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Desert tortoise road mortality in Mojave National Preserve, California

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Direct impact by motor vehicles is a known threat to the federally- and California state-listed Agassiz's desert tortoise (*Gopherus agassizii*). Tortoise sign adjacent to paved roads is depressed, indicating that roads can have a population-level effect extending up to 400 m away from the road edge. We found that temporarily erected warning signs equipped with flashing lights had no effect on driver awareness of a potential tortoise on the road and that population depression adjacent to roads with lower speeds and greater driver awareness was similar to roads with heavier traffic traveling at higher speeds and lower driver awareness. The management implications are that slowing traffic with lower posted speed limits and increased law enforcement and improving driver awareness may not reduce impacts to tortoise populations.

Key words: desert tortoise, *Gopherus agassizii,* Mojave Desert, Mojave National Preserve, mortality rate, road ecology, road kills

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Approximately 216 km of paved, two-lane roads bisect 312,605 ha of critical habitat designated for the desert tortoise (*Gopherus agassizii*) in Mojave National Preserve. Sections of Kelbaker, Kelso-Cima, Morning Star Mine, and Ivanpah roads (Figure 1) form a route between Las Vegas, Nevada, and inland cities in Southern California. Direct impacts by motor vehicles are among known causes of mortality for desert tortoise. In the central Mojave Desert, Boarman and Sazaki (1996) estimated at least one tortoise killed per 3.2 km of road per year along a heavily traveled road. They also reported a zone of depressed tortoise density extending outwards up to 800 m from the road edge. Other work has indicated that the depressed densities can extend 1,600 m (Nicholson 1978), 3.2 km (Karl 1989), or even 4.6 km (von Seckendorff et al. 2002). A road-edge effect of depressed tortoise density occurs along the paved roads through Mojave National Preserve, similar to the heavily traveled California State Route 58 studied by Boarman and Sazaki (1996), but with the additional finding that roads with more traffic can also have a demographic consequence (Nafus et al. 2013). Comparing roads with 60 or fewer vehicles per day with those carrying several hundred or more vehicles per day, Nafus et al. (2013) reported that live tortoises tended to be significantly smaller adjacent to the heavily traveled roads. Loss of adult tortoises to road mortality at an unsustainable rate could severely impact and, ultimately, drive local populations to extinction (Congdon et al. 1993).

Tortoise barrier fencing constructed parallel to roads is effective in reducing mortalities of tortoise and other species, while culverts under roads appear to mitigate the effects of habitat fragmentation (Boarman 1995). Construction and maintenance costs, however, often preclude barrier fencing as an attainable action by resource management agencies. Additionally, concerns have been raised about tortoises becoming trapped by barrier fencing (Wilson and Topham 2009). Roadside fencing detracts from the aesthetics of areas set aside for scenic beauty, such as national parks, whereas fences built farther from roads may result in substantial new disturbance during construction and loss of habitat. Other management actions have been suggested for reducing the impact of roads, including increased law enforcement to reduce traffic speeds, posting warning signs, and education to heighten public awareness with the intent of improving driver attention (National Park Service 2002, U.S. Fish and Wildlife Service 2011).

Our first objective was to estimate the loss of desert tortoise to motor vehicle impacts on paved roads and determine if larger-scale effects, such as road-edge population depression, were occurring in the Preserve. Our second objective was to investigate the effectiveness of management actions other than construction of barrier fencing, such as improving driver awareness through warning signs. Specifically, we looked for an improvement in driver response to a model tortoise at the road edge after installation of warning signs and compared road edge effects between heavily and moderately traveled paved roads. Traffic on the less-traveled road also proceeded at a lower speed, allowing us to infer, *a posteriori*, potential improvements to be obtained by slowing traffic.

Materials and Methods

Study area.—Mojave National Preserve is located in northeastern San Bernardino County, California, and contains portions of the Ivanpah and Fenner Desert Wildlife Management Areas (DWMA), designated as critical habitat for the desert tortoise (U.S. Fish and Wildlife Service 2011), and that are separated by a north-south trending mountain range. A series of two-lane paved roads carry heavy traffic between Las Vegas, Nevada, and the Palm Springs, California, area through the Ivanpah DWMA, whereas paved roads in the Fenner DWMA dead-end or convert to gravel surfaces. We selected a straight section of Morning Star Mine road in the Ivanpah DWMA and Essex road in the Fenner DWMA (Figure 1) as representative heavily and moderately traveled roads in desert tortoise habitat, respectively. Both sections were in creosote bush mixed scrub habitat (Thomas et al. 2009) ranging in elevation between 950–990 m and 810–850 m, respectively. Gravel roads between Kelso-Cima Road and Essex Road and between Ivanpah Road and Lanfair Road are the only connections between these two areas, which we treated as independent.

Traffic monitoring.—We collected data on traffic density and speed using a traffic radar device (StealthStat, Kustom Signals, Inc., Chanute, KS) mounted on a pole on the northwest side of Morning Star Mine road and on a post on the southwest side of Essex road. The traffic monitoring device was mounted along a straight and fairly level stretch of highway and data were collected for 2,515 hours on Morning Star Mine road and 2,143 hours

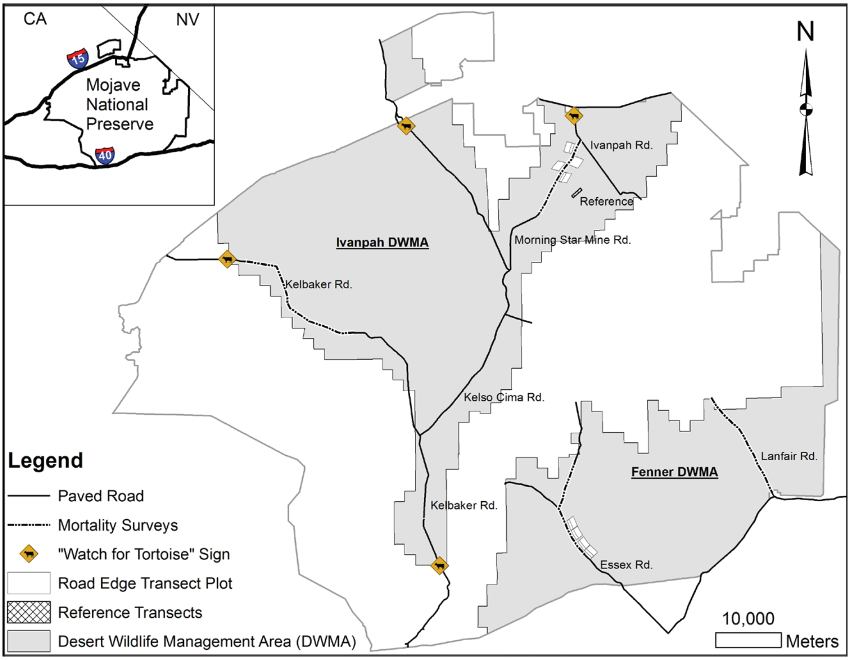

FIGURE 1.—Mojave National Preserve is shown with the Ivanpah and Fenner Desert Wildlife Management Areas (DWMA) that are designated critical habitat for the threatened desert tortoise. Plots for transects 0, 400, 800, and 1,600 m from road edge are shown in white on Morning Star Mine and Essex roads along with reference transects 3.3 km from Morning Star Mine Road. Sections of roads that were surveyed for evidence of road mortalities are indicated by a dashed line. The location where temporary, seasonal warning signs with flashing yellow lights were erected are indicated where paved roads enter designated tortoise habitat. San Bernardino County, California, 2008–2010.

on Essex road during the months of April and May, and September, and October, which are the desert tortoise active seasons. Speed was recorded for each passing vehicle and the number of vehicles counted per 15 minute interval, but with no discrimination of travel direction. Thus, the data indicate speed distribution and traffic density in both directions combined. Density of vehicles on each road was estimated by averaging over days after omitting partial days from the beginning and end of each sampling period.

Road edge effect.—We implemented transect surveys for tortoise sign following the method of Boarman and Sazaki (2006) at 0, 400, 800, and 1600 m from pavement edges at four plots each along Morning Star Mine and Essex roads plus four reference transects in the Ivanpah DWMA approximately 3.3 km from Morning Star Mine road, the nearest paved road (Figure 1). On each transect the Global Positioning System (GPS) coordinates were recorded for tortoise burrows, scat, carcasses, and live tortoises. Tortoise sign was corrected by combining adjacent sign (e.g. live tortoise inside a burrow) according to the methodology of Boarman and Sazaki (2006). We then used R 2.14.1 (R Development Core Team 2011) to conduct analysis of covariance on square root transformed total corrected tortoise sign with distance, road, and plot as potentially explanatory variables. We also analyzed the untransformed total sign on each transect using the generalized linear model procedure in R 2.14.1 (R Development Core Team 2011) with quasipoisson errors to account for overdispersion.

Effect of road signage.—We investigated the effect of warning signs by observing the response of motorists to a model tortoise placed at the road edge (Figure 2). Two concealed observers noted any behavior indicating that the driver of the vehicle, or the first in a closely spaced group of vehicles, had noticed the tortoise model, such as brake lights, slowing, swerving or stopping. Both observers were close enough to see head movements of the driver. "Watch for Tortoise" warning signs (Figure 3) were erected on all paved roads entering the Ivanpah DWMA boundary (Figure 1) in the spring of 2009, and were equipped with flashing yellow lights in the spring of 2010. We observed motorists for 37.2 hours on Essex road and 13.8 hours on Morning Star Mine road during the desert tortoise active

Figure 2.—Placement of the tortoise model was in a visible location at the pavement edge along a straight and relatively flat stretch of paved road. The tortoise model was sufficiently realistic as to be mistaken for a real tortoise at close range. Mojave National Preserve, San Bernardino County, California, 2008–2010.

seasons prior to setting up the warning signs; 13.7 hours on Essex road and 6.4 hours on Morning Star Mine road after signs were erected; and 26.9 hours on Essex road and 4.5 hours on Morning Star Mine road after the warning signs were equipped with flashing yellow lights. The longer observation times on Essex road were required to observe a comparable number of vehicles. Proportion of drivers responding to the tortoise model was analyzed by two-way factorial analyses of deviance with road and year as potentially explanatory factors using the generalized linear model procedure in R (R Development Core Team 2011) with binomially distributed errors.

Figure 3.—"Watch for Tortoise" warning signs were erected along paved roads at the entrance to desert tortoise critical habitat in 2009 and equipped with flashing yellow lights in 2010. Mojave National Preserve, San Bernardino County, California, 2008–2010.

Road mortality surveys.—Paved roads in the Ivanpah and Fenner DWMAs were divided into sections, each 1,610 m in length, for a total of 9 on Essex road, 13 on Kelbaker road, 10 on Lanfair road, and 8 on Morning Star Mine road. The difference in the number of sections per road was related to the length of road intersecting tortoise habitat and past experience of where tortoises were most commonly seen. At the beginning of each of 31 field-days over the course of 3 years, the road to be surveyed was randomly selected then sections along that road were randomly selected and surveyed according to the time available in the day. Selected stretches were inspected by walking, and we searched from the centerline to 5 m away from each road edge on both sides of the road for evidence of road mortalities of tortoise and other species. If the section had been previously surveyed, only evidence of new mortalities was recorded. We used the generalized linear model procedure in R 2.14.1 (R Development Core Team 2011), with quasipoisson errors to account for overdispersion, to conduct analysis of deviance with number of mortalities per transect as the dependent variable and road class with four levels of traffic density (i.e., vehicles per day) as a potential explanatory factor.

RESULTS

Traffic patterns.—Morning Star Mine road receives heavier traffic than Essex road because it connects Las Vegas, NV, to inland communities of Southern California, such as Palm Springs, Yucca Valley, and the Marine Corp Air Ground Combat Center at 29 Palms. Essex road intersects an isolated stretch of I-40 and ends at Mitchell Caverns State Park. Traffic also turns north off Essex road to reach the Hole in the Wall Visitor Center, Campground, and Interagency Fire Center. Mean speed on Morning Star Mine road was 112.8 ± 0.09 km/h (1 SE, n = 38,830) with a maximum recorded speed of 193.1 km/h compared to a mean speed of 96.4 ± 0.18 km/h (1 SE, n = 8,241) on Essex road with a maximum recorded speed of 180.2 km/h. The difference in means was significant (t = 80.0, df = 12,839, $P < 0.001$). The mean traffic density on Morning Star Mine road (370.6 ± 15.1 vehicles per day, 1 SE, n = 91) also differed (t = 17.9, df = 108, $P < 0.001$) from the mean traffic density on Essex road (87.6 ± 4.8 vehicles per day, 1 SE, n = 88). Over this period of observation, traffic densities were higher than data available from the County of San Bernardino (2013), which reported 325 vehicles/day on Morning Star Mine road and 59 vehicles/day on Essex road. County of San Bernardino traffic data for Kelbaker road was 183 vehicles/day south of Interstate 15 near Baker, California. Data on Lanfair road north of Goffs, California, was not available from the County of San Bernardino, but our observations indicated a low traffic volume, similar to the estimate of Nafus et al. (2013), of 35 vehicles per day.

Road edge effect.—Analogous to other work (e.g. Boarman and Sazaki 2006, Nafus et al. 2013), we saw a significant decrease in tortoise sign with proximity to roads (distance from road effect: $F_{1,34} = 21.2$, $P < 0.001$ for square root transformed data, and $F_{1,34} = 19.8$, $P < 0.001$ for total sign), including the background reference transects located 3.3 km from Morning Star Mine road (Figure 4). When the reference transects were omitted from the analysis, the distance effect was weak using the square root transformation ($F_{1,30} = 3.0$, P = 0.09), and not significant analyzing the counts directly ($F_{1,30} = 1.7$, $P = 0.2$). The difference in tortoise sign depression between Morning Star Mine and Essex roads was not significant ($F_{1,30} = 0.4$, $P = 0.55$).

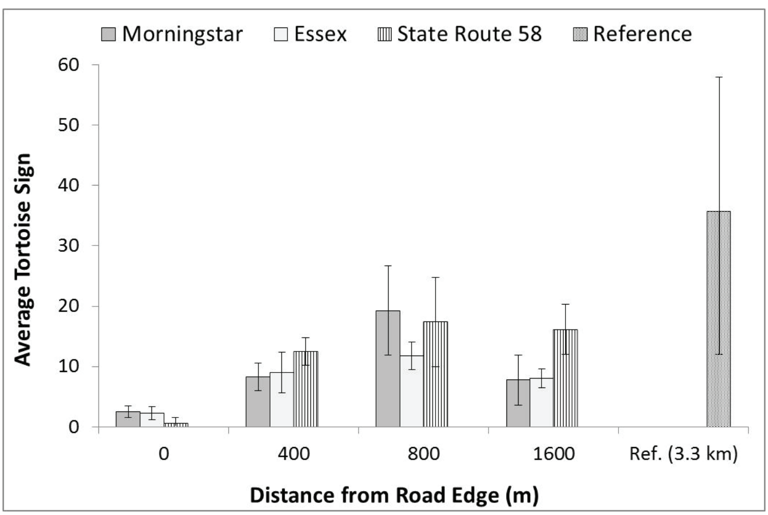

FIGURE 4.—Average tortoise sign (total count corrected by combining adjacent sign) for transects 0, 400, 800, and 1,600 m from road edge are shown comparing results from Morning Star Mine Road, Essex Road, California State Route 58, and reference. Error bars are one standard error (n = 4). Data for State Route 58 are from Boarman and Sazaki (2006) and are shown for comparison with data from Mojave National Preserve, San Bernardino County, California, 2008–2010.

Effect of road signage.—There was no noticeable change in driver behavior after erection of warning signs at the entrance to the DWMAs on Morning Star Mine road (year category effect: $\chi^2_{15} = 41.3$, $P = 0.4$). With no warning signs on Morning Star Mine road, 7 out of 195 (3.6%) motorists responded to the model; when warning signs were erected, 6 out of 104 responded (5.8%); and when the warning signs were equipped with bright flashing yellow lights, 7 out of 206 (3.4%) responded. Driver behavior did, however, differ significantly between Morning Star Mine and Essex roads (road category effect: $\chi^2_{16} = 10.8$, $P < 0.001$). On average 4% of the motorists on Morning Star Mine road reacted to the tortoise model compared to 14% on Essex road, with no significant variation year to year or with or without warning signs.

Road mortality surveys.—The first survey of each of the 40 sections distributed along 4 roads showed evidence of road mortalities such as animal remains, bloodstains on asphalt, scattered plastron and carapace bones and scutes per transect of 0.7 ± 0.24 (1 *SE*, $n = 9$) on average for Essex road, 1.0 ± 0.42 (1 *SE*, $n = 13$) on Kelbaker road, 0.2 ± 0.13 (1 *SE*, $n = 10$) on Lanfair road, and 1.0 ± 0.38 (1 *SE*, n = 8) on Morning Star Mine road. The difference between roads was not significant (road class effect: $F_{3,36} = 1.76$, $P = 0.17$). Over the course of 3 years, 135 surveys were completed on transects randomly selected from the 40 sections, which resulted in an average per transect of 0.66 ± 0.13 (1 *SE*, $n = 41$) on Essex road, 0.81 ± 0.36 (1 *SE*, $n = 16$) on Kelbaker road, 0.69 ± 0.19 (1 *SE*, $n = 36$) on Lanfair road, and 0.76 ± 0.16 (1 *SE*, $n = 42$) on Morning Star Mine road. Again, the difference between roads was not significant (road class effect: $F_{3,131} = 0.11$, $P = 0.95$). Given that the time interval between surveys of the same road section was typically several months and road mortality evidence disappeared over a period of a few days to weeks, these repeated surveys did not give any indication of the temporal rate of road mortalities. Anecdotal observations by park visitors and staff, however, indicated that between 0 and 10 tortoises were killed on roads per year in the Preserve from 2002 through 2012 (average = 5.3 ± 1.1 tortoises per year, 1 *SE*, $n = 11$).

Discussion

Desert tortoise population depression adjacent to roads has been well-studied and the effect found to extend from less than 175 m (Baepler et al. 1994) up to 4.6 km (Von Seckendorff Hoff and Marlow 2002). The results presented here (Figure 4) show a pattern of depressed tortoise sign similar to California State Route 58 (Boarman and Sazaki, 1996), extending outwards from the road edge to less than 400 m (Nafus et al. 2013). Our small sample size likely weakened the significance of the road-edge effect as compared with Nafus et al. (2013) and limitation of reference transects to only one area of the Ivanpah DWMA failed to adequately characterize the undisturbed background level. When compared to the results from California State Route 58 and the work of Nafus et al. (2013) on roads with high and intermediate traffic volume (M. Nafus, University of California, Davis, personal communication) in the Preserve, however, the similar patterns suggest an important management implication. Zones of desert tortoise population depression can apparently form along roads with moderate traffic density and lower speeds similar to those with heavier traffic and higher speeds. Thus, slowing traffic with lower speed limits and increased law enforcement may not benefit the adjacent tortoise population.

Much of the published literature on automobile and wildlife impacts involves deer, likely due to the danger posed to motorists. Lehnert and Bissonette (1997) found permanent passive and active signs located at mule deer crosswalks had no influence on long-term driver response. Though drivers slowed down initially, immediately after installation of signs, they quickly grew accustomed to their presence. Many of the drivers were commuters that traveled the road every day. Curtis and Hedlund (2005) found that temporary passive signs and active signs (e.g. with flashing lights) were promising methods for which more information was needed. They also indicated that general education, long-term passive signs, and lower speed limits appear to be ineffective. A comprehensive review of the literature (Danielson and Hubbard 1998) for the Iowa Department of Transportation concluded that passive warning signs were ineffective because drivers became complacent (Putman 1997). Pojar et al. (1975) found that lighted, animated signs did slightly reduce vehicle speed. Strongly enforced lower speed limits may reduce deer-vehicle collisions (Romin and Bissonette 1996). Intermittently lighted warning signs were recommended by Bruinderink and Hazebroek (1996), but Danielson and Hubbard (1998) found no scientific evidence of their effectiveness. We were motivated to undertake this study by recommendations in the Preserve's General Management Plan (National Park Service, 2002). The plan suggested that entrance signs and information kiosks, temporary signing, staffing of heavily used entrances on busy weekends, and temporary adjustment of speed limits would heighten awareness and slow traffic with the implication that heightened driver awareness and slower traffic would reduce tortoise mortality. Initially we set out to see if warning signs, temporarily erected during the tortoise active season and equipped with flashing yellow lights to improve their visibility, would have any noticeable effect on driver behavior. They did not and, in the absence of not improving driver awareness, they are unlikely to reduce tortoise impacts in any other way. Drivers on Essex road were on average about 3.5 times more likely to notice the tortoise model on the edge of the road than drivers on Morning Star Mine road, suggesting that they were more aware. Traffic on Morning Star Mine road proceeded at a mean speed 16.3 km/h faster than traffic on Essex road, yet the difference in depression of tortoise sign adjacent to the two roads and the difference in encounter rate of mortality remains between the two roads were not significant. This suggests that, even if warning signs and other measures did improve driver awareness and traffic was slowed, the effect on tortoise populations might not be noticeable.

Over a period of 11 years on average 5.3 tortoises were reported killed annually on paved roads in the Preserve. These observations were anecdotal and depended upon an observer being in that particular place at the right time. Inspections of recent road kills indicated that remains are rapidly scavenged and most evidence effectively disappears within a few days. During a survey in late April along Lanfair road, for instance, a freshly crushed carcass was encountered on the road centerline. Since the surveyor had been at this location earlier in the day, the time of mortality was known to have occurred between 1400 and 1515 Pacific Daylight Time. The carcass was revisited approximately 21 hours later and found to be mostly pieces scattered within a radius of 2 m from the point of impact. A small section of carapace scutes was found approximately 11 meters away. Approximately 92 hours after death the only evidence remaining on the road was a faded stain at the point of impact, two withered limbs approximately 8 meters from the point of impact, and a handful of centimeter-sized pieces of carapace and plastron. The remains were scattered over a radius of approximately 12 m from the point of impact and a piece of carapace dome was found approximately 22 m away. A recently (same day) killed adult male tortoise was encountered on Morning Star Mine Road during a mid-April survey the following year and a somewhat older carcass was found along the same road the previous year, both scavenged and the remains scattered over a period of a few days. Thus, the estimate of 5.3 tortoise road mortalities per year should be considered a minimum.

Modeling work by Congdon et al. (1993) showed that, because of delayed sexual maturity and high neonatal mortality, long-lived chelonians are unable to sustain increased mortality above natural levels and that an adult female mortality rate above 2% per year over natural deaths is not sustainable. Tortoise density in the Ivanpah DWMA may be in the range estimated for the Eastern Mojave Recovery Unit ($0.75 < 2.2 < 6.67$ tortoises/km^2, 95% *CI*) and Fenner DWMA in the range of the Colorado Desert Recovery Unit ($1.45 < 2.4 < 3.95$ tortoises/km^2, 95% *CI*) (U.S. Fish and Wildlife Service 2012). For the area of the Ivanpah DWMA (1,943 km^2) and Fenner DWMA (1,133 km^2) within the Preserve, using the lower 95% confidence interval bound, we could expect an estimated 1,550 adult female tortoises to be present. Two percent above the unknown natural mortality rate would be approximately 31 adult females per year. These rough estimates, assuming equal sex ratios in the population and killed on roads, suggest that direct motor vehicle impacts may account for 9% of the sustainable non-natural mortality rate.

Our results corroborate previous work indicating that motor vehicle traffic on paved roads through Mojave National Preserve poses a threat to the desert tortoise. In addition, we present new results showing that warning signs have no noticeable effect on driver behavior and that slowing traffic and raising driver awareness may be inadequate mitigations. Road barrier fencing, as prescribed in the Revised Recovery Plan for the Mojave Population of the Desert Tortoise (U.S. Fish and Wildlife Service 2011) may introduce other concerns (Nafus et al. 2013) and be too costly to be used effectively at the scale of the entire Preserve. Monitoring should be continued and mitigation, including construction of barrier fencing, should be implemented in an experimental framework with adequate controls. Management actions, such as road barrier fencing should, however, only be implemented with a period of monitoring before construction sufficient in order to allow for testing of hypotheses that address both the potential adverse as well as beneficial effects. Future research questions of interest to managers will likely address optimizing the location of road segments for barrier fencing; location and utilization of culverts or underpasses by numerous species; effectiveness of shorter segments of barrier fencing entirely within tortoise habitat; and, how to deal with the end of barrier fencing within tortoise habitat to avoid trapping animals on a fenced road. Additional considerations include construction techniques to minimize maintenance, minimization of the visual presence of fencing, and minimizing habitat disturbance during construction.

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