Effectiveness of Fences and Culverts for Protecting Desert Tortoises along California State Highway 58

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I. INTRODUCTION

Highway traffic has been, and continues to be, an important cause of mortality for the desert tortoise (*Gopherus agassizii;* Berry and Nicholson 1984), a species state- and federally-listed as threatened. In addition to gross mortality and illegal collections, roads and highways impact tortoise populations through restriction of movement. The restriction of movement may result in fragmented populations, which may increase the incidence of local extinctions and the potential for inbreeding and inbreeding depression. Fragmentation of populations and restricted gene flow may be more likely to occur with increases in traffic volume, width of highways, and time (Nicholson 1978). Because there are many roads and highways throughout desert tortoise habitat, the potential for road kills to affect tortoise populations is high. Consequently, mitigating road kills could help to facilitate recovery of tortoise populations.

In 1990, California Department of Transportation (Caltrans) erected tortoise-proof fencing along a section of State Highway (Hwy) 58 that was scheduled to be widened from two lanes to a four-lane divided highway (Boarman 1991; Boarman and Sazaki 1994). Culverts for flood protection were also installed. Crushed tortoise carcasses had been found along Hwy 58 (Appendix 1 in Boarman 1991), and the Bureau of Land Management (BLM) identified this particular section of highway as important tortoise habitat (Sievers et al. 1988). In 1990, the BLM, California Energy Commission, Caltrans, U. S. Fish and Wildlife Service, and the California Department of Fish and Game embarked on a cooperative monitoring project to determine the effectiveness of culverts and protective fencing in contributing to recovery of tortoise populations in the area near the fence (Boarman 1991; Boarman and Sazaki 1994).

The Review Board for the monitoring project (Appendix) developed four study questions that serve as the focus for the long-term project (Boarman 1991; Boarman and Sazaki 1994). (1) Is the fence an effective barrier for reducing road kills? (2) Does the fence facilitate "recovery" of the tortoise population near the highway? (3) Do culverts facilitate movements from one side of the highway to the other? (4) How do individual tortoises behave when they encounter the fence and culverts? Herein I discuss the results of the first four years of field work (1991 - 1994).

II. CHARACTERISTICS OF FENCE AND CULVERTS

The highway traverses relatively flat terrain consisting primarily of shadscale scrub and creosote bush scrub communities at elevations of 684 to 753 m. The fencing consists of 60-cm wide, 1.3-cm hardware cloth sunk generally 15 cm beneath ground level. The 48 to 63-m long culverts are made of 0.9 to 1.5 m-wide, corrugated steel pipe; 1.4-m, reinforced concrete pipe; or 3- to 3.6-m by 1.8- to 3-m, reinforced concrete boxes. The culverts cross beneath the highway and in August of 1992 were made accessible to tortoises (Fig. 1).

III. IMPACT OF HIGHWAYS ON TORTOISE POPULATIONS

B. Initial Survey of Tortoise Signs and Human Impacts

To obtain estimates of relative tortoise population densities and measures of human impacts, a series of surveys were conducted at each candidate site to record: 1) signs of tortoise presence for estimating relative tortoise densities, and 2) evidence of human impacts on each candidate study site. The data were also used to determine if tortoise densities increased with distance from the highway, as reported by Nicholson (1978).

1. Methods

The highway traverses relatively flat terrain consisting primarily of shadscale (*Atriplex* spp.) scrub and creosote (*Larrea tridentata*) bush scrub communities at elevations of 2245 to 2470 ft. The fencing consists of 24-inch wide, 1/2-inch hardware cloth sunk generally 6 in beneath ground level. The 156 to 206 foot-long culverts are made of 36 to 60 inch, corrugated steel pipe, 54 inch, reinforced concrete pipe, or 10 ft to 12 ft by 6 ft to 10 ft, reinforced concrete boxes. The culverts cross beneath the entire width of the highway and will eventually connect directly to the fence, thus providing an unobstructed pathway between both sides of the fenced highway (Fig. 3).

Surveys were conducted for tortoise sign and human impacts between March 20 and 31, 1991. The surveys consisted of a series of strip transects, which were each 10-yds wide and ran the width of each site, parallel to the highway. For each site there were four sets of three contiguous transects (Fig. 3). One set began immediately adjacent to the fence or pipeline right-of-way where it abutted the fence, the second was centered 1/4 mile from the fence, the third 1/2 mile, and the fourth ended 1 mile from the fence.

For tortoise population density, the exact location and characteristics of all tortoise sign (i.e., live animals, shells, tracks, scats, burrows, and pallets) were recorded on Desert Tortoise Strip Transect Forms (Appendix 5). The aspect, height, length, width, and condition of each burrow were measured. Human impacts were evaluated by noting all roads, trails, graded areas, structures, sheep scat, individual tire tracks, campsites, garbage, shooting areas or targets, balloons, and mining pits or markers present on each transect. Three photographs were taken at different portions of each set of transects.

For determining if there were significant differences ($\alpha = 0.05$) among candidate study sites and distances from the highway, the total number of tortoise sign along each transect were square-root transformed. The data were entered into a two-factor analysis of variance (ANOVA) with distance and study area being the between groups effects. Pair-wise comparisons among means were made, post-hoc, using the Student-Newman-Keuls test ($\alpha = 0.05$). A Spearman Rank Correlation Coefficient was estimated to test for an east-west gradient in tortoise sign among sites.

Estimates of tortoise densities were made by calibrating each observer's results using a correction factor derived by walking similar transects in three areas with known tortoise densities (Berry and Nicholson 1984b). The three calibration sites used were the Lucerne Valley, Stoddard Valley, and Fremont Peak permanent study plots established by the BLM for tracking desert tortoise populations (Berry 1984a). The correction factor for all three field workers was 16.5, which was multiplied against the total sign count for each set of three transects.

2. Results

Maps were produced that exhibited all tortoise sign and human impacts found along each transect (Appendix 6). The two-factor ANOVA of the transformed data showed significant differences among distances, sites, and their interaction (Table 1, Figs. 4 and 5). Post-hoc analyses indicated that the sites roughly fell into three groups: site AE with the lowest count, site CE with the highest, and all others in between. The seven sites that were south of the highway showed a nearly significant increase in tortoise sign from west to east ($r_s = 1.925$, $p = 0.0543$, $n = 7$). The post-hoc analysis also showed a significant difference in tortoise sign between 0, 0.25, and 0.5 mi from the highway, but not between 0.5 and 1.0 mi.

3. Discussion

Tortoise densities did differ among sites, with a possible increase in estimated densities from west to east. The highest density area, which was significantly higher than the others, was on the eastern most site.

There was also a significant increase in density with distance from the highway. The increase was significant up to 0.5 mile from the highway, densities leveled off beyond 0.5 mi. Nicholson (1978) also demonstrated a similar pattern of increasing density with distance from roads and highways. The slope and distance of the highway effect increased as a function of traffic level and age of the road. The causes for the pattern are likely to be road kills and illegal collections along highway edges (Berry and Nicholson 1984a). However, it has been suggested that noise from vehicular traffic may prevent tortoises from settling in the vicinity of the highway.

Our results are confounded by the existence of the 100-ft wide pipeline right-of-way along or near the fence in most sites. This likely had the effect of extending the low density zone farther from the highway than may otherwise have existed. In spite of the pipeline, we believe the gradation in tortoise density is due to the highway because a) the pattern existed on site D where there was no pipeline, and b) the All-American Pipeline was only laid in place in 1989.

There are significant differences among sites in the pattern of increasing density with distance from the highway. This is likely to be due to different levels and types of human impacts at each site. For instance, the southern sections of study areas BW and BE had an old airport (Hawes Airport) that was being removed. In spite of these differences among sites, it is noteworthy that there was an overall significant increase with distance.

III. REDUCTION IN ROAD KILLS

The highway sweeps project was designed to determine if the barrier fence prevents road kills. In winter of 1991 a series of transects were walked along the edges of two highways in San Bernardino Co., California. All desert tortoise carcasses or shell fragments found were recorded, mapped, and collected. We compared the results among two controls and the treatment (fenced) site. Fragments from 61 tortoises were found, and no statistically significant differences were obtained between fenced and unfenced sections (Boarman 1992). Those data could not be used to test for effectiveness of the fence because heavy construction activity was occurring along the fenced section. Using the same methods, the sites were resurveyed in July 1992 and 1993.

A. Methods

Between 2 and 18 July, 1992, and again between 13 and 16 July, 1993, 66 1.6-km transects were surveyed along both edges of Hwy 58 and Hwy 395, east and south of Kramer Junction (Fig. 3). The general study area was subdivided into three sites: Treatment, Control 1, and Control 2. The Treatment site consisted of both sides of Highway 58 where the tortoise-proof fence was in place. It began approximately 5.8 km east of Kramer Junction and extended east for 24 km (30 transects 1.6-km long). Control 1 was along a nearby section of Hwy 58 without a tortoise-proof fence. It began at the western-most end of the Treatment site and ran west along both sides of the highway for 4.8 km (6 transects 1.6-km long). Control 2 was along an unfenced section of Hwy 395. It began 12.3 km south of Kramer Jct and ran south for 24 km along both sides of the highway (30 transects 1.6-km long).

Each transect was 10-m wide and centered 5 m from the paved roadway. The 1.6-km segments were measured using a car odometer and were subsequently delineated with surveyor's flagging. The field worker walked parallel to the highway, at the unpaved edge of the graded shoulder, and scanned the ground for any tortoise remains or signs. If several fragments were found in a cluster generally less than 7 m in diameter, we assumed they were from a single animal. After locating the remains of a tortoise, the data were collected and remains were photographed before they were disturbed and collected. A unique carcass number was assigned and the location along the transect was noted and mapped. The physical conditions of the highway edge, including shoulder width, were recorded. A photograph was taken of each transect.

Data were also collected on other dead vertebrate species found on the transects. The species of all carcasses found on the unpaved shoulder were identified, times since death were estimated, and the location of the carcasses were mapped. In 1993, carcasses found on the paved highway were classified as mammal, bird, or reptile, and the total number per transect was tallied.

B. Results

Fragments from 16 tortoises were located in 1992 and from 6 tortoises in 1993. All but two of the animals found in 1992 were likely killed since the previous survey in winter 1991, and all of those found in 1993 were likely killed since the previous survey in July 1992. One very old carcass was found in the fenced area in 1992. One recent kill was located on 4.8-km long the Hwy 58 control site in both years. Thirteen were found on the 24-km long Hwy 395 control site in 1992 and 5 in 1993. One very old carcass, from an animal that likely died before the previous survey, was found in 1992 on the Hwy 395 control site.

Although the Treatment site was 24-km long, yielding 30 1.6-km transects (15 on each side of the highway), they were all partially or completely obliterated by heavy construction activities or very recent grading in 1992. Therefore, we could not use any of the transects for the analysis. In 1993, the construction had been completed for approximately 11 months, so the transects were likely only disturbed by normal grading activities during the past 11 months.

Most of the transects were determined to have been graded since the previous surveys. Width of the highway shoulder in the Treatment site ranged from 3 m to 40 m, but 24 of the 30 transects were nearly entirely obliterated by on-going construction in 1992. The shoulder width for the relatively unimpacted transects within the Treatment site ranged from 0.5 to 20 m and a majority of shoulder appeared to have been freshly graded. The width of the north shoulder of Control 1 was 2.5 to 20 m and for the south side was consistently 3 m, and both sides of the highway were freshly graded. The shoulders along Control 2 were 0 to 5 m in width and most transects had been graded since the previous survey.

In 1992, 23 carcasses representing 15 different species or genera of non-tortoise vertebrates were found (Table 4). Five (0.17 per transect) were within the treatment site and 18 (0.5 per transect) were within the control sites. No comparisons between control and treatment could be made because the heavy construction activity within the treatment site made those data of questionable value.

The non-tortoise data from 1993 were most interesting. Only 2 road kills were found on the 24 km of pavement along the fenced stretch while 224 were found along the 24 km unfenced stretch of Hwy 395 and 80 along the 4.8-km unfenced stretch of Hwy 58 (Table 5). This represents 100 to 200 times the amount of road kills along the unfenced stretches of highway. Data from animals found along the unpaved shoulder are less striking. Twenty-seven carcasses were found along the fenced stretch, 28 along the unfenced section of Hwy 395, and four along the shorter unfenced stretch of Hwy 58 (Table 6). The carcasses represented 18 different species or genera. Twenty of the carcasses on the fenced section were from jackrabbits (four jackrabbits were found along Hwy 395, and two along the unfenced section of Hwy 58). When jackrabbits are removed from the analysis, 3.4 times more road kills were found along the unfenced stretch of Hwy 395, and 2.4 times more along the unfenced section of Hwy 58 compared to the fenced section of Hwy 58.

C. Discussion

The fragments from a total of 16 tortoises were found in 1992. Fourteen of the shells were almost certainly killed since the previous survey 16 months earlier. These shells were crushed but many were still held together by dried tissue, a phenomenon that was absent from all carcasses located in the previous survey. One shell was found in the treatment site, but it consisted of only two very weathered bone fragments, which suggests the animals were killed more than four years earlier. Fourteen of the fifteen shells found in the control areas were relatively fresh; only one showed sufficient weathering to indicate it was killed prior to the previous survey. Heavy construction activity along the treatment site prevents a definitive statement concerning the effectiveness of the fence at preventing road kills from occurring.

Fragments from six tortoises were found in 1993, all were along unfenced sections of highway and all were dead for less than one year. There had been no significant construction along the treatment area during the prior 11 months, so the results are indicative of normal highway traffic along Hwy 58. It must be noted that the graded shoulder along much of fenced Hwy 58 is considerably wider than along the control sites, and this may also be responsible for some of the observed decrease in road kills if tortoises are less apt to cross a highway with a wide rather than narrow shoulder.

In all, a minimum of 1 tortoise was killed along each 2 km of the 24 km stretch of Hwy 395 in the 16 months prior to the July 1992 surveys and 1 along each 5 km in the 12 months prior to the July 1993 surveys. These are conservative estimates. For example, one field worker reported two fresh road kills in Control site 1 in June of 1992, but only one carcass was found on the surveys one month later, indicating that the sweeps did not locate all recent road kills. There are three explanations for how the surveys underestimate true mortality. First, much of that section of highway studied showed evidence of being graded since the previous survey. Grading activity is likely to spread and bury most tortoise remains. Second, several species of scavengers are known to occur in the area including common ravens, coyotes, and kit fox. These animals may remove tortoise carcasses to be eaten away from the road. Third, some tortoises are not killed instantly and may be able to walk some distance from the road before they die.

Far fewer other vertebrate carcasses were found within the fenced section of highway, particularly in 1993 (Tables 6, 7, & 8). Almost all snakes and most rodents found were along the unfenced sections.

This is the first detailed study of the frequency of tortoise deaths along roads. In 1990, Woodman (unpubl. data; see Appendix 1, Boarman 1991) found fragments from 58 tortoises along 27 km (5.4/km) of highway right-of-way along the same general stretch of Hwy 58 as covered by our study. Barrett (unpubl. data, see Appendix G in Boarman 1993) has compiled a non-exhaustive list of 22 road kills observed along various roads in Nevada; 17 of the kills were found in the Spring of 1992. It is difficult to infer from existing data the full impact vehicular traffic has on desert tortoise populations. Nicholson (1978), showed a significant decline in tortoise densities near highways, indicating that highways cause population-level impacts. This relationship was corroborated by our study (Boarman 1992; see also LaRue 1993). Detailed and long-term studies on the movements of tortoises near highways are needed to evaluate the causes for the declines along highway edges and the full impacts of vehicular traffic on individual tortoises as well as tortoise populations.

IV. CHANGE IN POPULATION DENSITY

V. CHANGE IN POPULATION DISTRIBUTION

VI. TORTOISE USE OF CULVERTS

We are approaching in three ways the question of whether culverts are used by tortoises for getting from one side of the highway to the other: (1) work is on-going with development of the state-of-the-art, automated system for determining tortoise use of culverts; (2) in Spring 1993, four culverts and one bridge were checked regularly for tortoise tracks; and (3) the population on the opposite side of the highway is being surveyed to identify dispersal of tortoises through the culverts.

At the individual-level, we have attached PIT tags to 94 animals and, in association with Mike Beigel of AVID, Inc., we have developed an automated-sensing system for detecting tortoise use of culverts. Sensing units will be located at both ends of all four culverts on the study site. For every tagged tortoise that walks into a culvert, the system will automatically record the identity of the tortoise, time, and date. The data will be downloaded periodically to a notebook computer. A prototype system was tested in the field in September and the entire system should be completely operational in time for the Spring 1994 field season. The automated-sensing system will allow us to determine if the animal crossed beneath the highway, when it crossed, and how long it took to do so. Ambient temperature will also be recorded throughout the day to correlate tortoise activity with ambient temperature. The sensing system will remain in place throughout 1994 and 1995 and perhaps longer.

A second test of individual use of culverts was implemented in Spring 1993. The southern entrances to four culverts and one bridge were checked for footprints weekly from April through June. After recording on a data sheet all visible tracks of any species, the ground was swept to erase all tracks. One week later the swath was checked, tracks recorded, and ground swept. The data have not been analyzed thoroughly, but a preliminary analysis indicated that: (1) no tortoise tracks were found during the surveys; and (2) other species made heavy use of the bridges and culverts, including kit foxes, coyotes, ground squirrels, and kangaroo rats.

At the population-level, we are determining if tortoises exhibit permanent, or long-term, dispersal from one side of the highway to the other. To accomplish this, in spring 1993 we conducted surveys on the north side of the highway to locate marked animals that may have dispersed from our primary study population south of the highway and to mark new animals. Eighteen unmarked tortoises were found and each one was marked, equipped with a PIT tag, and had data on size, location, and health recorded onto standard data sheets. So far, none of the animals have been found south of the highway. In 1995, we will again survey the north side of the highway to identify south-to-north dispersal through the culverts.

VII. EFFECT ON TORTOISE BEHAVIOR

Work from 1991 showed that there was a depression in tortoise numbers within approximately 0.5 km of the highway along Hwy 58 (Boarman 1992). One effect of the tortoise-proof fence is hypothesized to be an increase in use by tortoises of this depression zone. We predicted (Boarman et al. 1993) that over time, animals will feed and burrow closer to the highway after the fence is in place. To test this prediction, we attached radio transmitters to 36 tortoises in 1991 (Boarman 1992) and 15 in 1992 (Boarman 1993). In

1993, five major tasks were accomplished: (1) radio transmitters and Passive Integrated Transponders (PIT tags) were attached to most tortoises found that did not already have them; (2) radio-transmittered animals were tracked periodically to estimate home range sizes and to identify the extent of long-range movements; (3) the edge of the fence was surveyed regularly to observe tortoise encounters with the fence; (4) surveys were conducted on the north side of the highway, opposite the study site; and (5) culverts and bridges were checked for tracks left by animals using them. In addition, significant progress was made towards development of a state-of-the-art electronic identification system for monitoring tortoise use of culverts.

A. Study Plot Location and Characteristics

The study plot is located on the south side of Highway 58, approximately 11 km east of Kramer Junction (Fig. 2). It consists primarily of rolling hills to the north and relatively flat areas to the south. Vegetation is primarily an association of Mojave saltbush (*Atriplex spinifera*), bur sage (*Ambrosia dumosa*), and creosote bush (*L. tridentata*). Creosote is predominant in the northern portion of the study plot and saltbush dominates in the south. A small dry lake bed occurs at the southeast corner of the plot. The plot's substrate primarily consists of coarse sand or gravel with patches of cobblestone in the north and sandy loam in the south.

In 1991, the 1.6 km^2 study plot was surveyed and a grid system established that was identical to that used at other BLM permanent study plots (Boarman 1992). The northeast boundary of the site was along the highway barrier fence with the sides running at 90° angles southwest for 1.6 km. In 1993, an additional 20 0.16 km^2 quadrats were established in the northwest corner where tortoise densities were highest.

B. Methods

In 1993, radio transmitters and Passive Integrated Transponder (PIT) tags were attached to most animals found on or near the study plot that did not already have them. Methods used to attach transmitters and PIT tags were provided by Boarman (1992). Twice in the spring, each tortoise was marked, weighed, sexed, measured, photographed, and observed for health status using methods outlined in BLM (1992).

Between 8 April and 24 June, all transmittered animals were searched for every two to three days using one of two programmable scanning radio receivers (Telonics Receiver TR-2 with Telonics Scanner TS-1 and Sony ICF-PRO80 PLL Synthesized Receiver) and a hand-held “H-antenna” made by Telonics. Each time an animal was found, its location was recorded by pacing to the nearest grid lines, its behavior was noted, and the animal was observed for 5 min. A Health Profile Form for Desert Tortoises was usually completed when the animal was not in its burrow. On six occasions, signals from lost animals were searched for from the air, generally from a height of 305 m. The signals found from the air were subsequently searched for on the ground.

A 3.2-km stretch of the tortoise-proof fence was walked in search of tortoises and other vertebrates near the fence on the average of every 2 days during the study period (37 occasions). If a tortoise was found, the same data as for radio-tracked tortoises was recorded. A radio transmitter, if not already present, was attached and the animal was observed almost continuously until it left the vicinity of the fence.

C. Results and Discussion

In 1993, 82 tortoises were located south of the highway, on or near the study site; 33 of these were found for the first time. A total of 103 animals have now been marked south of the highway, on or near the study site between 1991 and 1993. An additional 18 were marked north of the highway in 1993. Radio transmitters were attached to 5 new animals, yielding a total of 52 equipped with radio transmitters, all on the south side of the highway. However, by November 1993, eight transmitters became detached, leaving 44 with transmitters. PIT tags were attached to 20 new animals south of the highway and 18 north of the highway for a total of 94 with PIT tags. Nine animals observed in 1992 were not found in 1993; four of them were animals that had moved over 4.5 linear km during spring of 1992. Of the 79 animals found in 1993 south of the highway for which sufficient data are available, 32 were adult or subadult females, 20 were adult or subadult males, and 27 were too young to determine sex (Table 1).

All of the animals (# 21, 24, 29, and 42) found in 1991 with wet "beaks" or noses (possible signs of Upper Respiratory Tract Disease [URTD]), were found again in 1992; and all had grown in size. Only #42 showed any signs of URTD. Three of them were found again in 1993; two (#21 and 29) had signs of URTD, one (#24) did not, and all three had grown in size. Number 42 lost its transmitter sometime after October 1992 and was not seen thereafter. Five other animals (#35, 36, 43, 56, and 71) exhibited signs of URTD in 1992. Of these, three (#43, 56, and 71) showed some signs of URTD in 1993, one did not (#35), and one was not found (#36). A total of 29 animals exhibited at least one sign of URTD in 1993, but only four (# 29, 62, 87, and 93) exhibited at least seven characteristic signs. An additional nine (#11, 14, 16, 21, 22, 54, 68, 71, and 75) showed three to five characteristic signs of URTD. One (#72) animal was found in 1992 with lesions indicative of shell disease. That animal was not found in 1993, but an additional ten animals (#11, 14, 33, 68, 75, 99, 117, 119, 121, and 122) south of the highway and five (#715, 716, 721, 722, and 726) north of the highway showed possible evidence of shell disease. One of these animals (#11) was collected for a necropsy and found to be free of shell disease and URTD in spite of clinical signs of URTD in the field (see below).

One unmarked juvenile tortoise carcass (midline carapace length [MCL] = 84 mm) was found on the study site in 1992. The carcass had holes in the carapace that were indicative of raven predation. In 1993, three unmarked carcasses were found on the study site, one of which was a juvenile with holes in the carapace that were characteristic of raven predation. Cause of death were not determined for the other two. None of the carcasses were of marked animals.

Home Range.--The location data collected will be analyzed to determine seasonal home range sizes. In 1993, sufficient data for determining seasonal home range size (arbitrarily defined as twenty-five or more locations) were obtained from 28 tortoises, and five additional animals had 10 to 24 locations. Home ranges were not measured from animals exhibiting long range movements, because they were all one-way movements, not normal daily movements within a home range. To compare home range sizes among sexes and age classes, very cursory analyses of home range sizes were estimated for the 28 tortoises with 25 or more locations by measuring the length (greatest distance between any two points) and width (widest span between two locations at right angels to the length). Area was roughly estimated by multiplying length by width, making the unrealistic assumption that the home ranges were rectangular in shape. The results allows for preliminary relative comparison among classes of tortoises, but should not be taken as true estimates of absolute home range sizes. In the future, more sophisticated methods will be used to analyze home range size.

Male home range areas and lengths were larger than those of females and unsexed immatures (Table 2; area: $F_{1,23} = 9.350$, $p = 0.006$; length: $F_{1,23} = 6.531$, $p = 0.018$). Subadult home range areas were not significantly larger than those of adults (Table 2; area: $F_{1,23} = 6.078$, $p = 0.216$; length: $F_{1,23} = 1.081$, $p = 0.309$), primarily because of the very broad-ranging movements of tortoise number 25 (514 ha). The interaction between sex and size class was nearly significant (area: $F_{1,23} = 7.527$, $p = 0.0116$; length: $F_{1,23} = 4.251$, $p = 0.0507$).

Long-distance Movements.--We detected several linear or long-distance movements (Gibbons 1986), which we define as being greater than or equal to 0.8 linear km (an approximate maximum size of normal home ranges) and obviously external to the normal, seasonal home range of the individual (if known). In 1992, of the 46 animals with sufficient data, 8 (17%) made such linear movements (Table 3). Of those eight, three (#23, 75, and 78) stayed in the vicinity of their final 1992 locations throughout the 1993 season, one (#77) moved to a new location, and four (15, 32, 52, 72) were not found in spite of intensive ground- and air-based searches.

In 1993, we recorded 8 out of 43 (19%) animals with sufficient data making such long-range movements: four of them were females, 1 was male, and 3 were too small to determine sex. The distances moved by tortoises in 1993 varied from 1.6 km to 15.5 km (mean = 9.45 +/- 8.282). It is noteworthy that in both years, such movements were mostly initiated by immatures (n=6; immature = 100-179 mm MCL) and subadult (n=8; subadult = 180-207 mm MCL) individuals; one was an adult. It is also interesting that the majority of movements of known sex individuals were made by females (5 versus 3 males; cf. Gibbons 1986). In all 28% (15/53) of the animals with 5 or more relocations exhibited these long-distance movements. It is important to note that the sample is biased towards movers because each year we mark new animals at the fence or on the plot and these animals were likely to have already initiated long-distance movements before they were first found.

The data were insufficient to determine if these movements represented dispersal events or relatively infrequent movements within a broad “lifetime home range.” Most movements probably do not represent a large annual home range; only one of the animals

(#77) is known to have returned to its original location. It is conceivable that the movements were somehow caused by the highway or fence, but, because we have no control site we are unable to evaluate this hypothesis.

Rates of movement were calculated for these long-distance-moving animals. The figures are based on total point-to-point distances over known periods of time, hence they do not represent actual distances traveled by tortoises taking zig-zag or circuitous routes. Over the course of the periods of the movement events the animals ranged between 0.1 to 0.5 (mean = 0.28 +/- 0.133) km per day. Their quickest burst of movements during the movement events ranged from 0.1 to 1.6 (mean = 0.79 +/- 0.562) km per day. One tortoise (# 114) found twice in a day while taking a long-distance movement, had moved 0.5 km over 8.33 hrs.

Fence Encounters.--In 1992, three tortoises were observed at the edge of the fence; two were immatures and one was a subadult male. In 1993, 25 observations were made of 7 individuals at or very near to the fence: two (#88 and 96) were immatures, one was a subadult male (#91), two were subadult females (#114 and 123), and two were adult males (#111 and 113). One animal (#96) established a home range near the fence after moving for 33 days. Two were found only once.

In 1993, 19 observations were made of lizards and snakes encountering the fence. One leopard lizard (*Gambelia wislenzii*), five Western whiptail lizards (*Cnemidophorus tigris*), one zebra-tailed lizard (*Callisaurus draconoides*), two coachwhip snakes (*Masticophis flagellum*), and one Mojave rattlesnake (*Crotalus scutulatus*) were found caught in the fence (two freed themselves and three were extracted by the observer and released). One leopard lizard and one Mojave rattlesnake climbed over the fence, while two Western whiptail lizards and two unidentified lizards freely passed through the fence. Three leopard lizards “rammed” the fence, apparently in failed attempts to pass through.

Plant Transects.--Sampling of annual and perennial plants was again conducted on the two belt transects that were established in 1991; one transect was in the creosote bush community and one in the saltbush community. Two additional belt transects were established, one in creosote bush and one in transition between creosote bush and saltbush communities. Details of the methods employed are in Boarman (1992) and BLM (1992). Ample winter rains this year resulted in a good yield of annual vegetation.

D. Problems Encountered

Extraction and Salvage of Entombed Tortoises.--On several occasions in April and May 1993, the transmitter signal from tortoise Number 11 was received from deep within an open burrow, but there was no indication that the animal had exited the burrow. On 18 May a fiber-optic scope revealed that the internal part of the burrow had collapsed. The field workers dug down through the top of the burrow towards the signal. The tortoise was found, tightly packed in the dirt. The animal's head was completely packed with hard dirt. Because the animal was somewhat lethargic and its shell had the "flaky" appearance of shell disease it was brought into the office on 20 May. It was soaked in tepid water for several hours on 22 May and the shell was washed with a brush and clean water. The shell still looked "flaky."

After observing photographs from 1991 and 1992, inspecting the tortoise, considering the limited extent of its movements in 1991 and 1992, and consulting with Dr. Bruce Homer, University of Florida, College of Veterinary Medicine, Dr. Kristin Berry made the decision to ship the animal to the University of Florida for a necropsy. The necropsy (Homer 1993) indicated no shell disease or URTD, but the tortoises suffered from a superficial cutaneous fungal infection, septicemia, and a copper deficiency. Dr. Homer concluded that the tortoise's generally poor condition was due to being entombed so long (Homer 1993).

Three additional tortoises (#14, 33, and 68) were also found buried within their burrows and were subsequently extracted in mid-April. Two of the animals were extracted from burrows that appeared to be inactive and unused. The third was extracted from flat ground that had no appearance of a burrow. All three tortoises showed some clinical signs of shell disease, but may have actually been suffering from a fungal infection similar to that of Number 11 (above). None of these animals were collected for necropsies. After extraction, all three animals exhibited home range movement patterns that were within the normal range for animals of similar size and sex in our study.

Loss of Transmitters.--Several transmitters have fallen off of tortoises. In 1991 one transmitter fell off, in 1992 two did, four were found in spring 1993, and eight between September and October 1993. The losses do not appear to be related to time-since-attachment because five of those found in September 1993 were attached in the previous May or June. The epoxy on some seemed to be too pliable, although after discussions with the manufacturer of the Devcon 5-min Epoxy, we modified the mixing techniques, but the epoxy was still too soft. We plan on trying a different product next spring, perhaps Devcon Liquid Welder. This year we began attaching transmitters to the first right costal so the antenna would not be twisted so much, but this caused the post attaching the transmitter to the base plate to be at the rear of the transmitter. This placement allows the transmitter to be pulled up by the burrow roof or vegetation, which puts too much strain on the epoxy holding the plate to the carapace. To avoid these problems in 1994, we will stop using the carriage and will attach transmitters directly to the carapace.

Poor Transmission Distance of Transmitters.--We have experienced problems with poor range distance of the transmitters and have worked with the manufacturer to rectify the problem. Initially the transmitters were detuned to facilitate a longer life. Increasing the power drain will shorten the life of the battery while increasing the read range of the signal. We have also experimented with transmitter and antenna attachment methods, but have not come to a conclusion. Placement of a large 7-element Yagi antenna on a high point on the study site proved to be of little use in boosting the reception distance.

VIII. FENCE DESIGN

IX. FUTURE PLANS

The project will run for at least two more field seasons. The primary activities for spring 1994 will be to record the movements of radio-tagged animals with particular attention placed on animals making long-distance movements, implement the automated-sensing system for monitoring culvert use by tortoises, maintain radio transmitters, and perform a sweep of highway edges for tortoise carcasses. We may also initiate surveys for predator activities along the fence. At a minimum, in 1995 the population will be surveyed, using standard 60-day survey methods, to determine population size and distribution trends, and the north side of the highway will be surveyed. To obtain more reliable and definitive information on the fence's and culverts' impact on tortoise populations, the project should run for additional years beyond 1995.

The Review Board has identified and prioritized several additional tasks that would improve the study. In approximate order of importance, the additional tasks with estimated costs are to:

1. Maintain the current level of effort in 1995 and extend the study beyond 1995. ($20,000 - 50,000 per field year)

2. Extensive aerial tracking of this and other study sites to obtain data on long-distance movements/dispersal of tortoises. ($5000 to 25,000)

3. Conduct transects along Hwy 395 to validate as a control for the highway sweeps. ($5,000 - 15,000)

4. Establish additional study plots for various purposes: to determine if tortoises will cross under highway bridges; along a highway without a fence, which would be a control for the primary study plot; a site with only a fence, to look at the effect of a fence in a more remote area (e.g., East Mojave), etc. ($40,000 first year; $20,000 to 40,000 each additional field year)

Additional studies that should be conducted separate from the present one include:

1. Use by tortoises of culverts of various different designs (material, size, shape, etc.).
2. Develop less expensive replacements for hardware cloth and concrete barriers (In 1994, Clark County, NV, is planning on conducting this study, which is a follow up to Ruby et al., 1993).
3. Develop tortoise guards (like cattle guards) for use at gates and other gaps in fences.
4. Effectiveness of culverts placed in washes versus out of washes.

X. RECOMMENDATIONS

Considering the longevity of tortoises and the preliminary nature of this study, it is too early to make well-grounded management recommendations. However, there are some interesting trends that suggest preliminary management actions:

1. *Environmental analyses should consider direct impacts on mobile tortoises several km from the proposed project site.* Fifteen study animals exhibited what appear to be linear movements outside of normal home range movements in 1992 and 1993; this represents 28% (15/53) of the radio-transmittered animals for which five or more locations were obtained. The linear distances animals moved ranged from 0.8 to 15.5 km over the two-month study periods. Additional field work is necessary to determine if these were home range movements or dispersal events. Assuming that the results reported herein can be applied to other areas, the large number of animals making these long movements suggest that in any given spring, a significant proportion of animals in a given area may move considerable distances. These movements likely make the tortoises considerably more vulnerable to vehicle traffic, predation, vandalism, and other anthropogenic disturbances than if they stayed within a stereotypical home range. These data suggest that determinations of project impacts and population sizes are tenuous unless they consider the mobile nature of tortoises.

2. *Environmental analyses should consider indirect impacts of habitat and population fragmentation on tortoise populations.* Most of the animals (93%; 14/13) found to move 0.8 or more linear km initiated the movements as immatures or subadults. This observation suggests that a considerable amount of pre-mating dispersal occurs. Fragmentation of populations would (i) put many individuals at risk of mortality, and (ii) greatly reduce gene flow and individual movements among populations. Any environmental analysis for a proposed human activity that prevents such movements, even if not directly in high quality tortoise habitat, should evaluate the project's impact on dispersal among populations and subpopulations.

3. *Impact of habitat fragmentation on tortoise population viability is needed.* The impact of habitat fragmentation on population stability and gene flow are unknown,

but the results from 1992 and 1993 suggest that they may be great. I recommend that a project be implemented to study the genetic structure of populations and subpopulations to determine the extent and importance of dispersal. This, coupled with a more extensive study of the movements of radio-tagged tortoises, will provide valuable information on the potential impacts of many types of human activities.

4. *Barrier fences should be constructed along roads and highways in tortoise habitat.* The remains from 18 tortoises were found in July 1992 and 1993 along the shoulder of a 24-km long section of Highway 395, San Bernardino Co. These animals all showed definite signs of being killed by motorized vehicles, and all were killed in the previous 12 to 16 months. This conservative estimate suggests that road kills are a major source of mortality. Based on data presently available, I recommend that barrier fences and other measures be required along all major highways and roads in tortoise habitat. If population fragmentation, at the level demonstrated by highways, is shown to greatly impact tortoise populations, then barriers are all the more important.

Furthermore, the results from 1993 indicate that large numbers of non-tortoise vertebrates are also killed along highways and that tortoise barrier fences are extremely effective at preventing such mortality. Construction of such fences may help to sustain the biodiversity by reducing road-related mortality among many species, although research on the impacts of barriers and resultant population fragmentation are required to evaluate the full impact of barrier fences.

5. *Actions should be implemented to ensure that gates remain shut.* We have found the gates along the tortoise-proof fence left open on some occasions. Once the gate was conclusively left open by pipeline personnel. I recommend that (i) all

affected parties be informed of the importance of keeping the gates closed, and (ii) gates be self-closing or safe tortoise-grates, similar to cattle grates, be designed and installed.

6. *Storm-drain culverts need to be designed to facilitate tortoise movements.* We found design flaws in using storm-drain culverts for tortoises. Caltrans contractors installed large energy-dissapating boulders at the exits of culverts along Highway 58, but the boulders created a dangerous and impassable barrier for tortoises. Caltrans then covered the boulders with dirt, but water flowing through the culverts created an impassable lip or trough at the outlets. A solution has not yet been found, but at the moment, the culverts as designed cannot be considered adequate for facilitating movements of tortoises.

7. *A reevaluation of standard tortoise survey methods is needed.* One radio-tagged tortoise was extracted from a totally obliterated burrow; three other radio-tagged tortoises were extracted from burrows that were partially caved in. All three of these burrows would have been classified as inactive during standard clearance surveys. Because the burrows were all caved in at some point, a fiber-optic scope would not have found the tortoises. Digging up the burrows probably would have failed to find at least two of the animals. Clearly these standard methods of finding and removing all tortoises would likely have resulted in two to four unintentional takes had the burrows been on a project site. However, some of these animals may have died while entobmed, representing natural mortality. An evaluation is needed of the methods for determining tortoise presence and densities for construction clearance and other purposes.

XI. ACKNOWLEDGEMENTS

Marc Sazaki has contributed substantially to all phases of the project. Sherry Barrett, Dr. Kristin Berry, Ray Bransfield, Stan Ford, Frank Hoover, Jack Kawashima (deceased), Dr. Jim Spotila, Dr. Sam Sweet, and Dr. Mike Weinstein provided ideas and suggestions for design and analysis of the project. William Clark, Gilbert Goodlett, Glenn Goodlett, Bryan Jennings, Tracy Okamoto, and Ray Romero performed most of the field work and provided data, reports, and figures that were used to prepare portions of this report. Jeff Lovich, Marc Sazaki, Michael Weinstein, and Gary Zunino commented on an earlier draft of this report. Dr. David Strauss and members of his graduate course on statistical consulting provided valuable advice on the statistical analyses. The fence and culvert construction was funded by Caltrans. Funds for the monitoring project were provided by the California Energy Commission (Contract Nos. 700-89-007, 700-90-015, and 700-91-005 to BLM), Federal Highways Administration, Nevada Department of Transportation, and the Bureau of Land Management. California Department of Fish and Game conducted four aerial surveys for radio-tagged tortoises. Clara Stapp, BLM cartographer, prepared the maps. Mention of specific product names (e.g., Devcon, AVID) does not constitute an endorsement of those products.

IX. LITERATURE CITED

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Table 1. Size-age class distribution of live tortoises found on or near the study plot.

Spring 1992

Size-age Class	Unidentified Sex	Males	Females	Total	Percent
Juvenile 1	0			0	0
Juvenile 2	0			0	0
Immature 1	9			9	14.8
Immature 2	22			22	36.1
Subadult		5	5	10	16.4
Adult 1	3	8	11	18.0	
Adult 2		5	4	9	14.8

Spring 1993

Unidentified

Size-age Class	Sex	Males	Females	Total	Percent
Juvenile 1	3			3	3.8
Juvenile 2	1			1	1.3
Immature 1	6			6	7.6
Immature 2	17			17	21.5
Subadult		7	11	18	22.8
Adult 1	6	12	18	22.8	
Adult 2		7	9	16	20.3

Table 2. Preliminary estimated relative home range sizes of tortoises for 1993.

See p. 6 for discussion of limitations of these data.

Length (km)

Size-age Class	parameter	Unidentified Sex	Males	Females	Total
Immature	mean	0.45			0.45
	sd	0.532			0.532
	n	(6)			(6)
Subadult	mean		1.52	0.24	0.88
	sd	1.940	0.062	1.343	
	n	(2)	(2)	(4)	
Adult	mean		0.66	0.52	0.57
	sd		0.143	0.245	0.224
	n		(6)	(13)	(19)

Area (ha)

Size-age Class	parameter	Unidentified Sex	Males	Females	Total
Immature	mean	20.1			20.1
	sd	38.30			38.30
	n	(6)			(6)
Subadult	mean		257.9	5.1	131.5
	sd	363.25	3.56	255.53	
	n	(2)	(2)	(4)	
Adult	mean		30.9	17.2	21.5
	sd		10.50	13.32	13.84

n	(6)	(13)	(19)

Table 3. Long-distance* movements of radio-transmittered tortoises.

Tortoise ID No.	Sex	Size/Age Class	Size (MCL in mm)	Linear Distance* (km)
Spring 1992				
15	female	subadult	191	6.2
23	unknown	immature 2	142	0.8
32	male	subadult	202	4.5
52	unknown	immature 2	162	4.6
72	unknown	immature 2	163	7.0
75	female	subadult	201	1.8
77	female	subadult	199	0.8
78	male	subadult	183	5.0
Spring 1993				
48	unknown	immature 2	157	1.6
62	unknown	immature 1	123	7.0
77	female	subadult-adult 1	208	2.6
88	unknown	immature 2	151	2.9
91	female	subadult	193	5.0
111	male	adult 1	214	13.3
114	female	subadult	200	15.5
123	female	subadult	183	4.5

* - Linear distance = straight-line distance between two most distant points.

Table 4. Carcasses of vertebrates found in each study site on sweeps of highway edges in 1992.

Species	Number per Site		
	Treatment Site	Control 1	Control 2
desert tortoise (*Gopherus agassizii*)	1	1	14
leopard lizard (*Gambelia wislizenii*)	1		
zebra-tailed lizard (*Callisaurus draconoides*)	1		
desert iguana (*Dipsosaurus dorsalis*)			1
kingsnake (*Lampropeltis getulus*)			1
longnose snake (*Rhinocheilus lecontei*)			1
gopher snake (*Pituophis melanoleucus*)			1
patch-nosed snake (*Salvadora hexalepis*)			1
glossy snake (*Arizona elegans*)			1
Mojave rattlesnake (*Crotalus scutulatus*)			1
barn owl (*Tyto alba*)		1	
lesser nighthawk (*Chordeiles acutipennis*)			1
jackrabbit (*Lepus californicus*)	2	1	3
mouse (*Peromyscus* sp.)	1		2
kangaroo rat (*Dipodomys* sp.)			2
domestic dog (*Canis familiaris*)			1

Table 5. Carcasses of vertebrates found in each study site on sweeps of paved sections of highways in 1993.

Class	Hwy 395 Unfenced	Hwy 58 Unfenced	Hwy 58 Fenced
Mammals	193	31	1
Reptiles	31	49	0
Unknown	0	0	1
TOTAL	224	80	2
Linear Distance (km)	24.0	4.8	24.0

Table 6. Carcasses of vertebrates found in each study site on sweeps of unpaved shoulders of highways in 1993.

Species	Hwy 395 Unfenced Total	Hwy 58 Unfenced	Hwy 58 Fenced	
jackrabbit (*Lepus californicus*)	4	2	20	26
desert tortoise (*Gopherus agassizii*)	5	1	0	6
deer mouse (*Peromyscus maniculatus*)	4	0	2	6
domestic cat (*Felis domesticus*)	2	0	1	3
shovel-nosed snake (*Chionactis occipitalis*)	1	0	1	2
Mojave rattlesnake (*Crotalus scutulatus*)	2	0	0	2
kit fox (*Vulpes macrotis*)	1	0	1	2
glossy snake (*Arizona elegans*)	1	0	0	1
burrowing owl (*Athene cunicularia*)	1	0	0	1
coyote (*Canis latrans*)	1	0	0	1
sidewinder rattlesnake (*Crotalus cerastes*)	0	1	0	1
Merriam's kangaroo rat (*Dipodomys* merriami)	1	0	0	1
kangaroo rat (*Dipodomys* sp.)	1	0	0	1
American kestrel (*Falco sparverius*)	1	0	0	1
loggerhead shrike (*Lanius ludovicianus*)	0	0	1	1
desert woodrat (*Neotoma lepida*)	1	0	0	1
common poorwill (*Phalaenoptilus nuttallii*)	1	0	0	1
gopher (*Thomomys bottae*)	0	0	1	1
unknown bird	1	0	0	1
TOTAL	**28**	**4**	**27**	**59**
Linear Distance (km)	24.0	4.8	24.0	52.8

APPENDIX

Review Board Members

A Review Board was established in 1990 to contribute to the design, implementation, and analysis of the project. Nine professional biologists, all experienced with desert tortoises, compose the review board for the project. The Review Board met on four occasions: November 8, 1990; January 16, 1991; July 25, 1991; and October 8, 1992.

Sherry Barrett, Wildlife Biologist, U. S. Fish and Wildlife Service.

Dr. Kristin H. Berry, Desert Tortoise Specialist, Bureau of Land Management.

Ray Bransfield, Wildlife Biologist, U. S. Fish and Wildlife Service.

Stan Ford, Biologist, California Department of Transportation.

Dr. Whitfield Gibbons, Senior Biologist, Savannah River Ecology Laboratory.

Frank Hoover, Inland Fisheries Biologist, California Department of Fish and Game.

Marc Sazaki, Aquatic Biologist, California Energy Commission.

Dr. Sam Sweet, Associate Professor of Biology, University of California, Santa Barbara.

Dr. Mike Weinstein, Biostatistician and Vertebrate Ecologist, El Morro Institute.