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# The Effect of Roads, Barrier Fences, and Culverts on Desert Tortoise Populations in California, USA

WILLIAM I. BOARMAN,[1] MARC SAZAKI,[2] AND W. BRYAN JENNINGS[3]

[1]*U.S. Geological Survey, Biological Resources Division, 6221 Box Springs Blvd., Riverside, CA 92507, USA [e-mail: william_boarman@usgs.gov]* [2]*California Energy Commission, 1516 Ninth St., Sacramento, CA 95814, USA* [3]*Department of Zoology, University of Texas, Austin, TX 70712, USA*

ABSTRACT: **Roads and highways pose several direct and indirect threats to turtle and tortoise populations. As barriers they inhibit dispersal and subsequent gene flow between subpopulations and metapopulations. In providing access to turtle and tortoise populations, they foster such threats as development, vandalism, and collecting. Increased diversity and productivity of vegetation, resulting from enhanced hydrological conditions beside roads, attracts tortoises, which place them at greater risk of direct mortality from both predators and motorized vehicles.**

**Roadkills are a substantial source of mortality in desert tortoises, *Gopherus agassizii*, in California (USA) as evidenced by data on roadkills from two highways. Desert tortoise populations are depauperate along highways and this depression may extend for at least 0.8 km or more from the road. Our study of the movements of desert tortoises equipped with radio transmitters suggests that tortoises living near highways move considerable distances over short periods of time and that these movements may place the tortoises at great risk of traffic-related mortality. Other studies show that common ravens, *Corvus corax*, predators on juvenile desert tortoises, are more common along heavily-traveled roads than away from them.**

**A 24 km long tortoise-proof fence was erected along one highway in California. The barrier fence is made of 60 cm wide, l cm mesh hardware cloth, sunk 15 cm into the ground. The fence is supported by a 1.5 m high, six-strand wire fence. Several storm drain culverts span the highway. We report on a project that is now underway to monitor the effectiveness of the fence in preventing roadkills and facilitating the recovery of the local tortoise population. We are also measuring use of the culverts by tortoises to determine whether storm drain culverts are an effective mitigation for the fragmenting effects of the fence and highway.**

Causes of increased mortality and reduced natality must be investigated when a population of animals is declining to the point of being threatened with extirpation. When the causes are known, actions to reverse the population declines must be developed and implemented. However, before broad application, the action should be tested in a realistic setting, particularly when the action may be costly in terms of resources (financial, material, or human) or public relations.

Desert tortoise, *Gopherus agassizii*, populations in the Mojave and Colorado deserts of the southwestern United States of America are listed as "Threatened" by the United States Fish and Wildlife Service (USFWS, 1990). Several of these populations are suffering rapid declines from many causes including disease, predation by ravens, on- and off-road vehicle traffic, livestock grazing, and loss of habitat (USFWS, 1994). Many various and complex human uses of the desert have cumulative, harmful effects on the tortoises. We report here on the harm highway traffic has on desert tortoise populations and on the progress of research to determine the effectiveness of barrier fences to decrease the harm.

## Effects of Highways on Desert Tortoise and Other Animal Populations

Desert tortoise populations are depleted within at least 0.8 km of highway edges (Nicholson, 1978; Boarman, 1992; Boarman et al., in prep.) and may be affected as far away as 3.5 km from the highways (von Seckendorff Hoff and Marlow, this volume). A preliminary study (Nicholson, 1978) revealed that the distance and intensity of the population depletion may increase with level of traffic and age of the road. The causes for the population declines are not well documented.

Highways are direct sources of mortality when animals are struck by motor vehicles while moving within their home ranges or while dispersing. Large numbers of animals are often killed along roads (Lalo, 1987; Bennett, 1991). Many collisions are accidental, but D. Sheppard (pers. comm.) demonstrated that people will often turn their vehicles towards turtles to hit them intentionally. On three surveys conducted during a 2.5-year period, we found the remains of 39 dead tortoises along a 24 km section of highway in the western Mojave Desert of California (Boarman et al., 1993; Boarman, 1994). This was probably an underrepresentation of actual tortoise deaths because some carcasses may have been removed by scavengers (e.g., common ravens, *Corvus corax*, and coyotes, *Canis latrans*) before our survey and because some animals probably do not die instantly and may have moved well away from the highway edge (LaRue, 1993).

One indirect impact of linear corridors such as roads on surrounding animal populations is the fragmentation of the populations by the reduction or prevention of movement of individuals across the corridor. Population fragmentation can elevate the risk of localized extinctions from stochastic or catastrophic events or from inbreeding depression (Gilpin, 1987).

A second profound indirect impact of linear corridors such as highways or other roads is their promotion of dispersal of other sources of detriment. Frenkel (1970) and Johnson et al. (1975) found that the proportion of exotic species of plants, which may be of lower desirability or nutritional value than endemic forage to tortoises (Jennings, 1993; Avery, this volume), increased closer to roads in California. Common ravens, predators of juvenile desert tortoises (Berry, 1985; Boarman, 1993), are significantly more common along highways than in power line corridors and in the open desert (Knight and Kawashima, 1993). Highways also provide access by humans to otherwise inaccessible habitat, which in turn allows more commercial development and such activities as livestock grazing and recreation.

Vegetation along roads—particularly in arid regions—can be more productive and diverse, in part because of favorable hydrological conditions beside roads (Johnson et. al., 1975). Indeed, Johnson et. al. (1975) found that annual and perennial diversity and productivity (density, cover, and biomass) were considerably higher (as much as 17.85 times greater) along paved roads than in control areas in the western Mojave Desert. Moreover, several plant species that desert tortoises prefer, such as *Astragalus lentiginosus* (Luckenbach, 1982), *Euphorbia albomarginata* (Burge and Bradley, 1976; Jennings, 1993), and *Sphaeralcea ambigua* (Burge and Bradley, 1976; Hansen et. al., 1976) exist along roadsides in the western Mojave Desert (Jennings, 1992). Thus, the availability of appropriate forage along roadsides may attract desert tortoises, which could put them at greater risk of mortality from motor vehicles (Coombs, 1977; Jennings, 1992).

Highways also provide access for tortoise collectors, which may explain a significant proportion of the loss of tortoises along highway edges. Desert tortoises have long been sources of food for people in the southwestern deserts of the United States (Schneider and Everson, 1989) and are frequently taken as pets (Berry and Nicholson, 1984).

Chaco tortoises, *Geochelone chilensis*, are found along road edges in Argentina for an entirely different reason. Cattle grazing has denuded major portions of Chaco tortoise habitat. Because cattle are often killed by vehicles on roads, many roads in Argentina are fenced. The result is habitat along the road edge undisturbed by grazing cattle, which serves as a refuge for tortoises (T. Waller, pers. comm.).

**Design of Barrier Fences as Mitigation of Impacts from Highway**

Traffic-related mortality of desert tortoises may be reduced by erecting barrier fences along the edges of roads and highways. Several features must be considered for a specific fence design: height, burying depth, opacity, mesh size, durability, and maintenance. Optimal design depends on function, duration, animal behavior, and environment. The height of the barrier depends on the size of the animals that are to be excluded and their ability to climb or jump over a barrier. Depth depends on the ability of the animals to dig under the fence to surface on the other side and the depth to which the animals can burrow. If other species may create an opening beneath the fence, the sizes and behavior of these animals must be considered in the fence design.

Opacity should be determined by the animal's response to different mesh sizes and to solid barriers, and by the function of the barrier. Ruby et al. (1994) demonstrated that desert tortoises attempted to push through wide-mesh fence materials but left the edge of opaque ones after a short time. In response to intermediate-sized mesh (1 cm), tortoises did not attempt to get through but continued to walk along the fence for longer periods of time. Thus, to keep animals out of a specific area (e.g., a construction or building site), an opaque barrier may be most useful. However, if the intent is to direct animals to a passageway (e.g., a culvert or bridge), a non-opaque, intermediate-mesh fence is useful because it permits visibility of the other side and maintains the animal's interest in getting to the other side of the barrier (the animal would probably leave the edge of a solid barrier rather than search for an opening). The mesh size must not be so large that it captures and traps or injures the animals, nor so small that it either appears opaque to the animal or catches too much debris or other smaller animal species (Engelke et al., 1993).

Durability and maintenance of fences depend on biotic and abiotic factors and the time span the barrier must be in place: humans, vehicles, or large wild or domestic animals that may contact the fence; the presence of flowing water or blowing sand; the intensity of sunlight; and excessive acidity or alkalinity of the soil. Durability also varies with differential degeneration of the fence material in various environments (e.g., Ruby et al., 1994).

**Barrier Fence Project**

In 1991 the California Department of Transportation erected a tortoise-barrier fence along a 24 km section of State Highway 58, San Bernardino County, California, USA. The fence consists of six strands of 10 gauge galvanized steel wire and 60 cm wide, 1.3 cm mesh hardware cloth, which is buried to a depth of 15 cm beneath ground level and extends 45 cm above the ground (Figure 1). The top three wire strands are barbed to prevent access by humans and livestock; the three bottom strands are not barbed to facilitate installation of the hardware cloth and to allow medium-sized mammals to climb over without being injured. The hardware cloth is attached by steel rings to the bottom two strands for structural support. The fence is supported by 2 m metal posts spaced approximately 3 m apart.

Gates, which are required to allow access to private property along the highway edge, were also designed as barriers to tortoises. The same hardware cloth used on the fence is attached to the lower part of the gate (Figure 1). To prevent tortoises from escaping beneath the gates, they are hung close o the ground and flush to 20 × 20 cm wood beams that are buried in the ground from gatepost to gatepost.

To facilitate movement by tortoises under the highway, culverts designed for rainwater runoff were adapted for use by tortoises. The barrier fence was installed to form funnels into the storm drain culverts (Figure 2). The 48–63 m long culverts range approximately 1–3.6 m in diameter and are constructed from corrugated steel pipe or reinforced concrete. The fence and culverts connected in this manner provide an unobstructed pathway between the opposite sides of the fenced highway.

In 1991 we implemented a cooperative study by several state and federal agencies. The four primary goals of the study are to determine (1) whether the barrier fence reduces road kills, (2) whether tortoise populations recover along the highway edge, (3) whether tortoises use culverts to cross beneath the highway, and (4) how individual tortoises interact with the fence and culverts. Fieldwork began in 1991 and will continue through 1997 or longer (Boarman et al., 1993; Boarman and Sazaki, 1994).

To determine whether the barrier fence reduces direct mortality, in 1993 we began to compare the number of road-killed tortoises along a fenced highway with those along an unfenced highway. Once per year we survey on foot both sides of two highways: 24 km of the fenced Highway 58 and 24 km of the unfenced Highway 395, which are approximately 8–38 km apart. In 1993 we found five carcasses (1/4.8 km of highway) along the unfenced Highway 395 and none along the fenced section of Highway 58. All carcasses were from animals that had been dead for less than one year (Berry and Woodman, 1984). The numbers of roadkills found may have been less than the actual number of animals killed because some carcasses may have been removed by scavenging common ravens, coyotes, and kit foxes (*Vulpes macrotis*); by highway maintenance; by vehicles driving and parking on the shoulder; and by weather. Furthermore, some animals may have died after moving too far off the highway to be seen by field-workers (LaRue, 1993).

To determine whether tortoises use more of the habitat closer to the highway, we established a permanent study site in 1991 in a 1.6 km² area contiguous with the fence along Highway 58. With standardized procedures (Berry, 1984;

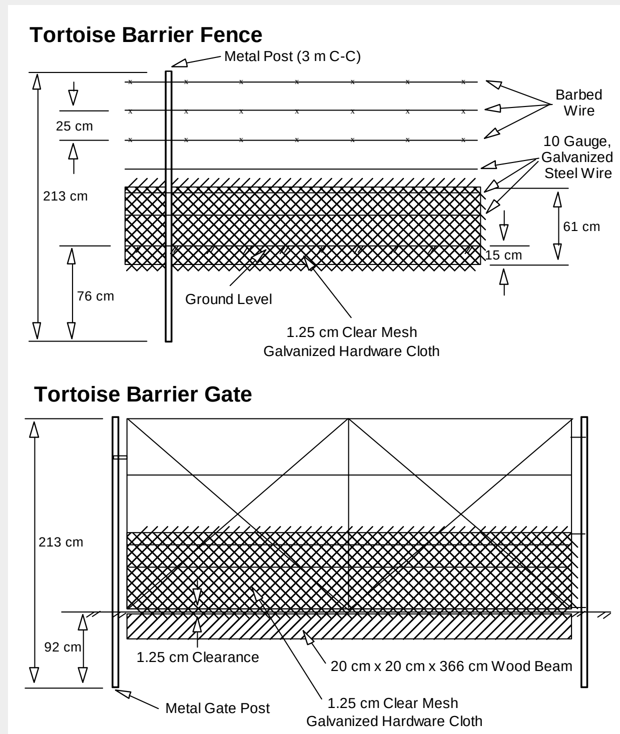


Figure 1. The barrier fence and gates constructed along State Highway 58, San Bernardino County, California, USA. The fence and gates are designed to prevent desert tortoises from wandering onto the highway.

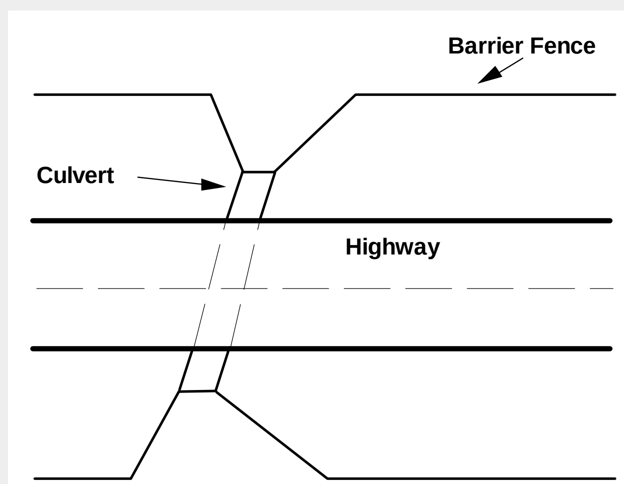


Figure 2. The barrier fence along State Highway 58 shown in relationship to culverts and highway. The fence is attached to the edges of culverts to funnel moving tortoises into the culvert so they can safely cross beneath the highway.

Boarman et al., 1993) we sampled the population to determine its density. All tortoises found were permanently marked, and their locations were mapped. We again sampled the population in 1995 and will do so every four years to detect changes in population density.

Between 1991 and 1993 radio transmitters were attached to 52 tortoises, and in 1992 and 1993 we mapped the location of 28 radio-marked tortoises every 2–3 days throughout spring, when surface activity is greatest. These locations will be compared with future data to determine whether tortoises are increasing their use of the area near the highway. By radio tracking tortoises, we learned that many animals make long-distance, one-way movements. In 1992 and 1993, 15 of the 52 radio-marked tortoises moved between 0.8 and 7.0 linear km over periods of 2–47 days (Boarman, 1994). Only one of these animals returned to its previously known seasonal home range. (Two animals moved 13.3 and 15.5 km but are removed from the analysis because one was assisted across the road and another across the barrier fence by field-workers.) The reasons for the long-distance moves are uncertain, but the risk is clear: one of the 15 animals was killed on the road, three of the 15 attempted to cross heavily traveled highways and would certainly have been killed if they had not been carried across by people (two by field-workers, one by a well-intentioned citizen), and the fates of six are unknown despite of our intensive efforts to track the animals.

Culverts are monitored in two ways: Passive Integrated Transponder (PIT) tags were attached to 94 tortoises on or near the study site. PIT tags are electronic microchips with coiled antennas all enclosed in a 1 × 14–18 mm glass tube. They are programmed to transmit a unique code when they pass through a magnetic field emitted by an electronic reading coil (Camper and Dixon, 1988). In cooperation with M. Beigel, American Veterinary Identification Devices (AVID, Inc.), we are developing an automated reading system (ARS) that records and stores the PIT tag identity, time, and date each time a tagged tortoise passes over the coil. An ARS has been placed at both ends of four culverts in the study site to indicate when a tortoise enters and passes through the culverts. In addition, we are periodically checking for tracks in previously swept soil at the entrances to four culverts and beneath one bridge. No tortoise tracks were found in 1993, but the tracks of several other animal species (kit fox; coyote; jackrabbit (*Lepus californicus*); and unidentified species of snakes, lizards, and rodents) were found; many had crossed through to the other side.

Finally, to determine how individual tortoises respond to the fence and culverts, we periodically survey a 3.2 km section of barrier fence, which includes four culverts. When an animal is found near the fence, we attach a radio transmitter (if one is not already attached) and observe the animal more regularly. In 1992 and 1993, 10 animals were observed at or near the fence. Some moved away from the fence, and others moved along the fence for various distances (up to 6.5 km). Animals at the fence tried to climb, bite, walk along the edge of, and rest at the fence. One tortoise, which had probably walked beneath a poorly adjusted gate approximately 50 m away, was observed along the fence on the highway side. None of the tortoises we observed was injured by the fence. We found five other species of reptiles, leopard lizard (*Gambelia wislizenii*), zebra-tailed lizard (*Callisaurus draconoides*), Mojave rattlesnake (*Crotalus scutulatus*), coachwhip snake (*Masticophis flagellum*), and western whiptail lizard (*Cnemidophorus tigris*), climbing over, running through, or getting caught in the fence. Dead individuals of the former three species were also found on the highway (Boarman, 1994).

## CONCLUSIONS

Roads can harm animal populations in many ways, by direct mortality, population fragmentation, and alteration of habitat. The detrimental effects of new and existing roads must be considered in the design of animal preserves and in other management actions. Preliminary data suggest that barrier fences can reduce mortality of desert tortoises and other species of animals, but may only increase population fragmentation by the road if animals cannot or do not use a safe means of crossing corridors such as culverts.

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