MITIGATION MEASURES TO REDUCE HIGHWAY MORTALITY OF TURTLES AND OTHER HERPETOFAUNA AT A NORTH FLORIDA LAKE

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Abstract: Roads built through or near wetlands cause significant mortality of reptiles and amphibians and create barriers to migration and dispersal. I investigated the number of times turtles and other herpetofauna attempted to cross a 4-lane highway at Lake Jackson, Florida, USA, during a period of severe drought (Feb–Apr 2000). Levels of road mortality were so high that I designed and installed a temporary drift fence system to work with an existing drainage culvert and for the next 2.5 years I evaluated its effectiveness at reducing road mortality and facilitating migration. I monitored roads and fences several times per day for 44 months, during both drought and non-drought conditions. A total of 10,229 reptiles and amphibians of 44 species were found either road killed or alive behind drift fences: 8,842 turtles, 838 frogs, 363 snakes, 152 lizards, 32 alligators, and 2 salamanders. Drift fences combined with intensive monitoring greatly reduced turtle road kills and facilitated the use of an under-highway culvert. Along a 0.7-km section of the highway, turtle mortality before installation of the fence (11.9/km/day) was significantly greater than post-fence mortality (0.09/km/day) and only 84 of 8,475 turtles climbed or penetrated the drift fences. Pre-fence data provided strong evidence that turtles cannot successfully cross all 4 lanes of U.S. Highway 27, as 95% of 343 turtles were killed as they first entered the highway adjacent to the shoulder and the remaining 5% were killed in the first two traffic lanes. According to a probability model, the likelihood of a turtle successfully crossing U.S. Highway 27 decreased from 32% in 1977 to only 2% in 2001 due to a 162% increase in traffic volume. Therefore, at least 98% of turtles diverted by the fences probably would have been killed if fences were not in place. The results of this study represent the highest attempted road-crossing rate ever published for turtles (1,263/km/year). Because of demographic and life history constraints, turtle populations may incur irreversible declines in areas where road mortality is high, especially when mass migrations are triggered by periods of drought.

JOURNAL OF WILDLIFE MANAGEMENT 69(2):549–560; 2005

Key words: culvert, drift fence, drought, Florida, herpetofauna, mass migration, migration barrier, road mortality, sinkhole lake, turtle.

Highways cause significant levels of wildlife mortality and can create barriers to migration, dispersal, and genetic exchange (Wilkins 1982, Reh and Seitz 1990, Rodda 1990, Vos and Chardon 1998). Differential road mortality of individuals of different sexes or life stages can affect the demography and the dynamics of populations (Moore and Mangel 1996, Mumme et al. 2000, Steen and Gibbs 2004, Aresco 2005). Such changes may alter the structure and function of communities and ecosystems adjacent to the road (Trombulak and Frissell 2000). Understanding the ecological consequences of highways and developing ways to mitigate their effects has become an important goal of many conservation biologists (Mader 1984, Rosen and Lowe 1994, Yanes et al. 1995, Forman and Alexander 1998, Trombulak and Frissell 2000, Forman et al. 2003).

Before current wetland protection laws were enacted, thousands of kilometers of roads were constructed through wetlands and caused the loss, fragmentation, and degradation of habitat via dredging, filling and alteration of hydrologic regimes (Evink 1980, Johnston 1994, Mitsch and Gosselink 2000). Reptiles and amphibians are among the fauna most negatively affected by poor transportation planning near wetlands (Ehmann and Cogger 1985, Fahrig et al. 1995, Ashley and Robinson 1996, Hels and Buchwald 2001, Smith and Dodd 2003). Highways can be significant barriers to their breeding migrations, seasonal migrations induced by drought or water level fluctuations, and normal foraging forays and dispersal (Bernadino and Dalrymple 1992, Gibbs 1998, Carr and Fahrig 2001). The "road-effect zone," the maximum distance from a road at which significant ecological effects can be detected, varies among species and individuals depending on their maximum distance and frequency of movement (Forman and Deblinger 2000, Carr and Fahrig 2001). Road-effect zones range from <200 m for sedentary species to >2.0 km for turtles, crocodilians, and some frogs (Forman and Alexander 1998, Forman 2000, Carr and Fahrig 2001) and can cause population declines and other negative demographic effects such as altered sex ratios (Kuslan 1988, Fahrig et al. 1995, Steen and Gibbs 2004, Aresco 2005).

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Roads built through or near wetlands are an especially significant source of mortality for turtle populations (Ashley and Robinson 1996, Wood and Herlands 1997, Fowle 1996, Haxton 2000). Overland movements of freshwater turtles are common: turtles are frequently observed attempting to cross roads when females emerge from water to nest, when adults or juveniles move overland between aquatic habitats (Carr 1952, Buhlmann and Gibbons 2001, Joyal et al. 2001), and when mass migrations occur during periodic droughts. In addition, roadsides create artificial disturbed and open habitats that may be attractive to nesting females but may cause significant annual road mortality (Wood and Herlans 1997, Haxton 2000). A probability model by Gibbs and Shriver (2002) demonstrated that excessive annual road mortality (>5% of individuals) probably occurs in populations of terrestrial and large-bodied freshwater turtles in many regions of the United States. Demographic studies of turtles suggest that even low levels (2–3%) of additive annual mortality of adults can contribute to population declines (Brooks et al. 1991, Congdon et al. 1993, 1994). Few published studies have evaluated the design and effectiveness of projects that attempt to mitigate the effects of roads on freshwater turtles (Dodd et al. 2004) and tortoises (Boarman et al. 1997, Guyot and Clobert 1997).

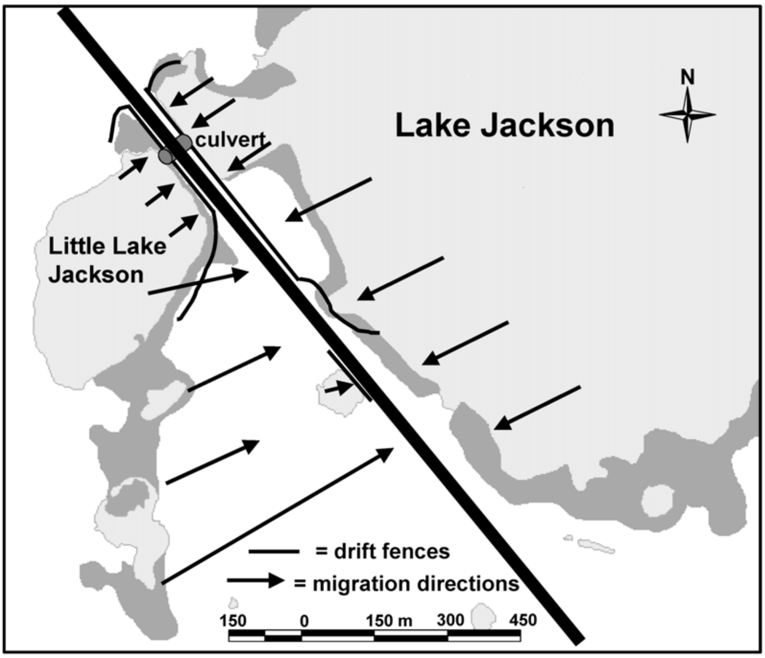

Fig. 1. Study area where U.S. Highway 27 crosses Lake Jackson, Florida, USA, showing the location of temporary fences and under-highway culvert. Arrows indicate general direction of migrations of turtles and other herpetofauna.

In this study, I recorded the number of times turtles and other herpetofauna attempted to cross a raised highway bisecting a northern Florida lake, and calculated the rate of road mortality during a 40-day period. I then designed and installed a temporary drift fence system to work with an existing culvert on a section of the highway, and evaluated its effectiveness in reducing road mortality and facilitating migration over the next 2.5 years, a period which included a drought as well as normal rainfall patterns.

STUDY AREA

My study was conducted at Lake Jackson, a 1,620-ha lake located 11 km north of Tallahassee in northwestern Florida, USA. Lake Jackson is a closed basin, and the water depth fluctuates seasonally and among years in a pattern that is typical of shallow, sinkhole lakes in the region (Brenner et al. 1990). Water level is determined naturally by rainfall and by drainage through two sinkholes. During drought conditions, a lowering of the water table draws lake water into the groundwater through the sinkholes and most of the lake bottom dries. This phenomenon has occurred 9 times during the last 100 years (Hughes 1967, Wagner 1984). Lake Jackson is designated as an Aquatic Preserve by the state of Florida.

In 1963–1965, U.S. Highway 27 was rebuilt as a 4-lane, divided highway (44 m wide) on a raised road-bed 2.1 m above normal high water. The road runs along 920 m of the lake shoreline then cuts directly across a 300-m wide arm of Lake Jackson, isolating a 21-ha portion of the lake now known as "Little Lake Jackson" (Fig. 1). A metal drainage culvert (3.5 m in diameter × 46.6 m long) under U.S. Highway 27 is now the only connection between Lake Jackson and Little Lake Jackson. The average depth of both lakes is approximately 2 m, but Little Lake Jackson holds water even during severe drought. Currently, U.S. Highway 27 experiences an average traffic flow of 21,500 vehicles per day (224 vehicles/lane/hr) and is a major truck route from Interstate 10 to Georgia and Alabama (Florida Department of Transportation 2002).

I conducted my study from 2000 to 2003 both during and following a severe 3-year drought (1998–2000: 97.4 cm total rainfall deficit). In 2000, rainfall was 59.1 cm below the normal average. Rainfall was 1.0 cm above average in 2001, 3.25 cm below average in 2002, and 16.7 cm above average in 2003 (Northwest Florida Water Management District, unpublished data). Average annual rainfall at Tallahassee, Florida, USA, is 165.6 cm (Northwest Florida Water Management District, unpublished data).

As Lake Jackson dried between February and July 2000, turtles and other herpetofauna emigrated to the west towards Little Lake Jackson, which held water throughout the drought. Heavy rain associated with 2 tropical storms (Alison and Barry) caused Lake Jackson to refill in 2001, and turtles migrated back from Little Lake Jackson from March to September. In 2002 and 2003, both Lake Jackson and Little Lake Jackson held water and normal seasonal movements of turtles occurred in both directions.

METHODS

Monitoring and Fence Design

I monitored the highway several times daily during 2 periods: before the construction of a temporary fence system (22 Feb–3 Apr 2000) and after the fence was constructed (4 Apr 2000–1 Nov 2003). In the pre-fence survey, I searched a 700-m section of the highway, right-of-way, and grassy median of both the north and southbound lanes for live and dead animals 2–4 times daily.

I designed and constructed the temporary barrier using 0.6-m-high woven vinyl erosion control fencing with pre-attached wooden stakes. The fence was installed at the edge of the mowed right-of-way along 700 m of U.S. Highway 27N during 31 March–4 April 2000. The bottom edge was buried ca. 20 cm so that the above-ground height of the fence was ca. 0.4 m. The barrier was designed to work as a drift fence, diverting animals away from the highway and directing them into the under-highway culvert (Fig. 1). The north and south ends of the fences were turned back gradually towards the lake at least 80–100 m to prevent animals from simply wandering around the ends and onto the highway (Fig. 1). From 8 to 11 September 2000, I installed a 600-m fence of the same design along the right-of-way and shore of Little Lake Jackson on the west side of U.S. Highway 27 (Fig. 1). I monitored all fences for migrating animals daily from the date of construction to 1 November 2003. I walked along the inside edge of the entire length of each fence. I monitored the fences 4 times daily in 2000 and 2001 (0900–1100 hr, 1200–1400 hr, 1600–1700 hr, 1800–2000 hr) and 2 times daily in 2002–2003 (1100–1200 hr and 1600–1700 hr). In addition, I checked both the culvert and roadway for live and dead animals. I recorded the identity and number of tracks (when possible) observed on the sand and mud in the culvert during dry periods, wiping the substrate clean after each count. From November to February each year (a period of reduced activity of herpetofauna), I checked the fences only once per day, and I did not check them when maximum daytime temperature fell below 14°C. Total sampling effort was 1,367 days and a total of 5,664 hours.

I recorded the species of all animals observed, captured, or found dead. I recorded the location of each road kill on the highway and removed all road kills from the highway to ensure that they were counted only once. Capture and handling of live animals was conducted under Florida Fish and Wildlife Conservation Commission (FFWCC) permit #WX01666 and salvage of dead animals under FFWCC permit #WS01621. I collected all live animals along each fence and released them on the opposite side of the highway (in the direction that they were traveling) at the edge of the water. Terrestrial species (e.g., southern black racer [*Coluber constrictor*], common five-lined skink [*Eumeces fasciatus*]), and some semi-aquatic species (e.g., southern leopard frog [*Rana sphenocephala*]) observed along the fences were not transported across the highway unless they were obviously attempting to cross the fence and moving directly towards the road. Green anoles (*Anolis carolinensis*) were abundant on the fences and in the adjacent vegetation; this species was not counted. Nesting female turtles, gravid female turtles apparently searching for nest sites (i.e., voiding large volume of bladder-water when handled); or post-nesting turtles (identified by soil on rear margin of shell and rear legs) were left alone and not transported across the highway.

Animals found alive or dead along the fences or on the highway were classified as (1) alive at fence (AAF), (2) alive on road (AOR), (3) alive on drying lake bottom adjacent to fences (AOB), (4) dead at fence (DAF), or (5) dead on road (DOR). Animals classified as AOB were primarily turtles and were collected as they left drying pools and began migrating towards the highway.

Mark–recapture of Turtles

To estimate the total number of individual turtles crossing the highway (rather than the total number of crossings), I measured and determined the sex of all turtles and individually marked 16% of Florida cooters (*Pseudemys floridana*), 10% of yellow-bellied sliders (*Trachemys scripta*), 34% of eastern mud turtles (*Kinosternon subrubrum*), and 47% of Florida softshells (*Apalone ferox*). Marked turtles represented a small sample of turtles selected haphazardly from those captured each day in 2000–2001. To estimate the proportion of turtles that moved from Little Lake Jackson to Lake Jackson that were already counted when migrating earlier from Lake Jackson to Little Lake Jackson, I used recapture rates of marked turtles to estimate the total number of turtles encountered (number of individuals = total captures – [total post-fence captures × proportion of marked individuals recaptured]).

Evaluating the Effectiveness of Temporary Fences

I evaluated the effectiveness of the temporary fences in reducing road mortality of turtles by comparing the numbers of DOR and AOR turtles found per km of road per day on the 700-m stretch of highway before and after fences were installed. I also compared pre-fence mortality during the drought migration (22 Feb–3 Apr 2000) to post-fence road mortality for the same period during part of the refill migration (22 Feb and 3 Apr 2001). Although fairly short in duration, the 40-day pre-fence survey was conducted during a period of normal activity for turtles in northern Florida.

I also compared the number of DOR and AOR turtles found on the 700-m section of highway adjacent to the fences to those found on the 500-m stretch of highway immediately south of the fences during the post-fence period (4 Apr 2000–1 Nov 2003). I used chi-squared tests for all comparisons.

Probability of Road Mortality in an Attempted Crossing

I used the equation of Gibbs and Shriver (2002) modified from Hels and Buchwald (2001) to estimate the probability of a turtle being killed in one attempted crossing of U.S. Highway 27:

$$P_{\text{killed}} = 1 - e^{-Na/v},$$

where N is traffic rate in vehicles/lane/sec during 80% of daily volume, a = width of the kill zone (2 tire widths per lane plus 2 times weighted average shell length of 5 species), and v = turtle walking speed (m/sec). I estimated average turtle walking speed (v) to be 0.05 m/sec from direct observations of individuals on U.S. Highway 27, and I identified an average kill zone/lane of 2.4 m. I used average annual traffic volume from 1977 to 2001 at the study area on U.S. Highway 27 in the calculation to estimate the change in probability of successful crossing with an increase in traffic.

RESULTS

Summary of Highway Monitoring

In 44 consecutive months, I found 10,229 reptiles and amphibians of 44 species either behind the fences or on the highway (Table 1). In total, I recorded 8,842 turtles of 10 species (86.4% of captures), 838 frogs of 10 species (8.2%), 363 snakes of 15 species (3.5%), 152 lizards of 6 species (1.5%), 32 American alligators (*Alligator mississippiensis*; 0.3%), and 2 salamanders of 2 species (Table 1, Fig. 2). Greater numbers of turtles were found crossing during the lake drydown and lake refill periods, whereas the numbers of frogs, snakes, and alligators were higher in relatively normal years (Fig. 2).

Road Mortality and Attempted Crossings of Turtles

From February 2000 to November 2003, I found 4,924 turtles (56%) along the Lake Jackson (east) side of U.S. Highway 27, and 3,918 (44%) along the Little Lake Jackson (west) side. Ninety-nine percent of turtles were found between March and September. Prior to the construction of the temporary fences, 343 turtles were found DOR on 700 m of U.S. Highway 27 in 40 days (22 Feb–3 Apr 2000) and 24 turtles DOR on U.S. Highway 27 at Little Lake Jackson in 4 days (8–11 Sep 2000; prior to installation of fencing on west side of the highway). I found 6 turtles DOR and 409 turtles AAF during the comparable 40-day and 4-day periods of the 2001 refill migration after the fences were built. Following construction of the temporary fences (4 Apr 2000–1 Nov 2003), 8,475 turtles were found on or along the north and southbound lanes of U.S. Highway 27. This total included 7,532 AAF, 548 AOB, 245 DOR, 95 DAF, and 55 AOR (Table 2). From 22 February to 7 September 2000,

Table 1. Forty-four species of reptiles and amphibians found either behind the fences or on U.S. Highway (dead or alive) at Lake Jackson, Leon County, Florida, USA, 22 Feb 2000–1 Nov 2003. “Alive” includes number alive at fences (AAF) and alive on the road (AOR) and “Dead” is number found dead on road (DOR); the number in parentheses shows those dead at or near fences (DAF). An asterisk indicates a State of Florida Species of Special Concern.

Species	Alive	Dead	Total
Salamanders (n = 2)			
Central newt, *Notophthalmus viridescens*	1	0	1
Two-toed amphiuma, *Amphiuma means*	0	0 (1)	1
Anurans (n = 838)			
American bullfrog, *Rana catesbeiana*	1	35	36
Eastern spadefoot, *Scaphiopus holbrookii*	1	4	5
Greenhouse frog, *Eleutherodactylus planirostris*	0	1	1
Green treefrog, *Hyla cinerea*	2	37	39
Narrow-mouthed toad, *Gastrophryne carolinensis*	5	0	5
Pig frog, *Rana grylio*	7	57	64
Southern cricket frog, *Acris gryllus*	309	3	312
Southern leopard frog, *Rana sphenocephala*	69	202	271
Southern toad, *Bufo terrestris*	84	18	102
Squirrel treefrog, *Hyla squirella*	2	1	3
Turtles (n = 8,842)			
Chicken turtle, *Deirochelys reticularia*	2	0	2
Eastern box turtle, *Terrapene carolina*	18	3	21
Eastern mud turtle, *Kinosternon subrubrum*	75	20	95
Florida cooter, *Pseudemys floridana*	3,353	276 (68)	3,697
Florida softshell, *Apalone ferox*	224	26 (1)	251
Gopher tortoise, *Gopherus polyphemus**	2	3	5
Stinkpot, *Sternotherus odoratus*	710	61(4)	775
Snapping turtle, *Chelydra serpentina*	11	5 (1)	17
Suwannee cooter, *Pseudemys concinna**	3	0	3
Yellow-bellied slider, *Trachemys scripta*	3,737	218 (21)	3,976
Snakes (n = 363)			
Banded watersnake, *Nerodia fasciata*	19	44	63
Cornsnake, *Elaphe guttata*	10	4	14
Cottonmouth, *Agkistrodon piscivorus*	33	8	41
Eastern gartersnake, *Thamnophis sirtalis*	13	5	18
Eastern kingsnake, *Lampropeltis getulus*	7	1	8
Eastern mudsnake, *Farancia abacura*	0	3	3
Eastern ribbonsnake, *Thamnophis sauritus*	3	1	4
Florida green watersnake, *Nerodia floridana*	13	63	76
Gray ratsnake, *Elaphe obsoleta*	11	4	15
Northern Florida swampsnake, *Seminatrix pygaea*	1	6	7
Red-bellied snake, *Storeria occipitomaculata*	1	0	1
Southern ring-necked snake, *Diadophis punctatus*	1	0	1
Rough greensnake, *Opheodrys aestivus*	0	1	1
Scarletsnake, *Cemophora coccinea*	3	0 (2)	5
Southern black racer, *Coluber constrictor*	103	3	106
Lizards (n = 152)			
Broad-headed skink, *Eumeces laticeps*	4	0	4
Common five-lined skink, *Eumeces fasciatus*	126	0	126
Eastern glass lizard, *Ophisaurus ventralis*	14	0	14
Green anole, *Anolis carolinensis*	NA	NA	NA
Little brown skink, *Scincella lateralis*	7	0	7
Six-lined racerunner, *Cnemidophorus sexlineatus*	0	1	1
Crocodilians (n = 32)			
American alligator, *Alligator mississippiensis* *	25	7	32
Total	9,010	1,219	10,229

4,818 turtles were found migrating from Lake Jackson to Little Lake Jackson during the lake dry down. Turtles began migrating back to Lake Jackson following heavy rain in early September and a tropical storm on 22 September 2000. In 2001, 3,299 turtles migrated from Little Lake Jackson back to Lake Jackson as it refilled following heavy early spring rains and 2 tropical storms (11 Jun and 6 Aug 2001).

Of the 572 *P. floridana* marked during the initial migration from Lake Jackson in 2000, 48% (n = 236) were recaptured in 2001 during the return migration. Except for *P. floridana*, no other turtle species were marked during the 2000 migration. However, in late 2000 to early 2001, 384 *T. scripta* were marked and released at Little Lake Jackson and 31% (n = 119) were later recaptured at the Little Lake Jackson fence as they migrated back to Lake Jackson. In addition, 32 *K. subrubrum* were marked in 2001 with 7 recaptures and 95 *A. ferox* were marked in 2001 with 13 recaptures. In total, 1,185 turtles were marked, out of 8,475 turtles cap-

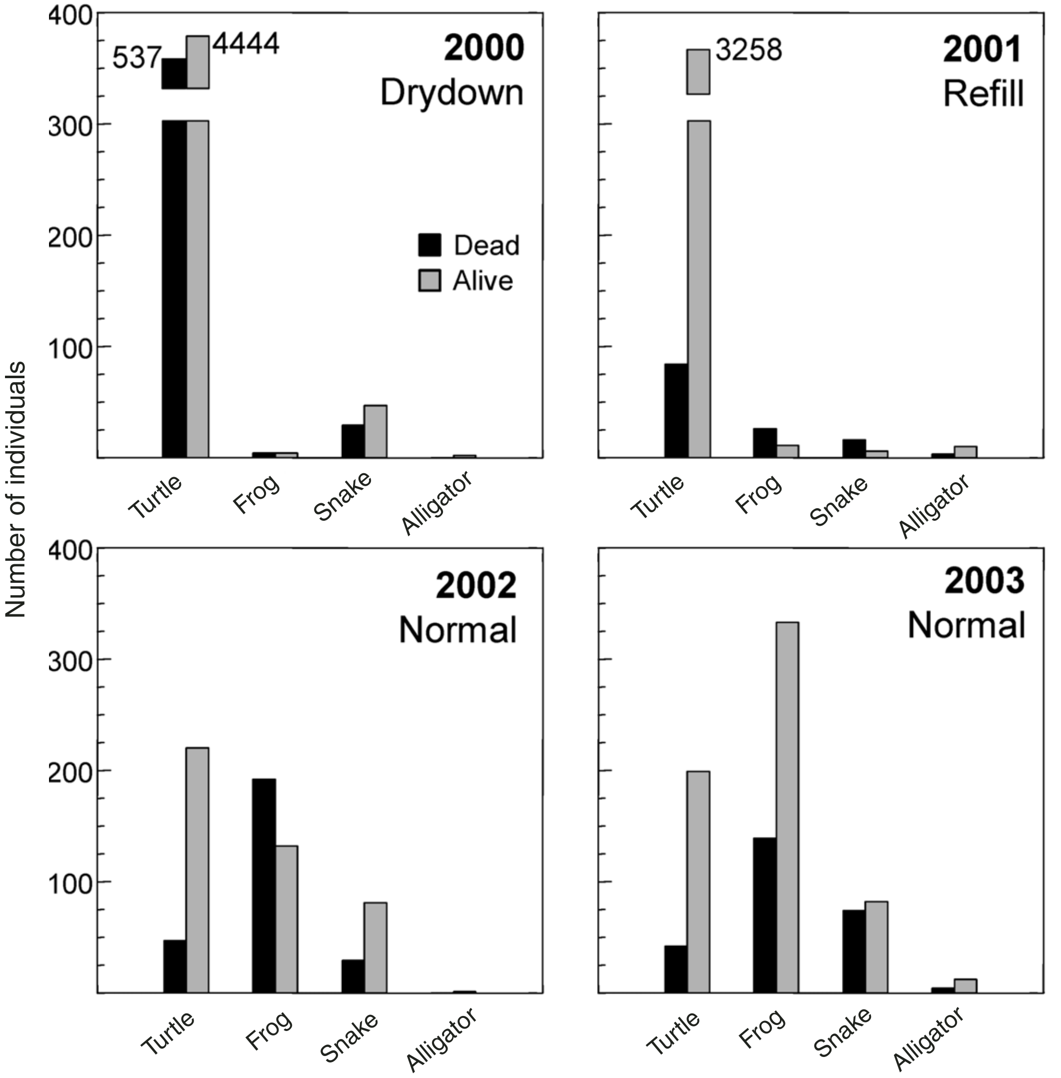

Fig. 2. Number of individuals of turtles, frogs, snakes, and alligators found alive at fences or dead on the road in 2000 (lake drydown migration), 2001 (lake refill migration), and 2002–2003 (normal years) on U.S. Highway 27, Lake Jackson, Florida, USA.

tured after the fence was built. As 33% (n = 389) were recaptured, I estimated that 2,796 turtles were captured twice (during both the initial and return migrations) and thus approximately 5,678 individuals were encountered, including those DOR before the fence was built.

Probability of Road Mortality in an Attempted Crossing

Data from the pre-fence survey indicated that 95% of 343 turtles were killed as they first entered the highway adjacent to the shoulder, while the remaining 5% were killed in the first 2 traffic lanes. During February–March 2000, turtles were observed migrating only from Lake Jackson to Little Lake Jackson (east to west) as Lake Jackson was drying and no DOR or AOR turtles were found west of the median. These data demonstrated that hardly any turtles could successfully traverse all 4 lanes. Solving the probability equation for 2001 traffic volume yielded a 98% probability of a turtle being killed in 1 attempted crossing, which closely matches the direct observations (Fig. 3). The estimated probability of a turtle successfully crossing U.S. Highway 27 decreased from 32% in 1977 to only 2% in 2001 (Fig. 3).

Table 2. Number of individuals of 10 turtle species found dead or alive behind the fences or on U.S. Highway 27 at Lake Jackson, Florida, USA, 22 Feb 2000–1 Nov 2003. Each individual was classified as alive at fence (AAF), dead on road (DOR), alive on road (AOR), dead behind fence (DAF), or alive on drying lake bottom adjacent to fences (AOB).

Species	Total	AAF	DOR	AOR	DAF	AOB
Chelydra serpentina	17	6	5	1	1	4
Deirochelys reticularia	2	2	0	0	0	0
Gopherus polyphemus	5	0	3	2	0	0
Kinosternon subrubrum	95	75	20	0	0	0
Pseudemys concinna	3	2	0	0	0	1
Pseudemys floridana	3,697	3,305	276	10	68	38
Sternotherus odoratus	775	449	61	7	4	254
Terrapene carolina	21	17	3	1	0	0
Trachemys scripta	3,976	3,470	218	25	21	242
Total	8,842	7,532	612	55	95	548

Efficacy of the Drift Fences for Turtles

Overall, the road mortality rate of turtles was significantly less after fences were installed (0.09 DOR/km/day) compared to before (11.9 DOR/km/day) ($\chi^2 = 11.6$; $P = 0.001$). When the pre- and post-fence road mortality rates were compared only for the period in the 2001 refill migration in which the pre-fence monitoring was done (22 Feb–3 Apr) the result was nearly identical to the overall comparison (post-fence rate of 0.21 DOR/km/day; $\chi^2 = 11.3$; $P = 0.001$).

After the fences were constructed, significantly fewer turtles were found DOR at the fences than on the road immediately to the south of the fences. In total, 84 turtles were found DOR + AOR at the fence array and 216 were DOR + AOR on the highway to the south of the fences (Table 3) ($\chi^2 = 58.1$; $P < 0.0001$). Thus, only 84 of 8,475 (<1%) turtles found after the fence was built actually accessed the highway by climbing or penetrating the temporary fences.

Most mortality of turtles behind the fences was due to predation. Of 95 turtles found dead behind the fences, 92 were killed by predators and 3 apparently overheated. Nocturnal mammalian predators killed turtles that left the water in the early evening (1700–2000 hr) and were diverted by the fences but did not reach the culvert before nightfall. Raccoons (*Procyon lotor*) were the primary predators, but I also observed a gray fox (*Urocyon cinereoargenteus*) at dusk carrying a live *T. scripta*. Most DAF turtles were found concentrated in a wooded area 235–300 m south of the under-highway culvert. These turtles were primarily adult *P. floridana* and *T. scripta* moving from Lake Jackson as it dried to Little Lake Jackson in May–June 2000. Several hatchling and small juvenile turtles were found being attacked by red fire ants (*Solenopsis invicta*) and later died. Several turtles were taken by humans at the fences, either for pets (*P. floridana*, *T. scripta*) or meat (*A. ferox*).

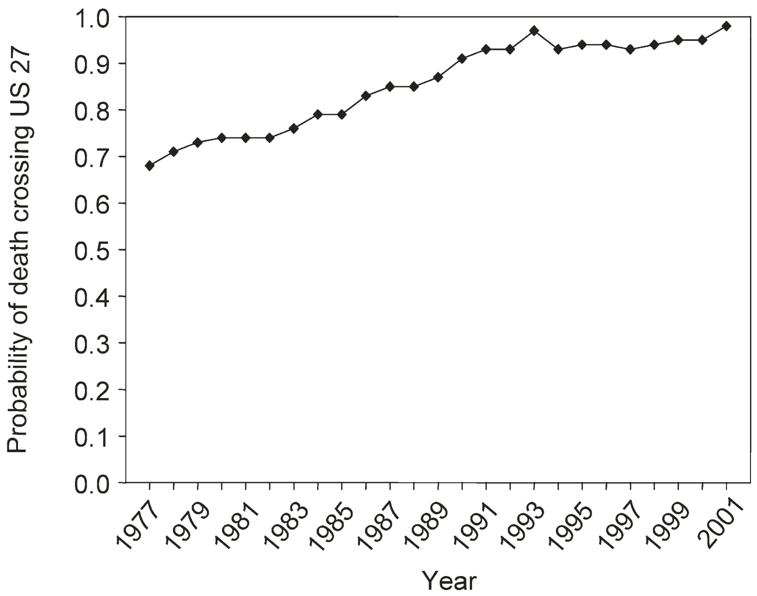

Fig. 3. Annual change in probability of a turtle being killed by a vehicle while attempting to cross U.S. Highway 27 at Lake Jackson, Florida, USA, as a function of traffic volume (vehicles/lane/second) from 1977–2001. Probability of being killed is calculated using the equation: $P_{death} = 1 - e^{-Na/v}$ where N = traffic volume / lane / second; a = kill zone width, v = walking speed of turtles (m/sec), adjusted for hours turtles move (80% traffic volume 0700–2100).

Road Mortality of Other Herpetofauna and Efficacy of Temporary Fences

Other than turtles, 1,088 of 1,387 (78%) of the reptile and amphibian species observed at the fences or on the highway were terrestrial (e.g., *C. constrictor*, cornsnake [*Elaphe guttata*],

Table 3. Pre-fence (44 days) and post-fence (1,327 days) comparisons of DOR + AOR turtles on U.S. Highway 27 at Lake Jackson, Florida, USA. The location of post-fence turtles were classified as either "At fence" (on the 700 m section of U.S. Highway 27 next to the fences) or "Not at fence" (on the 500 m stretch of highway south beyond the extent of the fence array).

Species	Pre-fence	Post-fence: At fence	Post-fence: Not at fence	Total DOR + AOR
Apalone ferox	0	5	30	35
Chelydra serpentina	1	2	3	6
Kinosternon subrubrum	16	0	4	20
Gopherus polyphemus	0	0	5	5
Pseudemys floridana	217	21	48	286
Sternotherus odoratus	19	39	10	68
Terrapene carolina	0	0	4	4
Trachemys scripta	114	17	112	243
Total	367 (55%)	84 (13%)	216 (32%)	667

southern toad [*Bufo terrestris*]), and semi-aquatic species (e.g. *R. sphenocephala*, cottonmouth [*Agkistrodon piscivorus*], southern cricket frog [*Acris gryllus*]). The upland and semi-aquatic species were often observed foraging or basking in the vegetation at the fences. In total, 26% of the 1,088 individuals of upland and semi-aquatic species observed were found DOR. Seventy-four percent were found AAF and either remained at the fences or were diverted from the highway.

In contrast, aquatic species had higher road mortality rates. I recorded 299 individuals of aquatic species (e.g., pig frog [*Rana grylio*], watersnakes [*Nerodia* spp.]), with 76% DOR, 22% AAF, and 2% DAF. The temporary fences prevented only a quarter of the total number of individuals of the aquatic species (not including turtles) from being killed on the highway. All of the aquatic, semi-aquatic, and terrestrial species were able to climb or scale the temporary fence and access the highway (except for the two-toed amphiuma, *Amphiuma means*; Aresco 2002). Overall, the temporary fences apparently diverted some species and may have reduced the total road-kill rate, especially of small anurans (e.g., *B. terrestris*, narrow-mouthed toad [*Gastrophryne carolinensis*]). However, species such as small frogs are difficult to detect and count after being killed on the highway (e.g., *A. gryllus* and *G. carolinensis*), because they are either completely obliterated or stick to tires and/or vehicles and are carried away from the study site (see Hels and Buchwald 2001). Also, numbers of some species were significantly underestimated and others were completely missed by walking the fences and highway only during daylight hours.

Culvert Use

I observed *T. scripta* ($n = 6$), *P. floridana* ($n = 8$), and *A. ferox* ($n = 1$) moving into or out of the 3.5-m diameter culvert. In addition to direct observations, I recaptured 2 marked turtles at the Little Lake Jackson fence that were previously marked and released on the Lake Jackson side. These turtles probably moved through the culvert back to Little Lake Jackson. Furthermore, in 2000 and 2001, sets of tracks from >200 individual turtles (primarily *T. scripta* and *P. floridana*) were observed on the sand and mud in the culvert indicating that these turtles walked through the culvert. I also observed juvenile and adult *A. mississippiensis* ($n = 4$), numerous *R. sphenocephala*, *R. grylio*, *R. catesbeiana*, and an *E. guttata* moving through the culvert. Alligator tracks were also frequently observed (>25 sets of tracks). I did not oserve any direct predation on turtles by mammals or alligators in or near the culvert, nor did I find any evidence (e.g., turtle carcasses) of predation by mammals at the culvert.

DISCUSSION

This study documented that heavy road traffic on U.S. Highway 27 at Lake Jackson, Florida, USA, causes significant mortality of reptiles and amphibians, especially turtles, that attempt to cross the highway in both drought and non-drought years. Road mortality and attempted crossings of turtles was clearly greatest during the migrations that occur when Lake Jackson dries and refills following drought. I estimated that the fence along U.S. Highway 27 intercepted most of the emigrating turtles from a 405-ha area (the northwest subbasin of Lake Jackson) as it dried in 2000, including many turtles that had migrated to the northern part of the lake in 1999 when the southern part dried. Previous studies of the response of turtle populations to pond or lake drying indicated that most individuals emigrated in the direction of the nearest remaining water bodies (Cagle 1944, Gibbons et al. 1983). Similarly, at Lake Jackson, turtles did not move randomly in all directions from the drying lake. Turtle tracks in wet mud on the drying lake bottom were easily visible and indicated that almost all individuals moved directly towards Little Lake Jackson on the other side of U.S. Highway 27, apparently detecting water from a distance of at least 2 km. An aerial photograph taken 150 m above drying Lime Sink at Lake Jackson on 17 May 2000 shows a distinct line of hundreds of turtle tracks heading to the west in the general direction of Little Lake Jackson approximately 2.1 km away (T. Scott, Florida Geological Survey, personal communication).

My observations provide strong evidence that few turtles can successfully cross all four lanes of U.S. Highway 27. Pre-fence data and a probability model indicated that 98–100% of all turtles are killed in one attempted crossing. Therefore, it is reasonable to estimate that at least 98% of the turtles diverted by the fences (5,564 individuals at a rate of 1,263 road kills/km/yr) would have been killed on U.S. Highway 27 during this study if fences had not been in place and turtles had been allowed to access the highway. Thus, mass migration events in response to periodic natural drydowns can potentially cause irreversible declines of populations of 6 turtle species in Lake Jackson: *T. scripta*, *P. floridana*, *S. odoratus*, *A. ferox*, *K. subrubrum*, and snapping turtles (*Chelydra serpentina*).

The mass migration and mortality at U.S. Highway 27 represented turtles from at least 25% of the total lake area (405 ha northwest subbasin). Without mitigation, the loss of 25% of virtually the entire turtle population every 12 years due to traffic mortality would be a severe bottleneck event and a population sink (Pulliam 1988). Road mortality during drydowns alone would likely cause long-term population declines even with immigration from other areas of the lake (Congdon et al. 1993). In addition to significant mortality that occurs on roads adjacent to many wetlands during drought, traffic deaths are also a major source of additive mortality for turtles during non-drought years. Frequent terrestrial activity of freshwater turtles is well documented for several species including *T. scripta*, *P. floridana*, *A. ferox*, *K. subrubrum*, *C. serpentina*, and the chicken turtle (*Deirochelys reticularia*; Bennett et al. 1970, Gibbons 1970, Wygoda 1979, Obbard and Brooks 1980, Gibbons et al. 1983, Buhlmann and Gibbons 2001). Such movements are associated with nesting in spring and summer, annual local migration patterns that correspond to hormone cycles (e.g., movements of male turtles over land in late summer and early spring in search of mates), dispersal of juveniles and subadults, and newly emerging hatchlings searching for water. I found 509 turtles DOR or AAF during non-drought years (2002–2003). These turtles included nesting females, migrating males and juveniles, and hatchlings leaving nests (Aresco 2004). The rate of terrestrial recaptures of turtles in this study (33% in drought/refill years and 5% in non-drought years) demonstrated that aquatic turtles move overland frequently at Lake Jackson. These data suggest that where roads bisect wetlands, even if a turtle successfully crosses the road one time, it is likely that it will emigrate back across the road, with a high probability of being killed by vehicles. Thus, conservation measures for freshwater turtles should consider their annual and seasonal overland movements that frequently require road crossings (Burke and Gibbons 1995, Joyal et al. 2001, Marchand and Litvaitis 2004). Recent studies provide strong evidence that road mortality is an increasingly significant threat to freshwater and terrestrial turtles to the extent that populations may be declining near roads (Mitchell and Klemens 2000, Gibbs and Shriver 2002, Marchand and Litvaitis 2004). For example, road mortality of five species of turtles on the 3.6-km Long Point Causeway on Lake Erie was 716 in 4 years (50/km/yr; Ashley and Robinson 1996). On the Cape May peninsula in southern New Jersey, northern diamondback terrapins (*Malaclemys terrapin*) attempt to find nest sites on shoulders of raised roadways built across salt marshes, resulting in high annual road mortality of females (Wood and Herlands 1997). In a 7-year census between 1989–1995, researchers counted 4,020 road-killed females (23/km/yr). In Montana, numerous painted turtles (*Chrysemys picta*) were killed while crossing between pothole ponds located on either side of a 6.5 km section of U.S. Highway 93 (53/km/yr) (Fowle 1996; K. Griffin, University of Montana, personal communication). During a 1-year study of wildlife mortality (pre-ecopassage construction) on a 3.2-km stretch of U.S. Highway 441 crossing Paynes Prairie, Florida, 187 turtles were found DOR (58/km/yr) (Smith and Dodd 2003). In the present study at Lake Jackson, Florida, I counted 8,842 turtles either DOR or attempting to cross 1.2 km of U.S. Highway 27 in 44 months (2,007/km/yr). After adjusting for >1 capture for some individuals, the road-kill rate was estimated at 1,263/km/yr. Although road-kill rates of turtles may be greater in other areas, the rate of attempted crossing by turtles at Lake Jackson is the highest published to date.

Demographic and life history traits of turtles, including long generation times and naturally high rates of egg and juvenile mortality, limit the annual recruitment of populations (Congdon et al. 1994). In populations in undisturbed habitat, these traits are offset by high lifetime fecundity, as adults typically have few natural predators (Congdon et al. 1993, Doak et al. 1994). However, turtle populations may not be able to recover from sudden or regular losses of large numbers of breeding adults. For example, Fonnesbeck and Dodd (2003) found that a disease outbreak in the flattened musk turtle, *Sternotherus depressus*, lowered survivorship from 98–99% to 82–88% for only a short period in 1985 but caused a 50% population decline by the following year from which the population has not recovered after 17 years. Even small increases in annual mortality rates of mature females can lead to long-term population declines or changes in population structure (Brooks et al. 1991, Congdon et al. 1993, 1994). At Lake Jackson, 6–29% of females are killed annually on the highway during the nesting season, resulting in male-biased population sex ratios of 3 species (Aresco 2005). This level of mortality alone could be sufficient to cause long-term population declines when combined with relatively slow growth to maturity (e.g., 10–12 yrs for *P. floridana*) and low levels of recruitment (Congdon et al. 1994; M. J. Aresco, unpublished data).

Many highways in North America—formerly rural roads that some turtles could cross successfully—have experienced a 100–200% increase in traffic volume over the last 2 decades (e.g., 162% increase from 1977–2001 at U.S. Highway 27) (National Research Council 1997, Florida Department of Transportation 2002). For long-lived species with long generation times, there may be a lag time between current road mortality rates and observable population declines (Doak 1995, Findlay and Bourdages 2000). Additional studies should be initiated nationwide to quantify both direct mortality and demographic effects caused by highways.

MANAGEMENT IMPLICATIONS

My study demonstrated that vinyl erosion control fencing in combination with an existing culvert is an effective and inexpensive temporary method of reducing road mortality and facilitating highway crossings of turtles until a more permanent design can be constructed. Turtles used the large-diameter culvert in which light was visible from each side and a natural sand/silt substrate was present. The configuration of the ends of the fences, which were turned back towards the lake bottom for several hundred meters, prevented most turtles from accessing the highway from around the ends. However, turtles of the genera *Apalone*, *Kinosternon*, *Terrapene*, and especially *Sternotherus* and *Chelydra* are exceptional climbers. Therefore, drift fences require daily monitoring to remove turtles from behind fencing before they can climb over. The low rate of trespass of turtles at the fences in my study would have undoubtedly been much greater if the array was not intensively patrolled. The fencing can be angled slightly inward in order to make it more difficult for turtles to successfully climb over. Temporary erosion fencing also requires frequent maintenance from damage incurred by mowers and stormwater flow and must be replaced every 18 months as the wooden stakes rot and woven vinyl fabric breaks down from exposure to direct sunlight. A more permanent barrier should include such design features as a smooth, vertical surface (~1 m tall) and an overhanging, inward facing lip, combined with a series of large culverts installed to provide underhighway passages.

ACKNOWLEDGMENTS

I thank E. Walters, M. Gunzburger, L. London, J. Walters, P. Richards, M. Schrader, D. Jackson, and G. Guyot for their help in constructing and monitoring the drift fences. The Florida Department of Transportation (FDOT) provided fencing material and I thank D. Zeigler, J. Boan, and L. Irwin of the FDOT Environmental Management Office. I thank D. Winchester and J. Dougherty of Leon County for providing logistical support. K. Dodd, F. James, M. Gunzburge, J. Travis, E. Walters, and an anonymous reviewer provided helpful comments that improved the manuscript. The Defenders of Wildlife donated materials and equipment to allow for replacement and maintenance of the temporary fences and I especially thank J. McMurtray. I acknowledge the support of the National Science Foundation through grant DEB99-03925 to J. Travis.

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Associate Editor: Russell.