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ROAD DENSITY NOT A MAJOR DRIVER OF RED-EARED SLIDER (*TRACHEMYS SCRIPTA ELEGANS*) POPULATION DEMOGRAPHICS IN THE LOWER RIO GRANDE VALLEY OF TEXAS

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***Abstract*.—In recent years there have been concerns over the conservation and management of freshwater turtle populations in the state of Texas. In 2008 and 2009, we completed several investigations addressing anthropogenic impacts on freshwater turtles in the Lower Rio Grande Valley (LRGV) of Texas. Here, we use a model selection approach within an information-theoretic framework and simple linear regressions to investigate effects of road density and number of surrounding water bodies on relative abundance and sex ratio of Red-eared Sliders (*Trachemys scripta elegans*). We sampled 36 sites across three counties in the LRGV. We used a GIS (Geographic Information System) and county road maps to estimate the total length of road within 1 km radius circular buffers centered on the midpoint of trap lines at each site and hydrology maps to estimate number of water bodies within the 1 km buffer. Based on model selection results, the number of surrounding water bodies best explained the relative abundance of turtles, while road density best explained sex ratio differences. However, predictors in both models showed little explanatory power. Our failure to identify road density as a strong predictor of decreased turtle abundance gives additional weight to conclusions drawn from our recent work that suggested declines of Red-eared Sliders in the LRGV are due to commercial harvest and land use changes.**

Key Words.—conservation; GIS; human impacts; turtles; urbanization

INTRODUCTION

A variety of anthropogenic factors are known to influence semi-aquatic freshwater turtle populations. Arguably the most pervasive threats to freshwater turtles across the world are habitat loss, degradation, and fragmentation (Klemens 2000). Landscape alterations can influence spatial and temporal habitat availability and quality, with significant impacts on turtle population dynamics (Marchand and Litvaitis 2004; Ryan et al. 2008; DeCatanzaro and Chow-Fraser 2010). The influence of roads on populations, communities, and ecosystems has been of interest to ecologists for nearly a century (e.g., Stoner 1925; Oxley et al. 1974; Foster and Humphrey 1995; Carr and Fahrig 2001; Langen et al. 2009). Forman (2000) estimated that 19% of the United States is ecologically affected by roads. The affected area today is undoubtedly even larger because road networks continue to grow (e.g., the total length of public roads increased from 6,187,082 km in 1990 to 6,507,834 km in 2009; U.S. Department of Transportation. 2011. Highway Statistics 2009. http://fhwa.dot.gov/policyinformation/statistics/2009/vmt422.cfm [Accessed 15 November 2011]). Road ecologists recognize that roads link together landscapes for humans, but fragment them for other organisms (Forman and Sperling 2003). Roads can impact both abiotic (e.g., hydrology, erosion, and sound) and biotic (e.g., species behavior and survivorship) ecosystem parameters (Coffin 2007). Roads can affect wildlife populations through direct road mortality or road avoidance, which in turn can alter population connectivity and demographics (Forman and Alexander 1998; Trombulak and Fissell 2000).

Turtles are thought to be particularly vulnerable to road mortality because of their relatively slow travel speeds (Ashley and Robinson 1996; Steen and Gibbs 2004; Szerlag and McRobert 2006). Semi-aquatic turtles move across landscapes in search of mates, food resources, nesting sites, and suitable aquatic habitats (Graham et al. 1996; Aresco 2005; Andrews et al. 2008; Roe et al. 2009, 2011). Adults are more likely to make overland movements than juveniles (Gibbons et al. 1990). Thus, we would expect that adults are more susceptible to road mortality. This is particularly detrimental given that population persistence for many freshwater turtle species is dependent upon high adult survivorship (Congdon et al. 1993, 1994).

Several studies concluded that male turtles travel over land more than females (Morreale et al. 1984; Tuberville et al. 1996), while others concluded that females moved more than males due to nesting migrations (Steen and Gibbs 2004; Aresco 2005; Gibbs and Steen 2005). Further, with respect to inter-pond movement, House et al. (2010) found no difference between the movement of males and females or adults and juveniles. Despite equivocal conclusions about movement rates, it is generally accepted that female turtles are particularly susceptible to road mortality because they tend to be attracted to open nesting habitats along roads (Haxton 2000; Steen and Gibbs 2004; Aresco 2005; Steen et al. 2006; Szerlag and McRobert 2006). When population-level road impacts are detected, the typical effects include reduction in turtle abundances (Ryan et al. 2008), male-biased sex ratios (Aresco 2005; Gibbs and Steen 2005; Patrick and Gibbs 2010), and reduction in mean turtle size due to adult-biased mortality (Patrick and Gibbs, 2010).

Land cover and number of water bodies surrounding the focal area of interest can affect animal movement. For example, Langen et al. (2009) found that number of surrounding water bodies increased movement, and as a consequence, increased the probability of road mortality for amphibians. Beaudry et al. (2008) found that clustered wetlands can create road mortality hotspots for semi-aquatic turtles due to high levels of movement among the wetlands. Other studies have found high levels of turtle movement among wetland complexes, with movement rates declining as wetland distance increased (Bowne et al. 2006; Roe et al. 2009). Thus, if inter-pond movement rates are not affected by the presence of roads, we would expect the potential for road mortality to increase as number of nearby water bodies increases.

In 2008 and 2009, we investigated anthropogenic impacts on freshwater turtles in the Lower Rio Grande Valley (LRGV) of Texas, with the goal of providing useful information for managing freshwater turtles in the state (Brown et al. 2011; Brown et al. 2012). To increase our understanding of anthropogenic impacts on freshwater turtles in the LRGV, in this study we investigated relationships between roads and turtle demographics. We focused on the Red-eared Slider (*Trachemys scripta elegans*), the most abundant freshwater turtle species in the LRGV. We tested for relationships between road density and sex ratio, relative abundance, and mean size (i.e., straight line carapace length). Based on previous research, we hypothesized that as road density increased, sex ratios would become more male-biased. We also hypothesized that total number of captures as well as total female captures would decrease with increased road density. Finally, we hypothesized that the mean size of adult males and females would decrease as road density increased.

MATERIALS AND METHODS

Study sites.—This study was conducted in three counties of the LRGV of Texas: Cameron, Hidalgo, and Willacy. We used a Geographic Information System (GIS; ArcMap 9.3.1, ESRI, Redlands, California, USA) to locate sites that spanned the distribution of road densities in the study area. We obtained GIS layers containing water bodies and roads from the Texas Natural Resources Information System (available at http://www.tnris.org/). After identifying potentially suitable sampling sites through GIS, we ground-truthed sites and sought permission to trap turtles. We selected sites if they contained water and we were able to access them. Further, to account for any inherent county-level differences that could bias results, we selected sites that encompassed the full distribution of road densities within each county and sampled 12 sites per county (Table 1; Fig. 1). Ultimately, we trapped turtles at 36 sites across the three counties, including 26 ponds and 10 canals.

Methods.—We conducted this study between May and July of 2009. We trapped turtles using 76.2 cm diameter hoop nets baited with canned fish, fresh fish, or shrimp. We standardized trapping effort at 50 trap days per site and checked traps daily. For all turtles captured, we recorded sex, took standard measurements, and marked individuals for future identification. We determined sex using secondary sexual characteristics. Male Red-eared Sliders have elongated foreclaws and an anal opening on the tail that extends past the edge of the carapace, while adult females lack these characteristics (Ernst and Lovich 2009). When plastron length (PL) was < 100 mm, we considered the turtles to be juveniles (Gibbons and Greene 1990). We measured carapace length and width, plastron length and width, and body depth using Haglof calipers accurate to 1.0 mm (Haglof, Madison, Mississippi, USA). We estimated mass using Pesola precision scales accurate to 20 g (Pesola, Baar, Switzerland). We individually marked turtles using carapace notches (Cagle 1939).

We used a GIS and county road maps from 2009 retrieved from the Topologically Integrated Geographic Encoding and Referencing system (TIGER) to estimate the road density at each site. Distances traveled overland can vary greatly among semi-aquatic turtle species (Steen et al. 2012). Therefore, species-specific movement patterns should determine the scale at which land must be characterized to better understand landscape impacts on populations (Wiens 1989). Red-eared Sliders are one of the more vagile semi-aquatic turtle species. They can disperse great distances, with some nesting females traveling up to 1,400 m (Steen et al. 2012), but typical home-range sizes are < 1 km^2 (Schubauer et al. 1990; Ernst and Lovich 2009).

TABLE 1. Site information for water bodies included in this investigation of road impacts on Red-eared Slider (*Trachemys scripts elegans*) population demographics in the Lower Rio Grande Valley of Texas (LRGV), including county, road density (km/km^2) within a 1-km radius buffer, number of surrounding water bodies within the same buffer, and water body type (pond or canal).

County	Road density (km/km^2)	Number of surrounding water bodies	Water body type
Cameron	0.69	6	Pond
Cameron	0.99	1	Pond
Cameron	1.32	2	Pond
Cameron	1.94	7	Canal
Cameron	3.43	2	Pond
Cameron	3.54	10	Pond
Cameron	4.54	6	Pond
Cameron	5.17	2	Pond
Cameron	6.15	12	Pond
Cameron	9.03	1	Canal
Cameron	10.01	12	Pond
Cameron	11.81	9	Canal
Hidalgo	1.95	2	Canal
Hidalgo	2.02	7	Canal
Hidalgo	2.13	8	Pond
Hidalgo	2.43	6	Pond
Hidalgo	2.62	6	Pond
Hidalgo	3.79	2	Pond
Hidalgo	5.29	5	Pond
Hidalgo	5.91	9	Pond
Hidalgo	5.98	4	Pond
Hidalgo	6.2	8	Pond
Hidalgo	7.87	4	Canal
Hidalgo	11.31	2	Pond
Willacy	1.34	7	Pond
Willacy	1.43	2	Canal
Willacy	1.47	2	Canal
Willacy	1.62	1	Pond
Willacy	2.32	0	Canal
Willacy	2.79	2	Pond
Willacy	3.56	3	Pond
Willacy	3.97	1	Canal
Willacy	4.83	4	Pond
Willacy	7.13	1	Pond
Willacy	7.64	1	Pond
Willacy	9.73	3	Pond

Therefore, we created 1 km radius circular buffers centered on the midpoint of the trap line at each site. The majority of sites were at least 2 km apart to maintain spatial independence of both predictor and response data. However, in Willacy County the number of accessible sites with high road densities we found to be more limited. Five sites in this county were > 1 km but < 2 km apart from another sampled water body, and thus road density data were not independent for these sites, as the buffers shared some roads. Using Hawth's analysis tools (available at: http://www.spatialecology.com/htools/download.php), we calculated the total road length within each buffer which represented the road density near each site. The TIGER files classified roads into primary interstate and state highways, secondary state and county highways, local neighborhood and rural roads, vehicular trail roads, and driveway roads. In our analyses, highway roads accounted for over 80% of road density assessed at all sites. We calculated road density as km of road length per km^2, and road densities ranged from 0.7 km/km^2 to 11.8 km/km^2. In addition, we used hydrology maps (available at http://datagateway.nrcs.usda.gov/) to estimate the number of water bodies surrounding each site within the 1 km buffer. The number of surrounding water bodies ranged from zero to 12. We did not include the other land cover data in our analyses because the land use surrounding water bodies was similar across sites (urban and suburban), with the exception of agricultural land use around the majority of low road density sites.

In each analysis we used QQ-plots to ensure the data were approximately normally distributed. We used a model selection approach within an information-theoretic framework to determine which factors, if any, influenced turtle relative abundances and sex ratios (Burnham and Anderson, 1998). We ranked models by their Akaike Information Criterion values corrected for small sample size (AIC_C), and considered models to have high support when $\Delta AIC_C < 2$ (Zuur et al. 2009).

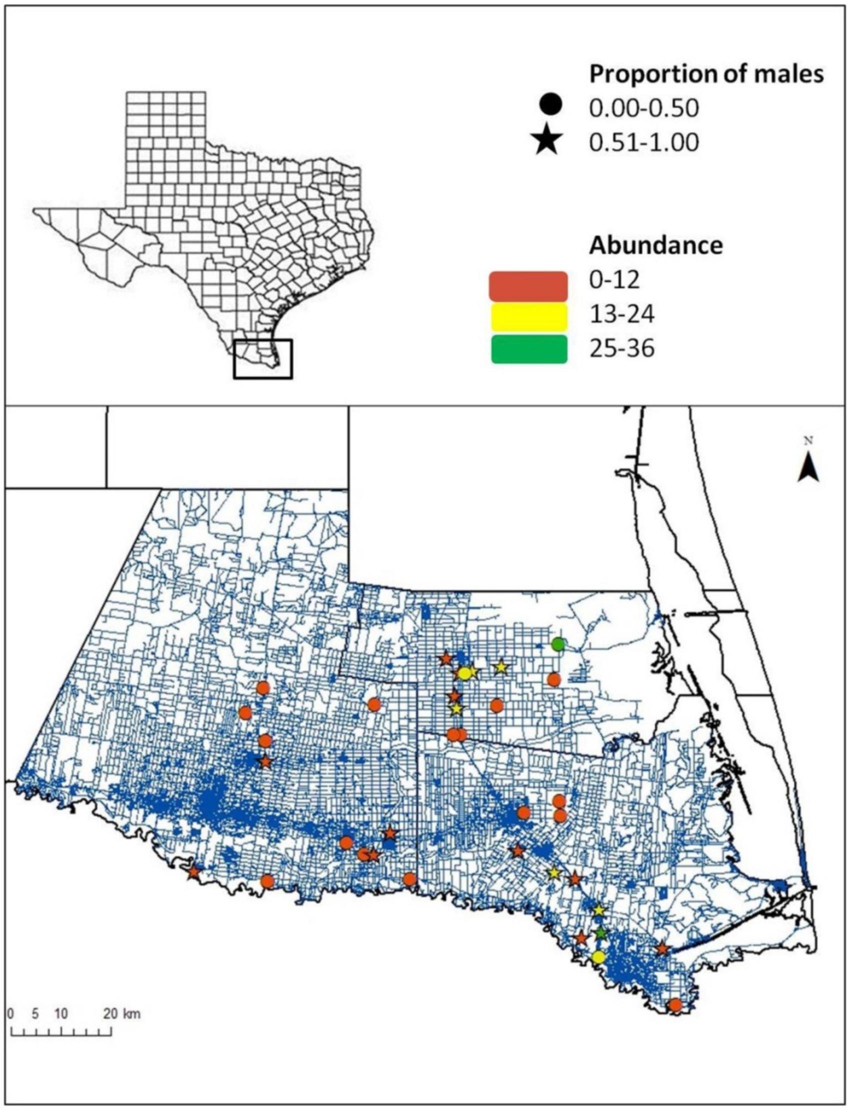

FIGURE 1. Map of the Lower Rio Grande Valley of Texas (LRGV; Cameron, Hidalgo, and Willacy counties shown clockwise from bottom right). The map displays the road network in the study areas and the 36 trapping locations (10 canals and 26 ponds). The sites are color coded by number of captured turtles (red: 0-12; yellow: 13-24; green: 25-36) and shape coded by proportion of males (circle: 0-0.50; star: 0.51-1).

We tested four models: no predictors (i.e., the null model), road density as a predictor, number of water bodies as a predictor, and both road density and number of water bodies as predictors (i.e., the global model). We calculated 85% and 95% confidence intervals (CI) for the model with the highest support to assess significance of model parameters. Although using a 95% CI is conventional, assessing 85% CIs is better suited for model selection based on AIC (Arnold 2010). We assessed relative abundance, sex ratio, and adult size relationships with respect to road density.

We used the total number of captured turtles over the 50 trap day period as our relative abundance metric, testing both total captures and total captures of adult females. Unfortunately, we were unable to estimate total abundance at sites due to low proportions of recaptures (for traditional mark-recapture models), and variable temporal distributions of trapping effort (for N-mixture models). Although the trap effort in our study was not homogeneously distributed among sites, Brown et al. (2011) found that capture efficiency was not affected by temporal distribution of effort in our study area. However, we note that because this relative abundance metric does not account for potential differences in spatial or temporal detection probability, it could misrepresent true differences among sites. Sex ratio was expressed as the proportion of males at each site. For the sex ratio analysis, we used adult captures only and excluded one site where we captured only a single

TABLE 2. Results from a model selection analysis using Akaike Information Criterion, corrected for small sample size ($\mathrm{AIC_C}$), to test the influence of road density (km/km^2) and number of water bodies within a 1 km radius buffer surrounding water bodies on number of Red-eared Slider (*Trachemys scripta elegans*) captures. The model containing only the number of water bodies as a predictor ranked highest, but with little support over the null model.

Predictor	Number of parameters	$\mathrm{AIC_C}$	Delta $\mathrm{AIC_C}$ (Δ_i)	$\mathrm{AIC_C}$ Weight (w_i)
Water	3	160.391	0.000	0.428
Null	2	160.834	0.443	0.343
Roads+Water	4	162.866	2.475	0.124
Roads	3	163.219	2.828	0.104

TABLE 3. Results from a model selection analysis using Akaike Information Criterion, corrected for small sample size ($\mathrm{AIC_C}$), to test the influence of road density (km/km^2) and number of water bodies within a 1 km radius buffer surrounding water bodies on sex ratio of Red-eared Sliders (*Trachemys scripta elegans*). The model containing only the road density as a predictor ranked highest, but with little support over the null model.

Predictor	Number of parameters	$\mathrm{AIC_C}$	Delta $\mathrm{AIC_C}$ (Δ_i)	$\mathrm{AIC_C}$ Weight (w_i)
Roads	3	-75.290	0.000	0.422
Null	2	-74.922	0.367	0.351
Roads+Water	4	-72.692	2.598	0.115
Water	3	-72.630	2.660	0.112

juvenile turtle. For the adult size analyses, we computed the mean carapace length for each sex at each site and used this value as our response variable. We did not include recaptures in any analyses. We conducted all statistical analyses using program R 2.7.2 (The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Across the 36 sites, total captures of Red-eared Sliders ranged from zero to 36 and female captures ranged from zero to 18 (Fig. 2). At two sites we captured zero turtles and at one site we captured a single juvenile. Proportion of males ranged from zero to one among 33 sites. For the total capture analysis, the model containing number of surrounding water bodies as a predictor had the highest support (Table 2). For the sex ratio analysis, the model containing road density as a predictor had the highest support (Table 3; Fig 3). The 95% CIs included zero for both the total capture and sex ratio models, but the 85% CIs did not (0.086–1.381 and 0.003–0.053, respectively), suggesting that a weak relationship exists. Mean female carapace length ranged from 142.9 mm to 254.0 mm, and mean male length ranged from 118.3 mm to 227.0 mm. Neither female (85% CI = -0.044–0.009) nor male (85% CI = -4.352–0.711) size was associated with road density (Fig. 4).

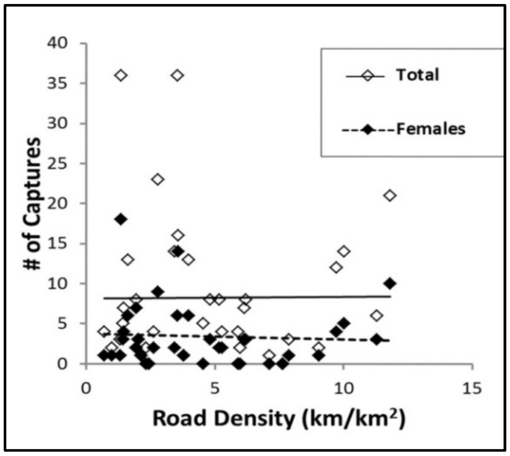

Figure 2. Total number of captured Red-eared Sliders (*Trachemys scripta elegans*) and number of female captures only, in relation to surrounding road density for 36 sites in the Lower Rio Grande Valley (LRGV) of Texas sampled in the summer of 2009. The data indicate no strong relationship between captures and road density.

DISCUSSION

Roads have been shown to affect freshwater turtle populations through habitat fragmentation and direct road mortality. We studied freshwater turtle demographics across a road density gradient in the LRGV. Our analyses indicated no strong relationships between road density and population demographics of Red-eared Sliders. However, we found weak evidence of skewed sex ratios in high road density areas, which is consistent with previous studies (Aresco 2005; Steen and Gibbs 2004). Earlier studies also reported an increase in movement frequency when wetlands are clustered, and cautioned about potential decreases in turtle abundance due to increased road mortality (Beaudry et al. 2008). Our results did not support this potential; in fact, there

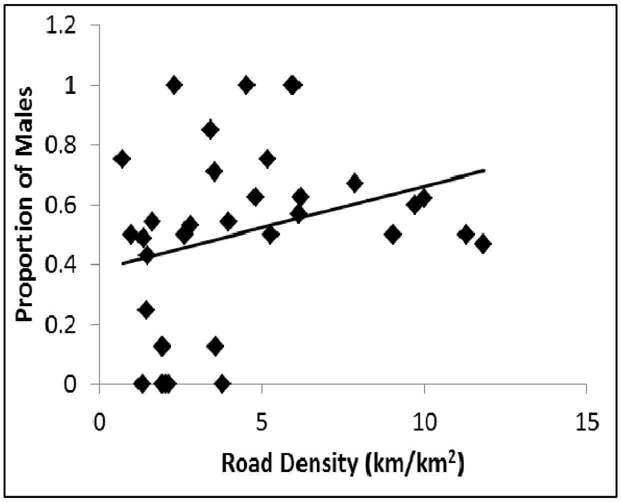

FIGURE 3. Relationship between sex ratios and road density for Red-Eared Sliders (*Trachemys scripta elegans*) at 33 sites in the Lower Rio Grande Valley (LRGV) of Texas in the summer of 2009. The data indicates a weak relationship (r^2 = 0.081) exists between sex ratio and road density.

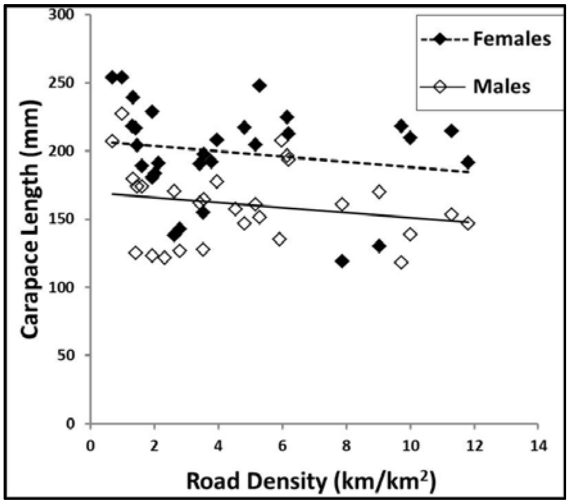

FIGURE 4. Mean female and male carapace length of Red-eared Sliders (*Trachemys scripta elegans*) in relation to road density based on 34 sites in the Lower Rio Grande Valley (LRGV) of Texas sampled in the summer of 2009.

was a weak positive relationship between the number of surrounding water bodies and turtle abundance.

It should be noted that the Red-eared Slider is probably the most adaptable freshwater turtle in the world; it is a species that thrives under a wide variety of environmental conditions (Ernst and Lovich 2009). Therefore, it is possible that Red-eared Sliders in the LRGV have modified their behavior within high road density areas. Rees et al. (2009) concluded that turtles in suburban areas did not use terrestrial habitat as much as turtles in reserves, indicating potential behavioral adaptations that might minimize road mortality. In addition, Beaudry et al. (2008) found that in the areas with busy roads and wetlands on both sides of the road, semi-aquatic turtles do not cross the roads; this could be additional evidence of turtles acclimating to roads but it is also possible that turtles that tend to cross the roads have already been killed and only the sedentary individuals are left.

In some cases increased mortality could be offset by higher reproductive success, either through density-dependent responses or due to higher quality water bodies. For example, reducing the density of individuals in ponds resulted in increased recruitment and survival for Northern Snake-necked Turtles (*Chelodina rugosa*, Fordham et al. 2009). Similarly, suburban water bodies appeared to be higher quality habitat than water bodies in nature reserves for the Eastern Long-necked Turtle (*Chelodina longicollis*) in Australia, potentially due to higher productivity (Roe et al. 2011). Finally, Western Pond Turtle (*Actinemys marmorata*) populations inhabiting high productivity wastewater treatment plants in California had the greatest mean clutch sizes reported for the species and among the fastest growth rates and largest individual sizes reported (Germano 2010). Therefore, although roads in urban environments contribute to direct mortality of turtles and habitat fragmentation, other anthropogenic habitat modifications may increase habitat productivity.

It could be argued that road density is not the best metric for estimating road mortality risk for turtles because it does not explicitly account for traffic levels. Studies have shown that higher traffic can result in increased road mortality for amphibians (Fahrig et al. 1995; Mazerolle 2004) and semi-aquatic turtles (Langen et al. 2012). Unfortunately, we were unable to obtain traffic or human population density information at the scale necessary to test this correlation in our study. However, the highest road density sites were located in heavily urbanized areas with high traffic levels. In contrast, the lowest road density sites were located in rural agricultural areas with correspondingly low overall traffic levels. Thus, although we did not specifically account for traffic in this study, we believe that in our study area this metric was appropriate, and our analyses should have detected road effects on turtle populations if strong relationships existed. The LRGV is a unique region for studying anthropogenic effects on freshwater turtles for three reasons: substantial commercial turtle harvest in the 1990s (Ceballos and Fitzgerald 2004), rapid human population growth (i.e., the human population increased by 119% between 1981 and 2007 [U.S. Census Bureau 1992, 2008]), and available historic survey data (Grosmaire 1977). The results of our previous work (Brown et al. 2011a; Brown et al. 2012) indicated a significant decrease in turtle abundance in the LRGV and suggested that these changes were likely driven by commercial harvest and habitat alteration (e.g.

decreasing water levels at wildlife refuges to manage for waterfowl and shorebirds). Because we did not find strong evidence for a road-effect in this study, we believe our results lend further support to these previous findings (i.e., Brown et al. 2011a; Brown et al. 2012).

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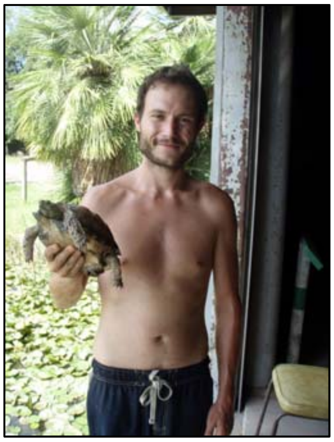

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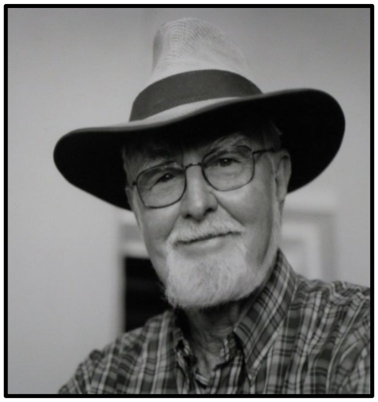

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