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Effects of roads and roadside fencing on movements, space use, and carapace temperatures of a threatened tortoise

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ABSTRACT

Roads are widespread features of many landscapes that can negatively affect wildlife, most notably through animal-vehicle collisions. Roadside fencing has increasingly been installed to help eliminate this source of mortality. While fencing may reduce road mortality, other types of wildlife responses to this novel barrier are not well understood. Here, we examined the movement behavior, space use, and carapace temperatures of Mojave Desert Tortoises (*Gopherus agassizii*) as they interacted with a roadside fence and an unfenced road. Using GPS loggers, we tracked tortoise movements for two years at 15-min intervals. We found that carapace temperatures were greater near structures (fence or unfenced road) than away from structures; tortoises near the unfenced road had higher mean carapace temperatures, but tortoises along the fence experienced more extreme upper temperatures that approached the species' thermal limit. Movement speeds were also higher along the structures than away from them. Tortoise home range sizes decreased with proximity to the fence or road; fragmentation of home ranges and road-crossing avoidance may have contributed to smaller home ranges along the fenced and unfenced road, respectively. While tortoises crossed the road significantly less than expected by chance, they did so primarily in May and July and in areas with washes, indicating that placement of roadside fencing and animal underpasses could be optimized by targeting areas where roads intersect washes. Taken together, our results suggest that roadside fencing can affect behavior, space use, and thermal ecology of tortoises, which may require refinements to future conservation strategies involving roadside fencing.

1. Introduction

Roads have direct and pervasive effects on animal populations (Spellerberg, 1998; Trombulak and Frissell, 2000; Fahrig and Rytwinski, 2009; van der Ree et al., 2015). Populations can become fragmented when roads act as barriers to animal movement, either through mortality when animals are killed crossing roads, or because animals avoid crossing roads altogether (Anderson, 2002; Forman et al., 2003; Andrews et al., 2005; Shepard et al., 2008). Roads also contribute to habitat loss and degradation (Forman and Alexander, 1998); not only are paved areas uninhabitable for many species, but many species have reduced abundances that extend for hundreds of meters on either side of roads, resulting in road-effect zones (Forman and Deblinger, 2000; Eigenbrod et al., 2009; Shanley and Pyare, 2011; Peaden et al., 2015). These road-effect zones add to the total extent of habitat that is sometimes lost to roads. Additionally, roads often have more severe effects on species with certain ecological and life history traits, such as those with large home ranges, low reproductive rates, and otherwise high adult survival (Carr and Fahrig, 2001; Waller and Servheen, 2005). In contrast, some taxa, such as carnivores, carrion-feeding birds, and small mammals, may occasionally benefit from roads (e.g., Agha et al., 2017), which can increase access to resources, such as prey or carrion, and act as movement corridors (Whittington et al., 2011; Abrahms et al., 2016; Dickie et al., 2016). Current research on the negative effects of roads often focuses on quantifying the extent of habitat lost near roads, the numbers of animals killed on roads, and potential mitigation strategies to limit or reverse road effects (Forman and Deblinger, 2000; van Langevelde et al., 2009; Peaden et al., 2015).

Concern for the effects of roads on wildlife has led to multiple mitigation strategies (Forman et al., 2003) that have been used by transportation and natural resource agencies to reduce vehicular collisions with wildlife. Although mitigation measures may entail multiple techniques, including wildlife underpasses and land bridges, recent efforts have increasingly focused on the use of roadside fencing to prevent

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animals from entering roads. However, the long-term effectiveness of roadside fencing is not well understood (Glista et al., 2009). For example, the benefit of reduced vehicle-wildlife collisions may be offset by unintended negative consequences of fencing for some species (Hayward and Kerley, 2009; Gadd, 2012). Additionally, a spatially explicit population model showed that the effects of road fencing on population persistence can depend on frequency of traffic mortality and on individual behavior of animals in a population (e.g., road avoidance; Jaeger and Fahrig, 2004). Roadside fencing can fragment and isolate local populations (see Carr et al., 2002 for examples), which is likely to be more detrimental to population persistence than is road mortality when traffic volume is low or when behavioral avoidance of roads by the species is high (Jaeger et al., 2005).

Although roadside fencing can reduce the risk of wildlife-vehicle accidents (Boarman, 1995; Aresco, 2005; Glista et al., 2009), there is a lack of information on space use and behavioral responses to roads and roadside fencing for many species. Even with this lack of understanding, species that are highly sensitive to roads, such as those with increased local extinction probability from road mortality, have been targets for mitigation fencing (Clevenger and Waltho, 2000; Aresco, 2005; Hayward and Kerley, 2009; Peaden et al., 2015). Several studies have documented cases of mortality and altered behavior in response to fencing for several wildlife species (van Dyk and Slotow, 2003; Klar et al., 2009; Gulsby et al., 2011). However, the majority of studies on road fencing mitigation techniques and wildlife responses to date have focused on mammals (53% of studies, Taylor and Goldingay, 2010), very few of which are species of conservation concern. Among studies focused on roadside fencing, reptiles are under-represented (8% of studies, Taylor and Goldingay, 2010).

Reptiles, especially turtles and tortoises, of which > 50% are listed as critically threatened or endangered (IUCN, 2014), tend to be highly susceptible to the effects of roads (Andrews et al., 2015; Gibbs and Steen, 2005). Roads may be especially detrimental to many turtles and tortoises due to their defensive behavior of withdrawing into their shell, ultimately increasing the amount of time spent on roads. Additionally, many turtles undertake periodic movements for thermoregulation, foraging, mating, or nesting, all of which can further increase the risk of mortality (Andrews et al., 2015). For example, Aresco (2005) found that along a highway, up to 98% of turtles are killed in crossing attempts, many of which are nesting females. As a result, roadways can skew sex ratios of turtles, which could contribute to decreased population growth (Aresco, 2005). Road mortality, coupled with naturally low recruitment and high juvenile mortality of turtles and tortoises may all contribute to precipitous, unrecoverable population declines (Doak et al., 1994; Fonnesbeck and Dodd, 2003; Aresco, 2005; Nafus et al., 2013). As roadside fencing is increasingly implemented to mitigate wildlife road mortality (van der Gift et al., 2013), including mortality of turtles and tortoises, research is needed to evaluate the effectiveness and potential for negative consequences of mitigation fencing for these species.

The Mojave Desert Tortoise (*Gopherus agassizii*) has experienced significant population declines from habitat fragmentation and road mortality (United States Fish and Wildlife Service, 2011). Road mortality can drastically reduce tortoise densities for the first 200–400 m from roads (Boarman and Sazaki, 2006; Nafus et al., 2013; Peaden et al., 2015), and at least one study has suggested reduced abundances may extend up to 1–4 km from a road (von Seckendorff Hoff and Marlow, 2002). In response to the threat that roads pose to desert tortoise populations, roadside fencing has been installed in many areas as a widespread mitigation measure to reduce desert tortoise mortality (US Fish and Wildlife Service, 2011). Evidence to date suggests that fences have been effective, reducing desert tortoise mortality from vehicle collisions by up to 93% in some areas (Boarman and Sazaki, 2006). A previous study reported observations that suggest potential negative effects of fencing, including tortoises observed climbing fences and pacing along fences (Boarman et al., 1997). Mitigation fencing is often installed without a full understanding of broader impacts that can occur, such as effects on animal movements, behavior, and space use. Because fences are being used throughout much of the range of the desert tortoise, it is imperative to better understand their effects on this threatened species.

Here, we evaluated the fine-scale movement behavior, space use, and carapace temperatures of desert tortoises as they interacted with a road or newly installed roadside fence (referred to collectively hereafter as “structures”) to better understand how they are affected by these structures. Specifically, we addressed the following questions: 1) To what extent does the proximity to a road or fence alter movement behavior, space use, or thermal profiles of desert tortoises? 2) To what extent does a low traffic volume road act as a barrier to tortoise movement; how frequently do tortoises cross and do they avoid crossing such roads less than expected by chance? 3) Are locations and times of road crossings non-random with respect to space or time? By answering these questions, we aim to increase our understanding of multiple, individual-level responses to fencing and unfenced roads that can contribute to more effective implementation of mitigation fencing.

2. Methods

2.1. Study area

We conducted our study at two sites in Ivanpah Valley, California, USA. One site was within the Mojave National Preserve (MNP) along an unfenced, paved 2-lane road (50 vehicles per day; Nafus et al., 2013) and the other site was 11 km north and just to the west of Interstate 15 (I-15; 50,000 vehicles per day; Peaden et al., 2015), where roadside fencing was installed just 3 months before our study began. Both locations had similar habitat with dominant vegetation of creosote (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*). However, major anthropogenic features were closer to the I-15 site, with a nearby utility scale solar energy development, a California agricultural vehicle inspection station under construction just east of the study site, and a tortoise-proof fence installed parallel to the interstate to prevent tortoise ingress and mortality from heavy equipment during construction of the new inspection station (Fig. 1). Vegetation was removed for 3 m along either side of the fence and all vegetation was removed in the construction site. The fence was constructed using galvanized wire mesh and therefore was not likely to alter carapace temperatures directly; it also allowed animals a clear view of habitat beyond the fence (Fusari, 1982). Our comparison study site in the MNP was chosen for its proximity to an unfenced, low traffic volume road that runs through the site and contributes to tortoise mortality (Peaden et al., 2015). Vegetation 3 m on either side of the unfenced road is removed annually, leaving bare soil.

2.2. Data collection

In summer of 2013, we captured a total of 15 adult tortoises with midline carapace lengths > 210 mm (Berry and Christopher, 2001; MNP: 5 males and 4 females; I-15: 4 males and 2 females). All 15 animals were captured within 1 km of the unfenced road (MPN site) or the roadside fence (I-15 site). Two study animals at the I-15 site had been previously re-located from inside the newly fenced exclusion area prior to construction of the California agricultural vehicle inspection station; when we began our study, we captured those two animals outside of the fenced construction area. We individually marked each tortoise upon capture by notching unique combinations of marginal scutes (Cagle, 1939). We outfitted all animals with VHF radios (Holohil RI-2B, Holohil Systems Ltd. Ontario Canada), Global Positioning System loggers (G30L, Advanced Telemetry Systems Inc. Isanti, MN) and iButton temperature loggers (1922L, Maxim Integrated, San Jose, CA). We affixed VHF radios to the first left costal scute of female tortoises and the fifth vertebral scute of males using gel epoxy (Devcon 5 Minute Epoxy