be present within the fenced road section. Instead, these animals may follow the fence, or they already know where the fence ends, and then cross the road at grade at or near the fence-end. Safe crossing opportunities may reduce such fence-end runs when placed close to or at fence-ends (Allen et al. 2013). Fence-end runs may not be considered a problem unless there is also a concentration of wildlife-vehicle collisions at fence-ends. However, fence-end runs can be reduced if the location and length of wildlife fencing is not only based on wildlife-vehicle collision data (unsuccessful wildlife crossings) but also on successful wildlife crossings as these are not necessarily in the same location (Clevenger et al. 2002, Neumann et al. 2012). As an alternative to using successful wildlife crossing data, the fence may also simply extend beyond a particular habitat that may be associated with the target species; this can also be expected to reduce the probability of fence-end runs. By definition, road sections with relatively long and contiguous wildlife fencing (e.g., at least several miles or kilometers) are less likely to have a fence-end run issue than relatively short road sections with wildlife fencing (Huijser et al. 2016a, b). For long road sections the road length near the fence-ends where a fence-end run may occur is relatively short compared to the total road length than is fenced. In contrast, for short road sections with wildlife fencing, the road length near the fence-ends where a fence- end run occurs may overlap the entire fenced road section.

Wildlife fencing should typically be implemented on **both sides of a road with the fence ends ending opposite of each other**. If a fence is present on one roadside only, animals that approach from the other side still get on the road, and they may spend more time on the road because a fence on the other side of the road does not allow them to leave the road corridor. Fence-ends that do not end on opposite sides of the road (i.e., “staggered”) can lead to similar problems, and they may result in an increased probability that animals wander off into the fenced road corridor rather than cross at grade at a fence-end. Exceptions may exist where only one side of the road has suitable habitat for the target species. However, if other species that are also affected by the fence are present on both sides of the road, fencing on both sides of the road is still advised.

Fence-end treatments
In addition to an appropriate length of a wildlife fence and appropriate start and end locations, treatments at fence-ends may reduce the likelihood of a fence-end run and increase the effectiveness of the fenced road section in reducing direct road mortality. These treatments may include:

1. **Angle the fence away from the road at the fence-end.**
   In many cases a wildlife fence is angled away from the road at a fence-end. In some cases, the fence angles only slightly away from the road (e.g., 45°) whereas it is 90° (perpendicular) to the road in other cases (Kruidering et al. 2005). There are also “turn-arounds” where the wildlife fence first angles away from the road at 90° and then bends back another 90° (180° in total) essentially paralleling the main fence for some distance (Kruidering et al. 2005, Brehme et al. 2020). However, for the Mojave desert tortoise, sharp angles in the fence should be avoided as this is associated with tortoises attempting to climb the fence. Angles should be no sharper than 120° (Pers. com. Kerry Holcomb, US Fish and Wildlife Service). The main purpose of having a wildlife fence angle away from the road is to discourage animals from crossing the road at grade at the fence- end; it helps avoid a “fence-end run” effect. Note that additional measures (e.g., wildlife guard) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence-end. Fences that angle way from the road may encroach on adjacent property unless the fence is installed closer to the edge of the pavement.

2. **Bring fence-ends close to the paved road surface.**
   In some cases the fence angles towards the road surface at a fence-end. The main purpose of having a wildlife fence angle towards the road surface at a fence-end is to discourage animals from wandering off into the fenced right-of-way. Such an angled fence does not help avoid a fence-end run effect though. Bringing a fence close to the road surface typically results in having the fence and the end post in the “clear zone.” In general, the clear zone should be free of obstacles so that drivers whose vehicle has left the paved road surface may still recover and regain control of the vehicle without crashing into large objects. This means that measures must be taken to prevent cars from

crashing into the fence and fence posts at the fence-end. Break-away structures may be used to limit the danger to humans (e.g., Gagnon et al. 2010). Alternatively, guard rails or Jersey barriers can deflect vehicles that have left the roadway at fence-ends where the fence-end has been brought close to the road surface. Note that additional measures (e.g., wildlife guards) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence-end.

3. Boulder fields.
   Boulder fields may be used at fence-ends between the paved road surface and fence-ends, and, in case of a divided highway, also in the median. It is an alternative to bringing a fence-end close to the paved road surface as boulder fields are believed to discourage wildlife, especially ungulates, from walking into the fenced road corridor. Boulder fields may also be a barrier for Mojave desert tortoises and help keep them out of a fenced road section, but tortoises may also become trapped in between the boulders and die (Gardipee et al. 2017). Boulder fields next to the shoulder or pavement may not be appropriate at curves or high-speed roads as boulder fields are a hazard to cars that have run off the road. However, guard rails or Jersey barriers can be placed in between the pavement and the boulder field to deflect vehicles before they would hit the boulder field. On the other hand, the use of a shield (guard rails or Jersey barriers) can be a safety hazard in itself (AASHTO 2006). Note that additional measures (e.g., wildlife guard) may need to be installed in the travel lanes to substantially reduce the likelihood that wildlife enters the fenced road corridor at a fence-end.

Note that some fence-end treatments can be combined (e.g., a **split fence-end where the fence both angles away from the road and also angles towards the road**) (Figure 2).

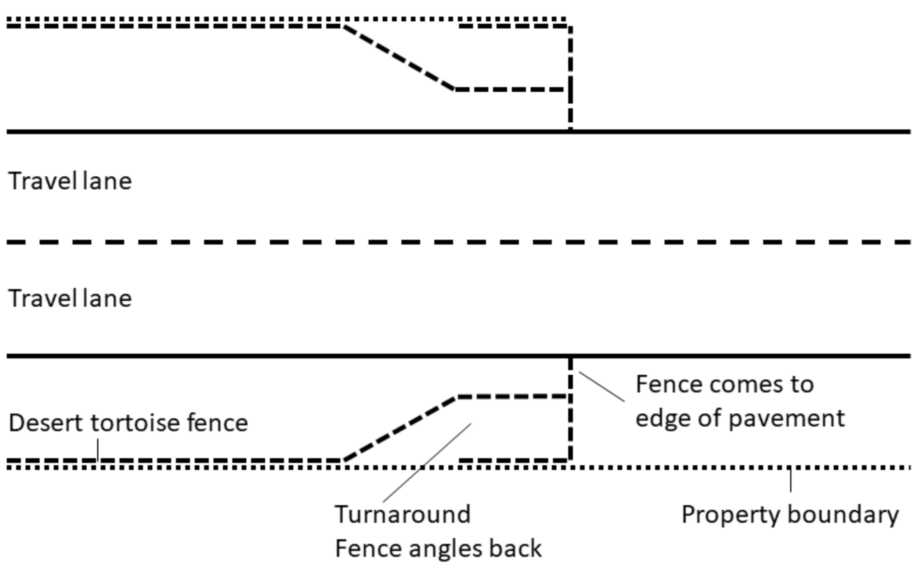


Figure 2: Fence-end configuration with a split fence-end. One end forms a turnaround, the other end comes close to the edge of the pavement. **While 90° angles are shown here, the fence angles for the Mojave desert tortoise should be no sharper than 120°** (Pers. com. Kerry Holcomb, US Fish and Wildlife Service).

Boulder field at a fence-end, shielded through a guard rail, Alberta, Canada.

Flattened and destroyed gate at a vehicle access point associated with a Mojave desert tortoise fence, I-15 near Barstow, California. Here the fence has, or had, a gate for a dirt road, but the fence was flattened by vehicles. This suggests that gates that require people to get out of the vehicles to open them are not always effective and may result in a gap in the fence, allowing Mojave desert tortoises to access the highway.

A gate associated with Mojave desert tortoise exclusion fencing, Hwy 58 near Kramer Junction, California. Note that the design of this gate resulted in gaps which affected its function as a barrier to Mojave desert tortoises (see images below).

Gap under a gate associated with Mojave desert tortoise exclusion fencing, Hwy 58 near Kramer Junction, California. The gate does not have a buried component, and it had enough flex to result in permanent openings, partially as a result of tumbleweeds being blown against the fence.

Automatic gate with a push-button to open (to the right of vehicle because of right hand driving), Addo Elephant National Park, Eastern Cape, South Africa

Snug fit of a gate at a wildlife fence, south of Otterlo, The Netherlands. The snug fit discourages animals from crawling under the gate.

Swing gate, set at an angle so it closes through gravity, The Netherlands.

Horse swing gate, Heugterdijk, Weerterbos, near Maarheze, The Netherlands. The center of the metal swing gate is set at an angle so that gravity automatically brings the metal gate in line with the fence. Here the gate is in the process of closing.

Gap at a gate associated with Mojave desert tortoise exclusion fencing, Hwy 58 near Kramer Junction, California. The gate does not have a buried component, and it had enough flex to result in permanent openings, partially as a result of tumbleweeds being blown against the fence.

Combined drainage and escape for small animal species under a wildlife guard, Arizona, USA. While the metal bar design of this particular wildlife guard is not appropriate as a barrier for Mojave desert tortoises, the openings on the concrete walls on the side allow invertebrates, amphibians, reptiles, small mammals and other species that may fall in between the metal bars to escape to the safe side of the fence (not the roadside). For wildlife guards that have a fully enclosed pit with contiguous walls wooden planks or metal strips are sometimes attached, allowing animals to climb out of the pit. Wildlife guards are no longer recommended because Mojave desert tortoises may still cross and there may be maintenance issues if debris (e.g., tumbleweed) gets stuck in the pit (Pers. com. Kerry Holcomb, USFWS).

Escape ramp for small mammals, reptiles, amphibians and invertebrates from pit under wildlife guard (cattle guard), National Park Hoge Veluwe, The Netherlands. While the metal bar design of this particular wildlife guard is not appropriate as a barrier for Mojave desert tortoises, the escape ramp may allow invertebrates, amphibians, reptiles, small mammals and other species that may fall in between the metal bars to escape to the safe side of the fence (not the roadside). Note that the effectiveness of escape ramps is not tested, and their use for Mojave desert tortoises would need to be investigated before wide-spread use.

Tortoise guard consisting of two I-beams, welded together with connectors, for Mojave desert tortoise, US Hwy 93 (MP 58 NB) near Overton, Nevada. The tortoise approaches from the safe side of the fence (not the roadside). Note, that larger adult tortoises may not fit within, and may be able to gain access to the roadside across this structure. **This design is no longer recommended** because Mojave desert tortoises may still cross, and the structure does not stand up to heavy vehicles and high temperatures, and they are susceptible to erosion (Pers. com. Kerry Holcomb, USFWS; Kristina Drake, USFWS; Glen Knowles, USFWS).

Barrier on a hiking trail, designed to keep Mojave desert tortoises out of an area, St. George, Utah. Hikers may step over this barrier to continue on the trail, while tortoises cannot gain access to the road on the other side.

3.6. Barrier construction

The functionality of barriers can be affected by erosion and sedimentation. Low lying areas and desert washes are especially vulnerable to these processes. Preferably, **fences or other barriers should be placed in relatively high areas** that are less susceptible to erosion and sedimentation. However, barrier placement may be determined by right-of-way boundaries or property lines, which could preclude optimal placement relative to topography.

Mojave desert tortoises tend to follow washes (Jennings 1993, Peaden et al. 2017). Where desert washes or low-lying areas cross the road or are close to the road, culverts or larger underpasses may need to be installed for hydrological purposes. Such underpasses can also be made suitable for Mojave desert tortoises to cross to the other side of the road (see the separate crossing structure document). The **barriers can then be constructed on higher ground on the side of a desert wash or low-lying area as this makes it less likely that the fences will be affected by erosion and sedimentation processes.** In some cases, it may be possible to renegotiate right-of-way boundaries to allow optimal placement of barriers to minimize maintenance effort associated with erosion and sedimentation processes.

Mojave desert tortoise exclusion fence on the left, located on high ground adjacent to a desert wash leading to a culvert under US Hwy 93 (MP 58) near Overton, Nevada.

In some cases, Mojave desert tortoise fencing may need to cross a desert wash. While there is no robust low maintenance solution for these situations at this time, practitioners have attached logs or wood posts at the base of the fence (see image below). The expectation is that, during a flood event, the fence can “float” on top of the rushing water. When the water subsides, the logs weigh the fence down and make it connect to the surface again. In practice these designs require more attention than a fence located in high and dry areas.

Mojave desert tortoise exclusion fencing across a desert wash, St. George, Utah. Here the fence crosses a desert wash. The cedar logs will float and lift up the fence during a flooding event. This minimizes damage to the fence because of flooding and debris.

Mojave desert tortoise exclusion fencing across a desert wash with sedimentation at the fence, US Hwy 93 (MP 58 NB) near Overton, Nevada. The sedimentation reduces the effective height of the fence, and it may eventually threaten the integrity of the fence. Also note that the fence material has been cut in multiple overlapping segments to allow for the change in angle because of the change in slope (see next image for details).

Detail of Mojave desert tortoise fencing, US Hwy 93 (MP 58 NB) near Overton, Nevada. Because of the change in slope (higher bank towards the right), the fence material was cut and installed in multiple overlapping segments.

Mojave desert tortoise fencing with soil erosion, I-11, near Boulder City, Nevada. Note that the animals may now move in the erosion gully under the fence. Also note that the fence appears to have only been dug 6 inches into the ground rather than the recommended minimum 12 inches.

Mojave desert tortoise fencing installed across a low lying area, along I-15 near Barstow, California. Here debris (rocks, sand, garbage) has built up against the fence because water runs down the slope against the fence.

At crossing structures, the fence should angle from the property boundary towards the road and the crossing structure. As Mojave desert tortoises tend to follow the washes, **the fences should "funnel" all Mojave desert tortoises that move in and along the banks of desert washes**. This is a second reason, besides erosion and sedimentation processes, that the **fencing should be located on higher ground on the sides of washes or low-lying areas, rather than inside washes**.

Mojave desert tortoise fencing connected to a concrete box culvert (lower left), US Hwy 95 (MP 125 NB) near Indian Springs, Nevada. Note that the fences angle from the property boundary towards the culvert to funnel the animals towards the culvert. Also note that the property boundary fence continues through the wash (this property boundary fence is not a barrier to Mojave desert tortoises).

Mojave desert tortoise fencing, US Hwy 95 (MP 121.6 SB) near Indian Springs, Nevada. This is a right-of-way and cattle fence installed across the wash, intended to keep cattle from entering the culvert (which is to the right). The Mojave desert tortoise fencing (upper right) angles away from the property boundary towards the culvert.

Mojave desert tortoise fencing and a concrete box culvert, US Hwy 95 (MP 127.5 SB) near Indian Springs, Nevada. Note that the fence on the near side is located on top of the bank of the desert wash, and not in the wash or on the bank.

Funnel fencing for Mojave desert tortoise and a box culvert (foreground), US Hwy 95 (MP 126.5 SB) near Indian Springs, Nevada. Note that the fence on the left is on higher ground, on top of the bank of the wash, and not within the wash or on the bank.

Fences should have a tight connection to the structure or wingwalls of the structure so that Mojave desert tortoises cannot access the fenced road corridor. In some cases, it is best to **have the fence run behind and on top of the culvert** and not have any break in the fence. Do not assume large rocks or boulders are a barrier for Mojave desert tortoises and do not allow for gaps in the fence at large rocks.

Mojave desert tortoise fencing connected to the wingwall of a culvert, Hwy 58 near Kramer Junction, California. While the connection between the fence and wingwall is tight and should not allow Mojave desert tortoises to access the fenced road corridor, the effective height at the connection is only about 11 inches instead of the recommended 22-24 inches. The fence material should have been continued until the point where the wingwall has a height of 22-24 inches.

Mojave desert tortoise fencing connected to a culvert, US Hwy 95 (MP 121.6 NB) near Indian Springs, Nevada. Note concrete access paths for Mojave desert tortoises constructed along the fence.

Mojave desert tortoise fencing connected to a culvert, I-15 near Barstow, California. Here debris (rocks, sand) has built up against the fence, threatening its integrity.

Mojave desert tortoise fencing leading up to culverts primarily designed for hydrology, I-15 near Barstow, California. Note that the fence does not physically connect to the structure and that riprap (rocks) fills the gap. However, it would have been better to leave no gap in the fence and have the fence continue on top of the bank above the boulders.

Mojave desert tortoise fencing connected to a culvert, US Hwy 93 (MP 58 NB) near Overton, Nevada. The fencing would be a more effective barrier if it was continued above the culvert without any gap in the fence.

Mojave desert tortoise fencing connected to twin culverts, US Hwy 93 (MP 69.5 NB) near Overton, Nevada. The fencing would be a more effective barrier if it was continued above the culvert without any gap in the fence.

Turtle fence and a dry culvert used by turtles, Valentine National Wildlife Refuge, Ballard's South, Valentine, Nebraska, USA. This culvert is 30 inches wide, 22 inches tall. Note that this turtle fence has no gap and continues behind and on top of the culvert.

Open medians with separate crossing structures for the two travel directions should have Mojave desert tortoise fencing installed to prevent tortoises from accessing the fenced road corridor in the median.

3.7. Barrier maintenance

Maintenance of Mojave desert tortoise fencing may be inadequate or lacking. In practice, fence inspection and maintenance may be underfunded and not a priority for transportation agency maintenance personnel and therefore it may not happen, or it happens too infrequently. Since most of the fencing is located away from the travel lanes or the shoulder, problems with Mojave desert tortoise fencing cannot be effectively detected from a moving vehicle. Proper fence inspection may require walking the fence line. Therefore, it may be best to outsource fence inspection, and repair and maintenance. While erosion and sedimentation processes result in the greatest need for maintenance and repair, destruction by (off-road) vehicles, vegetation growth, blowing garbage and dead vegetation (e.g., tumble weeds) can also threaten the functionality of a Mojave desert tortoise fence.

Mojave desert tortoise fencing, I-15 near Barstow, California. The fence is in disrepair and a shrub has grown through the fence, reducing its effective height.

Dead vegetation has blown against the Mojave desert tortoise fence, reducing the barrier effect of the fence to keep tortoise from accessing the highway, Aerospace Hwy, Hwy 14 near Inyokern, California. Note that the height of the fence, as installed, is insufficient to begin with.

Mojave desert tortoise fencing with windblown garbage, I-15 near Barstow, California. While this garbage does not pose an immediate threat to the integrity of the fence, tortoises and other wildlife species may consume garbage with potentially lethal consequences. In addition, because fences catch windblown garbage, they make the presence of garbage more visible to people, affecting landscape aesthetics.

3.8. Shade structures

Artificial shade structures can provide shelter from the sun for Mojave desert tortoises. This is especially relevant if tortoises walk along a fence and overheat, but cannot find natural shade or a suitable crossing structure quickly enough (Peaden et al. 2017). Artificial shade structures resemble a natural burrow dug by tortoises and may be especially useful for individuals that are new to the area (e.g. translocated individuals) or that are captive in a small area (Ruby et al. 1994, Peaden et al. 2017). Recommended material is a 12-15 inch (61-38 cm) interior diameter PVC pipe (schedule 40 or 80), buried into the soil (U.S. Fish and Wildlife Service 2020). The recommended minimum length of the pipe is 6 ft to ensure shade and to potentially allow shelter for more than 1 tortoise (U.S. Fish and Wildlife Service 2020). The structure should have 2 openings. This allows a tortoise to escape if one opening is blocked by debris (U.S. Fish and Wildlife Service 2020). Regular maintenance is required to ensure that tortoises can access the shade structure, especially after precipitation events that could have caused erosion and sedimentation. When conducting maintenance, exercise caution as tortoises or other animal species (e.g., snakes) may be present inside the structures (U.S. Fish and Wildlife Service 2020). The fill inside the pipe should leave 12-15 inches (30 cm) clearance (between the soil and the ceiling, and inside the structure between the left and the right interior walls). This allows large tortoises to turn around and not get trapped inside the shade structures (U.S. Fish and Wildlife Service 2020). The outside of the pipe should be covered with at least 3-4 inches (7.5-10.2 cm) of soil and rocks for temperature insulation (U.S. Fish and Wildlife Service 2020). If the structure is in-line with the face, take care that the overall height of the shade structure does not allow the tortoises to climb over the fence. The shade structures can be placed in line with the fence (U.S. Fish and Wildlife Service 2020), but mind potential issues with property boundaries. NVDOT recommends the structures to be placed at a minimum of 12 inches (60 cm) from the fence. A spacing of at least 1000 ft (305 m) has been recommended (U.S. Fish and Wildlife Service 2020). Alternatively, native shrubs may be planted or encouraged to grow close to the fence to provide shade. For the south side of an east-west road, the shrubs would be on the “safe-side” of the fence, for the north side, the shrubs would be on the “road-side” of the fence. For barrier walls integrated into the roadbed, shade caves or shade pipes could be located behind the barrier walls (on the habitat side of the barriers) and covered by the material that forms the roadbed to provide insulation.

A natural burrow dug by a Mojave desert tortoise along the edge of a desert wash, St. George, Utah.

Artificial shade structure for Mojave desert tortoises, along US Hwy 93 (MP 58 NB) near Overton, Nevada.

Mojave desert tortoise feces in a culvert, St. George, Utah. Culverts may resemble Mojave desert tortoise burrows and can function as a place to shelter from the sun or cold temperatures. The presence of feces indicates that a Mojave desert tortoise was present, and it may be an indication that it spent substantial time within the culvert.

4. CROSSING STRUCTURES

4.1. Purpose

The authors distinguish among the following types of crossing structures:

- **Existing structures built for other purposes without modifications for wildlife.** The primary purpose of crossing structures that were not originally constructed for wildlife is often to allow for people (including e.g., vehicles), livestock, or water to cross under (underpasses) or over (overpasses) the road. Their location, type, dimensions, and the distance between them is dictated by their primary - non-wildlife - function. No modifications have been made to encourage use by wildlife species.
- **Modified structures.** These structures are similar to the previous category. However, modifications have been made to enhance use by wildlife species**. Modifications can make existing structures, originally built for other purposes, more suitable, or somewhat suitable, for some wildlife species**. For a modified structure to be considered successful, it should at least result in enhanced use by wildlife, compared to unmodified structures. For example, an existing culvert originally built for hydrology is made more suitable for Mojave desert tortoises by later adding substrate or other material to reduce erosion and sedimentation processes at the culvert and make the culverts better accessible to Mojave desert tortoises. However, the location and dimensions of the structures are **not influenced** by the need or goal to provide safe crossing opportunities for Mojave desert tortoises.
- **Multifunctional structures.** Structures that are truly multifunctional would have their location and design influenced by the different functions, in this case including functions related to wildlife movement of the Mojave desert tortoise. For example, a multifunctional structure could be a structure in a drainage or desert wash that is located and designed to pass both water and allow for use by Mojave desert tortoises. Both the hydrological function and the movement by the Mojave desert tortoises **influence** the location, design, construction, and maintenance. For a multifunctional structure to be considered successful, it should achieve certain stated objectives, including those related to wildlife movements, in this case by Mojave desert tortoises.
- **Designated wildlife crossing structures.** Designated wildlife crossing structures have their location and design primarily informed by goals related to wildlife movement of certain target species. For example, the location, design, construction and maintenance of a crossing structure, or set of crossing structures, is **optimized** for the movement of Mojave desert tortoises. For a Mojave desert tortoise crossing structure to be considered successful, it should achieve certain stated objectives related to Mojave desert tortoise movements (see later).

Modified crossing structures, multifunctional crossing structures, and designated wildlife crossing structures should all allow for safe passage by wildlife under or over a road. However, **stand-alone crossing structures that are not connected to wildlife fences or other barriers do not necessarily reduce direct road mortality** (Rytwinski et al. 2016). In addition, structures that are tied into wildlife fences or other barriers have higher use by wildlife as the **fences**

"funnel" the animals towards the structure (Dodd et al. 2007, Gagnon et al. 2010). Therefore, **as a general rule, crossing structures for wildlife should be combined with wildlife fences or other barriers** (see also Chapter 3).

While modified, multifunctional, or designated crossing structures for Mojave desert tortoises need to allow Mojave desert tortoises to move to the other side of the road, these types of culverts can also function as:

- An artificial burrow to shelter from the sun. This may be especially important when Mojave desert tortoises may develop hyperthermia when pacing along a recently installed fence (Peaden et al. 2017).
- An artificial burrow for overwintering. However, depending on the size of the culvert, precipitation, and erosion and sedimentation processes, this can also present a hazard to tortoises (Lovich et al. 2011).

4.2. Effectiveness

The **effectiveness of crossing structures for wildlife movement** should be based on one or more wildlife movement parameters, potentially including how movement may improve population viability and genetic connectedness. Note that wildlife use of a structure without context or reference is not an effectiveness parameter; it is simply a tally of how many individuals from what species use a crossing structure over a certain period. Verifying whether a structure or set of structures are effective requires additional data, e.g., related to achieving a pre-stated objective, or compared to another treatment (e.g., a control). Examples of effectiveness parameters for crossing structures used by wildlife may include:

- Increased population viability: Increased movement between populations on both sides of a road contribute to having a larger and better-connected population with increased population persistence.
- Increased wildlife movement: Increased wildlife movement between two sides of a road e.g., compared to a road without crossing structures or a road without modified or designated crossing structures. However, the increase in movement may or may not be sufficient to result in a viable population, especially when population densities and reproductive rates are already low. Regardless of a potential increase in movement, the movement rates may or may not be similar to the level of connectivity in roadless habitat.
- Reduced genetic isolation: Individuals originating from different sides of the road breed and thereby reduce genetic isolation for the populations on either side of the road. This can contribute to increased heterozygosity, decreased loss of alleles, reduced probability of genetic drift, and a greater ability to adapt to changing environmental conditions and allow for evolutionary adaptation.

Structures are more likely to be effective if they are:

- **In suitable habitat.** The Mojave desert tortoise occupies *"a variety of habitats from flats and slopes dominated by creosote bush scrub at lower elevations to rocky slopes in blackbrush and juniper woodland ecotones at higher elevations. Desert tortoises occur from below sea level to an elevation of 2,225 meters (7,300 ft). Throughout the Mojave Desert, tortoises occur most commonly on gently sloping terrain with sandy-gravel soils* *and where there is sparse cover of low-growing shrubs, which allows establishment of herbaceous plants. Soils must be friable enough for digging of burrows, but firm enough so that burrows do not collapse.* ***Typical habitat for the desert tortoise in the Mojave Desert has been characterized as creosote bush scrub below 1,677 meters (5,500 ft), where precipitation ranges from 5 to 20 centimeters (2 to 8 inches), the diversity of perennial plants is relatively high, and production of ephemerals is high"*** (U.S. Fish and Wildlife Service 2011). The U.S. Fish and Wildlife Service has identified "**critical habitat**" for the Mojave desert tortoise that makes it easier to verify if conservation measures for the Mojave desert tortoise are in the correct region and habitat (U.S. Fish and Wildlife Service 2011). Critical habitat is *"the specific areas within the geographic area, occupied by the species at the time it was listed, that contain the physical or biological features that are essential to the conservation of endangered and threatened species and that may need special management or protection. Critical habitat may also include areas that were not occupied by the species at the time of listing but are essential to its conservation"* (U.S. Fish and Wildlife Service 2017). In addition, habitat suitability for the Mojave desert tortoise has also been modelled (Nussear 2009), and while there is great overlap with "critical habitat", there are also some differences as "critical habitat" is not only influenced by ecological conditions, but also by jurisdictions and policy.

- **In the correct specific location.** The structures should be located where the target species is willing to approach the road and where they may have an interest in crossing the road. It is also possible to plan for structures in habitat that is currently unsuitable or unoccupied, but where habitat restoration or reintroduction is to take place. In other words, **crossing structures should be located strategically at specific locations in suitable habitat or suitable corridors that connect existing or future habitat patches on either side of a road**. More specifically, **Mojave desert tortoises tend to follow desert washes** (Jennings 1993, Peaden et al. 2017). Where desert washes or low-lying areas cross the road or are close to the road, culverts or larger underpasses may already be in place for hydrological purposes. Such existing underpasses can potentially be made suitable or more suitable for Mojave desert tortoises to cross to the other side of the road. Alternatively, multifunctional structures may be designed, constructed, and maintained for both hydrology and use by Mojave desert tortoises. Another option is to design, construct, and maintain wildlife crossing structures optimized for Mojave desert tortoises, either near crossing structures for water or as stand-alone crossing structures in higher and drier areas. Note that existing structures for water may still need modifications if they present a risk for injury or death to Mojave desert tortoises or other species (see later). Also note that as fences should extend for many miles, fences are also located in habitat that is relatively high and dry. Therefore, additional crossing structures for Mojave desert tortoises and other species for which the fence may be a barrier, should be considered in higher and drier habitat as well.
- **The correct crossing structure type (i.e., underpass vs. overpass).** While there are no comparative data, Mojave desert tortoises are known to use underpasses, including culverts of a few feet in diameter. Culverts are somewhat similar to Mojave desert tortoise burrows and combined with the fact that Mojave desert tortoises follow drainages, underpasses, including culverts, are likely the "correct" type of crossing structure (Boarman et al. 1998). However, that does not mean that larger underpasses (e.g., box culverts, bottomless culverts, bridges) or overpasses are not readily used by

Mojave desert tortoises or that they would be less suitable. To really identify the “most suitable” type of crossing structure one could count the number of animals willing to come close to different structure types and then calculate the acceptance rate for each structure type. In theory, all other parameters should be the same between the different structure types, but that is rarely the case outside of a laboratory setting. Note that the concept of “correct” and “suitable” also applies to the dimensions of an underpass or overpass (see next point).

$$Acceptance = \frac{Number\ of\ individuals\ passing\ through\ a\ structure}{Number\ of\ individuals\ approaching\ a\ structure}$$

A multifunctional concrete culvert with natural substrate leading up to it, primarily designed for hydrology, but adapted for use by Mojave desert tortoises, US Hwy 95 (MP 125 SB) near Indian Springs, Nevada.

Wildlife overpass primarily designed for desert bighorn sheep, I-11, near Boulder City, Nevada.

- **Of the correct dimensions.** Dimensions are usually calculated from the animal's perspective. The width of an underpass is equivalent to the road length above an underpass. The width of an overpass is equivalent to the road length under an overpass. The height of an underpass is the distance between the bottom of an underpass and the ceiling. Overpasses have no "height". The length of an underpass or overpass is equivalent to the distance between the two entrances or approaches on the two sides of a road. While there are no comparative data, Mojave desert tortoises are known to use metal corrugated culverts or corrugated metal pipes (CMP). Combined with the fact that Mojave desert tortoises follow drainages (Jennings 1993, Peaden et al. 2017), most underpasses, including culverts (e.g., 2-3 ft in diameter), are likely among the "correct dimensions" for a crossing structure for Mojave desert tortoises. However, that does not mean that larger underpasses (e.g., box culverts, bottomless culverts, bridges) or overpasses are not readily used by Mojave desert tortoises or that they would be less suitable. The "most suitable" dimensions of a crossing structure could be identified by calculating the acceptance rate for different designs (see previous point).
- **Not too far apart.** The appropriate space between crossing structures relates to the connectivity goals. Different goals may result in different spacing between structures. Examples of goals are:
    - Achieve a "viable population" for the two populations on the two sides of a road combined. The connectivity needs to be sufficient to allow for one larger population combined for the two sides of a road. The effective combined

population size would need to be "sufficiently large" to have a very low probability of extirpation because of stochastic events over a long time (e.g., several hundreds of years). Depending on the (remaining) populations and depending on the movement rates at the structures, this could be achieved with relatively few strategically placed structures that would allow for breeding animals and dispersers to successfully reach the other side of the road. However, if Mojave desert tortoise populations have been depleted in areas adjacent to roads already, fences in combination with crossing structures are insufficient. In those cases, population augmentation or reintroduction, and reducing unnaturally high densities of predators (e.g., raven, coyote) is likely required (Peaden et al. 2017, Chapter 6).

- Maintain ecological integrity of Mojave desert tortoise populations by allowing (almost) all individuals that live adjacent to the road to have access to at least one suitable crossing opportunity. This means that the diameter of the home range, or distance that individual Mojave desert tortoises are commonly willing to walk along a fence should be a guide for the spacing of suitable crossing structures.
- Allow for dispersing individuals to reach the other side of the road and recolonize an area or strengthen a small and isolated population. Dispersal movements are typically rare, and it is important to have a dispersing animal successfully cross the landscape, including roads. The distance that all (or almost all) dispersing individuals are willing to move along a fence before turning back should be guiding for the appropriate space between suitable crossing structures. If a dispersing animal happens to be equipped with a transmitter, distances traveled, including distances traveled along a fence can help inform appropriate spacing of crossing structures.

Overall, the current general guidance is to space suitable structures 670 m (0.42 miles) apart to achieve connectivity for adult Mojave desert tortoises (U.S. Fish and Wildlife Service 2014). This is based on a home range size of 45 ha (square sized, each side is 670 m) (U.S. Fish and Wildlife Service 2014).

4.3. Undesirable effects and possible solutions

- **Stand-alone crossing structures that are not connected to wildlife fences or other barriers do not necessarily reduce direct road mortality** (Rytwinski et al. 2016). In addition, structures that are tied into wildlife fences or other barriers have higher use by wildlife as **fences "funnel" the animals towards the structure** (Dodd et al. 2007, Gagnon et al. 2010). Therefore, **as a general rule, crossing structures for wildlife should be combined with wildlife fences or other barriers** (see Chapter 3).
- Fences designed for Mojave desert tortoises may also be a barrier for other small species (e.g., small mammals, reptiles and amphibians). If the location, type, dimensions, and spacing of these crossing structures does not meet the biological needs of these other species, effective mitigation measures for the Mojave desert tortoise may be harmful to those other species. **Therefore, rather than only considering the conservation of the Mojave desert tortoise along roads, evaluate the effects of roads and traffic, as well as conservation measures for a wide range of species.** This will ultimately be

beneficial to the conservation of the Mojave Desert ecosystem rather than only a single species and potentially causing negative effects to other species. Mitigation measures for multiple species may affect the location and design of fences and other barriers, as well as the location and design of modified, multifunctional, or designated wildlife crossing structures.

- Mojave desert tortoise fences typically cover many miles in road length (see Chapter 3). This means that fences are located in both relatively low areas that are more likely to flood and experience washouts during storm events, as well as relatively high areas. While it is “good practice” to provide crossing structures for Mojave desert tortoises in desert washes (Jennings 1993, Peaden et al. 2017), installing crossing structures only in these locations result in a lack of crossing opportunities in relatively high and dry areas. **Therefore, installing crossing structures in relatively high and dry areas, in addition to those in low areas and desert washes, should be considered. This will benefit both Mojave desert tortoises and other species that may be affected by the Mojave desert tortoise fences and that may depend on connectivity in high and dry areas.**
- While likely rare, Mojave desert tortoises may become trapped or killed within culverts during flood events, especially if there is substantial erosion and sedimentation in the area (e.g., as a result of construction activities). For example, a large sediment flow has been documented to completely fill a 0.6 m (2 ft) diameter corrugated steel culvert (also known as a corrugated metal pipe (CMP)) and entomb an overwintering Mojave desert tortoise inside a culvert (Lovich et al. 2011). While the animal was alive when removed from the culvert, it was found dead 18 days later, potentially because of pneumonia contracted while being buried in the culvert. Larger diameter concrete box culverts or corrugated steel culverts (also known as corrugated metal pipes (CMP)) (e.g., at least about 3.3 ft or 1 m in diameter) may be less likely to fill with sediment (Lovich et al. 2011). Inspection by qualified biologists prior to commencement of project activities or maintenance should occur to reduce the likelihood of tortoises becoming trapped or harmed.
- Erosion processes, especially at the outflow of culverts, can make it difficult or impossible for Mojave desert tortoises to access the crossing structure (Grandmaison et al. 2012). Tortoises can also become trapped within spaces in the riprap or drown in plunge pools if they cannot climb out (Gardipee et al. 2017). Larger culverts reduce water velocity and erosion and sedimentation processes. In addition, consider placing larger rocks mixed in with finer rocks and gravel at the outflow. Alternatively, installing tortoise fencing such that a 2-3 foot swath of natural habitat remains along the sides of the outflow may allow Mojave desert tortoises to approach and leave the underpass. Construction of concrete tortoise ramps along plunge pools is not recommended as erosion may cause them to fail.

4.4. Planning

Selection of road sections
Crossing structures for Mojave desert tortoises (and other wildlife species) should typically be prioritized along:

1. Road sections where roads and vehicles are a substantial barrier to the animals and where improving connectivity increases the likelihood of Mojave desert tortoise population persistence or recovery within adjacent habitat.
2. Road sections where Mojave desert tortoise fences have been installed as the fences make the transportation corridor into a near absolute barrier for this species. However, most paved roads without tortoise fences are already considered a near absolute barrier for Mojave desert tortoises because few tortoises are believed to cross successfully (i.e., most tortoises that attempt to cross are likely killed by vehicles) (Pers. com. Kerry Holcomb, USFWS). The Mojave Desert Tortoise Exclusionary Fence Installation Prioritization Index (DTEFIPI) indicates where Mojave desert tortoise fences are most needed (Pers. com Kerry Holcomb and Florence Deffner, USFWS). The planning process for installation of fencing in any priority road segment should include an inspection of existing culverts to determine their suitability as potential tortoise crossings and an analysis to identify potential sites for construction of new crossing structures. Early coordination with DOT hydrology staff is also recommended to determine whether existing culverts can be modified for dual purpose and suitability of potential sites for construction of new culverts.

If the objective is to recover Mojave desert tortoise populations, e.g., through population augmentation or reintroduction, crossing structures are an important tool, as they could help the animals on both sides of the road form one larger population with higher population persistence probability. Crossing structures for Mojave desert tortoises should be installed where connectivity is needed most and where a reduction in the barrier effect is likely to increase the likelihood of Mojave desert tortoise population persistence or recovery within adjacent habitat. If such crossing structures are connected to fences or other barriers, direct road mortality can be reduced as well. Fences or other barriers can also guide individual animals to the crossing structures and increase the use of the crossing structures, but this has not been investigated yet for Mojave desert tortoises (Dodd et al. 2007; Gagnon et al. 2010). In summary, all roads that bisect important habitat for Mojave desert tortoises should be mitigated, beginning with the road sections where Mojave desert tortoises are still present in the surrounding landscape.

Location of the crossing structures in relation to the right-of-way boundary
In general, the longer a crossing structure is, the less likely it is that animals will enter it and successfully cross to the other side. Long length of a structure (i.e., road width) can be somewhat compensated though by having a greater width and height, but the usefulness of the associated "openness ratio" is unproven and disputed (Clevenger & Waltho 2005, Meese et al. 2007, Clevenger & Huijser 2011, U.S. Fish and Wildlife Service 2014). Nonetheless, it appears best to not make a structure longer than necessary. In other words, the structure should not be extended to the edge of the right-of-way. Rather, the length of an underpass should be as short as possible, but long enough not to receive debris (including snow from snowplows) from the roadway above. Extending the structure until e.g., the edge of the shoulder of the road may also reduce

visual and noise disturbance from traffic. Furthermore, slightly longer structures can also reduce the slope of the roadbed, and thereby reduce potential erosion. Having an opening in the median between 2 separate structures (one for each travel direction) may also be beneficial.

For rectangular structures:

$$Openness = \frac{Width * Height}{Length}$$

For circular structures:

$$Openness = \frac{\pi * r^2}{Length}$$

Wildlife fences are normally placed on the edge of the right-of-way, but they should angle towards crossing structures where crossing structures are located (see Chapter 3).

Mojave desert tortoise fencing has been installed within the open median to prevent larger tortoises from climbing over the curb and accessing the highway (US Hwy 95 (MP 125 NB) near Indian Springs, Nevada). The open median results in two separate structures (one structure for each travel direction) rather than one longer culvert structure and the fence guides the animals between the two structures. Data collected through culvert monitoring studies suggest this open median design may be conducive to enticing tortoise movement across wide four-lane highways. It is generally considered good practice to design and construct the 2 structures such that there is a direct line of sight through both of them (i.e., you can see through the 2 culverts from the west side to the east side of the road).

Functions of the crossing structure
Crossing structures placed in desert washes almost always function as a way for water to cross to the other side of the road. As Mojave desert tortoises tend to follow desert washes (Jennings 1993, Peaden et al. 2017), it can be cost efficient to design multifunctional crossing structures at these locations. Note that a multifunctional crossing structure is fundamentally different from a structure that is designed for hydrology and that may or may not have been modified to enhance use by Mojave desert tortoises. A truly multifunctional structure would take all the functions into consideration during the design process and carry that through during the construction and operation and maintenance phases (see earlier in this chapter).

4.5. Design

Since Mojave desert tortoises tend to follow desert washes (Jennings 1993, Peaden et al. 2017), underpasses are likely the primary type of crossing structure for the Mojave desert tortoise. However, the dimensions of underpasses may vary from small diameter culverts (e,g, 2 ft diameter) to extended bridges (dozens or hundreds of yards wide). As far as the authors know, there are no comparative data available on the relatively suitability of different dimensions of underpasses for the Mojave desert tortoise. However, structures that are minimally designed for hydrology tend to suffer more from erosion issues than structures that allow more space for passing water. Increased erosion may result in the following potential problems:

- Threat to the integrity of the crossing structure and the roadbed.
- Mojave desert tortoises may not be able to approach or leave a crossing structure, and may become trapped between large rocks at the approach or exit, or may drown in the pools in between boulders (see earlier).
- Unnatural levels and patterns of erosion and sedimentation.

Mojave desert tortoises have been recorded entering, occupying, and sometimes crossing through underpasses that have different dimensions (Table 1). During a multi-year monitoring study in southern Nevada, tortoises were observed to successfully cross through corrugated metal pipe (CMP) culverts ranging 24” to 36” in diameter and up to 111 feet long (openness ratio (OR) = 0.04 to 0.07). This site was located within a fenced section of U.S. 93, a major two-lane highway with high traffic volume (BLM and DCP 2022). A second study site was located within a fenced section of U.S. 95, a major four-lane highway, also with high traffic volume. At this site, tortoises were observed to cross distances up to 225 feet through concrete box culverts (OR = 0.11 to 0.40) and open medians (82.25 to 104.5 feet length) (BLM and DCP 2022). Both types of culvert designs evaluated in this study appear to facilitate movement, primarily by adult tortoises, and the burrow-like appearance of CMPs may entice use as shelter by tortoises. Over 50 species of mammals (16), reptiles (18), birds (14), and insects (9) were documented using culverts at both study sites, suggesting that tortoise fences connected to culverts potentially also reduce direct road mortality for other species.

However, it is currently not known which dimensions of crossing structures are most suited (i.e., most readily accepted) by Mojave desert tortoises. In principle though, culverts that are 2-3 ft in diameter are likely “suitable” for Mojave desert tortoises and larger structures may be similarly suitable or more suitable rather than less suitable (Table 1, BLM and DCP 2022). Hydrology is likely dictating the minimum size of the structure rather than Mojave desert tortoises. However, there is a caveat; structures that are minimally designed for hydrology tend to suffer from erosion that may make structures unsuitable for Mojave desert tortoises. Therefore, multifunctional structures should be designed large enough for erosion to not threaten the functionality of the structure for Mojave desert tortoises. The resulting recommended dimensions for an underpass are best determined by hydrologists and geomorphologists in collaboration with Mojave desert tortoise biologists.

Desert washes and associated culverts for both hydrology and for Mojave desert tortoises are likely the best locations and most practical structure type for Mojave desert tortoises to cross roads. However, tortoises have been observed to travel over gentle inclines, suggesting that certain types of wildlife overpasses may facilitate movement of desert tortoises across roads. While wildlife overpasses primarily designed for Mojave desert tortoises will likely be very rare, there may be opportunities for modifying existing overpasses built for other purposes and there may also be opportunities to have Mojave desert tortoises influence the location and design of multifunctional crossing structures. Design parameters that may benefit use of overpasses by Mojave desert tortoises include nearby seasonal water, shrub and herbaceous plant cover, potentially supplemented by rocks or woody debris provide cover that blends in with the landscape. Alternative materials (e.g., fiber reinforced polymers) can be considered for the construction of overpasses, which may offer benefits related to sustainability, faster construction, and reduced maintenance.

Table 1: Structure type and dimensions "used" by Mojave desert tortoises.

Structure Type	Height	Width	Diameter	Length	Openness Ratio	Finding	Source
Storm drain culvert	N/A	N/A	0.6 m, 1.97 ft	66 m, 217 ft	0.01	Tortoises readily entered and crossed, though it may take them many hours.	Boarman et al. 1998
Concrete box culverts	1.22 m, 4 ft	2.44 m, 8 ft	N/A	70 m, 230 ft	0.14	Tortoises readily entered; some used it to cross the road	Ruby et al. 1994
Wildlife underpass	3.7 m, 12 ft	15.2 m, 50 ft	N/A	51.8 m, 170 ft	3.53	A live desert tortoise found in structure.	Arizona Game and Fish Department 2020
Corrugated metal pipe	N/A	N/A	0.61 to 0.91 m, 2 to 3 ft	25.6 to 33.8 m, 84 to 111 ft	0.04 to 0.07	Tortoises observed to enter and completely pass through on multiple occasions.	BLM and DCP 2022
Concrete box culverts with open medians	0.91 to 1.22 m, 3 to 4 ft	6 ft	N/A	24.9 to 31.9 m, 82.25 to 104.5[*1]	0.17 to 0.40[*2]	Tortoises observed to enter and completely pass through on multiple occasions.	BLM and DCP 2022

[*1] Length for concrete box structures only. Total crossing length including box culvert structures and open medians: 110.25 ft to 225 ft.
[*2] Estimated for concrete box culvert structures only. Length of open medians: 22-28 ft.

4.6. Construction

Construction in highly erodible soils such as those in the Mojave Desert should pay great attention to preventing or minimizing unnatural erosion and sedimentation processes during the construction of crossing structures. The design should be such that unnatural erosion and sedimentation is also avoided or minimized during the operational phase. In general, the inflow (upstream side) of the culverts has far fewer erosion issues than the outflow (downstream side). Plunge pools should be filled in with finer substrate to reduce the likelihood of trapping Mojave desert tortoises. In addition, drainage should be sufficient for water to disappear relatively quickly to reduce the risk of Mojave desert tortoises drowning.

Great care should be given to the approaches of the crossing structure to make sure that they are and will continue to be accessible to Mojave desert tortoises. Furthermore, there should be no gaps in between the fences or other barriers and the crossing structures that would allow Mojave desert tortoises to access the road. Also, consider barriers (e.g., large boulders) on the approaches to block unauthorized use by motorized vehicles (e.g., ATVs).

Culverts, primarily designed for hydrology, but also for Mojave desert tortoises, Hwy 58 near Kramer Junction, California. There is no erosion or sedimentation at this approach that would constitute a barrier to tortoises. However, having one open structure, not separated by dividing walls, would likely be better for wildlife use in general.

Riprap in front of culverts to reduce erosion, I-11, near Boulder City, Nevada. While beneficial to combatting erosion and sedimentation issues, the size and placement of the riprap most likely results in a substantial barrier to Mojave desert tortoises.

This is what the riprap field looks like from the perspective of a desert, I-11, near Boulder City, Nevada. The riprap is likely an absolute or near absolute barrier to tortoises.

Riprap filled in with finer rocks and sand, in front of culverts to reduce erosion, I-11, near Boulder City, Nevada. This does not appear to be a barrier to Mojave desert tortoises.

Mojave desert tortoise fence and a culvert US Hwy 95 (MP 127.5 SB) near Indian Springs, Nevada. Riprap stabilizes the slope between the fence and the culvert. Mojave desert tortoises that follow the fence cannot easily access the culvert; they would have to navigate the riprap on the slope first. Design and construction of culverts, fences, and measures aimed at erosion control should ensure that tortoises can easily access the culvert, including when they follow the fence.

Mojave desert tortoise fence and a culvert with concrete pathways leading up to the entry, US Hwy 95 (MP 121.6 SB) near Indian Springs, Nevada. This inflow shows no noticeable erosion; Mojave desert tortoises of any size can easily access this culvert across the entire width of the culvert.

Mojave desert tortoise fence connected to a culvert with concrete pathways leading up to the entrance, US Hwy 95 (MP 121.6 NB) near Indian Springs, Nevada. A deep plunge pool was constructed to address the high water volume and velocity at this outflow. This resulted in substantial erosion and a steep slope, somewhat stabilized by large riprap. The riprap was filled in with smaller substrate to minimize the threat of entrapment of tortoise within gaps formed by the riprap. Concrete pathways were constructed to allow potential use by Mojave desert tortoises for accessing the culvert. The pathways may not be wide enough to allow larger tortoises to turn around with the risk of falling into the plunge pool and erosion is currently undermining the integrity of these pathways. Therefore, this type of culvert access design is not recommended for tortoises.

Mojave desert tortoise fence connected to a concrete box culvert with a substantial drop-off, large riprap, accumulated tumbleweed, and eroded pathways likely result in a barrier for Mojave desert tortoises, US Hwy 95 (MP 125 NB) near Indian Springs, Nevada. Drop-offs greater than 4 inches may not be accessible for most tortoises (Pers. com. Kerry Holcomb US Fish and Wildlife Service). The cracked substrate within the deep plunge pool is an indication that standing water accumulates after storm events, which may attract tortoises that are then at a risk of drowning. The tumbleweed accumulation may block or discourage use by Mojave desert tortoises and should be addressed through regular maintenance (i.e., removal of the tumbleweeds). However, access to this culvert and plunge pool was eventually blocked because it was not possible to address the safety issues for tortoises with the existing hydraulic characteristics.

Mojave desert tortoise fence connected to a corrugated metal pipe (culvert) (CMP) with concrete pathways on both sides for Mojave desert tortoises, US Hwy 93 (MP 58 NB) near Overton, Nevada. Note that erosion resulted in a drop-off at the outflow of the culvert and this is likely a barrier to juvenile tortoises. While this culvert is passable for Mojave desert tortoises, improvements can be made by reducing the height of the drop-off.

Close-up with adult tortoise model at a corrugated metal culvert (Corrugated Metal Pipe (CMP), US Hwy 93 (MP 58 NB) near Overton, Nevada. Note that the height of the drop-off at the outflow of the culvert is likely a barrier for smaller size tortoises. While adult tortoises have been observed to pass through this culvert, regular monitoring and maintenance to address the effects of erosion can help keep a culvert passable by a both adult and juvenile tortoises.

An adult tortoise model demonstrates how this concrete pathway may allow access to the culvert entrance, US Hwy 93 (MP 58 NB) near Overton, Nevada. As noted above, the drop-off at the outflow of the culvert is a potential barrier to juvenile tortoises.

An adult tortoise model in a corrugated metal culvert (Corrugated Metal Pipe (CMP)), US Hwy 93 (MP 58 NB) near Overton, Nevada. Adult tortoises have been observed passing through these types of culvert structures, regardless of whether natural substrate was present (BLM and DCP 2022).

4.7. Maintenance

Erosion and sedimentation processes are likely the greatest maintenance concern and effort for crossing structures in the Mojave Desert. Erosion may result in deep drop-offs that can cause the crossing structures to become completely inaccessible to Mojave desert tortoises. In addition, tumble weeds and other debris carried by water or blown by wind can make a crossing structure inaccessible or unusable for Mojave desert tortoises. Note that larger structures are likely to have fewer maintenance issues as erosion and sedimentation, and weeds or other debris are less likely to result in physical barriers to Mojave desert tortoises. Regular inspection of culverts, especially prior to high movement periods for Mojave desert tortoises is recommended. Inspection, and at least some maintenance efforts will likely have to be outsourced as it is not or insufficiently done by DOT maintenance personnel.

Erosion along a concrete pathway leading up to a concrete box culvert, US Hwy 95 (MP 127.5 NB) near Indian Springs, Nevada. The riprap is filled with finer sediments that allows Mojave desert tortoises to access the culvert. However, it appears that the finer sediments are washing out and resulting in cavities that could trap Mojave desert tortoises.

Culvert primarily constructed for hydrology, but the culvert may also allow for passage by Mojave desert tortoises I-15 near Barstow, California. However, this culvert is blocked by tumbleweed.

Tumbleweeds block Mojave desert tortoises approaching or leaving culverts, Hwy 58 near Kramer Junction, California.

Mojave desert tortoise fence blocking access to a culvert that is considered a danger (e.g., entrapment between riprap or drowning in a deep plunge pool), US Hwy 95 (MP 125 NB) near Indian Springs, Nevada. The decision to block tortoises from accessing the culvert implies that the danger associated with accessing and using a culvert is considered greater than the benefits of potential crossings.

5. POPULATION AUGMENTATION AND REINTRODUCTION

5.1. Background

Population augmentation or reinforcement is the intentional release of individuals into an existing wild population whereas reintroduction is the intentional release of individuals into an area that is historic range but where the species is no longer present (IUCN/SSC 2013). Both population augmentation and reintroduction aim to restore or enhance population viability through increasing the population size, increasing genetic diversity, or increasing the representation of specific demographic groups (IUCN/SSC 2013). Important requirements for population augmentation or reintroduction may include (partially based on IUCN/SSC 2013, U.S. Fish and Wildlife Service 2021):

- Direct or indirect human impacts were the primary cause of the Mojave desert tortoise population decline or extirpation.
- Mojave desert tortoise population density in the potential release area should be well below the estimated carrying capacity or below what constitutes a viable population (< 3.9 adult tortoises/km^2 is considered not viable).
- The area must be in the historic range of the Mojave desert tortoise (unless the historic range has become unsuitable, other areas have become suitable, and the species would otherwise go extinct in the wild).
- The habitat must be of suitable quality (biotic and abiotic) for the foreseeable future.
- The area must be large enough to sustain a viable population.
- The threats that caused severe population decline or extirpation must have been correctly identified and sufficiently addressed to a level where population recovery is possible or likely. For Mojave desert tortoises, it is essential that adult survival is high enough to maintain a viable population.
- Potential benefits and potential negative impacts of population augmentation or reintroduction should be identified and evaluated. This includes ecological, social and economic aspects.
- The source or founder animals should have similar characteristics as the original or remaining wild animals. These characteristics may include parameters related to genetics, morphology, physiology and behavior. Usually, source or founder animals that originate from nearby locations are considered the most suitable.
- The source or founder animals should be screened for disease and pathogens to both maximize the health of translocated individuals and to minimize the risk of introducing a new pathogen into the release area.
- **Note that the list above is not necessarily complete, nor are all points necessarily applicable to the Mojave desert tortoise. In addition, this list does not reflect the policy of any agency or other organization. The purpose of this paragraph is to illustrate that population augmentation or reintroduction is complex and that it must meet certain criteria and that the arguments for and against should be carefully weighed based on ecological, social, and economic parameters. Population breeding and augmentation or reintroduction of Mojave desert tortoises is subject to regulations and permits, including from the U.S. Fish and Wildlife Service.**

5.2. Population augmentation or reintroduction of Mojave desert tortoises

Roads and traffic are associated with severe Mojave desert tortoise population size reduction in areas adjacent to roads. There is reduced Mojave desert tortoise presence, or even complete absence (based on sign of Mojave desert tortoise or lack thereof), within a zone adjacent to roads extending up to 230 or 800 meters from roads (Boarman et al. 1997, Boarman & Sazaki 2006, Hughson & Darby 2013, Peaden et al. 2015, Peaden et al. 2017, Zylstra et al. 2023). Direct road mortality is considered the leading cause of population decline in areas close to roads (Peaden 2017). While fences can stop further population decline, population recovery after the implementation of fences may be very slow, especially along high-volume roads (Peaden 2017). Recovery of such populations likely requires additional conservation measures, including population augmentation or reintroduction.

For population augmentation or reintroduction to be considered in areas close to roads (e.g., at a minimum up to 800 m, but consider op to 6.5 km (U.S. Fish and Wildlife Service 2021), the probability of direct road mortality should be sufficiently reduced. Assuming that road removal or road closure are not among the options for most roads, wildlife fences designed to keep Mojave desert tortoises off the road are required before population augmentation or reintroduction can move forward. Note that wildlife fences should typically be combined with wildlife crossing structures under or over the road (see chapter 3 and 4).

5.3. Source or founder animals

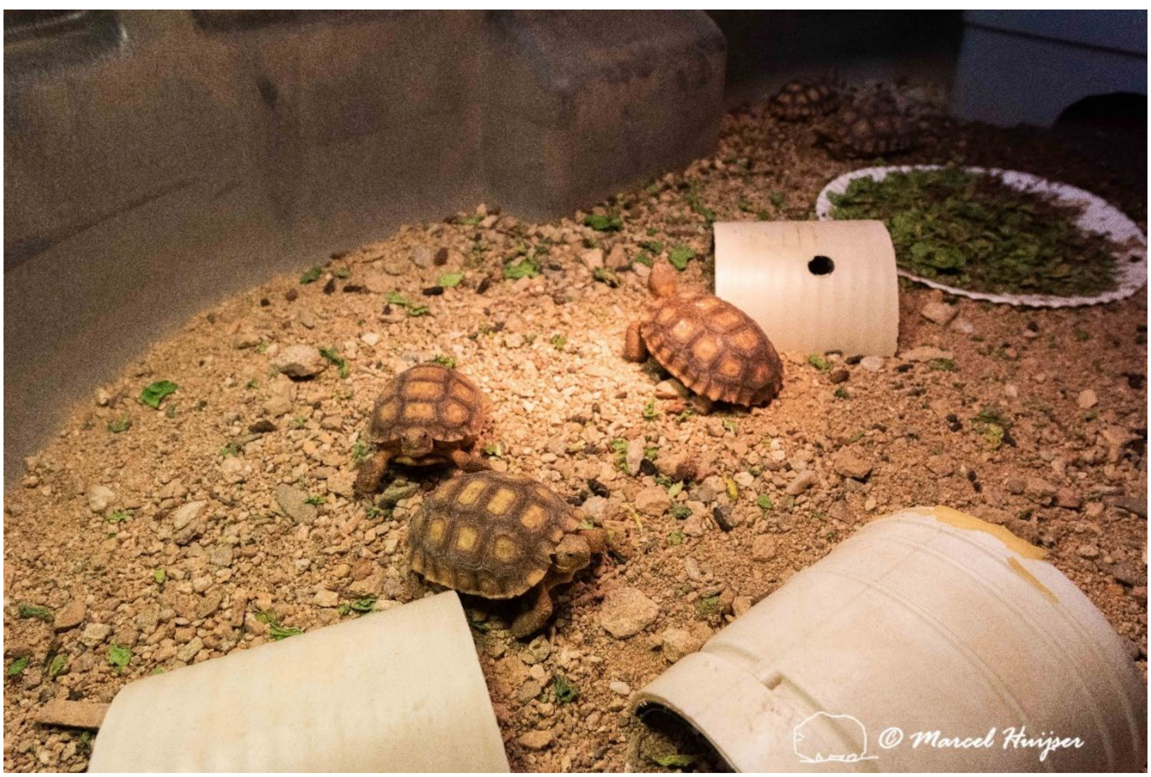
The source or founder animals can come from a captive or a wild source. **Captive sources can include animals from zoos, or animals that have been obtained from private individuals or from captive breeding ("head-start") facilities which have population augmentation or reintroduction as their main purpose.** While there are encouraging results from several "head-start" facilities in the Mojave Desert, the "production" of desert tortoises is still relatively low. There is currently an over-abundance of Mojave desert tortoises in the captive population cared for by private individuals. This can be considered as one of the potential sources for breeding age animals to be introduced into the wild population (UNLV 2018). A robust screening program would likely have to be implemented to identify eligible tortoises for population augmentation. Note that breeding and population augmentation or reintroduction of Mojave desert tortoises is subject to regulations and permits, including from the U.S. Fish and Wildlife Service and that private individuals cannot launch private initiatives. Wild sources may come from areas where the species can no longer live because of an imminent impact that causes habitat loss or a severe reduction in habitat quality (e.g., habitat loss or loss of habitat quality because of human impact). These wild animals are then removed from harm's way and would be able to continue to live in the release area where they contribute to the population augmentation or reintroduction effort.

5.4. Effectiveness

For population augmentation or reintroduction to make a meaningful contribution towards species recovery, the survival of the released animals should be at least similar to wild born individuals. It is best though to keep the smaller and younger animals protected from predators until they are less vulnerable and have a higher survival probability. This would allow population augmentation or reintroduction efforts for juveniles to be much more effective. Additionally, improved management plans for selected release sites and known predators (e.g., ravens), when appropriate, may improve augmentation effectiveness. Certain habitat types and regions may be considered or prioritized for augmentation to increase the effective population size (e.g. through higher numbers, greater density, and improved connectivity), and meet or exceed the thresholds for a viable population. However, successful augmentation across the tortoise range would require **upscaling captive breeding or head-start facilities**, as many populations are currently well below minimal viable density estimates required to keep the species present in the landscape.

Improved husbandry, clinical and physiological monitoring of health, biosecurity practices, and predator deterrents within head-start facilities would likely increase the number of suitable individuals available for augmentation. Additionally, experimental husbandry practices, such as specialized indoor captive rearing of juvenile tortoises at the Ivanpah Desert Tortoise Research Facility, Mojave National Preserve, California have yielded faster growth than outdoor head-starting and recorded wild tortoise populations (Daly et al. 2018, 2019, Tuberville et al. 2019, McGovern et al. 2020, Nagy et al. 2020). However, indoor head-started tortoises have relatively soft shells. **Allowing their shells to harden in an outdoor facility and keeping them in a protected environment until they reach a carapace length greater than 100 mm (4 inches) before releasing them into the wild is likely to increase their survival** (Nagy et al. 2015, Daly et al. 2018). Despite its potential or likely positive contribution to population restoration (Burke 2015, Tuberville et al. 2015), population augmentation may still need to be combined with habitat restoration and reducing populations of human-subsidized predators (Daly et al. 2019).

Captive breeding facility for Mojave desert tortoise, Ivanpah Desert Tortoise Research Facility, Mojave National Preserve, California. The fence and netting protect the tortoises from terrestrial and aerial predators.



Captive breeding facility for Mojave desert tortoise, Mojave National Preserve, California.

6. PREDATOR MANAGEMENT ALONG ROADS

Roads, associated structures, disturbance in the right-of-way, and traffic can allow new species to live in an area where they were originally not present (Huijser & Clevenger 2006). Other species may be already present in an undisturbed ecosystem, but roads and traffic can allow them to reach much higher population densities.

Ravens (*Corvus corax*) and coyotes (*Canis latrans*) are important predators for the Mojave desert tortoise (Boarman 2003, Kristan III & Boarman 2003, Esque et al. 2010, Cypher et al. 2018, Segura et al. 2020, Kelly et al. 2021, Parker et al. 2022). Ravens primarily kill hatchlings and juveniles (especially when the shell is still soft during the first 5-7 years), whereas coyotes can also kill juvenile and adult Mojave desert tortoises (U.S. Fish and Wildlife Service 2011). Roads, traffic, and associated structures provide subsidies, such as trash, roadkill, and other food sources for ravens and coyotes along transportation corridors. Fence posts, road signs, billboards, bridge structures, utility towers, sewage ponds, and buildings can allow for unnatural perching, roosting, and nesting sites for ravens (U.S. Fish and Wildlife Service 2011). In the southwest, ravens have increased by an estimated 1000% between the mid-1980s and 2011 (U.S. Fish and Wildlife Service 2011)

Measures to reduce the unnatural presence and high abundance of ravens and coyotes may include (Boarman 2003, U.S. Fish and Wildlife Service 2011):

- Limiting or eliminating unnatural food sources (e.g., thrash, landfills, roadkill). Preventing and removing food sources can help limit the presence and abundance of ravens and coyotes.
- Limiting or eliminating unnatural structures that can serve as perching, roosting, or nesting sites for ravens. If unnatural structures cannot be removed, try to make them inaccessible or unsuitable (e.g., spikes (Avery & Genchi 2004, Dwyer & Doloughan 2014, Dwyer et al. 2020) or "rollers" (Vogelbescherming Nederland 2017, Dekker 2021) that make structures including signs less suitable to perching, roosting or nesting.
- Population control of ravens and coyotes (e.g., trapping and subsequent removal, direct killing, reducing reproduction through egg removal or making eggs non-viable through egg oiling) (Shields et al. 2019). However, population control may only be effective if it occurs on a large spatial scale (Fleischer et al. 2008).

William Boarman holds a shell of a juvenile Mojave desert tortoise that was predated by a common raven.

Wire mesh and metallic flashers installed to discourage raven nesting on Snow Mountain Overpass, U.S. 95, Las Vegas, Nevada.

Billboards in the Mojave Desert provide nesting opportunity for ravens who then predate on juvenile Mojave desert tortoises, Las Vegas, Nevada.

Billboards in the Mojave Desert provide nesting opportunity for ravens who then predate on juvenile Mojave desert tortoises, Las Vegas, Nevada.

Raven roosting on billboard, U.S. 95, Las Vegas, Nevada.

Florence “Flo” Deffner

Raven nest with fledglings on billboard structure, I-15, Las Vegas, Nevada.

7. MEASURES FOR PARK ROADS

Wildlife fences and crossing structures are the most effective combination of mitigation measures to reduce direct road mortality and to allow for safe wildlife movements under or over roads (see Chapter 3 and 4). However, in protected areas, fences may impact landscape aesthetics, and they "isolate" visitors on the road from the surrounding landscape. In such cases barrier walls integrated into the roadbed may be an alternative to fences, at least for small terrestrial animal species such as Mojave desert tortoises (see Chapter 3).

"Park roads" do not necessarily need to allow for "efficient" (i.e., fast) transportation from point A to point B. The main purpose of park roads is to allow visitors to be in an area and experience the surrounding landscape, including the wildlife. This means that there are other measures available to managers if the main objective is to reduce direct road mortality of wildlife. Such measures may include:

- Night-time or seasonal road closures. During periods where risk of direct road mortality is high, roads may be temporarily closed. During those closed periods, direct road mortality is eliminated.
- Speed reduction. While vehicle speed management is complex, vehicle speed may be limited through reduced legal posted speed limit and associated measures that affect the design speed of a road (e.g., curves, narrow lanes, no road shoulder, speed bumps). However, the effectiveness of vehicle speed reduction in reducing road mortality is unknown, and it may still be ineffective for juvenile tortoises that may be too small to be noticed by drivers.

Gates for seasonal road closure to reduce road mortality of Mojave desert tortoise, Mojave National Preserve, California.

Maximum speed limit 25 MPH with speed radar to control speed, primarily for Mojave desert tortoise, St. George, Utah.

Speed bump to control speed, primarily for Mojave desert tortoise, St. George, Utah.

Park roads allow for contact between park managers and visitors. Entrance or fee stations may allow for outreach on how to behave in the protected area, including on and along roads. Measures may include:

- A personal talk with an employee at the entrance or fee station.
- Brochures.
- Warning signs and speed signs at the entrance station, supplemented by other warning signs along the road in the protected area.

The main goal of outreach is to provide the public with information about Mojave desert tortoises on and near roads or tracks, and to increase awareness about the conservation status of the species and the threats to their continued existence in the wild. In addition, outreach can help grow support for measures that are effective in reducing direct road mortality and that allow for safe road crossings by Mojave desert tortoises. However, outreach as a stand-alone measure cannot be expected to reduce direct road mortality and to reduce the barrier effect of roads and traffic (Huijser et al. 2021).

Park staff hands out brochures for Mojave desert tortoise at entrance station Snow Canyon State Park, St. George, Utah.

Warning sign and speed limit sign for Mojave desert tortoise at entrance station Snow Canyon State Park, St. George, Utah.

Warning sign, share the road, for Mojave desert tortoise, Snow Canyon State Park, St. George, Utah.

Warning sign for Mojave desert tortoise, Joshua Tree National Park, California.

Warning sign for Mojave desert tortoise, snakes and coyotes, Joshua Tree, California.

Road shoulders allow drivers to regain control of their vehicle after departing the travel lanes. However, road shoulders also result in habitat loss as natural vegetation may no longer be present in the road shoulder. Reclaiming road shoulders through habitat restoration can reverse this habitat loss. Typically, road shoulders are made inaccessible through curbs, rocks, or other objects that discourage vehicles from leaving the road. In addition to reversing habitat loss, direct mortality of wildlife can be reduced or eliminated in the (former) road shoulder. This may be especially relevant for Mojave desert tortoises as they may crawl under parked vehicles along the road for shade. Once the vehicle starts moving again, these tortoises are at risk of being crushed.

Graded road shoulder results in habitat loss and a place for vehicles to park, Joshua Tree National Park, California. Tortoises may crawl under parked vehicles for shade and are at risk of being crushed once the vehicle starts moving again.

Large rocks along edge of pavement to discourage off road parking that destroys vegetation and that could kill Mojave desert tortoise, Snow Canyon State Park, St. George, Utah.

Curb to keep vehicles from leaving the pavement and parking along the roadside, Joshua Tree National Park, California. Denying vehicles access to the road shoulder can be combined with habitat restoration. The rough surface of the curb is to potentially allow Mojave desert tortoises to escape from the road.

Tortoise trot, or gap in the curb, allowing Mojave desert tortoise to leave the road, Joshua Tree National Park, California.

While the shoulder is still accessible to vehicles, this gentle sloped curb allows Mojave desert tortoises to leave the road, Twentynine Palms, California.

8. UNPAVED ROADS

While recommendations for unpaved roads are not the focus of this report, obvious measures include road removal, road closure, and night-time or seasonal road closure. However, these measures may not be feasible everywhere. Fences in combination with crossing structures are most needed along paved highways and it may never be considered practical or desirable to have these measures implemented along unpaved roads.

In practice, measures along unpaved roads are often restricted to warning signs and instructions not to leave the unpaved roads (gravel, dirt, two-track). Having vehicles not leave the roads prevents widespread damage to vegetation, soil, and hydrology which can result in unnatural erosion and sedimentation processes. In addition, off road driving puts Mojave desert tortoises at higher risk of being crushed by vehicles compare to having vehicles stay on the (unpaved) roads. However, even when vehicles stay on unpaved roads, there are still wide range of impacts, including in desert ecosystems, including direct killing of Mojave desert tortoises (e.g., Doak et al. 1994, Huijser & Walder 2021). Note that warning signs about the presence of Mojave desert tortoises cannot be expected to result in a reduction in direct mortality (Hughson & Darby 2013).

Warning sign, do not drive off road for Mojave desert tortoise, near Jean, Nevada.

Sign, driving off established roads prohibited, Joshua Tree National Park, California.

9. ACTIONS BY THE PUBLIC

Members of the public can make contributions to Mojave desert tortoise conservation as a volunteer. This includes efforts related to road ecology. Examples include:

- Mojave desert tortoise and Mojave desert tortoise roadkill monitoring. Recording the location of Mojave desert tortoises, dead or alive, including road-killed tortoises, and threats to Mojave desert tortoises (e.g., raven presence and abundance) can help identify areas where managers may consider taking action (e.g., Tortoise Group 2022). Examples of such actions can include the implementation of mitigation measures along roads (fences in combination with crossing structures) or reducing the numbers of predators that may have reached unnaturally high abundance. Note that there is a safety protocol that needs to be followed (Tortoise Group 2022).
- Removing live Mojave desert tortoises from the road. Move the tortoise in the same direction it was headed, and place as far from the road as you can. Note that there is a safety protocol that needs to be followed (Tortoise Group 2022).
- Fence inspection, maintenance and repair. Fences for Mojave desert tortoises need to be inspected regularly, this may be a low priority for most DOT maintenance departments, and some form of outsourcing these tasks is likely needed. Erosion and sedimentation processes, accidental or deliberate destruction by people and vehicles can make Mojave desert tortoise fences not functional, which jeopardizes the effectiveness of fences in keeping the tortoises off the road and guiding them to crossing structures under or over the road.
- Inspection, maintenance and repair of crossing structures. Crossing structures may become inaccessible because of erosion and sedimentation processes or because of debris collecting in the culverts or at their entrances (e.g., trash, tumbleweed). This reduces the likelihood that a tortoise can or will enter the culvert to go to the other side of the road. Some problems can be quickly corrected (e.g., debris at the entrances, while erosion and sedimentation, or debris inside the culvert may require attention from DOT engineers and maintenance personnel. However, volunteers can detect and report potential maintenance issues, which is the first step in getting them addressed.
- Support politicians and agencies that argue for and implement effective conservation measures. This is crucial for successful implementation of effective measures (barriers in combination with crossing structures), and for some roads, road removal, road closure, and enforcement of measures aimed at Mojave desert tortoise conservation.
- Contribute financially to Mojave desert tortoise protection through donations. Supporting NGOs directly through donations or through e.g., purchasing a Mojave desert tortoise license plate (if available in your area). Clark County Desert Conservation Program has a “Desert Tortoise” license plate. Proceeds support conservation measures of the Multiple Species Habitat Conservation Plan (MSHCP) and promote public education about conservation of Mojave desert tortoises.
- Encourage other people to contribute to Mojave desert tortoise conservation as well.

License plate to support Mojave desert tortoise conservation.

REFERENCES

AASHTO. 2006 AASHTO Roadside Design Guide.

Allen, T.D.H., M.P. Huijser & D.W. Willey. 2013. Effectiveness of wildlife guards at access roads. Wildlife Society Bulletin 37(2): 402-408.

Arizona Game and Fish Department. Wildlife compatible fencing. Arizona Game and Fish Department, Phoenix, Arizona, USA. https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download/?cid=nrcseprd1080807&ext=pdf

Arizona Game and Fish Department. 2020. Evaluation of measures to reduce wildlife-vehicle collisions and promote connectivity in a Sonoran Desert Environment – State Route 77 Santa Catalina – Tortolita Mountain Corridor. Progress Report. Arizona Game and Fish Department Wildlife Contracts Branch, Arizona, USA. http://www.sonorandesert.org/wp-content/uploads/2021/01/2020-12-21-SR-77-Progress-Report-.pdf

Avery, M.L. & A.C. Genchi. 2004. Avian perching deterrents on ultrasonic sensors at airport wind-shear alert systems. Wildlife Society Bulletin 32(3): 718-725.

Berish J.E. & P.A. Medica. 2014. Home range and movements of North American tortoises. In: D.C. Rostal, E.D. McCoy & H.R. Mushinsky (Eds.). Chapter 11 in: Biology & conservation of North American tortoises. Johns Hopkins University Press.

Bissonette, J.A. & W. Adair. 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. Biological Conservation 141(2): 482-488.

Bissonette, J.A. & S. Rosa. 2012. An evaluation of a mitigation strategy for deer-vehicle collisions. Wildlife Biology 18(4): 414-423. DOI: 10.2981/11-122

BLM and DCP. 2022. Southern Nevada culvert monitoring project, unpublished data. Bureau of Land Management (BLM) and Clark County Desert Conservation Program (DCP). Las Vegas, Nevada, USA.

Boarman, W.I. 1992. Problems with management of a native predator on a threatened species: Raven predation on desert tortoises. Proceedings of the Fifteenth Vertebrate Pest Conference 1992. 8. https://digitalcommons.unl.edu/vpc15/8

Boarman, W.I. 2003. Managing a subsidized predator population: Reducing common raven predation on desert tortoises. Environmental Management 32(2): 205-217.

Boarman, W.I. & M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: Success of barrier fences and culverts. In: Evink, G., D. Ziegler, P. Garrett, & J. Berry (Eds). Trends in addressing transportation related wildlife mortality. Proceedings of the transportation related wildlife mortality seminar. State of Florida, Department of Transportation, Tallahassee, Florida, USA.

Boarman, W.I., M. Sazaki & W.B. Jennings. 1997. The effect of roads, barrier fences, and culverts on desert tortoise populations in California, USA. Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles – An International Conference, New York Turtle and Tortoise Society. pp. 54-58.

Boarman, W.I., M.L. Beigel, G.C. Goodlett & M. Sazaki. 1998. A passive integrated transponder system for tracking animal movements. Wildlife Society Bulletin 26: 886-891.

Boarman W.I. & M. Sazaki. 2006. A highway's road-effect zone for desert tortoises (*Gopherus agassizii*). Journal of Arid Environments 65: 94-101.

Brehme, C.S., J.A. Tracey, J. Kingston, J.B. Sebes, T.K. Edgarian & R.N. Fisher. 2020. Effectiveness of turnarounds in changing the trajectory of reptiles and amphibians in San Diego, CA. In: Brehme, C.S. & R.N. Fisher. 2020. Research to Inform Caltrans Best Management Practices for Reptile and Amphibian Road Crossings. USGS Cooperator Report to California Department of Transportation, Division of Research, Innovation and System Information, 65A0553. https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/final-caltrans-usgs-report-herproadresearch-rev.pdf

Brehme, C.S., J.A. Tracey, B.A.I. Ewing, M.T. Hobbs, A.E. Launer, T.A. Matsuda, E.M. Cole Adelsheim & R.N. Fisher. 2021. Responses of migratory amphibians to barrier fencing inform the spacing of road underpasses: a case study with California tiger salamanders (*Ambystoma californiense*) in Stanford, CA, USA. Global Ecology and Conservation 31: e01857

Burke, R.L. 2015. Head-starting turtles: Learning from experience. Herpetological Conservation and Biology 10(Symposium): 299-308.

Campbell, T. 1986. Some natural history observations of desert tortoises and other species on and near the Desert Tortoise Natural Area, Kern County, California. Proceedings of the Desert Tortoise Council Symposium 1983: 80-83.

Clevenger, A.P., B. Chruszcz & K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29: 646-653.

Clevenger, A.P., B. Chruszcz, K. Gunson & J. Wierzchowski. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks - Movements, mortality and mitigation. Final Report (October 2002). Report prepared for Parks Canada, Banff, Alberta, Canada.

Clevenger, A.P. & M.P. Huijser. 2011. Wildlife crossing structure handbook. Design and evaluation in North America. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Cserkész, T. & B. Ottlecz, Á. Cserkész-Nagy & J. Farkas. 2013. Interchange as the main factor determining wildlife–vehicle collision hotspots on the fenced highways: spatial analysis and applications. European Journal of Wildlife Research 59: 587-597.

Cuperus, R., K.J. Canters, H.A. Udo de Haes & D.S. Friedman. 1999. Guidelines for ecological compensation associated with highways. Biological Conservation 90: 41-51.

Cypher, B.L., E.C. Kelly, T.L. Westall & C.L. Van Horn Job. 2018. Coyote diet patterns in the Mojave Desert: implications for threatened desert tortoises. Pacific Conservation Biology 24: 44-54.

Daly, J.A., K.A. Buhlmann, B.D. Todd, C.T. Moore, J.M. Peaden & T.D. Tuberville. 2018. Comparing growth and body condition of indoor-reared, outdoor-reared, and direct-released juvenile Mojave desert tortoises. Herpetological Conservation and Biology 13(3): 622-633.

Daly, J.A., K.A. Buhlmann, B.D. Todd, C.T. Moore, J.M. Peaden, T.D. Tuberville. 2019. Survival and movements of head-started Mojave Desert tortoises. The Journal of Wildlife Management 83(8): 1705.40-1710. DOI: 10.1002/jwmg.21758

Dekker, J.J.A. 2021. Kerkuilen op hun plek. De effectiviteit van rollers en zitpalen ter vermindering van verkeerslachtoffers onder kerkuilen bij de N242 en de A7 in de Wieringermeer. Jasja Dekker Dierecologie, Arnhem, The Netherlands. https://www.jasjadekker.nl/wp-content/uploads/2021/04/2018.003_Effectiviteit_rollers_zitpalen_2021-04-12.pdf

Doak, D., P. Kareiva & B. Klepetka. 1994. Modeling population viability for the desert tortoise in the Western Mojave Desert. Ecological Applications 4(3): 446-460.

Dodd, N.L., J.W. Gagnon, S. Boe & R.E. Schweinsburg. 2007. Role of fencing in promoting wildlife underpass use and highway permeability. In: Irwin, C.L., Nelson, D., McDermott, K.P. (Eds.), Proceedings of the 2007 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA, pp. 475-487.

Dwyer, J.F. & K.W. Doloughan. 2014. Testing systems of avian perch deterrents on electric power distribution poles in sage-brush habitat. Human-Wildlife Interactions 8(1): 39-55.

Dwyer, J.F., R.C. Taylor, G.A. French. 2020. Failure of utility pole perch deterrents modified during installation. The Journal of Raptor Research 54(2): 172-176.

Esque, T.C., K.E. Nussear, K.K. Drake, A.D. Walde, K.H. Berry, R.C. Averill-Murray, A.P. Woodman, W.I. Boarman, P.A. Medica, J. Mack & J.S. Heaton. 2010. Effects of subsidized predators, resource variability, and human population density on desert tortoise populations in the Mojave Desert, USA. Endangered Species Research 12: 167-177.

Fairbank, E., F. Deffner, S. Johnson & N. Maya. 2021. Mojave desert tortoise transportation ecology workshop report. Center for Large Landscape Conservation, Bozeman, Montana, USA. https://largelandscapes.org/wp-content/uploads/2021/11/Mojave-Desert-Tortoise-Transportation-Ecology-Workshop-Report.pdf

Fleischer, R.C., W.I. Boarman, E.G. Gonzalez, A. Godines, K.E. Omland, S. Young, L. Helgen, G. Syed & C.E. McIntosh. 2008. As the raven flies: using genetic data to infer the history of invasive common raven (*Corvus corax*) populations in the Mojave Desert. Molecular Ecology 17: 464-474.

Gagnon, J.W., N.L. Dodd, S.C. Sprague, K. Ogren & R.E. Schweinsburg. 2010. Preacher Canyon wildlife fence and crosswalk enhancement project evaluation. State Route 260. Final Report - Project JPA 04-088. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Gardipee, F.M., K. Holcomb, A. Holcomb & A. Rutledge. 2017**.** Use of wildlife underpasses by Mojave desert tortoises (*Gopherus agassizii*), Clark County, Nevada. Poster at the 2017 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina, State University, Raleigh, North Carolina, USA.

Grandmaison, D.D. & V.J. Frary. 2012. Estimating the probability of illegal desert tortoise collection in the Sonoran Desert. The Journal of Wildlife Management 76(2): 262-268.

Grandmaison, D.D., R.E. Schweinsburg & M.F. Ingraldi. 2012. Assessment of desert tortoise movement, permeability, and habitat along the proposed State Route 95 realignment. Report no. FHWA-AZ-12-650. Arizona Game and Fish Department, Phoenix, Arizona, USA. https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ650.pdf

Hanski, I. & C.D. Thomas. 1994. Metapopulation dynamics and conservation: A spatially explicit model applied to butterflies. Biological Conservation 68(2): 167-180. DOI: 10.1016/0006-3207(94)90348-4

Harless, M.L., A.D. Walde, D.K. Delaney, L.L. Pater & W.K. Hayes. 2010. Sampling considerations for improving home range estimates of desert tortoises: Effects of estimator, sampling regime, and sex. Herpetological Conservation and Biology 5(3): 374-387.

Hanski, I. & O. Ovaskainen. 2002. Extinction debt at extinction threshold. Conservation Biology 16(3): 666-673.

Hughson, D.L. & N. Darby. 2013. Desert tortoise road mortality in Mojave National Preserve, California. California Fish and Game 99(4): 222-232.

Huijser, M.P. & A.P. Clevenger. 2006. Habitat and corridor function of rights-of-way. Pages 233-254 in: J. Davenport & J.L. Davenport (Eds.): The ecology of transportation: Managing mobility for the environment. Series: Environmental Pollution, Vol. 10. Springer, The Netherlands.

Huijser, M.P., K.J.S. Paul, L. Oechsli, R. Ament, A.P. Clevenger & A. Ford. 2008. Wildlife-vehicle collision and crossing mitigation plan for Hwy 93S in Kootenay and Banff National Park and the roads in and around Radium Hot Springs. Report 4W1929 B, Western Transportation Institute – Montana State University, Bozeman, Montana, USA. Available from the internet: http://www.wti.montana.edu/RoadEcology/Projects.aspx?completed=1

Huijser, M.P., A.V. Kociolek, T.D.H. Allen, P. McGowen, P.C. Cramer & M. Venner. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. NCHRP Project 25-25, Task 84, National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington D.C., USA.

Huijser, M.P., E.R. Fairbank, W. Camel-Means, J. Graham, V. Watson, P. Basting & D. Becker. 2016a. Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife-vehicle collisions and providing safe crossing opportunities for large mammals. Biological Conservation 197: 61-68.

Huijser, M.P., W. Camel-Means, E.R. Fairbank, J.P. Purdum, T.D.H. Allen, A.R. Hardy, J. Graham, J.S. Begley, P. Basting & D. Becker. 2016b. US 93 North post-construction wildlife-vehicle collision and wildlife crossing monitoring on the Flathead Indian Reservation between Evaro and Polson, Montana. FHWA/MT-16-009/8208. Western Transportation Institute – Montana State University, Bozeman, Montana, USA.

Huijser, M.P., R.J. Ament, M. Bell, A.P. Clevenger, E.R. Fairbank, K.E. Gunson & T. McGuire. 2021. Animal vehicle collision reduction and habitat connectivity study. Literature review. Report No. 701-18-803 TO 1. Transportation Pooled-Fund Project TPF-5(358), Administered by the Nevada Department of Transportation. Western Transportation Institute, Montana State University, Bozeman, Montana, USA.

Huijser, M.P. & B.L. Walder. 2021. Ecological impacts of new and upgraded dirt roads in Cabeza Prieta National Wildlife Refuge and avoidance, mitigation and compensation strategies. Report 4W8967. Western Transportation Institute, Montana State University, Bozeman, Montana, USA.

Huijser, M.P. & J.S. Begley. 2022. Implementing wildlife fences along highways at the appropriate spatial scale: A case study of reducing road mortality of Florida Key deer. In: Santos S., C. Grilo, F. Shilling, M. Bhardwaj & C.R. Papp (Eds.). Linear infrastructure networks with ecological solutions. Nature Conservation 47: 283-302. https://doi.org/10.3897/natureconservation.47.72321

Hunt, H.G. 2014. Improved exclusion barriers for desert tortoises. Preliminary investigation. Caltrans Division of Research, Innovation, and System Information, Caltrans, California, USA.

IUCN/SSC. 2013. Guidelines for reintroductions and other conservation translocations. Version 1.0. IUCN Species Survival Commission, Gland, Switzerland. https://portals.iucn.org/library/efiles/documents/2013-009.pdf

Jaeger, J.A.G. & L. Fahrig. 2004. Effects of road fencing on population persistence. Conservation Biology 18(6): 1651-1657.

Jennings, W.B. 1993. Foraging ecology and habitat utilization of the desert tortoise (*Gopherus agassizii*) in the western Mojave Desert. Ph.D. Thesis, University of Texas Arlington, Texas, USA.

Kelly, E.C., B.L. Cypher & T.L. Westall. 2021. Predation on desert tortoises (*Gopherus agassizii*) by desert canids. Journal of Arid Environments 189: 104476.

Kristan III, W.B. & W.I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84(9): 2432-2443.

Kruidering, A.M., G. Veenbaas, R. Kleijberg, G.Koot, Y. Rosloot & E. van Jaarsveld. 2005. Leidraad faunavoorzieningen bij wegen. Rijkswaterstaat, Dienst Weg-en Waterbouwkunde, Delft, The Netherlands.

Lovich, J.E., J.R. Ennen, S. Madrak & B. Grover. 2011. Turtles and culverts, and alternative energy development: An unreported but potentially significant mortality threat to the desert tortoise (*Gopherus agassizii*). Chelonian Conservation and Biology 10(1): 124-129.

McGovern, P.A., K.A. Buhlmann, B.D. Todd, C.T. Moore, J.M. Peaden, J. Hepinstall-Cymerman, J.A. Daly & T.D. Tuberville. 2020. The effect of size on post release survival of head-started Mojave desert tortoises. Journal of Fish and Wildlife Management 11(2): 494-506.

Medica P.A., C.L. Lyons & F.B. Turner. 1981. A comparison of populations of the desert tortoise (*Gopherus agassizii*) in grazed and ungrazed areas in Ivanpah Valley, California. Final Report. Bureau of Land Management.

Meese, R.J., F.M. Shilling & J.F. Quinn. 2007. Wildlife crossings guidance manual. California Department of Transportation, Sacramento, California, USA.

Montana Department of Transportation. Wildlife friendly fence. Helena, Montana, USA. https://www.mdt.mt.gov/publications/docs/brochures/friendlyfences.pdf

Moore, L.J., A.Z.A. Arietta, D.T. Spencer, M.P. Huijser, B.L. Walder & F.D. Abra. 2021. On the road without a map: Why we need an "Ethic of Road Ecology". Frontiers in Ecology and Evolution 9: 774286. doi: 10.3389/fevo.2021.774286
https://www.frontiersin.org/article/10.3389/fevo.2021.774286

Nafus, M.G., T.D. Tuberville, K.A. Buhlmann & B.D. Todd. 2013. Relative abundance and demographic structure of Agassiz's desert tortoise (*Gopherus agassizii*) along roads of varying size and traffic volume Biological Conservation 162: 100-106.

Nagy, K.A. & P.A. Medica. 1986. Physiological ecology of desert tortoises in Southern Nevada. Herpetologica 42: 73-92.

Nagy, K.A., L.S. Hillard, M.W. Tuma & D.J. Morafka. 2015. Head-started desert tortoises (*Gopherus agassizii*): Movements, survivorship and mortality causes following their release. Herpetological Conservation and Biology 10(1): 203-215.

Nagy, K.A., B.T. Henen & L.S. Hillard. 2020. Head-started Agassiz's desert tortoises *Gopherus agassizii* achieved high survival, growth, and body condition in natural field enclosures. Endangered Species Research 43: 305-321. https://doi.org/10.3354/esr01067

Nussear, K.E., T.C. Esque, R.D. Inman, L. Gass, K.A. Thomas, C.S.A. Wallace, J.B. Blainey, G.M. Miller & R.H Webb. 2009. Modeling habitat of the desert tortoise (*Gopherus agassizii*) in the Mojave and parts of the Sonoran Deserts of California, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2009-1102, 18 p.

Neumann, W., G. Ericsson, H. Dettki, N. Bunnefeld, N.S. Keuler, D.P. Helmers & V.C. Radeloff. 2012. Difference in spatiotemporal patterns of wildlife road-crossings and wildlife-vehicle collisions. Biological Conservation 145: 70-78.

Nussear, K.E., T.C. Esque, R.D. Inman, L. Gass, K.A. Thomas, C.S.A. Wallace, J.B. Blainey, D.M. Miller & R.H. Webb. 2009. Modeling habitat of the desert tortoise (*Gopherus agassizii*) in the Mojave and parts of the Sonoran deserts of California, Nevada, Utah, and Arizona. U.S. Geological Survey Open-file Report 2009-1102.

Paige, C. 2008. A landowner's guide to wildlife friendly fences. Landowner/Wildlife Resource Program, Montana Fish, Wildlife and Parks, Helena, Montana, USA.

Parker, L.D., J.D. Quinta, I. Rivera, B.L. Cypher, E.C. Kelly, M.G. Campana, R.C. Fleischer, R. Boarman, W.I. Boarman & J.E. Maldonado. 2022. Genetic analyses are more sensitive than morphological inspection at detecting the presence of threatened Mojave desert tortoise (*Gopherus agassizii*) remains in canid scat and raven pellets. Conservation Science and Practice 2022; 4:e12689.

Peaden, J.M., T.D. Tuberville, K.A. Buhlmann, M.G. Nafus & B.D. Todd. 2015. Delimiting road-effect zones for threatened species: implications for mitigation fencing. Wildlife Research 42(8): 650-659.

Peaden, J.M. 2017. Habitat use and behavior of Agassiz's desert tortoise (*Gopherus agassizii*): Outpacing development to achieve long standing conservation goals. PhD Thesis, University of California, Davis, California, USA.

Peaden, J.M., A.J. Nowakowski, T.D. Tuberville, K.A. Buhlmann & B.D. Todd. 2017. Effects of roads and roadside fencing on movements, space use, and carapace temperatures of a threatened tortoise. Biological Conservation 214: 13-22.

Ruby, D.E., J.R. Spotila, S.K. Martin & S.J. Kemp. 1994. Behavioral responses to barriers by desert tortoises: Implications for wildlife management. Herpetological Monographs 8: 144-160. https://www.jstor.org/stable/1467078

Rytwinski T, K. Soanes, J.A.G Jaeger, L. Fahrig, C.S. Findlay & J. Houlahan. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLoSOne 2016 11(11):e0166941. https://doi.org/10.1371/journal.pone.0166941PMID:27870889

Segura, A., J. Jimenez & P. Acevedo. 2020. Predation of young tortoises by ravens: The effect of habitat structure on tortoise detectability and abundance. Scientific Reports 10: 1874. https://doi.org/10.1038/s41598-020-58851-5

Shields, T., A. Currylow, B. Hanley, S. Boland, W. Boarman & M. Vaughn. 2019. Novel management tools for subsidized avian predators and a case study in the conservation of threatened species. Ecosphere 10(10):e02895.10.1002/ecs2.2895

Todd, B.D., B.J. Halstead, L.P. Chicquoine, J.M. Peaden, K.A. Buhlmann, T.D. Tuberville & M.G. Nafus. 2016. Habitat selection by juvenile Mojave desert tortoises. The Journal of Wildlife Management 80(4): 720-728.

Tortoise Group. 2022. ROaDS-Road Warriors Data Collection App. https://tortoisegroup.org/wp-content/uploads/2022/04/ROaDS_Public-Road-Warriors-App.pdf

Tuberville, T.D., T.M. Norton, K.A. Buhlmann & V. Greco. 2015. Head-starting as a management component for gopher tortoises (*Gopherus polyphemus*). Herpetological Conservation and Biology 10: 455-471.

Tuberville, T.D., K.A. Buhlmann, R. Sollmann, M.G. Nafus, J.M. Peaden, J.A. Daly & B.D. Todd. 2019. Effects of short-term, outdoor head-starting on growth and survival in the Mojave desert tortoise (*Gopherus agassizii*). Herpetological Conservation and Biology 14(1): 171-184.

Turner, F.B., P.A. Medica & C.L. Lyons. 1980. A comparison of populations of the desert tortoise (*Gopherus agassizii*) in grazed and ungrazed areas in Ivanpah Valley, California. Bureau of Land Management Report.

UNLV. 2018. Estimates of the desert tortoise (*Gopherus Agazzizii*) domestic population in the greater Las Vegas area, Nevada. University of Nevada-Las Vegas (UNLV).

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determination of threatened status for the Mojave population of the desert tortoise. Federal Register 55:12178-12191.

U.S. Fish and Wildlife Service. 1994. Desert Tortoise (Mojave Population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Fish and Wildlife Service. 2005. Recommended desert tortoise fence specifications. U.S. Fish and Wildlife Service. https://eplanning.blm.gov/public_projects/nepa/41489/93713/113028/AppendixD_Desert-Tortoise-Fence-Specs.pdf

U.S. Fish and Wildlife Service. 2011. Revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, California. 222 pp.

U.S. Fish and Wildlife Service. 2014. Passages for connectivity of Mojave desert tortoise populations across fenced roads. Desert Tortoise Recovery Office, Reno, Nevada, USA. https://www.fws.gov/sites/default/files/documents/Passage%20spacing%20recommendations.27Mar2014.pdf

U.S. Fish and Wildlife Service. 2017. Critical habitat. What is it? U. S. Fish and Wildlife Service, Endangered Species Program, Falls Church, Virginia, USA. https://www.fws.gov/sites/default/files/documents/critical-habitat-fact-sheet.pdf

U.S. Fish and Wildlife Service. 2020. Shade structures for desert tortoise exclusion fence: Design guidance. U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 2021. Population augmentation strategy for the Mojave desert tortoise recovery program. Desert Tortoise Recovery Office, Reno, Nevada, USA. https://www.fws.gov/sites/default/files/documents/Mojave%20Desert%20Tortoise%20population%20augmentation%20strategy_2021FEB.pdf

U.S. Fish and Wildlife Service. 2022. Mojave Desert Tortoise (*Gopherus agassizii*) 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service, Desert Tortoise Recovery Office, Southern Nevada Fish and Wildlife Service Las Vegas, Nevada, USA.

van der Ree, R., C. Grilo & D. Smith (Eds.). 2015. Ecology of roads: A practitioner's guide to impacts and mitigation. John Wiley & Sons Ltd. Chichester, United Kingdom.

Vogelbescherming Nederland. 2017. Leven als een kerkuil. https://www.vogelbescherming.nl/actueel/bericht/leven-als-een-kerkuil

Woodbury, A.M. & R. Hardy. 1948. Studies of the desert tortoise, *Gopherus Agassizii*. Ecological Monographs 18: 145-200.

Zimmerman, L.C., M.P. O'Connor, S.J. Bulova, J.R. Spotila, S.J. Kemp & C.J. Salice. 1994. Thermal ecology of desert tortoises in the eastern Mojave Desert: Seasonal patterns of operative and body temperatures, and microhabitat utilization. Herpetological Monographs 8: 45-59.

Zylstra, E.R., L.J. Allison, R.C. Averill-Murray, V. Landau, N.S. Pope & R.J. Steidl. 2023. A spatially explicit model for density that accounts for availability: a case study with Mojave desert tortoises. Ecosphere 14(3):e4448.