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PASSAGES FOR CONNECTIVITY OF MOJAVE DESERT TORTOISE POPULATIONS ACROSS FENCED ROADS

March 27, 2014

Recommendations

1. Desert tortoise exclusion fencing should be strongly considered for roads with an average daily traffic volume over 200.
2. Passages associated with desert tortoise road fencing spaced 670 meters apart have the potential to restore adult connectivity to pre-road conditions[1].
3. Passages should be placed as close to the 670 m spacing as possible, especially where roads bisect occupied tortoise habitat. Passages should not be created in areas of extremely low habitat potential or where one side of the road is no longer habitable by tortoises.
4. Flexibility of spacing should accommodate placement of passages in association with washes where possible, because tortoises preferentially use washes for foraging and movement.
5. Culverts or other under-road passages should have an openness ratio (the structure's cross-section/length) of 0.4.
6. Regular maintenance should be performed as necessary to maintain road fencing and open corridors for tortoise movement, especially after storm events where fencing is damaged and debris blocks narrow passages.
7. Additional research is necessary to investigate the effects of roads and passages on desert tortoise genetics, demography, and population connectivity. It will also be helpful to conduct additional research on optimal design criteria (*e.g.*, width, height, placement) to ensure maximum use of passages.
8. Although culverts have been the primary type of wildlife passage used throughout the range of the Mojave desert tortoise, other forms of passage should be explored to encourage wildlife (tortoise) use.

In an unobstructed desert landscape, home ranges of individual tortoises overlap such that breeding and other types of social interactions occur (Harless *et al.* 2009), maintaining genetic and demographic connectivity among individuals and populations. However, depauperate desert tortoise populations have been observed along highways (LaRue 1993; Boarman *et al.* 1997), thereby reducing population connectivity across the road. Abundance of tortoise sign decreases closer to unfenced roadways (LaRue 1993; Hoff and Marlow 2002), resulting in a zone of population depletion of up to 2 miles from highways with the highest traffic volumes (Nicholson 1978; Karl 1989; Hoff and Marlow 2002; Boarman and Sazaki 2006). For animals like tortoises, long-lived and with low reproductive rates, negative population effects of roads can be particularly pronounced (Rytwinski and Fahrig 2012).

[1] The role of juvenile tortoise movements in connectivity is important to consider, but existing information did not allow for specific inclusion in these recommendations.

Fences reduce road mortality of desert tortoises and other wildlife species (Boarman *et al.* 1997) and facilitate successful reoccupation of habitat adjacent to roadways (Boarman 2009, USFWS, unpubl. data). Desert tortoise exclusion fencing (USFWS 2009) should be strongly considered for roads with an average daily traffic volume over 200 (based on results of Hoff and Marlow [2002] and Nafus *et al.* [2013]). However, fences do not alleviate the fragmenting effects of roads. Populations of tortoises are known to be at historically low densities (USFWS 2011) so that isolation due to roads increases susceptibility of populations to demographic and environmental stochasticity (Boarman *et al.* 1997; Boarman and Sazaki 1996, 2006; Forman and Alexander 1998; Trombulak and Frissell 2000; Latch *et al.* 2011). There are few data to evaluate the design and effectiveness of passages at minimizing the fragmenting effects of roads. Ultimate effectiveness would occur by restoring connections between tortoises whose home ranges would have overlapped if the road was not there. When encountering a physical barrier such as a fence, tortoises will follow the barrier for great distances, presumably to find a way around it (Fusari 1982; Ruby *et al.* 1994). Exclusion fencing interrupted by safe passages therefore has the potential to reduce animal-vehicle collisions and maintain landscape connectivity (Boarman *et al.* 1997).

To restore historical (*i.e.*, pre-road) connectivity potential, passages should be spaced approximately one home range apart so that tortoises living along the road have access to at least one road passage. Annual or seasonal home ranges for adult Mojave desert tortoises are 10 and 26 hectares for females and males respectively, estimated as averages across the set of studies described in Table 3 of Harless *et al.* (2010). However, guidelines for providing opportunities for demographic and genetic exchange may be based more practically on a multi-year home range estimate than a single-year estimate. Home ranges based on several years incorporate inter-annual variation in space use and reflect greater use of an area and greater potential overlap of home ranges by individual tortoises; basing recommendations for passage spacing on longer, lifetime (*i.e.*, 60+ years) home ranges could underestimate effects of routine, pre-road interactions. Moderate-term movement data ($\geq$4 years) from Joshua Tree National Park produced average home range estimates of 43 and 44 hectares for adult female and male tortoises, respectively (Vamstad *et al.* 2013). Therefore, we use a multi-year home range estimate of 45 hectares on which to base ideal passage-spacing recommendations, subject to change based on future data and research.

Home ranges depicted as abutting 45-hectare squares would be 670 meters on a side. This home range size was generated in relatively high-density tortoise habitat, which is also where more tortoises and more tortoise interactions would be disrupted by road construction; thus, where high-potential tortoise habitat exists on both sides of a road, passages should be closer to this ideal to restore pre-road levels of connectivity, with wider spacing in areas of lower habitat potential (see Nussear *et al.* 2009 for estimation of habitat potential). Passages should not be created in areas of extremely low habitat potential or where one side of the road is no longer habitable by tortoises. These determinations should be made by USFWS biologists for each project.

The spacing recommendations above address *physical barriers* to movement across a fenced road. In addition, most wildlife, including tortoises, have demonstrated through their aversion to using suboptimal passages that *behavioral obstacles* also exist (Lesbarrères and

Fahrig 2012). Physical as well as behavioral obstacles to movement must be overcome to restore connectivity. Desert tortoises have been documented to use storm-drain culverts to cross beneath fenced highways (Boarman *et al.* 1998). Culvert substrate (*e.g.*, sand, silt, gravel) has been shown to determine whether a tortoise uses the culvert as a passage (Foreman 2003). Examples of attempts to improve passability over rough substrate are found on the Federal Highway Administration's website:

http://www.fhwa.dot.gov/environment/wildlife_protection/index.cfm?fuseaction=home.viewArticle&articleID=110

http://www.fhwa.dot.gov/environment/wildlife_protection/index.cfm?fuseaction=home.viewArticle&articleID=138.

Cement box culverts rather than corrugated metal culverts are preferred because they hold the appropriate substrate conducive to tortoise passage (Boarman pers. comm. in McLuckie *et al.* 2004). Because tortoises preferentially use desert washes for foraging and movement (Jennings 1993), placement of passages in washes may facilitate tortoises using passages in those areas. The ability of tortoises to see light is an issue for whether they will use a tunnel, but exact thresholds are unknown; experience has shown that tortoises will generally use tunnels less than 100 feet long on their own (Caltrans Division of Research and Innovation 2012). In general, shorter culverts of a larger diameter are preferred (Arizona Interagency Desert Tortoise Team 2008), and an "openness ratio" – the structure's cross-section/length – of 0.4 has been recommended for medium-sized animals (Meese *et al.* 2007). Figure 1 illustrates examples of various passages.

Meese et al. (2007)

Ann McLuckie

River Mts, Kevin Purdy: Every Trail website

Figure 1. Examples of road passages. For a typical 4-lane interstate (86 ft wide), square passages should be at least 5.9 ft on a side and circular passages should be at least 6.6 ft in diameter to achieve an openness ratio of 0.4.

Although lighting may entice a tortoise to use the passage, noise and visual cues from passing vehicles have been shown to discourage movement by tortoises (Ruby *et al.* 1994). Other wildlife also have been observed to avoid entering passages in situations with high traffic volume, so recommendations have been made that sound-attenuating walls be placed above the entrance to reduce noise and light disturbance from passing vehicles (Tewes and Hughes 2001). Passages should be designed so that flooding does not lead to blockage with debris, and in particular so that there is sufficient unwetted width clear of debris to encourage use by desert tortoises (Ruediger 2001; Lovich *et al.* 2011; Lesbarrères and Fahrig 2012). Maintenance should be performed as necessary to ensure passageways for tortoise movement. If an existing drainage culvert is so small as to be an entrapment hazard to tortoises, it does not contribute to

connectivity potential and should be blocked with wire mesh (Lovich *et al.* 2011). Additionally, erosion below the ends of a passage can result in the passage becoming inaccessible to tortoises. Designs that minimize erosion potential are preferred, and issues should be corrected as they arise.

While we predict that implementation of these recommendations will strongly alleviate population-level impacts to connectivity while eliminating tortoise mortality on roads, the recommendations should be implemented through a process of adaptive management. Uncertainties surround the effectiveness of our specific quantitative recommendations and the ultimate effects of passage engineering and spacing on desert tortoise population genetics and demographic connectivity. Effective monitoring should occur in coordination with the installation of passages. Sites with existing data on tortoise populations surrounding a road and/or sites with ongoing monitoring already in place may provide important opportunities to refine recommendations and answer key questions. Is tortoise mortality negligible, or otherwise unimportant at the population level, along unfenced roadways with average daily traffic volumes less than 200? Does incorporation of passages at 670-meter intervals alleviate population-level effects of fragmentation; does a larger interval accomplish the same goal? Is the 670-meter interval appropriate when juvenile tortoise movements and contribution to connectivity are considered in the broader context of processes that maintain a population's viability? To what extent does an openness ratio of 0.4 (or other value) and other design features facilitate tortoise use of under-road passages? Answers to these questions will allow recommendations to be refined to meet the objective of maintaining ecologically relevant connectivity of desert tortoise populations.

Although our recommendations for passage spacing are based on ensuring that as many tortoises living along roads as possible can encounter a passage across the road, effectiveness of these passages will also depend on the willingness of tortoises to cross through them. Designs other than modified drainage culverts, such as open-span, extended stream crossings or bridges over larger washes, may be more effective at providing passage opportunities for tortoises as well as other Mojave Desert species (Lesbarrères and Fahrig 2012). Movement considered in the current recommendations may be important for accessing resources throughout different parts of a tortoise's home range, mate-searching by adults, or dispersal by smaller tortoises, but there is no information on how passage spacing may affect these movements differently. In general, we have no information on whether the constraint of movement for tortoises that live near fencing affects their survival and reproductive success. Research on any of these topics may inform us not only about effects of roads, fencing, and various passage types, but also about minimizing fragmentation effects of transmission and other infrastructure corridors.

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