Research Article

Freshwater Turtle Conservation in Texas: Harvest Effects and Efficacy of the Current Management Regime

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ABSTRACT The collapse of Asian turtle populations led to the creation of a worldwide freshwater turtle market in the 1990s. Texas is one of several states in the United States that has capitalized on this market. The Texas Parks and Wildlife Department (TPWD) recently instituted regulations designed to protect turtles from commercial harvest in public waters. Two counties in the Lower Rio Grande Valley (LRGV) accounted for 66.1% of known wild turtle harvest in 1999, with no reported harvest in subsequent years. We sampled 60 sites in the LRGV to determine if we could detect harvest effects. We also investigated the potential for sustainable harvest under the new harvest guidelines using source-sink dynamics implemented in a Geographic Information System (GIS) approach. We detected differences congruent with harvest effects for red-eared sliders (*Trachemys scripta*) and Texas spiny softshells (*Apalone spinifera*). Based on a GIS analysis of water bodies throughout the entire state, we estimated that only 2.2% of water bodies are protected under the current commercial harvest regulations. We determined source water bodies could supply 30.5% of sink water bodies in the LRGV, and we concluded that long-term sustainable turtle harvest is unlikely under the current management regime due to the intensity of commercial harvests, the low number of protected water bodies, and non-robust or non-interactive protected populations. One solution to this would be modification of the regulations to include season and bag limits, a management strategy currently implemented in various forms by 14 states in the eastern half of the United States.

KEY WORDS *Apalone* spp., commercial harvest, freshwater turtles, Geographic Information System (GIS), red-eared sliders, softshells, Texas, *Trachemys scripta*.

Despite being considered non-game animals by most wildlife management agencies, freshwater turtles have been harvested worldwide for centuries (Moll and Moll 2004). Freshwater turtles are currently harvested or procured for many purposes, including food, traditional Chinese medicine, turtle farms, pet trades, reptile expositions, zoos, and aquariums (Warwick et al. 1990, Fisher 2000, Gibbons et al. 2000, Ceballos and Fitzgerald 2004, Prestridge 2009). Turtle meat is considered a delicacy in many Asian countries, and excessive harvest for this market caused the collapse of Asian turtle populations and created a worldwide turtle market in the 1990s (Klemens 2000, Rhodin 2000, Guynup 2005). Texas is one of several states in the United States where entrepreneurs capitalized on this market (Ceballos and Fitzgerald 2004, Lowe 2009, Prestridge 2009).

At least 377,534 freshwater turtles were exported from Texas between 1995 and 2000, with the number of exports increasing annually (Ceballos and Fitzgerald 2004). During this period only 35,743 imports were reported, indicating Texas is a major supplier in the worldwide turtle market. Spiny softshells (*Apalone spinifera*) and red-eared sliders (*Trachemys scripta*) accounted for 87.9% of the take of the 16,110 wild-caught turtles reported in 1999 (Ceballos 2001). Furthermore, 69.9% of the take came from 3 counties in the Lower Rio Grande Valley (LRGV): Hidalgo (38.5%), Cameron (27.6%), and Willacy (3.8%). After 1999, regulation changes required only commercial dealers to file annual reports and allowed non-game collectors to sell their captures to dealers with commercial permits. This aggregative mechanism prevents determination of the geographically fine-scale harvest locations available for the 1999 season (Prestridge 2009). In fact, prior to 2007, the Texas Parks and Wildlife Department (TPWD) did not require commercial turtle harvesters to submit annual reports prior to permit renewal and consequently much of the take went unreported (J. Brennan, TPWD, personal communication). Commercial harvesters reported taking 46,879 red-eared sliders and softshells (*Apalone* spp.) from the wild between 2002 and 2007, with none taken from Hidalgo, Cameron, or

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Willacy counties. Based on TPWD harvest reports, commercial turtle harvesters apparently move from county to county annually, probably to maintain high capture-rates. Between 2003 and 2008, 40.2% of all amphibians and reptiles taken from the wild were red-eared sliders (Prestridge 2009).

Little information exists about the impacts of harvest and procurement on freshwater turtle populations. A higher catch-per-unit-effort was reported for painted turtles (*Chrysemys picta*) in non-harvested versus harvested lakes in Minnesota (Gamble and Simons 2004). Conversely, northern snake-necked turtles (*Chelodina rugosa*) in Australia responded to experimental population reduction with increased hatchling recruitment and survival (Fordham et al. 2009). Close and Seigel (1997) found harvested wetlands in Louisiana had significantly smaller male and female red-eared sliders. Because turtles are sold by weight for food markets, there is an incentive to harvest larger turtles.

Fisheries researchers have long been engaged in harvest impact studies, and this information can give insight into expected outcomes of intense turtle harvest, provided the taxa respond similarly to harvest. Selective harvesting has been responsible for population declines and alteration of population structures for several fish species. The use of selective gill nets caused a reduction in the mean length of European whitefish (*Coregonus lavaretus*) in the Gulf of Finland (Heikinheimo and Mikkola 2004). Long-term selective harvesting resulted in a decrease in size at maturity for North Sea plaice (*Pleuronecetes platessa*; Rijnsdorp 1993) and caused accelerated growth rates, a reduction in age at maturity, and a shorter life-span in Atlantic (Arctic-Norwegian) cod (*Gadus morhua*; Borisov 1978). Fordham et al. (2007) found a similar result with northern snake-necked turtles in Australia, confirming that reduced densities of large turtles resulted in accelerated growth rates and reduction in size at maturity.

In 2007, TPWD instituted regulations designed to protect non-game animals from over-harvesting (TPWD 2007). Under the new regulations, all freshwater turtles were protected from harvest on public lands and in public waters. However, the commercial take of the most commonly harvested turtle species remained unregulated on private property. These species included red-eared sliders, softshell turtles, and common snapping turtles (*Chelydra serpentina*). In 2008, TPWD began a 5-year investigation of freshwater turtle populations, involving several universities and agencies. The investigation was designed to provide useful information on population distributions, sizes, structures, and movements as a basis for future commercial harvest regulations.

The current regulations are based on a spatial harvest management model, where over-harvesting and subsequent population collapse in private waters is prevented by replenishment of turtles from public waters (i.e., source-sink). Public water includes all flowing waters and lakes, and all water bodies on state land (Texas Administrative Code §11.021). This harvest management regime has been used for decades by federal and state agencies for managing game species (e.g., National Wildlife Refuges [NWR] and Wildlife Management Areas) with variable but overall positive results (Burroughs 1946, Bellrose 1954, Halpern 2003).

Our objectives were 3-fold. 1) We sought to determine if intensive harvest in the LRGV of Texas produced detectable harvest effects, 2) we performed spatial analyses for the entire state using a Geographic Information System (GIS) to determine the level of protection gained under the current harvest restrictions, and 3) we investigated the potential for protected waters to serve as long-term source populations for harvestable (i.e., private) waters in the LRGV.

STUDY AREA

We conducted our study in Cameron (2,346 km^2), Hidalgo (4,066 km^2), and Willacy (1,545 km^2) counties in the LRGV (Fig. 1). Cameron and Hidalgo counties accounted for 66.1% of the reported wild turtle harvest in 1999, whereas Willacy County accounted for only 3.8% (Ceballos 2001). Agriculture dominated land use in the subtropical LRGV over the last century (Levine 2007). However, human population growth increased substantially over the last 3 decades, resulting in heavy urbanization in Cameron and Hidalgo counties (U.S. Census Bureau 1982, 2007). Between 1976 and 2006 the human populations in Cameron, Hidalgo, and Willacy counties increased by 205%, 281%, and 12%, respectively.

METHODS

Historical record information for harvested sites was minimal due to a lack of perceived harvest threat to turtle populations prior to 2007. Consequently, we were unable to obtain exact localities for turtle harvest in our study area. Therefore, we trapped turtles throughout 2 heavily harvested counties (Cameron and Hidalgo) and an adjacent low harvest county (Willacy) to investigate harvest impacts. In addition to heavy harvest, these counties offered us the opportunity to compare our data to a study conducted prior to commercial turtle harvest in the LRGV (Grosmaire 1977). We trapped turtles at sites within Cameron and Hidalgo counties likely harvested prior to the new regulations on turtle harvest, as well as sites unharvested in recent years (i.e., NWRs, state parks, and nature preserves). We did not randomly select water bodies because our ability to trap a given water body was contingent upon landowner, agency, city, or water district consent. Despite this constraint, we trapped qualitatively suitable water bodies throughout the 3 counties. Trapped sites were $\geq$1 km apart to avoid re-sampling the same populations. We avoided trapping in eastern and northern Willacy County, eastern Cameron County, and northern Hidalgo County, due to predominantly saline and hypersaline water bodies (U.S. Fish and Wildlife Service 2009). In addition, we avoided locations where trap theft or worker safety was clearly an issue. We trapped 21, 17, and 22 sites across Cameron, Hidalgo, and Willacy counties, respectively, completing 5,245 trap days between 10 May 2008 and 14 June 2008 and between 16 May 2009 and 7 July 2009. We conducted this research under TPWD permit

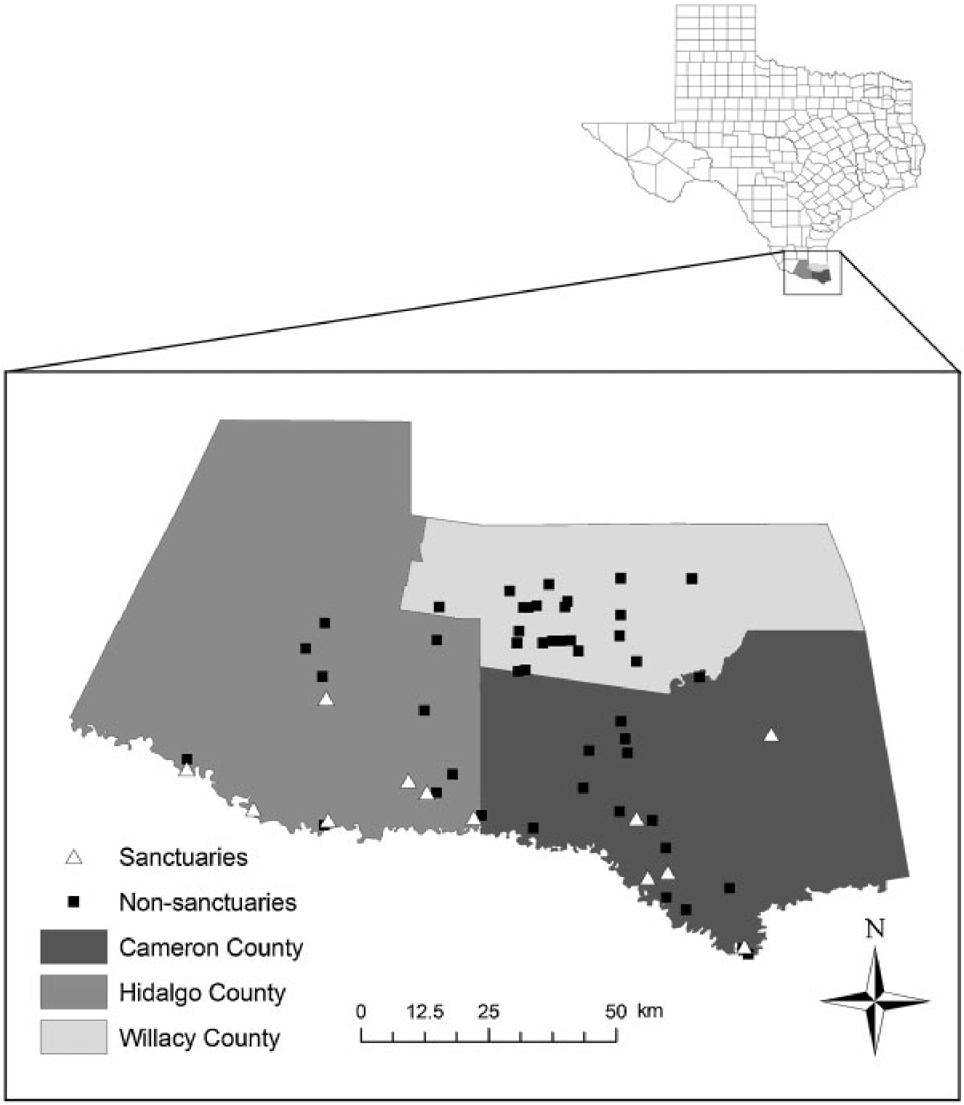

Figure 1. Lower Rio Grande Valley (LRGV) counties in which we studied freshwater turtle harvest in Texas, USA. We trapped 60 sites across these 3 counties, completing 5,245 trap days between 10 May 2008 and 14 June 2008, and 16 May 2009 and 7 July 2009. We avoided eastern and northern Willacy County, eastern Cameron County, and northern Hidalgo County, due to predominantly saline and hypersaline water bodies. Trapped sites were $\geq$1 km apart to avoid re-sampling the same populations.

SPR-0102-191. Trapping and handling methods were approved by the Texas State University-San Marcos Institutional Animal Care and Use Committee (Protocol No. 0715_0428_07).

Trapping Methods

We used 76.2-cm-diameter fiberglass single-throated hoop nets (Memphis Net & Twine Co., Memphis, TN) baited with canned fish, fresh fish, shrimp, or squid in non-consumable containers containing holes for scent dispersal. We re-baited traps every 2 days and when traps were moved. We systematically placed traps along canal, river, pond, and lake borders, securing them to reeds or other vegetation, equidistant to one another when possible. Distances between traps ranged from 2 m to 8 m, depending on the number we used and water body size. We typically moved a portion of the traps to new locations within the site every 2 days to avoid capture bias in locations subjected to multi-day trapping. This sampling design allowed us to maximize habitat coverage given geographic and effort constraints.

We recorded species, sex, carapace length and width, plastron length and width, body depth, and weight for all captures. We measured turtles using Haglof® tree calipers (Haglof, Madison, MS) accurate to 1.0 mm. We weighed individuals using Pesola® precision scales (Pesola, Baar, Switzerland) accurate to 20 g (mass <2,500 g) and 100 g (mass $\geq$2,500 g).

We determined sex using secondary sexual characteristics. Adult male red-eared sliders have elongated foreclaws, and the pre-cloacal portion of the tail extends beyond the edge of the carapace (Gibbons and Lovich 1990). The pre-cloacal portion of the tail in male Texas spiny softshells (*Apalone spinifera*) is also substantially longer (Conant and Collins 1998). We classified red-eared sliders as juveniles if plastron length was <100 mm and <160 mm for males and females, respectively (Gibbons and Greene 1990). We classified

Texas spiny softshells as juveniles if plastron length was <88 mm and <160 mm for males and females, respectively (Webb 1962). We did not assign a sex to juveniles unless obvious male characteristics were expressed. We individually numbered red-eared sliders using carapace notches (Cagle 1939) and imprinted unique numbers into the posterior edge of the carapace of Texas spiny softshells using a Dremel® (Dremel, Racine, WI).

Statistical Analyses

We used 1-way analysis of variance (ANOVA) to test for size and capture-rate differences among sanctuaries (i.e., NWRs, state parks, and nature preserves), non-sanctuaries (i.e., sites in Cameron and Hidalgo counties likely harvested prior to the new harvest regulations), and Willacy County (Kleinbaum et al. 1998). We initially included a habitat-type predictor in 2-way ANOVA models to determine if type of water body (i.e., still vs. flowing) explained turtle size differences. Because habitat-type was not significant in any analyses, we did not include it as a predictor in the final models.

We compared red-eared slider and Texas spiny softshell capture-rate using site as the sampling unit. We calculated capture-rate as the number of turtles captured per trap day, excluding recaptures. We excluded sites without captures to control for trapping potentially unsuitable habitat. We excluded sites with <50 trap days to maximize the probability that our capture data represented realistic abundance differences among populations. We used a square-root transformation to normalize Texas spiny softshell capture-rates (Fowler et al. 1998).

We compared adult male and female red-eared slider and Texas spiny softshell carapace lengths using individual turtles as the sampling unit. We used carapace length to compare mean length differences by sex. For all analyses we considered results to be significant if the probability of occurrence by random chance alone was ≤5% (i.e., $P \leq 0.05$). When results were significant, we used Tukey's Honestly Significant Difference (HSD) test to determine which means were different (Kleinbaum et al. 1998). We performed all statistical analyses using R (R Version 2.7.2, www.r-project.org, accessed 25 Aug 2008).

Spatial Analyses

We estimated the area and number of protected and unprotected water bodies under current harvest regulations throughout the state. In addition, we performed a more detailed examination of the counties included in this harvest investigation. We investigated the potential for protected water bodies in Cameron, Hidalgo, and Willacy counties to serve as source populations for unprotected (i.e., harvestable) water bodies. We performed all spatial calculations and generated all maps using ArcMap 9.3.

We obtained a base shape file of Texas counties from the Texas Natural Resource Information System (TNRIS 2009), and shapefiles of water bodies within the counties from the United States Geological Survey's National Hydrography Dataset (2009). We acquired locations of national, state, and city parks, as well as other public land from TNRIS (2009). We supplemented the protected layer by manually adding large public water bodies not delineated in the original shapefile. We used these layers to estimate the total area and number of protected water bodies in Texas.

We obtained base shapefiles of Cameron, Hidalgo, and Willacy counties from TNRIS (2009), and shapefiles of water bodies within the counties from the United States Geological Survey (2009). We used county grid maps from Texas Department of Transportation (TXDOT 2009) and Ortho-imagery files from the United States Department of Agriculture (2009) to include canals and other major water bodies missing from the National Hydrography Dataset. We considered water bodies protected if they occurred within public land (including all flowing waters), parks, or nature preserves. We attained locations of NWRs, TPWD property, National Park Service property, preserves, and city parks from the Texas General Land Office (2009). We left public areas readily accessible to poaching as protected, despite known poaching at some of these locations (M. Sternberg, U. S. Fish and Wildlife Service, personal communication), resulting in a conservative estimate of truly protected areas. We considered all remaining water bodies to be located on private land and therefore accessible for turtle harvesting.

We placed 1-km buffers around water bodies to determine the proportion of unprotected (sink) populations that theoretically could be continually recolonized by robust protected (source) populations. Sliders can disperse great distances, but typical home-range sizes are <1 km (Schubauer et al. 1990, Ernst et al. 1994). We clipped the protected layer from the total water bodies layer to determine the number of protected water bodies. The total number of water bodies within this clip was the number of protected water bodies, and the difference from the total was the number of unprotected water bodies. We then calculated total area of protected and unprotected water bodies. We determined the number of currently unprotected water bodies that could theoretically be supplied by robust source populations by calculating the difference between the protected and total number of water bodies present within the 1-km buffer.

We also investigated the potential for highways to interfere with turtle movements between protected and unprotected water bodies. We obtained a Texas roads shapefile from TNRIS (2009) and selected highways in the LRGV. We calculated total highway mileage that intersects with the 1-km buffers around protected sites. We also eliminated unprotected water bodies within the 1-km buffers that would require turtles to cross highways to reach them.

RESULTS

We captured 676 unique red-eared sliders and 185 unique Texas spiny softshells at 48 of the 60 trapped sites. Of these captures, 338 red-eared sliders and 57 Texas spiny softshells came from 10 of the 13 trapped sanctuary sites. We recaptured 26 red-eared sliders and 4 Texas spiny softshells, including 2 red-eared sliders and 1 Texas spiny softshell that we recaptured twice.

Table 1. Capture-rate (CR) by species (no. of turtles per trap day) of freshwater turtles captured between 10 May 2008 and 14 June 2008 and between 16 May 2009 and 7 July 2009 for predictors used we used to determine if intensive freshwater turtle harvest in the lower Rio Grande Valley (LRGV) of Texas resulted in lower captures per unit effort in harvested areas.

Predictor	Species	Mean CR	SD	*n*
Cameron County	Red-eared slider	0.142	0.13	11
Hidalgo County	Red-eared slider	0.086	0.059	6
Willacy County	Red-eared slider	0.289	0.255	11
Sanctuary	Red-eared slider	0.153	0.208	10
Non-sanctuary	Red-eared slider	0.123	0.112	17
Cameron County	Texas spiny softshell	0.059	0.084	11
Hidalgo County	Texas spiny softshell	0.04	0.05	6
Willacy County	Texas spiny softshell	0.088	0.114	11
Sanctuary	Texas spiny softshell	0.012	0.021	10
Non-sanctuary	Texas spiny softshell	0.052	0.073	17

Red-eared slider capture-rates were not different among sanctuaries, non-sanctuaries, and Willacy County ($F_{2,35} = 2.73$, $P = 0.079$). Texas spiny softshell capture-rates were also not different among sanctuaries, non-sanctuaries, and Willacy County ($F_{2,35} = 1.68$, $P = 0.201$). Among non-sanctuary sites, mean capture-rate was lowest in Hidalgo County for both species (Table 1). Mean capture-rate was higher in sanctuaries than non-sanctuaries for red-eared sliders, and lower in sanctuaries than non-sanctuaries for Texas spiny softshells.

Male red-eared slider carapace lengths did not differ among sanctuaries, non-sanctuaries, and Willacy County ($F_{2,252} = 0.18$, $P = 0.833$). Conversely, Tukey's HSD test determined female red-eared sliders were larger in sanctuaries than non-sanctuaries and larger in Willacy County than non-sanctuaries ($F_{2,247} = 5.02$, $P = 0.007$; Table 2). Male Texas spiny softshells were larger in sanctuaries than non-sanctuaries and larger in sanctuaries than Willacy County (Tukey's HSD test: $F_{2,88} = 13.16$, $P < 0.001$). Tukey's HSD test also determined that female Texas spiny softshells were larger in sanctuaries than non-sanctuaries and larger in sanctuaries than Willacy County ($F_{2,38} = 13.34$, $P < 0.001$).

Spatial Analyses

Our analyses indicated 1,432,800 ha of fresh water occurred in the state, with 45.2% protected from harvest under current regulations (Fig. 2). We estimated 1,007,464 water bodies in the state, with 22,637 protected (i.e., 2.2%). There were 23,703 ha of inland water in the study area, with 14,090 ha protected from harvest (i.e., 59.4%). Of the 14,090 ha of protected water, 53.9% was unsuitable habitat due to hypersaline or saline conditions. Based on our 1-km home-range buffer, 22.9% of harvestable water could be replenished by protected source populations.

The total number of water bodies in Cameron, Hidalgo, and Willacy counties was 1,069 with 269 protected (i.e., 25.2%). The percentage of harvestable water bodies potentially replenished by protected source populations was 30.5%. We estimated 184.8 km of highway intersected 1-km buffers around protected water bodies in the LRGV. When we considered highways as barriers to movement between water

Table 2. Mean carapace length (CL) by sex and species (mm) of freshwater turtles captured between 10 May 2008 and 14 June 2008 and between 16 May 2009 and 7 July 2009 for predictors we used to determine if intensive freshwater turtle harvest in the lower Rio Grande Valley (LRGV) of Texas resulted in smaller-sized turtles in harvested areas.

Predictor	Species	Sex	Mean CL	SD	*n*
Cameron County	Red-eared slider	M	161.4	30.6	49
		F	211.4	23.9	32
Hidalgo County	Red-eared slider	M	177.0	31.4	10
		F	205.5	27.2	11
Willacy County	Red-eared slider	M	160.4	31.8	80
		F	221.3	21.3	84
Sanctuary	Red-eared slider	M	160.6	31.0	115
		F	222.4	23.5	123
Non-sanctuary	Red-eared slider	M	162.5	31.7	61
		F	209.9	24.6	43
Cameron County	Texas spiny softshell	M	147.2	13.7	21
		F	289.9	42.1	7
Hidalgo County	Texas spiny softshell	M	165.0	32.1	6
		F	256.2	39.7	5
Willacy County	Texas spiny softshell	M	150.7	13.4	38
		F	259.7	43.4	12
Sanctuary	Texas spiny softshell	M	171.3	18.6	26
		F	351.7	61.8	17
Non-sanctuary	Texas spiny softshell	M	151.2	20.0	27
		F	275.8	42.9	12

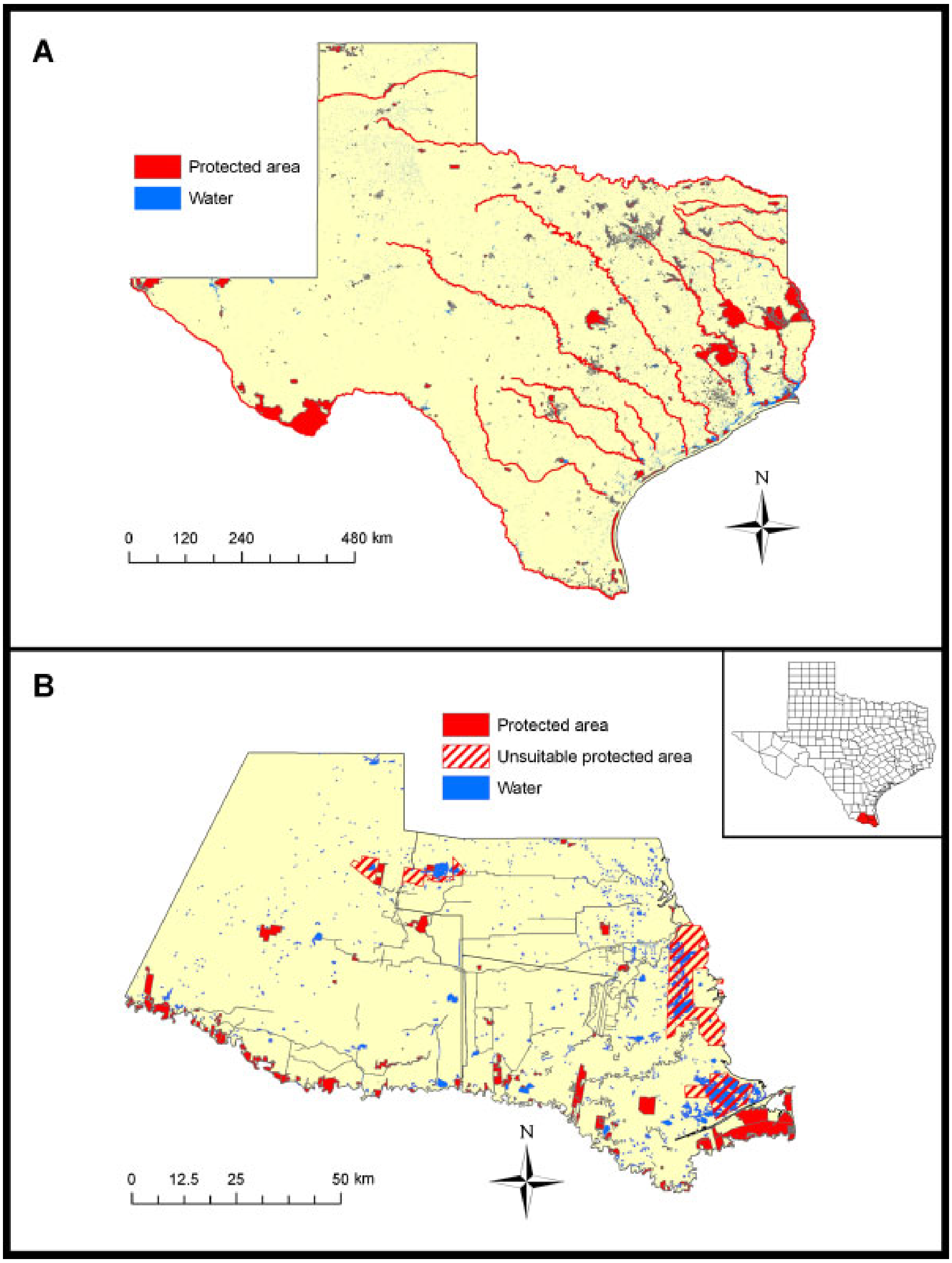

Figure 2. (A) Areas protected and unprotected from freshwater turtle harvest by the Texas Parks and Wildlife Department (TPWD) as of 2007 in the state of Texas, USA. No commercial harvest is permitted in public water bodies, whereas unregulated harvest of common turtle species is allowed in private water bodies. Approximately 94% of Texas is privately owned, resulting in 2.2% of the estimated 1,007,464 water bodies in the state being protected. (B) Water bodies protected and unprotected from freshwater turtle harvest in Cameron, Hidalgo, and Willacy counties, Texas, USA. Unsuitable protected areas contain protected water that is predominantly hypersaline. This unsuitable freshwater turtle habitat represents 53.9% of the protected water body area in this study. Although these unsuitable zones extend onto private properties, we did not have the data to map their extent. Based on our analyses there were 1,069 water bodies in our study area, 269 of which were protected (i.e., 25.2%).

bodies, the percentage of harvestable water bodies potentially replenished by protected source populations was reduced to 28.0%.

DISCUSSION

We found female red-eared sliders were larger in sanctuaries and Willacy County, compared to non-sanctuaries, congruent with our expected results based on previous research. However, we did not find differences between counties or sanctuaries and non-sanctuaries for male red-eared sliders, which may be explained by females being targeted more often for food markets due to their larger size, as well as replacements for turtle farm breeding stock. Male and female Texas spiny softshells were larger in sanctuaries compared to non-sanctuaries and Willacy County. We were told by numerous local fishermen that unlike red-eared sliders, softshell turtles were a valued food source in the LRGV. We were not surprised that Texas spiny softshells were smaller in

Willacy County than sanctuaries, given 64.3% of Texas spiny softshell captures in Willacy County came from heavily fished canals.

No capture-rate results were significant due to large among-site variability, although among non-sanctuary sites, capture-rates were lowest in Hidalgo County and highest in Willacy County for both species. Only 3 of the 13 sanctuary sites had robust red-eared slider populations (i.e., Edinburg Scenic Wetlands, Southmost Preserve, and TPWD fish hatchery), which is a consequence of most federal and state wildlife management areas in the LRGV primarily managing for shorebirds and waterfowl. Draw-down management results in periodic draining of wetlands or maintaining consistently low water levels to support foraging activity, which can create low-suitability turtle habitat (U.S. Fish and Wildlife Service 1997, Byron et al. 1999, Hall and Cuthbert 2000). These management decisions have resulted in the loss of previously robust freshwater turtle populations in favor of other management objectives. Grosmaire (1977) captured 257 unique red-eared sliders in 480 trap days at Santa Ana NWR using hoop nets, whereas we captured only 5 in 280 trap days. In addition to sanctuary management changes, turtle harvest near sanctuaries may be creating attractive sinks for turtles as densities are reduced in harvested waters. Increased dispersal into sinks would be an unintended consequence of the current TPWD management efforts that would manifest itself in higher movements of turtles from sanctuaries.

Turtle harvesting results in average body size reductions (Close and Seigel 1997, Gamble and Simons 2004), which is consistent with long-term fisheries research (Rijnsdorp 1993, Heikinheimo and Mikkola 2004, Harvey et al. 2006). Fisheries experiments revealed a reduction in size was caused not only by the harvesting of larger individuals, but also by a consequent shift in genetic dominance towards inherently smaller or slower growth-rate individuals (Heikinheimo and Mikkola 2004, Allendorf and Hard 2009). The influence of harvest on the genetics of freshwater turtle populations is needed to determine if investigators are detecting a temporary artifact of harvest, or a true shift towards smaller individuals. Previous research has shown home-range size and successful recruitment are positively correlated with body size in freshwater turtles (Schubauer et al. 1990, Tucker et al. 1998, Litzgus et al. 2008). Therefore, body size reductions could have negative consequences for recruitment, population, and meta-population dynamics.

Our spatial analyses showed protection under the current regulations favors a much greater area than number of water bodies in the LRGV, which is not surprising, as Laguna Atascosa NWR, United States Fish and Wildlife refuge tracts, reservoirs, and irrigation canals account for most of the total protected area. Unfortunately half of this area contains unsuitable freshwater turtle habitat, and many of the remaining sites do not house large freshwater turtle populations. Capture-rates per trap day in 5 of 7 trapped reservoirs (0.104, SD $= 0.1$, $n = 5$) were far lower than the mean capture-rate for all other sites (0.261, SD $= 0.4$, $n = 55$). Freshwater turtles are a primary food source for adult American alligators (*Alligator mississippiensis*; Delany and Abercrombie 1986). An abundance of American alligators, coupled with periodic saltwater intrusion into freshwater zones due to extreme weather, seems to maintain low habitat suitability for freshwater turtles at Laguna Atascosa NWR. We captured no turtles at the refuge in 100 trap days, and Grosmaire (1977) captured only 16 in 280 trap days. We were informed of known poaching at NWR tracts in recent years (M. Sternberg, U. S. Fish and Wildlife Service, personal communication), indicating that new regulations may not deter harvesting from public waters, despite their legal status.

Only 2.2% of the water bodies in state are protected under current harvest regulations, which is not surprising, as 94% of Texas is privately owned (Texas Center for Policy Studies 2000). The LRGV is particularly rich in NWRs, state parks, and preserves with 25.2% of water bodies protected. However, protected sites are largely clustered around the Rio Grande and coastal areas. Consequently, only 30.5% of harvestable water bodies could potentially exist in a source-sink system; 28.0% if highways are considered turtle movement barriers. Granted, this assumes all unprotected water bodies are harvested, which is not true. Non-harvested unprotected water bodies would also serve as source populations. However, known harvest coupled with non-robust populations in many protected water bodies leads us to conclude a sustainable source-sink system is not possible without additional restrictive regulations.

We focused on only one of a suite of factors influencing freshwater turtle populations in the LRGV. Substantial human population growth has occurred in this region over the last 3 decades, particularly since the enactment of the North American Free Trade Agreement (NAFTA) in the 1990s, resulting in extensive urbanization in Cameron and Hidalgo counties (U.S. Census Bureau 1982, 2007). Water is redirected from agricultural to urban use as the human population grows and expands (Levine 2007). Hidalgo County alone experienced a 59.7% increase in urban land-use between 1993 and 2003, with a corresponding 10.3% decrease in irrigated land and a 19.3% decrease in surface water (Huang and Fipps 2006). Increased urbanization leads not only to loss of suitable habitat, but also increased road mortality (Gibbs and Shriver 2002, Steen and Gibbs 2004, Aresco 2005*a*). We estimated 184.8 km of highway within 1 km of harvest-protected water bodies in the LRGV. The high density of major roads exemplifies the reality that protection from harvest does not mean turtles are protected from mortality.

Conserving adult freshwater turtles is crucial to long-term population viability due to low fecundity, low hatching success, and delayed maturity (Congdon et al. 1993, 1994; Heppell 1998). There is evidence additive mortality as low as 1–5% to adult age classes may be the threshold most turtles can tolerate before incurring negative population growth (Doroff and Keith 1990; Congdon et al. 1993, 1994). Furthermore, other factors like road mortality and changes in water levels can be important impact factors on population dynamics (Bodie and Semlitsch 2000, Aresco 2005*b*). South

Texas is historically drought-prone (Stahle and Cleaveland 1988), and turtle migrations are often a response to unsuitable habitat conditions driven by changes in water levels (Cagle 1950). Many public water bodies in the LRGV are as vulnerable to desiccation as private water bodies, which can severely affect source-sink dynamics.

Our spatial analyses indicate long-term sustainable harvest is unlikely to be maintained under the current regulations consequent of both inadequate distribution and assured viability of protected source populations. McCullough (1996) proposed an active form of spatial harvest management, where the number, size, and placement of protected areas changes in response to harvest trends, theoretically resulting in protected areas that serve as robust source populations. This zonal management would be one attractive alternative to the current regime because the only required population data are estimated numbers of individuals harvested per location per unit time, a current requirement for commercial turtle harvesters.

However, because successful spatial harvest management depends on dispersal from protected areas, it assumes protected areas continually house robust populations. There is no evidence for the ability of protected areas in the LRGV to maintain robust, long-term source populations for turtles. Furthermore, harvest response may be slow due to the definitive life-history characteristics of turtles (Gibbons and Lovich 1990, Ernst et al. 1994). If dispersal-rates are high, there may be a substantial time-lag before overexploitation is detected, possibly resulting in depletion of turtles populations. Therefore, although it would likely be more effective than the current management regime, slow response times and the inability to ensure protected habitats remain suitable make even active spatial control a risky harvest management tool for turtles. This management regime would also require private waters be included in the harvest control, which is in direct conflict with the current paradigm. Furthermore, enforcing these regulations on private property is probably not feasible, as the origin of a given turtle is reported by the harvester post-take.

MANAGEMENT IMPLICATIONS

The commercial take of turtles in Texas is now managed analogously to stocked fish when in actuality turtle population ecology is more analogous to that of waterfowl as a wildlife resource. Consequently, we recommend that a more conservative approach be taken for commercial harvest management. In addition to the spatial control already enforced, harvest regulations should be modified to prevent turtle harvest during breeding and nesting seasons. Furthermore, bag and size limits should be enforced for female turtles due to their substantially greater influence on population viability. This typical game management approach is currently being utilized in various forms by 14 states in the eastern half of the United States (Lowe 2009). Eight other states have banned commercial turtle harvest. Only Oklahoma has a turtle management regime similar to that of Texas. It may be possible to harvest Texas' freshwater turtles sustainably, but it will require greater regulatory effort from TPWD, and probably a much lower harvest-rate.

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