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FINAL PROJECT REPORT

INNOVATIVE MITIGATION OF SOLAR ENERGY IMPACTS ON DESERT TORTOISES

Head-starting and Habitat Selection of Juvenile Desert Tortoises

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Prepared by: University of California, Davis
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The authors alone are responsible for the contents of this report.

PREFACE

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Innovative Mitigation of Solar Energy Impacts on Desert Tortoises is the final report for the Use of Habitat Suitability Models and Head-Start Techniques to Minimize Conflicts between Desert Tortoises and Energy Development Projects in the Mojave Desert project (grant number 500-10-020) conducted by University of California, Davis and University of Georgia's Savannah River Ecology Laboratory. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

California is mandated by state policies to increase the amount of energy from renewable sources in coming years. Meeting this need may result in developing large, utility-scale solar and wind energy facilities across California's desert regions. Development of California's desert brings the risk of negative impacts on special-status species found in desert habitats, such as the state- and federally-protected Mojave Desert Tortoise (*Gopherus agassizii*). Policy makers and agencies are interested in finding ways to minimize negative impacts to special-status species and offset them by identifying viable mitigation methods that can promote the recovery and survival of these species.

To address these needs, the University of California, Davis and the University of Georgia's Savannah River Ecology Laboratory conducted a study on the efficacy of head-starting desert tortoises and the habitat selection of juvenile tortoises in the Mojave Desert. Head-starting is the process of producing and rearing an organism through the early stages of its life when survival is often expected to be low. Results of this study show that the mitigation measure of protecting hatchlings from predators and providing additional supplemental rainfall in outdoor enclosures substantially increases juvenile growth and survival relative to free-ranging juvenile tortoises. This can facilitate the release of many larger, more resilient juveniles in as little as 5-6 years without supplemental feeding.

Because juvenile tortoises are seldom seen in the wild, they rarely factor into decisions about the siting of new developments, and they are generally undetected during pre-construction surveys that are conducted before power plant construction to find tortoises. Thus, the research also identified several key attributes of high quality juvenile desert tortoise habitat. Tortoises made extensive use of small mammal burrows, creosote bushes, and areas of high perennial plant cover with many washes and rivulets. This information helps planners identify and avoid possible damage to high quality habitat, better conduct pre-construction surveys to find desert tortoises to minimize deaths of often undetected juvenile tortoises, and identify restoration targets when closing off-highway vehicular routes or restoring impacted areas.

Keywords: clearance surveys, desert tortoise, endangered species, head-starting, habitat selection, mitigation, permitting, recovery, restoration, siting, solar energy, wind energy

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EXECUTIVE SUMMARY

Introduction

Meeting California's energy demands in the 21st century requires careful development and environmentally sustainable application of new and existing technologies. This is particularly true given the mandate for more solar and other renewable sources to meet the state's growing energy demand and reduce greenhouse gas emissions. Plans to develop large-scale electricity generation facilities are targeting areas of the desert southwest due to its high amounts of solar insolation and amount of public land. With these plans comes increasing recognition of the need to minimize or offset the broad range of impacts to threatened habitats and species that is expected from these new energy projects.

Currently, there are two clear opportunities to maximize sustainability of proposed projects while minimizing negative consequences for species of concern. First, a better understanding of habitat characteristics that shape the distribution of special-status species can inform selecting energy project sites to minimize impacts and aid finding species that may need to be moved from harm's way in areas planned for development. Second, establishing or refining mitigation strategies can help ensure preservation of special-status species in suitable areas in a manner that may offset negative impacts to local populations caused by development.

The Mojave desert tortoise, *Gopherus agassizii*, is one of the most iconic special-status species increasingly at risk from development in California's desert regions. The US Fish and Wildlife Service and California Department of Fish and Wildlife list the desert tortoise as threatened under federal and state law due to rapid population declines in the latter half of the 20th century. As a protected species, the desert tortoise is in conflict with desert development that affects its populations and habitats. In an attempt to recover the species and minimize conflicts with development, the US Fish and Wildlife Service prescribes "head-starting" to increase desert tortoise populations. Head-starting is rearing juvenile animals through their early lives when survival is typically low and then releasing them after they have passed a critical period. To date, there has been little evaluation of the effectiveness of head-starting desert tortoises.

Rearing captive juvenile desert tortoises in a head-starting program presents a unique opportunity to study aspects of juvenile tortoise ecology that have heretofore been challenging. For example, habitat selection is a basic aspect of animal ecology that can provide many insights into a species' habitat requirements, community interactions, and sources of mortality. Because juvenile tortoises are seldom seen in the wild, they rarely factor into decisions about the siting of new developments, and they are generally undetected during pre-construction surveys that are conducted before power plant construction to locate any tortoises. Ideally, information about where juvenile tortoises are found and the kinds of resources important to them can be used to better limit overall impacts to this species. Providing such information requires careful study of the habitat selection and ecology of juvenile tortoises.

Project Purpose

This project evaluated the effectiveness of head-starting as a mitigation tool for helping desert tortoise populations recover. Desert tortoises have low survival as juveniles, are long lived,

slow growing, and can take 15-20 years to reach sexual maturity and begin reproducing. Methods that increase survival and growth rates of juveniles may enhance opportunities to recover declining populations and mitigate potential declines of tortoises from proposed development. This project also studied the habitat selection of free-ranging juvenile desert tortoises shortly after release to better understand their habitat and resource preferences on the landscape. This new knowledge would help locate new renewable energy projects (or any land disturbing activities) in a manner that avoids damaging this important habitat.

Project Results

Head-starting juvenile desert tortoises in semi-natural outdoor enclosures with added water from sprinklers and protection from predators greatly increased their growth and survival relative to free-ranging tortoises that were released and monitored in the field. Although predation is suspected to be high on young tortoises, the results suggest that the added benefit of head-starting at this site was from supplemental rain more than from protection from predators. Added water availability promotes greater plant growth and more opportunities for drinking, foraging, and other activity in outdoor enclosures. More deaths of free-ranging direct release animals were attributed to exposure or desiccation than predation.

Previous research suggests that juvenile tortoise survival increases and approaches that of adults when their carapace (the upper shell) reaches a length of 105 mm. The current study suggests that animals could reach this size in as little as 5.5 years after hatching with supplemental rainfall and without additional food supplements. Nevertheless, there was some indication that releasing even smaller juveniles in captivity for at least six months maintained a size advantage and had greater survival than younger animals released immediately after hatching. Ultimately, however, if the goal is to promote high survival of captive-raised animals after release, the results suggest that animals should not be released in their first three years of life when their carapace is still shorter than 105 mm.

Monitoring habitat selection by free-ranging juvenile desert tortoises identified several habitat characteristics important to juvenile tortoises. Juvenile tortoises strongly preferred areas where perennial plants (that live longer than one year) were nearer and covered more of the ground surface. Juvenile tortoises also selected areas that were closer to washes and had more washes within 5 meters of their locations. Juvenile tortoises were far more likely to use areas with more nearby small mammal burrows, and these areas tended to be associated with more creosote bush shrubs than white bursage shrubs. Creosote bush seeds are eaten by many small mammals, which in turn have extensive burrow networks that juvenile tortoises use to create their own resident burrows. Creosote bush is among the largest of the common perennial plant species in much of the Mojave Desert, providing shade from excessive temperatures and cover from visual predators. They also support more annual plants beneath their canopies, which in turn may provide greater foraging opportunities for growing juvenile tortoises.

Project Benefits

This project successfully demonstrated the value of a US Fish and Wildlife Service-prescribed recovery action that can be used to recover and mitigate declines of desert tortoises. This work showed the effectiveness of head-starting to improve growth and survival of juvenile desert

tortoises. This mitigation tool can be used to temporarily increase the population size of desert tortoises in areas that have been negatively affected or to offset losses expected from new energy development. Given the low survival of free-ranging juvenile desert tortoises, if populations are left alone and unaided, few juvenile tortoises will likely survive to adulthood, so recovery of depleted populations will be unlikely or, at best, take decades. Instead, prudent use of head-starting may facilitate recovery by producing larger or hardier juvenile tortoises that may better survive raven attacks or the harsh environment and so have a greater chance of reaching reproductive age when released at larger sizes. For the future, it is imperative to fully assess the long-term benefits and survival of juvenile tortoises released at larger sizes, but early results are promising.

A second benefit of this project is the important information gained about juvenile desert tortoise habitat requirements. Juveniles are rarely encountered and so are poorly studied, creating an important knowledge gap in understanding tortoise ecology. Information about the habitat requirements of juveniles is essential to preserve the species as required by law. By focusing on habitat selection of desert tortoises, this study provides project planners and wildlife agencies with better information about targets for pre-construction clearance surveys and habitat restoration in mitigation efforts, and it is can also help identify sites for future release of head-started juvenile tortoises.

Combining new knowledge about head-starting and habitat selection has direct potential benefits for facilitating renewable energy development. The project findings could potentially expedite the permitting of solar energy facilities, by enabling the siting of projects in lower value tortoise habitat and providing a tested mitigation option for remaining impacts. This could also improve the perception of renewable energy technology and lower project costs because of faster permitting.

CHAPTER 1: Introduction

1.1 Background and Context

Meeting California's energy needs in the 21st century requires careful development and environmentally sustainable application of new and existing technologies. This is particularly true given the clear mandate for the increased use of solar and other renewable sources to meet our nation's growing energy demand and reduce greenhouse gas emissions. As a result, there are increasing plans to construct large-scale electricity generation facilities, especially in parts of the desert southwest due to its high amounts of solar insolation and available public land. With these plans comes a greater recognition of the need to minimize or offset the broad range of impacts to threatened habitats and species that is expected from these new energy projects. Currently, there are two clear opportunities to meet the goals of maximizing sustainability of proposed projects while minimizing negative consequences for species of concern. First, a better understanding of habitat characteristics that shape the distribution of special-status species can inform selection of energy project sites to minimize impacts and permitting costs and aid finding animals that may need to be moved out of harm's way in areas planned for development. Second, the establishment or refinement of mitigation strategies can help ensure persistence of special-status species in suitable areas in a manner that may offset negative impacts to local populations caused by development.

Of the many species that inhabit the Mojave and Colorado Desert regions of California, perhaps none represents the plight and health of these habitats more so than the Mojave Desert Tortoise, *Gopherus agassizii* (US BLM 1980), hereafter called desert tortoise or tortoise (Figure 1-1). The US Fish and Wildlife Service, recognizing the rapid decline of the desert tortoise in the latter half of the 20th century, listed the species as threatened under the Endangered Species Act in 1990 (US FWS 1994). Consequent work in the intervening years since its listing has focused on increasing the understanding of the ecology and population dynamics of this fragile species in an effort to inform recovery and ensure its persistence.

Figure 1-1: Adult male desert tortoise

Source: J. Mark Peaden

Along with adult survivorship, juvenile survivorship and the length of the juvenile period are two of the most important demographic factors affecting stability and extinction probabilities of turtle populations (Congdon et al. 1993; 1994). Recent studies of hatchling Gopher Tortoise (*G. polyphemus*) survivorship have estimated survival from hatching to 1st year of life at less than 4% (Butler and Sowell 1996; Epperson and Heise 2003; Pike and Seigel 2006). A 1-yr study on survivorship of older juvenile Gopher Tortoises reported bimonthly survival of 69–100% for 1-4 yr olds (Wilson 1991). Researchers have noted that survival of juvenile tortoises, particularly hatchlings, is likely to be extremely variable from year to year due to unpredictable environmental conditions, resulting in episodic recruitment (Morafka 1994; USFWS 2011; Reed et al. 2009). Presumably only infrequent bouts of high recruitment are needed to maintain populations of these long-lived species. Alternatively, a small but consistent increase in juvenile recruitment or annual survival may also result in population persistence. Population modeling of Gopher Tortoises suggests that under scenarios of high annual adult survival, even minimal improvements in juvenile survival can increase population growth rates from declining to stable (Tuberville et al. 2009). Finally, juvenile survival at any given site can be dramatically decreased by the abundance of subsidized predators — predators such as ravens and coyotes whose abundance is artificially elevated due to food and water subsidies near development. In fact, the increased encroachment of human development into deserts, even at a small scale, has increased raven-driven mortality of young juvenile desert tortoises (Kristan and Boarman 2003) to such a degree that long-term persistence is threatened by a lack of recruitment into the reproductive adult population. Presumably, habitat quality also affects juvenile survival by providing refuge and nutritious forage. Therefore, scientists must gain a better understanding of the habitat use and vegetation-associations of hatchling and juvenile tortoises (Figure 1-2).

Figure 1-2: Juvenile desert tortoise

Source: Brian D. Todd

Given the important role that juvenile survivorship can have in tortoise populations, and the possibility that increased survival of young tortoises can aid population persistence, it is imperative to rigorously explore the use of head-starting as a mitigation tool for desert tortoise management. Head-starting is the process of producing and rearing an organism through the early stages of its life (Heppell et al. 1996). Head-starting is particularly suited to occasions when mortality is high early in life from causes like predation, a frequent scenario in turtles. Protecting young turtles from predation until they reach a larger, less vulnerable size can increase populations and has been used alongside other strategies to successfully recover several freshwater turtle species (*Pseudemys rubriventris*, Haskell et al. 1996; *Emys orbicularis*, Mitrus 2005; *Actinemys marmorata*, Vander Haegen et al. 2009; *Emydoidea blandingii*, Buhlmann et al., in press). The possibility of supporting recovery of desert tortoises via use of head-starting has led the US Fish and Wildlife Service (USFWS) to more closely consider its role in increasing tortoise populations. The Revised Desert Tortoise Recovery Plan, specifically, strategic element 3: "Augment Depleted Populations through a Strategic Program", recommends developing protocols and guidelines for population augmentation, including those specific to head-starting, to help recover the desert tortoise (USFWS 2011).

Although long-term use of head-starting to sustain a declining population may not be logistically feasible, temporary use of head-starting to augment a depleted population could provide necessary momentum to propel a population towards recovery while other strategies address underlying factors responsible for widespread population declines. Head-starting may prove to be even more effective if juvenile growth can be accelerated and survival increased via improved habitat or resource availability during the initial captive portion of their lives. This additional assistance may further increase the feasibility of head-starting as a mitigation tool for the conservation of threatened species. Although the juvenile period of desert tortoises may last for up to 15-20 years (Germano 1994a), unpublished data and published reports indicate that survival increases dramatically as juveniles grow and reach a minimum size threshold (K. Nagy

unpubl data), a size that may be reached under optimal captive conditions sooner than the time required in the wild (Jackson et al. 1976; 1978). Any evaluation of head-starting as a mitigation tool must examine the feasibility of increasing survival during this initial period and should also examine the feasibility of increasing growth to accelerate production and attainment of sexual maturity of recruits. Given that development of parts of the Mojave Desert is likely to negatively affect populations of the desert tortoise, the ability to promote recovery using mitigation strategies such as head-starting may be an important tool for minimizing the overall impact to this special-status species.

In recent years, one obstacle further hampering desert tortoise recovery efforts has been a limited understanding of the ecology, habitat use, and resource needs of hatchling and juvenile tortoises. This knowledge gap represents an important deficiency given the critical role that successful juvenile recruitment has in the recovery and persistence of wild desert tortoise populations (Reed et al. 2009). The ecology of juveniles has long been recognized as an important knowledge gap in a complete understanding of the life history of North American tortoises (Morafka 1994; Smith et al. 2006; USFWS 2011). Juveniles are notoriously difficult to monitor due to their small size and secretive behavior, and they are infrequently encountered in the wild despite intensive searching. Additionally, survivorship of juveniles is generally considered to be much lower than that of adults, further increasing the challenges of studying them. As a result, most studies of North American tortoises have focused on the adult stages. Despite the many studies and substantial conservation dollars spent on desert tortoises, the ecology of juveniles is largely unresolved.

Captive production of hatchling and juvenile desert tortoises in a head-starting program presents a unique opportunity to study aspects of juvenile tortoise ecology that have heretofore been challenging. For example, habitat selection is a foundational aspect of animal ecology that can provide many insights into a species' habitat requirements, community interactions, and sources of mortality (Morris 2003). Unfortunately, for the reasons mentioned above, there is a poor understanding of many of these aspects of juvenile tortoise ecology. Thus, juvenile tortoises rarely factor into decisions about the siting of new developments, and they are likely to be undetected during searches conducted prior to scheduled development. Ideally, information about where juvenile tortoises are found and the kinds of resources important to them can be used to better limit overall impacts to this species. Providing such information requires careful study of the habitat selection and ecology of juvenile tortoises.

1.2 Objectives

The primary objectives of this study were two-fold. First, the project sought to evaluate the effectiveness of head-starting juvenile desert tortoises as a mitigation and recovery tool for ensuring desert tortoise persistence. By producing and raising captive tortoises while releasing others shortly after hatching, the researchers aimed to compare growth and survivorship of wild, free-ranging juvenile tortoises to siblings raised outdoors in semi-natural conditions where they were protected from predators and provided with one of two levels of added "simulated" rain. The second objective was to study the habitat selection of free-ranging juvenile desert tortoises shortly after release to gain a better understanding of their habitat use

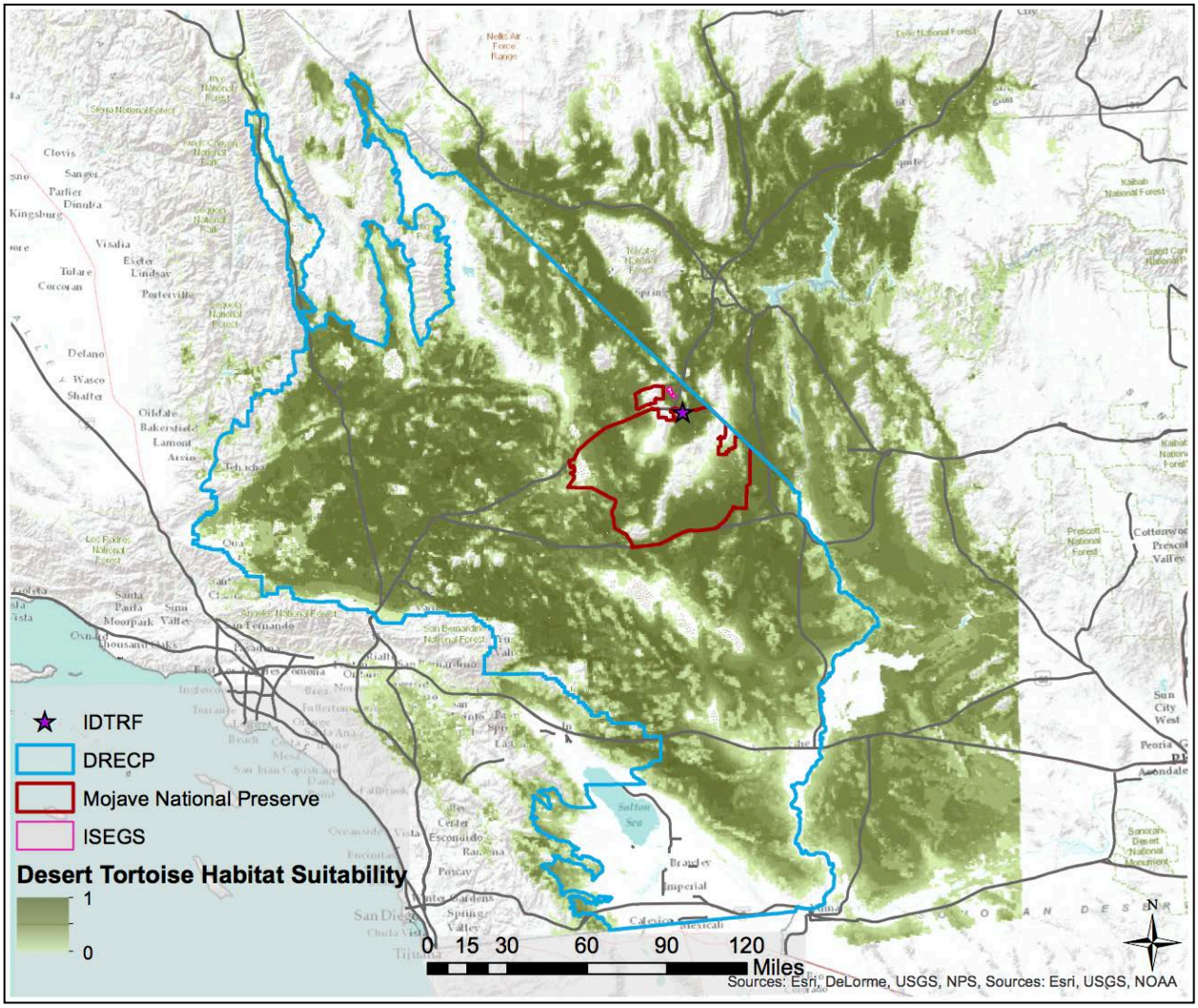
and resource needs on the landscape. The information gained from this work can be used to evaluate the potential benefits of head-starting tortoises as a mitigation and recovery tool in the face of proposed renewable energy development in the Mojave Desert. This work can also inform the decision-making process of infrastructure siting, improve the ability of pre-construction clearance surveys to locate juvenile desert tortoises, and provide targets for habitat restoration as a mitigation tool to offset impacts of new development.

CHAPTER 2: Methods

2.1 Study Site

This study was conducted in the northeastern section of the Mojave National Preserve (MNP), near the town of Nipton in San Bernardino County, California (Figure 2-1).

Figure 2-1: Map showing study site in northeastern Mojave Desert



Map of field site showing the location of the study site in the southwestern portion of Ivanpah Valley. The star denotes the location of the Ivanpah Desert Tortoise Research Facility (IDTRF) where the work was conducted. The light blue line denotes the approximate boundary of the Desert Renewable Energy Conservation Plan (DRECP). The red line denotes the boundary of the Mojave National Preserve. The pink line denotes the footprint of the Ivanpah Solar Electric Generating System (ISEGS). The green shading indicates the expected desert tortoise distribution from a model provided by the US Geological Survey (Nussear et al. 2009).

Two field sites were selected within the Ivanpah Valley of MNP that represented a continuum of habitats common in the Mojave Desert. These field sites were located 20 km to the southwest of the research facility (Figure 2-1). The creosote scrub (CS) site occurred at an elevation of 800–900 m and the habitat was dominated by creosote bush, *Larrea tridentata*, and white bursage, *Ambrosia dumosa*, intermixed with patches of galleta grass, *Pleuraphis rigida* (Figure 2-2). The yucca woodland (YW) site was also a creosote-dominated community but was intermixed heavily with Joshua tree, *Yucca brevifolia*; Mojave yucca, *Y. shidigera;* and white ratany, *Krameria grayi*, and had an elevation gradient of 950–1050 m (Figure 2-3). The minimum distance between these two field sites was 4 km, and no juvenile or adult animals monitored in our study traveled between the two sites. As has been noted previously for the Mojave Desert, even the relatively small distance between these two closely located sites was associated with differences in vegetation community structure and composition due to local variation in temperature, precipitation, soil composition, elevation, and exposure (Schlesinger et al. 1996; Caldwell et al. 2012).

Figure 2-2: Creosote scrub habitat

One of two habitats in the Mojave National Preserve where nesting females occurred and where juvenile desert tortoises were released as part of this study. Photo was taken on the same day as that of Yucca woodland habitat shown in Figure 2-3.

Figure 2-3: Yucca woodland habitat

One of two habitats in the Mojave National Preserve where nesting females occurred and where juvenile desert tortoises were released as part of this study. Photo was taken on the same day as that of Creosote scrub habitat shown in Figure 2-2.

A significant portion of the work was conducted at the Ivanpah Desert Tortoise Research Facility (IDTRF), located immediately adjacent to the Mojave National Preserve 20 km from the field sites. The IDTRF was built and designed by Arcadis US, Inc. with funding from Chevron Environmental Management Corporation and Molycorp Inc. It was built in 2010 and is operated in conjunction with the US National Park Service – Mojave National Preserve via funding and oversight from the National Park Trust, who manages the donated facility and funds. The facility was built to support research and recovery of the desert tortoise in the Mojave National Preserve and nearby environs and in this regard is unique. The IDTRF includes a field laboratory, an outdoor female nesting enclosure, and two outdoor juvenile rearing enclosures. All enclosures were approximately 30 x 30 m and constructed of chain-link fence walls with an outer perimeter of corrugated metal along the base that extended 1 m into the ground to bar terrestrial predators from entry. The enclosures were also completely covered by mesh netting to exclude any aerial predators, including ravens and any birds of prey (Morafka et al. 1997; Figure 2-4).

Figure 2-4: Example outdoor enclosures used in study

Enclosures were subdivided with sheet metal into smaller pens and equipped with manually-operated sprinkler systems fed by an underground aquifer. The female nesting enclosure was subdivided into 18 pens measuring 5 x 9 m and each of the two juvenile rearing enclosures was subdivided into 9 pens measuring 10 x 10 m. Enclosures contained native vegetation and natural cover (e.g., rocks, downed yucca logs) and thus mimicked the tortoises' natural environment outside the facility. Natural cover was supplemented with artificial burrows created from 53.34 cm length 10.16 cm-diameter perforated plastic pipes for hatchlings or 1 m length 30.48 cm-diameter cardboard tubes (concrete form casings, "sonotubes") for adult females, cut in half longitudinally and placed at a 30° angle, then buried underground (Figure 2-5.

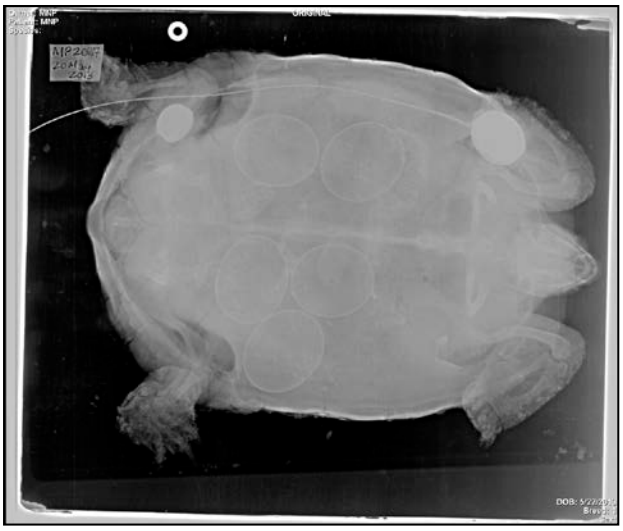
Figure 2-5: Construction of juvenile burrows

Nesting females and all captive head-start juveniles were provided with artificial burrows in the enclosures.

2.2 Propagation of Juvenile Tortoises

Beginning May 2011, the researchers captured, marked, and radio-tracked adult female desert tortoises from the YW and CS study sites. Females were radio-tracked at least twice per month during April – October each year when they were most active, and once per month November – March when their activity was reduced. In 2011–2013, the females were radiographed (Diagnostic Imaging Systems: Poskam, Colorado, USA; 60 kvp, 0.8 mAS, 74 cm focal length) every 10-14 days from mid-April through early July when they were most likely to produce their first clutch of eggs (Figure 2-6). Females with calcified eggs (Gibbons and Greene 1979) were placed individually into outdoor predator-proof nesting pens at the IDTRF, where they were allowed to nest. They were provided with adequate shelter from temperatures via artificial burrows and natural shrub cover inside the pens. Females that nested were returned immediately to their last burrow location; females that did not nest within 30 days were released back at their last burrow location without having nested.

Figure 2-6: Example x-ray of female tortoise with eggs



Nests were allowed to incubate in the ground where they were laid by the females. Beginning August – September each year, approximately 80 days after estimated nesting date, the pens were searched daily for emerging hatchlings. Hatchlings were removed from nesting pens when they were found and immediately weighed (to nearest 0.1 g) and measured (mid-line carapace length, MCL [mm] to nearest 0.1 mm; Figure 2-7). Hatchlings were individually marked by notching unique combinations of marginal scutes with nail clippers using the 1-2-4-7 coding system and codes assigned by USFWS (Cagle 1939). Finally, nesting pens were thoroughly searched for any unhatched eggs or unemerged hatchlings. In Spring 2012, researchers also received 14 hatchlings from the 2011 cohort via females collected at the nearby Ivanpah Solar Electric Generating Systems (ISEGS) site. The total number of live, viable hatchlings obtained over three years and used in the study was 197, representing 39 from 2011, 72 from 2012, and 86 from 2013 (Table 2-1).

Figure 2-7: Measuring a recent hatchling desert tortoise

2.3 Head-starting and Release of Juvenile Tortoises

2.3.1 Experimental Design

For each of the three annual cohorts (2011, 2012, 2013), hatchlings were assigned to one of three treatments in a stratified random design, with hatchlings from each clutch divided as equally as possible among treatments (see Table 2-1 for sample sizes). The three husbandry treatments were: 1) released into the CS and YW sites within the Mojave National Preserve shortly after hatching (hereafter referred to as "direct release"); 2) head-started in one of two outdoor juvenile enclosures and provided additional low levels of simulated rain from the sprinkler system (hereafter referred to as "low rain" or "LR"); and 3) head-started in an outdoor juvenile enclosure and provided additional high levels of simulated rain from the sprinkler system (hereafter, "high rain", "HR"). The "low rain" and "high rain" treatments were preferentially selected over "rain" and "no rain" treatments to promote vegetation growth in the pens, to guard against impacts from possible droughts, and in part due to stipulations required in Institutional Animal Care and Use Committee protocols and state and federal permits. The hatchlings assigned to the low rain and high rain treatments were distributed as equally as possible each year among three of the subdivided pens within the corresponding larger low rain and high rain treatment enclosures at a maximum density of approximately one individual per 10 sq m (6-7 individuals per pen in 2011, 10 individuals in 2012, and 10-11 individuals in 2013). No more than two siblings from each clutch were assigned to the same subdivided pen. In addition to permanently notching their marginal scutes, hatchlings were temporarily marked while in the pens using a small dab of nail polish on one of their vertebral or costal scutes. By assigning a temporary visual mark to each captive tortoise, individuals could be monitored visually without having to handle them.

Simulated rain was provided using sprinkler systems inside the pens, with the high rain enclosure receiving simulated rain nearly weekly and the low rain enclosure receiving simulated rain every other week or less often (Figure 2-8). Based on the flow rates measured for the aquifer-fed sprinkler system, low rain treatments received approximately 4.5 cm of added water annually and high rain treatments received approximately 9 cm of added water annually. Use of sprinklers was timed to mimic typical rainfall patterns in this portion of the Mojave, where monsoonal summer rains frequently occur but where winter rainfall is more prevalent. Water pressure limitations prevented the start of regimented rain treatments until April 2012. However, thereafter, when supplemental watering occurred, duration of watering was consistent between treatments, but watering frequency was always twice as high in the "high rain" as it was in the "low rain" treatment. Watering treatments were chosen as part of the research framework because it was expected that additional simulated rain could increase growth rates of head-started tortoises by stimulating growth of annuals on which hatchlings forage, and by providing well-hydrated hatchlings additional opportunities to forage on dry plant matter they may otherwise avoid. Hatchlings often emerge from their burrow to forage and drink when it rains; the water that animals gain during rainfall is important for nutrient balance and digestion efficiency (Nagy and Medica 1986; Peterson 1996; Oftedal 2002).

Figure 2-8: Supplemental rain using a sprinkler system

Because 2011 was a particularly dry year, no animals were released Fall 2011 as part of the direct release group. Rather, animals were first released Fall 2012. Juveniles were released as part of the direct release treatment Fall 2012 (n=18, from the 2011 and 2012 cohorts), Spring 2013 (n=18, from the 2011 and 2012 cohorts), and Fall 2013 (n=10, from the 2013 cohort only), making 46 total animals in the direct release treatment (Table 2-1).

Table 2-1: Sample size of animals in the three experimental treatments

	Cohort			
Treatment	**2011**	**2012**	**2013**	**Total**
Direct release	**12** (6 in Fall 2012; 6 in Spring 2012)	**24** (12 in Fall 2012; 12 in Spring 2013)	**10** (Fall 2013)	**46**
Low rain	**14**	**24**	**40**	**78**
High rain	**13**	**24**	**36**	**73**
Total	**39**	**72**	**86**	**197**

The number of hatchlings placed into each of the three treatments is provided in the table above. The age of animals that comprised the direct release treatment are provided in Table 2-2.

Age at release varied from 0–18 months, depending on timing of release and cohorts selected (Table 2-2). During each release, half were released at the CS site and half at the YW site (Table 2-2). Siblings were never released at the same site during the same release event. For the animals that were released later than the year they hatched, half were selected from the high rain and half from the low rain treatment enclosures.

Table 2-2: Age of animals in direct release treatment

Release season	Cohort	Age at release	Number of animals	Release site	Release date
Fall 2012	2011	12 mo	3	Yucca woodland	25 Sep 2012
Fall 2012	2011	12 mo	3	Creosote scrub	25 Sep 2012
Fall 2012	2012	0 mo	6	Yucca woodland	25 Sep 2012
Fall 2012	2012	0 mo	6	Creosote scrub	25 Sep 2012
Spring 2013	2011	18 mo	3	Yucca woodland	7 Apr 2013
Spring 2013	2011	18 mo	3	Creosote scrub	8 Apr 2013
Spring 2013	2012	6 mo	6	Yucca woodland	7 Apr 2013
Spring 2013	2012	6 mo	6	Creosote scrub	8 Apr 2013
Fall 2013	2013	0 mo	5	Yucca woodland	24 Oct 2013
Fall 2013	2013	0 mo	5	Creosote scrub	24 Oct 2013

Immediately before release, each tortoise was weighed and measured. A small VHF transmitter (Holohil System Limited, type BD-2, 4-mo battery life, 1.5 g) was also attached to the 4th or 5th vertebral scute of each released animal using liquid 5-minute two-part epoxy (Figure 2-9). The combined weight of transmitter and epoxy was <10% of tortoise body weight. Prior to release, each tortoise was checked for its ability to right itself with the attached transmitter.

Figure 2-9: Juvenile tortoise with radio transmitter

Source: J. Mark Peaden

At both the CS and YW sites, a release area was selected with its center located 1 km from the nearest roads and powerline rights-of-way. Tortoises were released individually within a 50 m radius of the center of its assigned release area. Each animal was released in early morning

within 2 m of an appropriately-sized existing burrow under cover while temperatures were cool. The specific release location for each individual was recorded using a handheld Global Positioning System unit (Garmin eTrex 20 or Garmin GPSmap 76CSx; ± 3 m). Because juveniles frequently used multiple burrows within a 1–3 m area, and because individual tortoise burrows were sometimes too close to each other to distinguish with the GPS unit, the researchers also marked each unique burrow that was used by a tortoise with a wooden popsicle stick labeled with tortoise ID and date. The researchers also visually estimated distance moved to the nearest 0.5 m when distance from the previous location was less than 3 m.

2.3.2 Collection of Growth and Survival Data

Hatchlings reared in high rain and low rain pens were weighed and measured in spring and fall each year to monitor survivorship and growth. During each sampling period, pens and burrows inside pens were searched thoroughly to document all live juveniles. All live hatchlings were measured (MCL, to nearest 0.1 mm) and weighed (to nearest 0.1 g) when found. The researchers recorded a hatchling as alive during any sampling period if it was either: a) observed alive during that sampling period, or (b) if it was not observed during that sampling period but was observed alive in any later sampling period. During each use of the sprinklers, surface activity of all tortoises was recorded. These data provided more frequent (i.e., in general at least monthly) determination of individual survivorship. Mortality was rarely directly observed, thus any hatchling that had not been seen alive in more than a year (i.e., not documented in the two most recent handling periods) was presumed to have died. However, because not all individuals were detected in each handling period, the results reported here should be considered minimum survivorship. Survivorship was adjusted based on the number of animals expected in the pens (i.e., accounting for tortoises removed from pens for release in the field). Also, the starting growth measurements of tortoises released into the field were the measurements recorded at the time they were transferred from the pens to the field.

Each direct release tortoise was radio-tracked 24 hours after its initial release and 1–2 times per week when they were active, or every 1–2 weeks during the winter when they were less active. Tortoises were radio-tracked using a Communications Specialist R-1000 receiver and a folding 3-element Yagi antenna. The location of each tortoise was recorded at each tracking event using the handheld GPS units. In addition, each juvenile was weighed and measured each time transmitters were replaced with new units with fresh batteries. Due to the small size of the units, transmitter battery life was typically 4-6 months, requiring transmitters to be changed at least three times per year.

Monthly survival for the entirety of the study was calculated for each direct release tortoise. When a dead tortoise was encountered, the researchers recorded the date it was found, measured and weighed it when possible, and attempted to determine the cause of death. Tortoises were occasionally lost due to unexpectedly early radio failures, but in several cases, they were subsequently found alive by intensively searching in the vicinity of their previous telemetry locations. However, for others that were never found and for which their cause of disappearance could not be determined, their fate was treated as a mortality for the purposes of estimating survivorship. Thus, survivorship estimates are conservative and reported values

may be slightly lower than actual survival. For each release event (Fall 2012, Spring 2013, Fall 2013), survival curves were developed for each release site (CS, YW) by calculating the proportion of individuals known alive each month from release through November 2014.

2.3.3 Statistical Analysis

Annual growth rates were calculated for individuals using Fall measurements and are expressed as change in mm MCL per year. Separate annual growth rates were calculated for Fall 2011 – Fall 2012, Fall 2012 – Fall 2013, and Fall 2013 – Fall 2014. Annual growth rates were compared among high rain, low rain, and direct release animals for each year using one-way ANOVA, with animals from different cohorts combined. There were no direct release animals Fall 2011 – Fall 2012; growth rates between high rain and low rain were thus compared in this year using a t-test. Animals without a starting and ending measurement for a given year were excluded from analyses of the corresponding year's growth rate calculations.

2.4 Habitat Selection of Released Juvenile Tortoises

2.4.1 Data Collection

The researchers collected data to examine habitat selection on all direct release animals beginning shortly after the first release in Fall 2012. As additional animals were released in Spring 2013 and Fall 2013, they too were added to the habitat selection study. Thus, the researchers were able to examine habitat selection of 46 different individuals released at either the CS or YW locations in the Mojave National Preserve. Animals were removed from study only when they died or were lost to transmitter failure or predator removal.

As described above, animals were radio-tracked twice each week when they were active, typically March–May each spring and late July–November each fall. When an animal was located, its location was recorded using a handheld GPS unit as described above. Habitat selection data for each animal was collected at least weekly depending on whether the animal had moved at least 10 m from its previous location.

Researchers collected habitat selection data in a case-control fashion where the animal's observed location was used as the case and a random point was used as a temporally- and spatially-paired control. Each paired random control point was located 200 m from the animal's location at a random azimuth. Habitat data were collected at both locations using the same protocol on the same day as described below.

The researchers recorded whether each animal was at a burrow or away from a burrow each time data were collected. They also recorded whether the animal was unseen/inactive, resting, walking, or foraging when found. At each observed and random point, researchers recorded whether the animal or the center of the random point was at a cover object (typically a perennial or large annual plant). For each point, researchers measured the distance to the nearest dry wash or rivulet and the distance to the center of the nearest three perennial species (≥10 cm height). Washes were areas incised into the desert floor that supported water flow during heavy rains and rivulets were smaller areas that supported some water flow during rains but which were not deeply incised into the desert floor. Researchers also counted the number of small mammal burrows within a square meter focused on the center of each plot.

At each plot, six transects were established radiating out from the plot center at 60^0 azimuths, with the first transect having an azimuth in the direction the observed tortoise was facing or the direction of the burrow entrance in which a tortoise was found. Along each 5 m transect at 1 m intervals (0 m recorded only on first transect; total 31 points), researchers recorded surface composition, including ground cover, substrate type, and presence of a dry wash or rivulet following the methods of Grandmaison et al. (2010). Ground cover included live perennials and live and dead annual vegetation, the type of live annual vegetation (grass or forb) and its height (cm), or litter/duff or bare soil or rock if no vegetation was present at the point. Substrate types included fine soil (particle size <0.05mm), sand (0.05-2 mm), gravel (2-64mm), cobble (65-250mm), boulder (>250mm), fine soil-gravel, fine soil-cobble and mixed substrate (multiple types). Also, perennials that intersected each transect line and their distances to center were recorded using nomenclature from the PLANTS Database (USDA 2014). At five 1 × 1 m plots randomly assigned along one of the 6 transects with one located at the center of the plot, researchers recorded percent perennial and annual vegetation cover, annual species richness, and substrate cover (Figure 2-10).

Figure 2-10: Square meter plot used to collect habitat data

2.4.2 Statistical Analysis

Researchers used a Bayesian analysis of hierarchical case-control logistic regression models, which treated tortoise points as the cases and the paired random points as controls. The model was hierarchical in that it included an individual-level random effect for model coefficients (the paired case-control model does not contain an intercept). The inclusion of these random effects properly places the individual as the sample unit, from which observations are considered sub-samples (Gillies et al. 2006). Perhaps equally important, allowing model coefficients to vary among individuals allowed selection to vary among individuals, and quantifies the amount of among-individual variation in the selection of each habitat attribute (Gillies et al. 2006). Treating the individual as a random effect also weights individuals by the number of locations, resulting

in individuals that contribute fewer data being pulled toward the population mean ("shrinkage;" Gelman and Hill 2006). The output of this model is a resource selection function, which is the relative probability that a given resource unit will be used, given its covariate profile (Keating and Cherry 2004), for both the population and individual desert tortoises.

Two separate models were fit to the data: one to estimate the selection of habitat components from animals when they were observed in burrows, and the other to estimate the selection of habitat components from animals when they were observed active on the surface. Observations of tortoises in burrows and observations of tortoises on the surface were modeled separately because habitat selection likely reflects different selection processes. Animals likely select burrows because of characteristics that identify them as a valuable refuge, whereas animals on the surface may be selecting foraging areas or areas that present the least cost to movement. No variables were included with a Pearson correlation coefficient ≥ |0.60| in the model to reduce collinearity among habitat variables. A reduced set of habitat variables that did not include percent cover of different-sized rocks or any habitat characteristics for which > 50% of the used and random observations were zero was run in a second model.

The complete list of starting variables in the logistic regression models included the presence of cover at the point, number of burrows per square meter, distance to nearest wash, perennial species richness along transects, mean distance to nearest three perennials, mean height of forbs, grasses, forbs and grasses combined, mean percent cover of perennials in quadrats, percent cover of dead annuals, percent cover of live annuals, percent cover of litter and debris, percent cover of logs, percent cover of live perennials and dead annuals, percent cover of live perennials, percent cover of rocks, percent cover of bare soil, percent cover of cobble, percent cover of fine soil, percent cover of gravel, percent cover of mixed cobble and fine soil, percent cover of mixed cobble, gravel and fine soil, percent cover of sand, percent cover of rivulets, percent cover of washes, percent cover of areas with no washes or rivulets, percent cover of rocks in each of the 5 size categories, percent of quadrats with forbs, percent of quadrats with grasses, and mean percent cover of all annuals in quadrats.

Models were analyzed using standard Markov Chain Monte Carlo (MCMC) methods. The predictor variables in each model were a vector of differences between the used and random pairs for each variable at each location. Priors were selected to be vague, with N(0,3.16) (mean, standard deviation) priors on model coefficients and U(0,10) priors on standard deviations, both on the logit scale. Posterior inference was based upon five chains of 100,000 iterations each, after a burn-in period of 100,000 iterations. Each chain was thinned by a factor of 50, keeping 10,000 iterations to describe the posterior distribution of each parameter. Each model was analyzed with JAGS 3.4.0 (Plummer 2013) called from R 3.1.0 (R Core Team 2014) using the package 'rjags' (Plummer 2014). Convergence was diagnosed by visual examination of history plots and using the Gelman-Rubin statistic (Gelman and Rubin 1992); no evidence for lack of convergence was observed (r-hat < 1.02 for all monitored parameters).

The researchers also used a canonical analysis of principal coordinates (CAP) to further examine differences in habitat between points where tortoises were found and the paired random points (Anderson and Willis 2003). A CAP is a type of constrained ordination that uses principal

coordinate analysis (PCO) of multiple variables to reduce the number of explanatory variables in a dataset to those that capture the greatest variance and are most correlated with response variables in the model. In this case, it reduces the many measured habitat characteristics into new composite axes that best correlate with the presence or absence of a tortoise at a given point. This is followed by a canonical discriminant analysis (CDA) to determine whether the single most important PCO axis can be used to differentiate points between those of tortoises and those of random paired points. The CAP uses a leave-one-out approach to determine the mis-classification error of all points in the model as a measure of the goodness of fit of the model. Finally, a permutation test is used to determine whether there is a significant difference in multivariate space between the tortoise points and the paired random points along the primary canonical axis 1. For complete details about CAP, see Anderson and Willis (2003).

Because ordination methods cannot account for repeated measures made on individuals, the mean habitat characteristics of each tortoise's use points and paired random points were used in the CAP. All data were transformed to ln(x+1) with no standardization and the analysis was based on Bray-Curtis distance for calculating dissimilarities. Two CAP analyses were performed: one for tortoise locations when tortoises were encountered at a burrow (data for 45 tortoises) and a separate one for tortoise locations when tortoises were encountered active on the surface outside of burrows (data for 35 tortoises). Habitat characteristics used in the CAP included the same variables as those used in the logistic regression case-control analysis described above. However, because there was no way to code for which plant species were found among the three nearest perennials in the logistic regression analysis, they could not be included. Thus, they were included here in the CAP in addition to those characteristics used in the logistic regression above. The number of each of the following perennial plants in the first three nearest perennials were included: *Ambrosia dumosa, Cylindropuntia echinocarpa, Cylindropuntia ramosissima, Datura wrightii, Echinocereus polycephalus, Ephedra nevadensis, Hymenoclea salsola, Krameria erecta, Larrea tridendata, Lycium andersonii, Machaeranthera canescens, Muhlenbergia porteri, Opuntia basilaris, Pleuraphis rigida, Salazaria mexicana,* and *Yucca schidigera*.

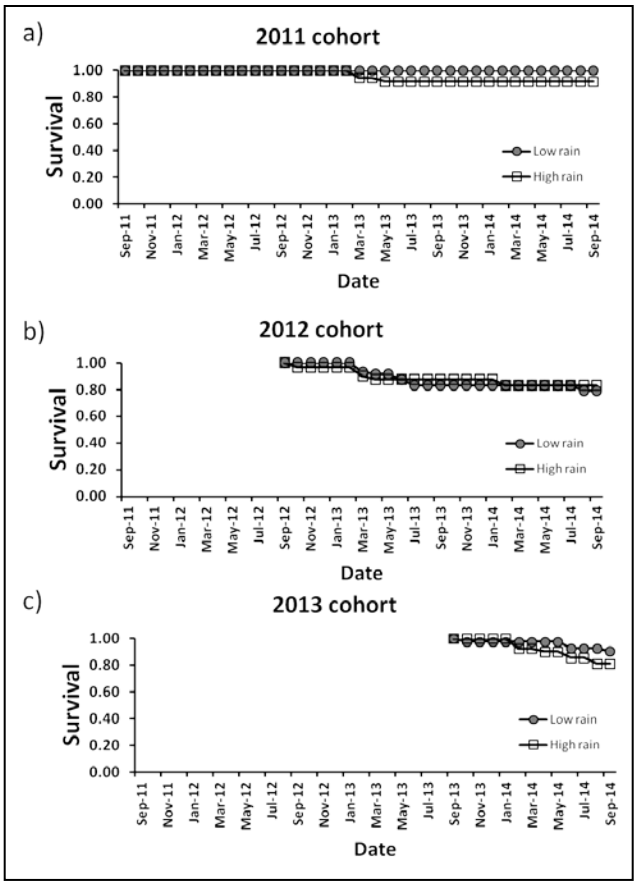
CHAPTER 3:
Head-starting of Juvenile Tortoises

3.1 Results

3.1.1 Survivorship

Overall survivorship of captive animals was high for all three annual cohorts (Figure 3-1). All 2011 hatchlings (100%) survived their first year (Figure 3-1a). The only mortality from the 2011 cohort over the course of the study was one tortoise from the high rain treatment that was found dead in March, 2013, after the second winter dormancy. Thus, both 2-yr and 3-yr survival of the 2011 cohort was 96.3% in the enclosures (Table 3-1). Of the 2012 cohort, five hatchlings (8.3%; 2 low rain, 3 high rain) failed to emerge from their first winter dormancy. Overall survival of the 2012 cohort was 85.4% after one year and 81.3% after two years, with similar survival observed between the low rain and high rain treatments (Table 3-1; Figure 3-1b). Of the 2013 cohort, four hatchlings (7.7%; 1 low rain, 3 high rain) failed to emerge from their first winter dormancy. Overall first year survival of the 2013 cohort was 84.3%, similar to the 2012 cohort (Table 3-1). However, in the 2013 cohort, survival in the high rain treatment (77.8%) was noticeably lower than that in the low rain treatment (90.0%; Table 3-1; Figure 3-1c).

Figure 3-1: Survival of low rain and high rain juveniles



Proportion of tortoises surviving in predator-proof enclosures and supplemented with high and low rain treatments. Data are presented for the a) 2011 (initial n=39), b) 2012 (initial n=60), and c) 2013 cohorts (initial n=76). Survival estimates are adjusted for animals removed from pens and released into the wild.

Table 3-1: Survival of low rain and high rain juveniles

Cohort	1 yr survival (%) Total/LR/HR	2 yr survival (%) Total/LR/HR	3 yr survival (%) Total/LR/HR
2011	100/100/100	96.3/100/92.3	96.3/100/92.3
2012	85.4/83.3/87.5	81.3/79.2/83.3	
2013	84.3/90.0/77.8		

Percent survival of animals raised in enclosures shown as total survival, low rain treatment (LR), or high rain (HR) treatment. Survival estimates exclude animals removed from pens and released into the wild.

The total number of animals surviving from the Fall 2012 direct release, which included both hatchlings and yearlings, was 33.3% at 1 yr and 22.2% at two years (Table 3-2; Figure 3-2). Of the 14 Fall 2012 animals lost during the two years of monitoring, five died in their winter burrows during the first dormancy period, four died on the surface (presumably due to exposure), four went missing and their fate could not be determined, and one appeared to have been predated

by a ground squirrel. At the end of the second year after release, estimated survival was similar between the CS and YW release sites (Figure 3-2a), although the two surviving in the CS site were released as hatchlings and the two at the YW site were released as yearlings.

Overall survival of the Spring 2013 direct release, which included 6 month-old and 18 month-old juveniles, was 55.6% at 1yr post-release and was similar between release sites (Table 3-2; Figure 3-2b). As of Fall 2014, approximately 1.5 years after release, overall survival was 38.9%. Of the 11 Spring 2013 animals lost between Spring 2013-Fall 2014, one drowned in its summer burrow, three died on the surface, one was predated by a canid, one was predated by a loggerhead shrike, and five went missing. Additionally, one tortoise was lost during monsoonal rains in late August 2013 when the wash it occupied flooded, but it was subsequently found alive on 24 September 2013 approximately 1.8 km from its previous location.

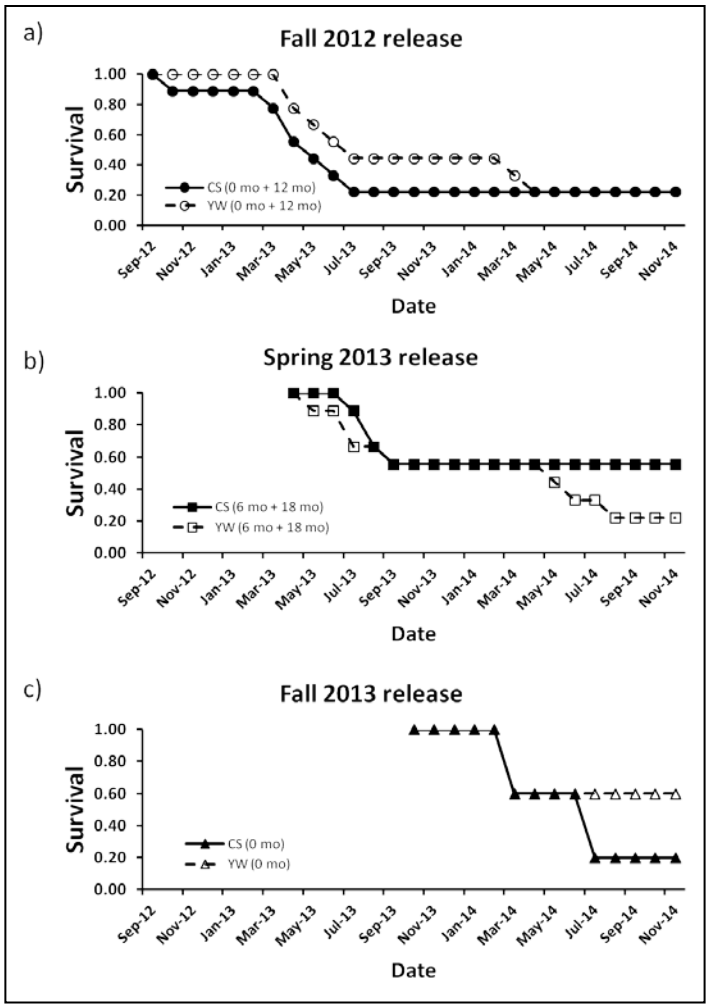
All 10 hatchlings (100%) released in Fall 2013 survived their first dormancy (Figure 3-2c). At 1 yr post-release, overall survival was 40.0% (Table 3-2), with only one animal known alive at the CS site and three known alive at the YW site. Of the six Fall 2013 animals lost during the 1 yr monitoring, one was found dead on the surface, another was found dead on the surface covered in fire ants, one was predated by a canid, and three went missing likely due to early radio failures.

Table 3-2: Survival of direct release juveniles

Release event	n	1 yr survival (%) All/CS/YW	2 yr survival (%) All/CS/YW
Fall 2012	18	33.3/22.2/44.4	22.2/22.2/22.2
Spring 2013	18	55.6/55.6/55.6	
Fall 2013	10	40.0/20.0/60.0	

Percent survival of direct release juvenile tortoises (data for age cohorts combined). Animals lost from the study were assumed to have died, and survival estimates are thus conservative.

Figure 3-2: Survival of direct release juveniles



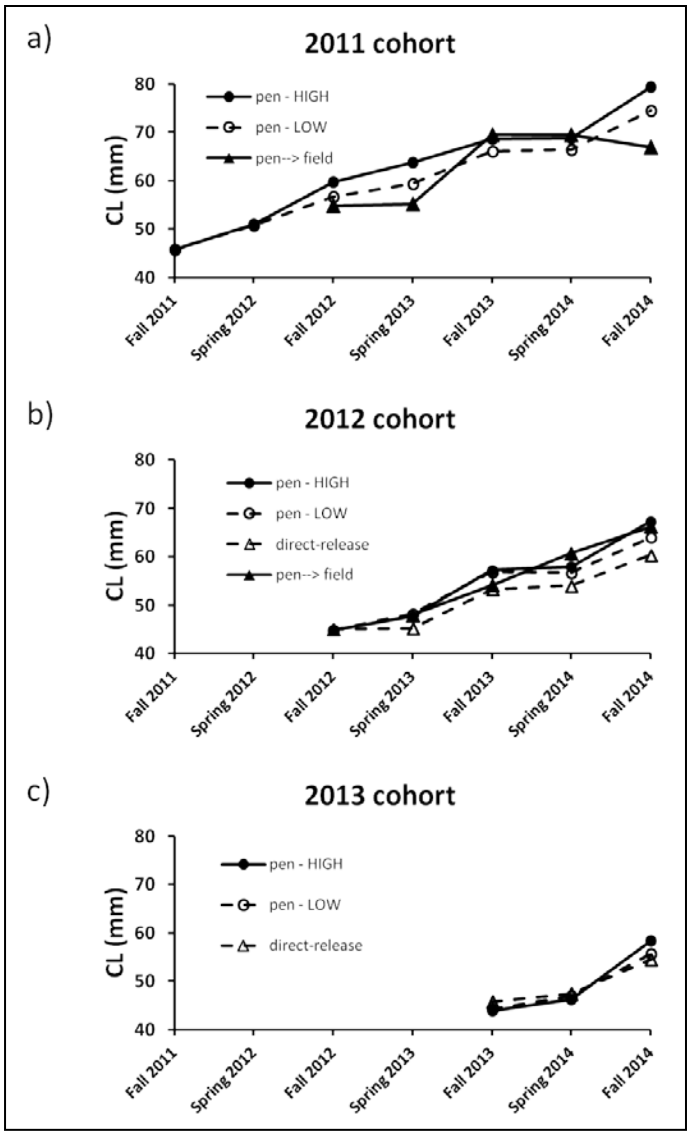
Proportion of direct release juvenile desert tortoises surviving in the creosote scrub habitat (solid lines, filled markers) and Yucca woodland habitat (dashed lines, hollow markers) during a) Fall 2012 release (top; n=9 per site), b) Spring 2013 release (middle; n=9 per site), and c) Fall 2013 release (bottom; n=5 per site). For the Fall 2012 and Spring 2013 releases, data for 2011 and 2012 released cohorts are combined. Animals lost from the study were assumed to have died, and survival estimates are thus conservative.

3.1.2 Growth

Average size of captive juveniles from each annual cohort (2011, 2012, 2013) increased while they were reared in outdoor enclosures (Figure 3-3). The initial mean size of all 175 hatchlings placed into enclosures, including 24 that were later released as part of the direct release treatment, was 44.7±2.15 mm MCL. After 1 year in enclosures, mean MCL was 58.2±0.82 mm (Cohort 2011), 57.1±0.45mm (Cohort 2012), and 56.7±0.64 mm (Cohort 2013). After two years in enclosures, mean MCL was 67.2±0.94 and 65.7±0.78 for the 2011 and 2012 cohorts respectively. After three years in enclosures, the mean MCL of the 2011 cohort was 76.7±1.24 mm.

For all annual cohorts and across all years of the study, mean size of tortoises in the high rain treatment was greater than the low rain treatment (Figure 3-3). Differences in growth between treatments became more obvious as juveniles aged. For example, in the 2011 cohort, the mean MCL of animals reared for three years was greater in the high rain pens (79.4±1.34 mm) than in the low rain pens (74.4±1.81 mm). Growth trajectories for the two treatments did not begin to diverge until after the first winter dormancy (Figure 3-3a). Although this could be due to the rain treatments not being initiated until Spring 2012, researchers observed the same pattern for the 2012 and 2013 cohorts, which were placed in pens after the rain treatments had begun (Figures 3-3b,c). Annual growth of juveniles between Fall 2011 – Fall 2012 was significantly higher in animals from the high rain treatment (13.9±0.99 mm/yr; n=19) than the low rain treatment (11.0±0.78 mm/yr; n=20; t=2.29, df=35, p=0.028). Annual growth was also higher in high rain (12.1±0.55 mm/yr; n=59) than low rain animals (9.77±0.52 mm/yr; n=67) during Fall 2013–Fall 2014 (t=3.038, df=122, p<0.003), but not during Fall 2012–Fall 2013 (t=0.246, df=56, p=0.807; overall mean MCL= 10.3 mm).

Figure 3-3: Growth of juvenile tortoises in all treatments



Mean size (carapace length [CL] in mm) of surviving juvenile tortoises from the a) 2011, b) 2012, and c) 2013 cohorts. The 2011 and 2012 cohorts include 24 animals initially reared in pens then subsequently released in the wild as part of the Direct Release treatment (pen-->field in legends). The 2012 and 2013 cohorts include animals in the initial size estimates that were never reared in pens but directly released into wild as hatchlings.

Due to loss of some animals following release, sample size for released juveniles was small (n=34 for animals whose fate could be definitively determined). Maximum time monitored in the field was 2 years. Tortoises that were directly released and had never spent time in pens (e.g., Fall 2013 animals) were consistently smaller than their siblings that spent at least some time in the pens (i.e., including tortoises transferred from pens to field), particularly those released from the high rain treatment (Figure 3-3b, 2012 cohort; Figure 3-3c, 2013 cohort). Data from the 2012 cohort suggest that animals initially reared in pens and transferred to the field a

short time later were able to maintain their size advantage over direct release siblings that were released immediately after hatching into the wild (Figure 3-3b). Although the mean MCL in Fall 2014 of 2011 cohort animals transferred from pens to the field is much smaller than 2011 animals kept in outdoor enclosures, this apparent disparity is likely due to there being only a single 2011 animal measured in Fall 2014 even though four survivors are still being radio-tracked.

No animals were released into the field prior to Fall 2012, thus comparison of annual growth of direct release animals versus low rain and high rain animals can only be made using data from the 2012 and 2013 cohorts, which were combined for analyses. Mean annual growth did not vary among high rain, low rain, or direct release animals during Fall 2012–Fall 2013 ($F_{2,77}$=0.288, p=0.751; overall mean MCL= 10.06 mm), but growth during Fall 2013–Fall 2014 did vary significantly ($F_{2,133}$=4.96, p<0.009). During Fall 2013–Fall 2014, growth of field animals (9.71±1.30 mm/yr; n=10) was similar to low rain animals (9.77± 0.52 mm/yr; n=67; t=0.040, df=12, p=0.969) and slightly lower than in high rain animals, although the trend was marginally non-significant (t=1.67, df=12, p=0.06).

3.2 Discussion

Not surprisingly, survivorship of the low rain and high rain juveniles inside the predator-proof enclosures was significantly higher than survivorship of all direct release juveniles released into the field. Annual survival in enclosures (with both rain treatments combined) ranged from a high of 100% (2011 cohort) to a low of 84.3% (2013 cohort), compared to 33.3–55.6% overall annual survival in the field (both release sites combined). Surprisingly, more of the mortalities in the field were attributed to exposure to extreme temperatures or desiccation than were attributed to predation. One instance of a juvenile tortoise found off the ground in a yucca shrub suggested predation by a loggerhead shrike (*Lanius ludovicianus*). Juvenile tortoise remains were often found with gnaw marks on them, perhaps by grounds squirrels (*Citellus* sp.), indicating either predation or scavenging; puncture marks on one tortoise shell suggested a mammalian predator. Juvenile tortoises that died in their burrows during winter were presumed to be simply victims of insufficient body reserves to survive dormancy; indeed two of these were hatchlings that moved the greatest distances in the months leading up to winter. It is possible that these animals simply spent more energy moving before winter that could have instead been used to sustain them over winter.

A few juvenile tortoises were found dead on the surface of the desert floor. These events occurred during active seasons and may simply indicate that small, relatively naïve tortoises occasionally miscalculate the distance from their burrows or fail to reach suitable shade before afternoon temperatures in the desert exceed their critical tolerances. Wilson et al (2001) found that juvenile tortoises had greater water loss rates than adults in both the laboratory and the field, highlighting their vulnerability to desiccation. Thus, in addition to providing protection from predators, the pen treatments may also enhance survival through the provision of supplemental water via the simulated rain treatments. There was not, however, a difference in survival between the high rain and low rain treatments, indicating the 4.5 cm rainfall

supplementation in the low rain treatment and protection from predators was sufficient to increase survival compared to the direct release group.

Although there are a few other head-starting programs for desert tortoises, due to the time required to rear animals to a "predator-proof" size and monitor their growth and survival, few published data are available with which to compare the present results. Early work by Morafka et al. (1997) documented 60% of animals surviving in protected outdoor enclosures to three years, compared to 92.3% for the 2011 cohort in the present study (the only cohort for which there are 3 yrs of data). Nagy et al. (unpublished data) documented 92% survival of predator-protected hatchlings at Ft. Irwin over the animals' first winter, and this was similar to survival of protected hatchlings through their first hibernation period in the present study.

Compared to captive animals, released or free-ranging wild juvenile tortoises are expected to have much lower survival. For example, Turner et al. (1987) observed only 47% survival of wild hatchlings through their first winter. Germano (1994b) estimated survival of 51% for wild tortoises in their first year in the eastern Mojave, at the high end of that found for direct release hatchlings over their first year in the present study. In one exceptional case, Hazard and Morafka (2002) found that 11 of 12 newly hatched juvenile tortoises survived their first winter through February. Very little has been published on the survival of free-ranging juvenile tortoises beyond their first winter. Bjurlin and Bissonette (2004), however, found that 88% of hatchlings survived to 2 years in the southern Mojave near Twentynine Palms, California. The present study offers the only other estimates of longer-term survival of free-ranging juvenile desert tortoises. Survival to 2 years was at least 22.2% and survival for the first year ranged from at least 33.3-55.6%. These estimates are conservative given that fate of some animals could not be determined due to premature radio failure.

Growth rates of animals in enclosures (low rain or high rain) were never lower than that observed for the field-monitored direct release animals. The larger size of high rain animals compared to low rain animals and significantly greater annual growth rates of high rain compared to low rain animals in at least some years suggest that rain supplementation can increase tortoise growth. Overall mean annual size increase of juveniles was 10 mm MCL, which corresponds to an approximately 25% increase in size during their first year of life. Nagy et al. (unpublished data) reported a similar 22% increase in MCL of their rain-supplemented hatchlings compared to an only 4.3% increase in those receiving only natural rainfall. Medica et al. (2012) found that annual growth of outdoor-reared juveniles strongly correlated with winter rainfall. Likewise, growth of juveniles in the field has been shown to be strongly influenced by precipitation patterns (Karl 1998; 10.8 mm MCL during high rain years versus 3.6 mm MCL during drought years). Therefore, fine-tuning the artificial rain treatments to better mimic the seasonal timing to which annual desert plants are adapted (Beatley 1974) may maximize forage plant availability. However, supplemental water currently provided at other times of the year (i.e., summer) likely directly benefits tortoise foraging and digestibility of dry plant material (Oftedal 2002). Based on these collective findings, supplemental rain appears to be an effective means of enhancing growth rates of young tortoises in semi-natural outdoor enclosures and an added 4.5 cm of supplemental rain appears sufficient to boost growth rates and survival.

Currently, the remaining juvenile tortoises in captivity are being raised to a target size of at least 110 mm MCL before release because previous studies have documented increased predation, primarily by ravens, on wild tortoises smaller than 110 mm MCL (Boarman 1993) and on released captive-raised tortoises smaller than 105 mm MCL (Nagy et al. 2007). Because the present project is still in a very early phase, most of the juveniles in the head-starting program have not yet reached the 105 mm MCL minimum release size recommended to provide protection from predators and survival that more closely matches that of adults (Nagy et al. 2011; Nagy and Hillard 2013). The 2011 cohort tortoises had hatchling MCLs of 44 mm and averaged 76 mm MCL in 2014. Assuming this rate of growth continues, the 2011 cohort would not reach 105 mm MCL until Spring 2017, when they were 5.5 years of age. The researchers in the present study opted, however, to release both smaller juveniles and new hatchlings to provide field estimates of survival of wild juvenile tortoises. Because head-starting is an expensive and labor-intensive undertaking, it was important to compare survival and growth of head-started animals to naïve hatchlings to quantify any potential benefits of head-starting relative to simply protecting nests. Also, because it can take an estimated 5-7 years for head-started desert tortoises to reach the minimum recommended release size (Boarman 1993; Nagy et al. 2007; Turner et al. 1987), the researchers conducted preliminary releases to determine the value of releasing at a smaller size and/or younger age after having spent less time in captivity.

Reducing the time individuals spend in captivity can potentially improve the feasibility of head-starting by minimizing foraging pressure on vegetation in enclosures and by making pens available for use by future cohorts sooner, allowing head-starting of a greater number of individuals. In addition, reducing time in captivity may be important for minimizing habituation of animals to humans or other selection for captive phenotypes such as atypical behavior. Finally, in pens, the diversity of forage plants is likely lower than what is available in the field and as a result may constrain diet selection of animals while they are in captivity. Preliminary data from the present study suggests that holding animals in pens even for short periods (6-18 months) has the positive benefit of improving survival and growth while animals are inside pens compared to that of similar aged-animals in the field.

Understanding the full extent to which head-starting can be used as an effective mitigation or recovery tool will require additional study. Because the growing body of evidence suggests that survival of juveniles in the field is naturally variable and much lower than that of adults, it will take multiple cohorts of releases to determine how repeatable the present results are under varying environmental conditions. Likewise, because the juvenile period is lengthy in desert tortoises (as in most tortoise species), it will take multiple years of monitoring the same head-started individuals to evaluate their long-term growth and survival. Thus, the researchers will continue measuring and monitoring current juveniles in the experimental treatments with the goal of releasing animals at larger sizes to examine their survival as well. In addition, the researchers propose to begin exploring the possibility of further accelerating juvenile growth and reducing time in captivity by rearing and feeding individuals indoors through their first winter when they would otherwise normally be dormant. Future research will also include conducting baseline population assessments at the release sites to quantify long-term effects of releases on demography and population size or structure of wild tortoise populations.

CHAPTER 4:
Habitat Selection of Released Juvenile Tortoises

4.1 Results

Data were collected at 351 paired observations of radio-tracked direct release animals. Of these, 201 pairs of observations were made on 45 animals that were found in or at burrows when they were radio-tracked. In contrast, 150 pairs of observations were made on 34 animals that were found active on the surface when they were radio-tracked.

The analysis of the full dataset for burrow observations with correlated variables removed identified evidence for selection of three habitat characteristics (Table 4-1). Animals at a burrow were 5,836 times more likely to be in cover than were random locations. For every additional burrow per sq m, the likelihood of it being a tortoise shelter site versus a random location was 26,590 times greater. For every 10% increase in mean percent cover by perennials, the likelihood of it being a tortoise shelter site versus a random location was 274 times greater. No other habitat characteristics were identified in this model as being significantly associated with animal burrow use points compared to random points.

The analysis of a reduced dataset for burrow observations where correlated variables and any variables for which >50% of the used and random observations were zero were removed had comparable results to the analysis of the full dataset (Table 4-2). Animals at a burrow were 3,806 times more likely to be in cover than were random locations. For every additional burrow per sq m, the likelihood of it being a tortoise shelter site versus a random location was 7,356 times greater. And for every 10% increase in mean percent cover by perennials, the likelihood of it being a tortoise shelter site versus a random location was 95 times greater. No other habitat characteristics were identified in this model as being significantly associated with animal burrow use points compared to random points.

The analysis of the full dataset for surface observations with correlated variables removed identified evidence for selection of three habitat characteristics (Table 4-3). These characteristics were different from those identified in the analyses of burrow observations. For every meter closer to a wash that a point was located, there was a 2.8 times greater likelihood of the point being a surface active animal rather than a paried random point. For every centimeter closer the nearest three perennials were to a point, there was a 1.2 times greater likelihood of the point being a surface active animal rather than a paried random point. Finally, for every centimeter decrease in the height of grasses at a point, there was a 50 times greater likelihood of the point being a surface active animal rather than a paried random point. No other habitat characteristics were identified in this model as being significantly associated with animal surface use points compared to random points.

The analysis of a reduced dataset for surface observations where correlated variables and any variables for which >50% of the used and random observations were zero were removed yielded selection for only one habitat characteristic (Table 4-4). For every meter closer to a wash that a point was located, there was a 2.5 times greater likelihood of the point being a surface

active animal rather than a paired random point. No other habitat characteristics were identified in this model as being significantly associated with animal surface use points compared to random points.

Table 4-1: Habitat selection results from burrow locations using full model

	Mean odds of use		
Habitat Characteristic	**Median**	**0.025 quantile**	**0.975 quantile**
Presence of cover	5835.98*	27.89	> 100,000
Number of burrows per m^2	26,590.43*	604.63	> 100,000
Distance to wash (m)	0.48	0.13	1.21
Perennial species richness	1.85	0.03	111.08
Mean distance to closest three perennials (cm)	0.90	0.76	1.03
Mean height of forbs and grasses (cm)	1.78	0.05	50.12
Mean height of forbs (cm)	0.40	0.04	2.83
Mean height of grasses (cm)	1.11	0.10	12.36
Mean percent cover perennials in quadrats (10%)	273.97*	4.22	19,707.04
Percent cover dead annual (10%)	0.23	< 0.01	28.86
Percent cover live annual (10%)	9.65	0.03	1,952.04
Percent cover litter and debris (10%)	2.22	0.01	474.05
Percent cover log (10%)	1.19	< 0.01	612.79
Percent cover live perennials and dead annuals (10%)	1.07	< 0.01	486.28
Percent cover live perennial (10%)	8.01	0.02	2396.29
Percent cover rock (10%)	14.58	0.10	1796.84
Percent cover bare soil (10%)	0.03	< 0.01	2.26
Percent substrate cobble (10%)	1.62	< 0.01	839.76
Percent substrate fine soil (10%)	0.39	0.01	16.84
Percent substrate gravel (10%)	0.60	0.01	60.45
Percent substrate mixed cobble and fine soil (10%)	1.08	< 0.01	422.17
Percent substrate mixed cobble, gravel, and soil (10%)	0.68	< 0.01	243.03
Percent substrate sand (10%)	0.26	0.01	13.29
Percent no wash or rivulet (10%)	0.17	< 0.01	19.06
Percent rivulet (10%)	1.05	0.01	138.93
Percent wash (10%)	4.70	0.04	785.63
Mean percent cover of rocks size 1 (10%)	0.21	< 0.01	14.43
Mean percent cover of rocks size 2 (10%)	0.90	< 0.01	174.84
Mean percent cover of rocks size 3 (10%)	1.08	< 0.01	283.06
Mean percent cover of rocks size 4 (10%)	1.05	< 0.01	504.96
Mean percent cover of rocks size 5 (10%)	1.22	< 0.01	619.78
Percent transects/quadrats with forbs (10%)	11.63	0.04	3359.83
Percent transects/quadrats with grasses (10%)	1.98	0.01	390.08
Mean percent cover annuals in quadrats (10%)	0.65	< 0.01	169.46

Results from a full model showing mean odds of juvenile tortoise selecting different habitat characteristics when located in a burrow, given a unit change in the habitat characteristic. Units used in the analysis are defined in parentheses after each habitat characteristic. Habitat characteristics with credible intervals not overlapping zero are denoted with an asterisk '*' next to their median odds of use value.

Table 4-2: Habitat selection results from burrow locations using reduced model

Habitat Characteristic	Mean odds of use		
	Median	**0.025 quantile**	**0.975 quantile**
Presence of cover	3806.07*	24.11	> 10,000
Number of burrows per m^2	7356.24*	205.02	> 10,000
Distance to wash (m)	0.59	0.20	1.13
Perennial species richness	1.72	0.05	63.97
Mean distance to closest three perennials (cm)	0.92	0.80	1.03
Mean percent cover perennials in quadrats (10%)	95.10*	3.06	4255.73
Percent cover dead annual (10%)	0.14	0.00	12.50
Percent cover live annual (10%)	32.75	0.24	4311.09
Percent cover litter and debris (10%)	2.04	0.01	363.39
Percent cover live perennial (10%)	0.10	0.03	3416.11
Percent cover rock (10%)	10.82	0.12	1000.22
Percent cover bare soil (10%)	0.05	0.001	1.89
Percent substrate fine soil (10%)	0.76	0.02	17.52
Percent substrate gravel (10%)	0.52	0.01	28.18
Percent substrate sand (10%)	0.44	0.01	17.25
Percent no wash or rivulet (10%)	0.10	0.00	4.27
Percent rivulet (10%)	0.74	0.01	50.79
Mean percent cover annuals in quadrats (10%)	0.64	0.00	100.57

Results from a reduced model showing mean odds of juvenile tortoise selecting different habitat characteristics when located in a burrow, given a unit change in the habitat characteristic. Units used in the analysis are defined in parentheses after each habitat characteristic. Habitat characteristics with credible intervals not overlapping zero are denoted with an asterisk '*' next to their median odds of use value.

Table 4-3: Habitat selection results from surface active locations using full model

Habitat Characteristic	Mean odds of use		
	Median	0.025 quantile	0.975 quantile
Presence of cover	107.86	0.36	24,397.89
Number of burrows per m^2	7.54	0.09	784.14
Distance to wash (m)	0.35*	0.08	0.91
Perennial species richness	2.38	0.02	249.22
Mean distance to closest three perennials (cm)	0.86*	0.70	0.99
Mean height of forbs and grasses (cm)	0.16	< 0.01	23.70
Mean height of forbs (cm)	8.75	0.22	363.62
Mean height of grasses (cm)	0.02*	< 0.01	0.54
Mean percent cover perennials in quadrats (10%)	11.01	0.12	951.54
Percent cover dead annual (10%)	0.69	0.01	108.08
Percent cover live annual (10%)	0.58	< 0.01	155.40
Percent cover litter and debris (10%)	0.37	< 0.01	103.89
Percent cover live perennials and dead annuals (10%)	1.11	< 0.01	502.80
Percent cover live perennial (10%)	1.18	< 0.01	382.53
Percent cover rock (10%)	20.82	0.19	2377.64
Percent cover bare soil (10%)	0.30	< 0.01	20.50
Percent substrate cobble (10%)	11.46	0.03	4044.46
Percent substrate fine soil (10%)	0.11	< 0.01	8.82
Percent substrate gravel (10%)	1.89	0.01	262.38
Percent substrate mixed cobble and fine soil (10%)	1.25	< 0.01	485.49
Percent substrate mixed cobble, gravel, and soil (10%)	0.78	< 0.01	3388.92
Percent substrate gravel and fine soil (10%)	2.41	0.02	226.33
Percent substrate sand (10%)	0.19	< 0.01	16.33
Percent rivulet (10%)	0.57	0.01	51.75
Percent wash (10%)	0.58	0.01	57.87
Mean percent cover of rocks size 1 (10%)	1.01	0.01	120.33
Mean percent cover of rocks size 2 (10%)	0.58	< 0.01	145.32
Mean percent cover of rocks size 3 (10%)	1.64	< 0.01	672.46
Mean percent cover of rocks size 4 (10%)	1.31	< 0.01	538.67
Mean percent cover of rocks size 5 (10%)	0.88	< 0.01	413.50
Percent transects/quadrats with forbs (10%)	9.21	0.02	3038.36
Mean percent cover annuals in quadrats (10%)	3.26	0.01	886.67

Results from a full model showing mean odds of juvenile tortoise selecting different habitat characteristics when surface active, given a unit change in the habitat characteristic. Units used in the analysis are defined in parentheses after each habitat characteristic. Habitat characteristics with credible intervals not overlapping zero are denoted with an asterisk '*' next to their median odds of use value.

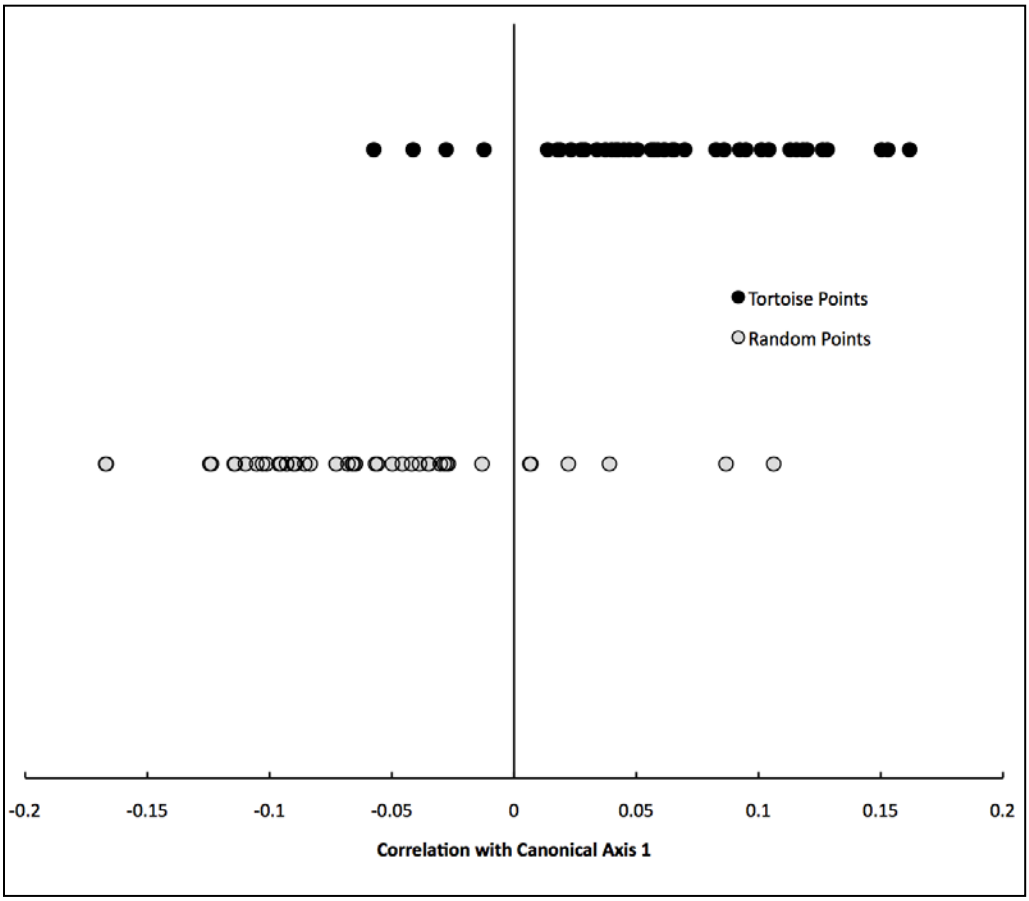
Table 4-4: Habitat selection results from surface active locations using reduced model

Habitat Characteristic	Mean odds of use		
	Median	0.025 quantile	0.975 quantile
Presence of cover	107.98	0.58	> 10,000
Number of burrows per m^2	16.21	0.27	1305.76
Distance to wash (m)	0.40*	0.08	0.94
Perennial species richness	1.87	0.04	123.54
Mean distance to closest three perennials (cm)	0.91	0.79	1.01
Mean percent cover perennials in quadrats (10%)	5.35	0.09	320.90
Percent cover dead annual (10%)	0.41	0.00	33.31
Percent cover live annual (10%)	3.80	0.03	437.17
Percent cover litter and debris (10%)	0.19	0.00	39.21
Percent cover live perennial (10%)	1.35	0.01	372.52
Percent cover rock (10%)	14.36	0.19	114.80
Percent cover bare soil (10%)	0.71	0.01	28.08
Percent substrate fine soil (10%)	0.09	0.00	4.80
Percent substrate gravel (10%)	0.80	0.01	74.04
Percent substrate mixed gravel and fine soil (10%)	2.34	0.04	185.05
Percent substrate sand (10%)	0.21	0.00	13.26
Percent rivulet (10%)	1.52	0.03	90.65
Mean percent cover annuals in quadrats (10%)	18.84	0.12	3229.96

Results from a reduced model showing mean odds of juvenile tortoise selecting different habitat characteristics when surface active, given a unit change in the habitat characteristic. Units used in the analysis are defined in parentheses after each habitat characteristic. Habitat characteristics with credible intervals not overlapping zero are denoted with an asterisk '*' next to their median odds of use value.

The CAP analysis of mean habitat characteristics at tortoise points and paired random points when tortoises were at burrows identified six PCO axes that achieved the maximum proportion of correct allocations (85.56%). These six PCO axes explained 83.21% of the variability in the original dissimilarity matrix. The CAP yielded one canonical axis with a squared correlation of ∂^2=0.58. The canonical test revealed a significant difference in the multivariate space between tortoise points and paired random points along the primary canonical axis 1 (P=0.0001 using 9999 permutations). A plot of the first canonical axis shows a pattern of differences between the tortoise points and paired random points (Figure 4-1). The correlations of the original habitat characteristics with canonical axis 1 shows that points where tortoises were found were associated with a greater number of burrows within 1 sq m, had a greater average percent coverage of perennial plants along transects, a greater number of *Larrea tridentata* among the three closest perennials, and a greater average proportion of washes, rivulets, and mixed fine soil and gravel along the transects (Table 4-5). In contrast, tortoise points had a lower mean proportion of area with no washes along transects and had fewer *Ambrosia dumosa* among the closest three perennials (Table 4-5).

Figure 4-1: Plot of burrow associated tortoise points and random points along canonical axis 1



Tortoise points and paired random points differed significantly along Canonical Axis 1 when data were collected while tortoises were associated with burrows. Tortoise points were associated with a greater number of burrows, more coverage of perennial plants, more creosote bushes and washes or rivulets, more mixed fine soil and gravel, and fewer white bursage bushes.

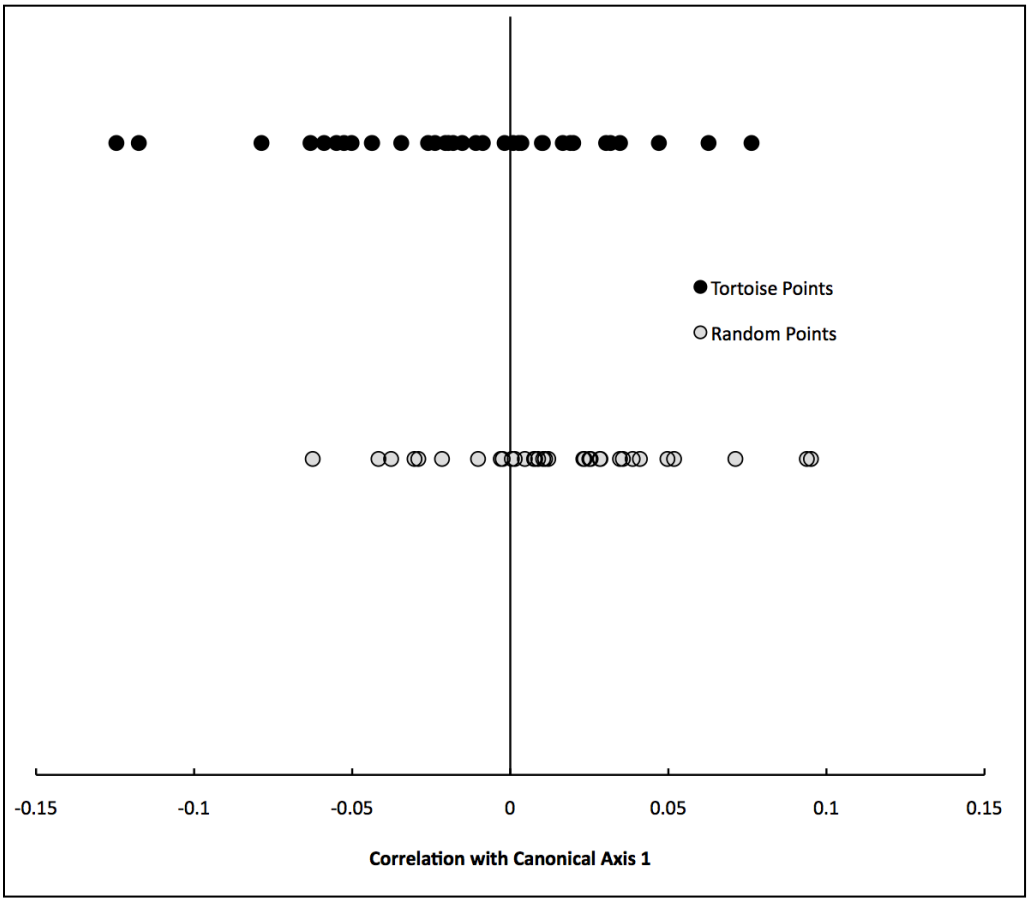
Table 4-5: Characteristics of burrow points with correlations of |r|≥ 0.20 with canonical axis 1

Habitat Characteristic	Correlation With Canonical Axis 1	Value at Random Points	Value at Tortoise Points
Number of Burrows	0.86	0.55	2.58
Mean Percent Coverage of Perennials	0.54	16.53	23.36
Number of Creosote Bushes in three closest perennials	0.47	0.61	0.81
Mean Proportion of Washes	0.29	0.03	0.07
Mean Proportion of Washes and Rivulets Combined	0.25	0.11	0.15
Mean Proportion of Mixed Fine Soil and Gravel	0.22	0.29	0.33
Mean Proportion of Area Without Washes	-0.23	0.89	0.85
Number of White Bursage in three closest perennials	-0.42	1.7	1.33

The habitat characteristics in this table had the strongest correlations with canonical axis 1 and were used to differentiate tortoise points and paired random points from data collected with tortoises associated with burrows.

The CAP analysis of mean habitat characteristics at tortoise points and paired random points when tortoises were active on the surface away from burrows identified eight PCO axes that achieved the maximum proportion of correct allocations (52.86%). These eight PCO axes explained 93.20% of the variability in the original dissimilarity matrix. The CAP yielded one canonical axis with a squared correlation of δ^2=0.12. The canonical test found no significant difference in the multivariate space between tortoise points and paired random points along the primary canonical axis 1 (P=0.39 using 9999 permutations). A plot of the first canonical axis shows no pattern of association between the surface active tortoise points and paired random points with habitat characteristics along canonical axis 1 (Figure 4-2). Because there was no difference between tortoise points and random points when tortoises were active on the surface, the correlations of individual habitat characteristics with canonical axis 1 are not shown.

Figure 4-2: Plot of surface active tortoise points and random points along canonical axis 1



There was no difference in tortoise points and paired random points along Canonical Axis 1 when data were collected while tortoises were active on the surface.

4.2 Discussion

Habitat selection is a behavioral process that reflects where animals choose to use areas to maximize their fitness (Fretwell and Lucas 1969). Maximizing fitness requires a tradeoff between meeting basic energetic demands and satisfying physiological requirements while limiting exposure to predators or environmental conditions that increase risk of mortality. Understanding how special-status species such as desert tortoises select habitat can be particularly important when making decisions about land use that affect tortoise populations or the habitat upon which they rely.

There are very few studies of habitat selection in desert tortoises, representing an important obstacle to effective decision-making. Nussear et al. (2009) provided a range-wide assessment of habitat suitability for the desert tortoise at a 1-sq. km resolution that included several climatic and environmental variables to predict the species' likelihood of occurrence. Similarly, Andersen et al. (2000) collected data across a 14,000-ha study site in the central Mojave Desert at Ft. Irwin and determined that tortoises in that area mostly occurred on southwest exposures

with loamy soils, while avoiding stony soils, northern exposures, and areas of very low plant cover. Although both of these studies are important steps in understanding habitat affinities of desert tortoises and their distribution at broad scales, these models provide little information about the types of resources available to tortoises within their habitats and which of these resources tortoises actually choose to use or avoid. Information about which habitat characteristics juvenile tortoises use can be particularly useful when making decisions about siting infrastructure, in performing pre-construction clearance surveys, selecting release sites for head-started or translocated tortoises, and in evaluating the role of habitat restoration to promote tortoise recovery or persistence. This limitation was addressed in the present study by examining habitat selection of desert tortoises by comparing habitat at areas where tortoises were located with that available to them based on paired random points taken nearby at a distance within their typical home range.

In the present study, researchers radio-tracked 46 juvenile tortoises that were released into the wild to determine the types of habitat characteristics they selected or avoided. Animals were released at one of two field sites in the Mojave National Preserve in the area where their mothers resided. Following release, these juvenile tortoises were free to move and establish home ranges and to select areas most suitable to them. The habitat characteristics that they chose to use or avoid provide several insights into the landscape features and environmental factors important to juvenile tortoises.

Two different methods were used to analyze habitat selection of the direct release juvenile tortoises. This was driven in part by the inability of conditional logistic regression models to handle perennial plant species identity in the model structure. The CAP analysis, however, can accommodate such information and, as described below, was useful in identifying perennial plants important to juvenile desert tortoises. Slight variation in the results of the two analyses is expected given that a CAP analysis partitions variation in the data to highlight habitat differences between treatments. Because creosote and white bursage were significant in the CAP analysis and explained much of the variation in the data between the tortoise used points and random paired points (see discussion below), some other habitat factors did not show up as important in the CAP analysis whereas they did in the logistic regression models. The results of the logistic regression and CAP analyses are otherwise qualitatively similar, providing added support for the overall findings discussed below.

Juvenile tortoises at burrows were typically found under cover in areas with more perennial plants than that found at random points. In particular, juvenile tortoises at burrows were associated with a greater number of creosote bushes than were random points. Creosote bushes likely provide at least a few key resources to juvenile tortoises. First, they tend to be among the largest perennial plants by volume in the creosote-white bursage communities that dominate much of the Mojave Desert (Lathrop and Rowlands 1983). Thus, they provide important canopy shade that can buffer animals from extreme heat and excessive water loss during warmer parts of the day and of the year. The availability of shade plants has been shown to be an important determinant of movement and activity in other tortoise species in arid environments (Moulherat et al. 2014). In fact, as discussed in Chapter 3, exposure appeared to be the leading cause of mortality in direct release tortoises, and juvenile tortoises appear to be at greater risk of

water loss than adults (Wilson et al. 2001). Although fewer deaths of the radio-tracked tortoises were attributed to predation, creosote bushes may also be important in limiting predation by concealing tortoises, making them harder to find by visual predators such as raptors and ravens among others. A similar study of habitat selection by adult Sonoran desert tortoises (*Gopherus morafkai*) also found that canopy cover was the single most important parameter in explaining tortoise habitat selection (Grandmaison et al. 2010).

Creosote bushes are also likely critical to juvenile desert tortoises for the indirect benefits they provide. Many desert-dwelling small mammals rely on creosote bushes for food and shelter, including the desert wood rat (*Neotoma lepida*; Karasov 1989), round-tailed ground squirrels (*Xerospermophilus tereticaudus*; Walsberg 2000), and the especially abundant Merriam's kangaroo rat (*Dipodomys merriami*; Nagy and Gruchacz 1994). Juvenile tortoises in turn appear to rely on vibrant small mammal communities that excavate extensive burrows near the base of creosote bushes. Over the course of the present study, the vast majority of radio-tracked juvenile tortoises appeared to make use of small mammal burrows much of the time and to repurpose existing mammal burrows for their own use; very few of the burrows that tortoises used ever appeared to have been dug exclusively by the tortoise. In fact, the logistic regression models indicated that juvenile tortoises selected areas with greater densities of small mammal burrows than those found at random points.

Although desert tortoises do not forage on creosote bushes or their seeds (Jennings and Berry 2015), creosote bushes may still provide added foraging opportunities for desert tortoises indirectly. Biomass of annual plants and smaller perennial species is often greater in the canopy zone beneath creosote bushes than outside the "dripline" (Muller 1953; Rowlands 1986); intershrub spaces appear to have even lower biomass of annuals (Reichman 1984; Rowlands 1986; Jennings and Berry 2015). Although various habitat characteristics related to annual plants were measured in the present study (i.e., proportion of ground covered by annual plants, number of transects intersecting annual plants), there was no direct support for selection of these elements by juvenile tortoises in any of the models. Annual plant germination and biomass can be highly variable among seasons and years (Beatley 1974), however, and it is likely that the positive selection by juvenile desert tortoises for areas with creosote bushes and more perennial plants encapsulates some aspects of increased foraging opportunities that are more easily measured than the spatially and temporally variable annual plants themselves.

Despite white bursage also being a co-dominant perennial plant with creosote, the habitat selection models showed that juvenile tortoises at burrows were more likely to be found in areas with fewer white bursage plants than were random points. White bursage and creosote often compete for resources and can displace one another (Fonteyn and Mahall 1978); these two plants are often evenly spaced as a result (Wallace et al. 2000). Thus, the selection by juvenile desert tortoises against white bursage probably reflects the animals' greater affinities for the larger creosote plants for the aforementioned reasons rather than any specific avoidance of smaller white bursage plants per se.

Washes were an additional habitat characteristic for which there was evidence of tortoise selection. Habitat in areas where tortoises were associated with burrows tended to have more

washes or rivulets than that found at random points. Also, when tortoises were active on the surface, they tended to be found closer to washes or rivulets than were random points. Although Grandmaison et al. (2010) found a similar pattern of selection for washes by adult Sonoran desert tortoises, their result likely reflects a different selection process than that taking place among the juvenile desert tortoises in the present study. Grandmaison et al. (2010) suggested that washes were important to their Sonoran desert tortoises because they were deeply incised and offered ample shelter sites in the form of caliche burrows. The habitat in the present study where juvenile desert tortoises were tracked does not have any caliche burrows and even incised washes here were in highly friable or loose soils. Instead, it is likely that washes are important to Mojave desert tortoises because they offer foraging opportunities and because they facilitate movement by tortoises (Barrett 1990; Jennings 1997; Riedle et al. 2008). Jennings and Berry (2015), for example, found that Mojave desert tortoises preferentially feed on rare plants such as the desert perennial *Astragalus layneae*, which is found more frequently along desert wash channels than elsewhere. Reichman (1984) found that within actual washes, seedbanks and desert plants are less common; washes thus may pose fewer obstacles to small desert tortoises as they move across the landscape. Choosing areas that offer clearer pathways for movement is also supported by the finding in the present study that juvenile desert tortoises selected areas with shorter grasses than that found at random points when the animals were active on the surface.

Also important in limiting impacts to special-status species are considerations during site preparation and pre-construction surveys. Juvenile tortoises are seldom encountered during clearance surveys and can be so difficult to find that they are often ignored completely (Morafka 1994). The present study highlights areas that may be especially important to search to better determine potential impacts on resident juvenile tortoises during the creation of Biological Opinions or Environmental Impact Assessments. Notably, the association of juvenile desert tortoises with areas of high small mammal activity and burrow complexes suggests that trapping for small mammals could be developed as a proxy for juvenile tortoise habitat. This finding also has bearing on restoration efforts. A vibrant small mammal community is likely important for the burrow resources it provides juvenile tortoises. Digging several different burrows of their own throughout their home range may be energetically costly for juvenile tortoises; the animals may be opportunistic instead, repurposing existing small mammal burrows as shelter sites. Thus, when aiming to restore habitat for desert tortoises, ensuring recovery of small mammal communities will likely be an additional factor to try to achieve. Restoring creosote bushes is yet another priority target to be considered in restoration efforts. The closure of off-highway vehicle routes is one proposed mitigation measure to benefit desert tortoises (USFWS 2011). Creosote is often greatly reduced at impacted sites subjected to soil compaction or other disturbance (Lovich and Bainbridge 2000). It is estimated that creosote can take up to 400 years to recover without restoration efforts (Prose and Metzger 1985). Thus, as part of a portfolio of mitigation options to benefit desert tortoises in the face of new proposed development, restoring habitat by planting creosote or sowing seeds may help recover habitat that is currently unsuitable for desert tortoises. The successful establishment of creosote for habitat restoration may facilitate the recovery of ephemeral desert annuals that are often more

abundant beneath the canopy of creosote bushes and that constitute much of the diet of wild tortoises (Jennings and Berry 2015).

Altogether, the results of the present study of juvenile tortoise habitat selection can be used to limit negative impacts of future energy development on desert tortoises in several ways. First, this study provides a means by which to identify high quality habitat for juvenile desert tortoises based on the habitat characteristics these animals select. Public land availability, leasing and rights-of-way access issues, cost-benefit analyses, and other factors can often restrict infrastructure siting at the landscape-level. However, it may be possible to adjust siting of planned development at a finer scale or to adjust footprints of proposed designs. For example, some modification was made to the footprint of the Ivanpah Solar Electric Generating System to reduce the size of the heliostat field, the large mirror array that surrounds the solar plant power towers (USBLM 2010). The results of the present study indicate several key aspects of desert tortoise habitat preferentially selected by juvenile desert tortoises that can inform such processes. Namely, targeting areas of lower perennial abundance with fewer large creosote bushes, small mammal activity, and washes and rivulets will likely reduce impact to desert tortoises.

CHAPTER 5: Conclusions

5.1 Summary of Major Findings

Head-starting juvenile desert tortoises in semi-natural outdoor enclosures with supplemental rain and protection from predators greatly increased their growth and survival relative to free-ranging tortoises that were released and monitored in the field. Although predation is suspected to be high on young tortoises, the results found here show that much of the benefit of head-starting at this location was derived from supplemental rain more so than protection from predators. Added water availability promotes greater plant growth and more opportunities for drinking, foraging, and other activity in outdoor enclosures. A greater number of mortalities of free-ranging direct release animals were attributed to exposure or desiccation than predation, further supporting the idea that exposure and limited water can be potentially more critical to juvenile survival than are the effects of predators at some sites. In other areas, predation of juveniles may be high and protection from predators afforded by the outdoor enclosures is likely critical to boosting survival.

The current study suggests that animals could reach 105 mm MCL in as little as 5.5 years after hatching via supplemental rainfall and without additional food supplementation. This is the size at which juvenile tortoise survival is suggested to increase and approach that of adults (Nagy et al. 2011; Nagy and Hillard 2013). Nevertheless, there was some indication that release of even smaller juveniles that had been in captivity for at least 6 months had greater survival than younger animals released immediately after hatching. Ultimately, however, if the goal is to promote high survival of captive-raised animals after release, comparison of the results here with previously reported data suggest that animals should be released after they have obtained a size larger than the animals released in the present study.

The monitoring of habitat selection by free-ranging juvenile desert tortoises identified several habitat characteristics important to juvenile tortoises and slight variation between encounters when tortoises were at burrows versus active away from burrows. At burrows, juvenile tortoises showed a strong preference for areas that were closer to perennial plants and had greater coverage of perennial plants. They also selected areas that had more washes within 5 m. Juvenile tortoises were far more likely to use areas that had a greater number of small mammal burrows nearby, and these areas tended to be associated with more creosote shrubs than white bursage shrubs. Seeds of creosote shrubs are sought after by many small mammals, which in turn have extensive burrow networks that juvenile tortoises use to create their own resident burrows. Creosote is also among the largest plants of the common perennials in much of the Mojave Desert and consequently provides shade and cover from excessive temperatures and from visual predators. They also support greater biomass of annual plants beneath their canopies, which in turn may provide greater forage resources to growing juvenile tortoises. When tortoises were active on the surface away from burrows, they tended to be found closer to washes and perennial plants than were random points, likely reflecting their searching for plants to forage on, which are often found along edges of washes and beneath the dripline of

perennial plants. When active, tortoises also tended to be found in areas of shorter grasses, perhaps because they frequently graze on grasses or because they can see farther and move more freely when grasses are short.

5.2 Challenges

In completing this research, the project participants identified a few key challenges:

- Desert tortoises are a slow-growing and long-lived species. Needing 5-6 years before captive-raised tortoises reach a larger size and can be released may be untenable or infeasible in some circumstances. Future research should address the use of supplemental food and the possibility of keeping animals indoors over their first winter as means to accelerate growth and shorten the amount of time needed for animals to reach larger sizes. There is little research on the efficacy of such approaches with desert tortoises and it will be important to understand possible unintended consequences of such methods. For example, faster growth in young tortoises may lead to nutritional deficits, inhibit reproduction at sexual maturity, or alter their behavior if they are kept indoors over winter. Understanding such consequences will be key in improving the value and utility of head-starting as a mitigation and recovery tool for desert tortoises.

- Although juvenile tortoise survival is suggested to increase once animals reach 105 mm MCL, this remains largely untested. Ongoing work should address this knowledge gap by releasing animals at increasingly larger sizes than those released in the present study, including up to and beyond the 105 mm MCL target. Such information would be particularly useful in providing a more complete picture of the amount of time and investment needed to raise tortoises to a releasable size. The current researchers plan to address this in coming years using these and additional animals as part of a longer study.

- The results of the present study suggest that small mammal communities play an important role in facilitating juvenile desert tortoise survival and habitat use because of the number of burrows they provide on which juvenile tortoises depend. Future work should address the degree to which small mammal abundances could be used as proxies for assessing juvenile tortoise habitat quality, and the degree to which juvenile tortoises depend on existing burrows to survive in harsh environments.

- Creosote bush is a dominant plant throughout much of the Mojave Desert. However, the work in the present study may reflect the importance of creosote in just one portion of habitat from a much broader range of habitats that can be found supporting desert tortoises elsewhere. It is likely that other habitat characteristics, such as caliche caves, Joshua trees (*Yucca brevifolia*), or others, may be important components of juvenile tortoise habitat elsewhere in the Mojave. Although it may be logistically difficult to replicate the current study elsewhere, doing so may reveal other elements important to desert tortoise habitat in other parts of their range.

5.3 Applications and Recommendations

The project team identified several specific, high-value activities that can be used to minimize impacts to desert tortoises or promote recovery via mitigation activities:

- Head-starting tortoises with at least 4.5 cm of annual supplemental rainfall in outdoor enclosures greatly increases survival of juvenile desert tortoises and accelerates their growth. As a mitigation tool, this can be used to temporarily increase the population size of desert tortoises in areas that have been negatively affected or that are slated for new development. Given the low survival of free-ranging juvenile desert tortoises, if populations are left alone and unaided, recruitment of juvenile tortoises will likely be minimal and recovery of depleted populations will be unlikely or take decades at best. Instead, the judicious use of head-starting may facilitate recovery by producing robust individuals that have greater survival and odds of recruitment if released at larger sizes.

- When gravid females or juvenile tortoises are displaced due to development, the results of the present study suggest that captive outdoor rearing of their nests and of juveniles is a feasible and effective means of increasing their survival and eventual return to nearby populations. Based on the present data, growth rates can also be increased in a manner that may reduce the time to release to 5-6 years.

- Although it may be difficult to relocate planned infrastructure kilometers away from proposed sites, even slight changes in infrastructure footprints may preserve habitat elements important for juvenile tortoises. In particular, retaining areas with the greatest perennial cover, signs of active small mammal communities, numerous larger creosote bush shrubs, and many smaller washes and rivulets may all promote the persistence and recruitment of juvenile desert tortoises. During clearance surveys, these areas should be checked thoroughly to accurately determine the number of tortoises potentially affected by development or to move animals from harms way as part of a translocation effort. To date, juvenile tortoises are largely undetected in such efforts. Understanding juvenile habitat selection can also improve site selection and protocols for future releases of head-started animals.

- Habitat preservation and restoration are important mitigation measures being considered among a larger portfolio of options to promote desert tortoise persistence and recovery in light of planned development. The closure of off-highway vehicular routes or preservation of formally impacted areas alone will likely not be sufficient to restore tortoise population in these areas. Based on the current study, these areas should also see active restoration of plant and animal communities to ensure their value to desert tortoises. The replanting, translocation, or sowing of creosote bush is a necessary step to rehabilitating or restoring desert tortoise habitat, and the current study suggests that recovery of an active small mammal community will likely also be important in ensuring suitability of habitats to juvenile desert tortoises.

- Desert tortoises live as juveniles for as long as 15 years or more before becoming adults. Thus, it will be important to continue studying the juveniles released on this project to track their growth and survival. Additionally, as a means of possibly reducing the time it takes for tortoises to reach larger sizes or even adulthood, it may be useful to study the captive husbandry of newly hatched tortoises indoors through their first winter, a technique that has been shown to greatly accelerate juvenile growth in other turtle species.

5.4 Benefits to California

As state energy demands increase as well as mandates to reduce greenhouse gas emissions, policy makers are forced to meet mandated renewable energy portfolio targets via increased use of solar and other renewable sources. As a result, there is growing pressure to develop many parts of California's desert due to the abundance of solar insolation and large tracts of undeveloped land. This development poses challenges for sustainable development given the broad range of impacts expected to affect special-status species. The desert tortoise is listed as a threatened species with protected status under both state and federal law, it is important to identify ways to minimize or reduce impacts to desert tortoises via mitigation measures that promote the species' persistence and recovery.

One of the primary benefits of this project was the successful demonstration of the value of a USFWS-prescribed recovery action that may be used to recover and mitigate declines of desert tortoises. This work provides a rigorous test of the effectiveness of head-starting in improving growth and survival of juvenile desert tortoises to increase desert tortoise population sizes. It will be imperative in future years to more fully assess the long-term benefits and survival of juvenile tortoises released at larger sizes, but early results are promising.

A second benefit of this project is the important information gained about juvenile desert tortoise habitat needs. Juveniles are often missing from studies of tortoise ecology, and information about their habitat requirements is sorely needed to promote persistence of the species. Without adequate suitable habitat for juveniles, consistent lack of recruitment will lead to extended long-term declines of this species. Through its focus on habitat selection of desert tortoises, this project provides planners with better information about habitat needs of desert tortoises that can inform project siting and help identify areas that should be extensively searched during pre-construction surveys to better find tortoises that may be affected. The work also provides targets for habitat restoration that may be useful in mitigation efforts.

Through its focus on a science-based evaluation of prescribed recovery actions and improved information about habitat use of tortoises, this project helps minimize conflict between promoting conservation of special-status species and supporting sustainable deployment of increased renewable energy development in California's deserts. Ultimately, it aids agencies in making better decisions that balance the preservation of California's unique natural heritage with the energy needs of its citizens.

GLOSSARY

Term	Definition
ANOVA	Analysis of variance
CAP	Canonical analysis of principal coordinates
CDA	Canonical discriminant analysis
Clearance surveys	Surveys conducted to locate tortoises and burrows ahead of planned site development to provide assessments of tortoise populations in Biological Opinions and Environmental Impact Assessments and to aid in the safe relocation of animals to avoid harm during construction.
Creosote scrub (CS)	One of two study sites inside the Mojave National Preserve where females were used to produce nests and where juvenile tortoises were released as part of the direct release group to study survival, growth, and habitat selection. This site was located only 4 km east of the Yucca woodland habitat and had an elevation of 800-900 m.
Direct release	All animals in this project that were released into the wild to compare growth and survival against animals held in captivity. The ages of direct release animals varied and are provided in Table 2-2.
Head-starting	The process of producing and rearing an organisms through the early stages of its life.
High rain (HR)	One of two captive treatment groups where animals were kept in semi-natural predator proof outdoor enclosures and provided with approximately 9 cm of added annual rainfall from a sprinkler-fed aquifer.
IDTRF	Ivanpah Desert Tortoise Research Facility
ISEGS	Ivanpah Solar Electric Generating System
Low rain (LR)	One of two captive treatment groups where animals were kept in semi-natural predator proof outdoor enclosures and provided with approximately 4.5 cm of added annual rainfall from a sprinkler-fed aquifer.
MCL	Median Carapace Length. A measure of size used in desert tortoises. The carapace is the hard upper shell of the tortoise.
MCMC	Markov Chain Monte Carlo
MNP	Mojave National Preserve

PCO	Principal coordinate analysis
Subsidized predator	Predators such as ravens and coyotes whose abundance is generally greater around human-modified habitats due to subsidies in the form of added water availability or food resources from refuse or other sources.
USBLM	United States Bureau of Land Management
USFWS	United States Fish and Wildlife Service
Yucca woodland (YW)	One of two study sites inside the Mojave National Preserve where females were used to produce nests and where juvenile tortoises were released as part of the direct release group to study survival, growth, and habitat selection. This site was located only 4 km west of the creosote scrub habitat and had an elevation of 950-1050 m.

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