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Author(s): Steven H. Pearson and Jon J. Wiebe
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Distribution, Sex Ratios, and Size Distributions of Diamond-Backed Terrapins (*Malaclemys terrapin*) in the Deltaic Plain of Louisiana

Steven H. Pearson[1] and Jon J. Wiebe

Louisiana Department of Wildlife and Fisheries, 646 Cajundome Boulevard, Lafayette, LA 70503, USA

Abstract: Diamond-Backed Terrapins (*Malaclemys terrapin*) are emydid turtles found in estuarine systems along the Gulf and Atlantic coasts of the United States between Texas and Massachusetts, and in Bermuda. Reductions in many terrapin populations have been documented throughout the species' range in association with habitat loss, overharvesting for consumption, bycatch in commercial and recreational fishing gear, and collection for the pet trade. Information on populations within Louisiana is limited, with survey efforts being performed only recently throughout the state's coastal zone. From 2012 through 2014, we sought to determine the distribution of Diamond-Backed Terrapins within the Deltaic Plain region of Louisiana, describe sex ratios and size class structure within select management basins, and establish marked populations to promote continued study of the species. Of the 27 terrapin sampling sites initially selected, 24 were chosen for further evaluation; a subset of these same locations were sampled more intensively in 2014. In all years, we utilized unbaited fyke nets. The presence of Diamond-Backed Terrapins was associated with a variety of coastal marsh vegetative communities (e.g., intermediate, brackish, and saline). Basin-specific analyses revealed variation in mean size, and sex ratios skewed toward males within all basins indicating higher female mortality rates or male-biased recruitment. These efforts confirm the presence of Diamond-Backed Terrapins across the Deltaic Plain region of the Louisiana coastline, and inform future examinations of the regional and range-wide abundance and population dynamics of the species.

Key words: Abundance; Coastal brackish and salt marsh; Reptilia; Testudines

Diamond-backed Terrapins (*Malaclemys terrapin*) are emydid turtles found in estuarine systems along the Gulf and Atlantic coasts of the United States between Texas and Massachusetts (Ernst and Lovich 2009); a disjunct population persists in Bermuda (Parham et al. 2008). Populations of Diamond-Backed Terrapins are well studied within segments of their range and long-term, ongoing research programs exist in many states (Mitro 2003; Butler et al. 2004; Dorcas et al. 2007). Reductions in terrapin populations have been documented throughout the species' range in association with harvesting for consumption, loss of habitat, and bycatch in commercial and recreational fisheries gear (e.g., crab traps, shrimp trawls; Seigel and Gibbons 1995; Butler et al. 2006; Drabeck et al. 2014). The continued collection of terrapins for the pet trade likely also contributes to reduced population sizes, as has been seen with other turtle species (Cheung and Dudgeon 2006; Pitt and Nickerson 2013).

Across the range of Diamond-Backed Terrapins, Louisiana contains the largest amount of potential habitat of any state, with extensive and dynamic coastal marsh environments equaling approximately 652,800 ha (Selman et al. 2014). In Louisiana, Diamond-Backed Terrapins are listed as a S3 species by the Louisiana Natural Heritage Program (state rank listed as "rare and local throughout the state;" LNHP 2015) and globally ranked as a G4 species ("apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery;" LNHP 2015). Collectively, these rankings indicate that terrapin populations persist within portions of their established range, but precise locality and population trends along the Louisiana coast are unknown. Within Louisiana, information on terrapin populations has been historically limited, with only recent efforts devoted to assess the abundance and distribution in southwestern Louisiana (e.g., Selman et al. 2014).

Louisiana's coast is categorized into two broad marsh regions: Deltaic Plain and Chenier Plain. Deltaic Plain marshes exist between Southwest Pass in Vermillion Bay eastward along the Gulf Coast to the Mississippi state line and beyond, whereas Chenier Plain marshes occur west of the Deltaic Plain to the border with Texas and beyond (McBride et al. 2007; GCJV 2009; Fig. 1). Louisiana's Deltaic Plain marshes are characterized by shallow bays with low gradient marshes that are broadly categorized as saline, brackish, intermediate, and fresh, utilizing established salinity gradient criteria and associated vegetative communities (Sasser et al. 2014; Selman et al. 2014). Even though potential habitat for Diamond-Backed Terrapins is considered widespread, there has been little effort to systematically survey for Diamond-Backed Terrapins within the state's Deltaic Plain region.

Here, we sought to expand the understanding of the population ecology of Diamond-Backed Terrapins in Louisiana, with particular focus on the Deltaic Plain region. Specifically, we wanted to determine the distribution of Diamond-Backed Terrapins within the region, describe the sex ratio and size distribution of the species throughout the Deltaic Plain marshes, and establish marked populations to promote continued study of terrapin populations along Louisiana's coast.

Materials and Methods

Sampling Locations

On account of the diverse and expansive coastal zone in Louisiana, a variety of data sources was utilized to narrow the scope of potential sampling locations. Site selection considered established habitat criteria (Palmer and Cordes 1988; Roosenburg et al. 1999), museum specimen collection locations (see Selman et al. 2014), and incidental capture/

[1] Correspondence: e-mail, stevenhpearson@gmail.com

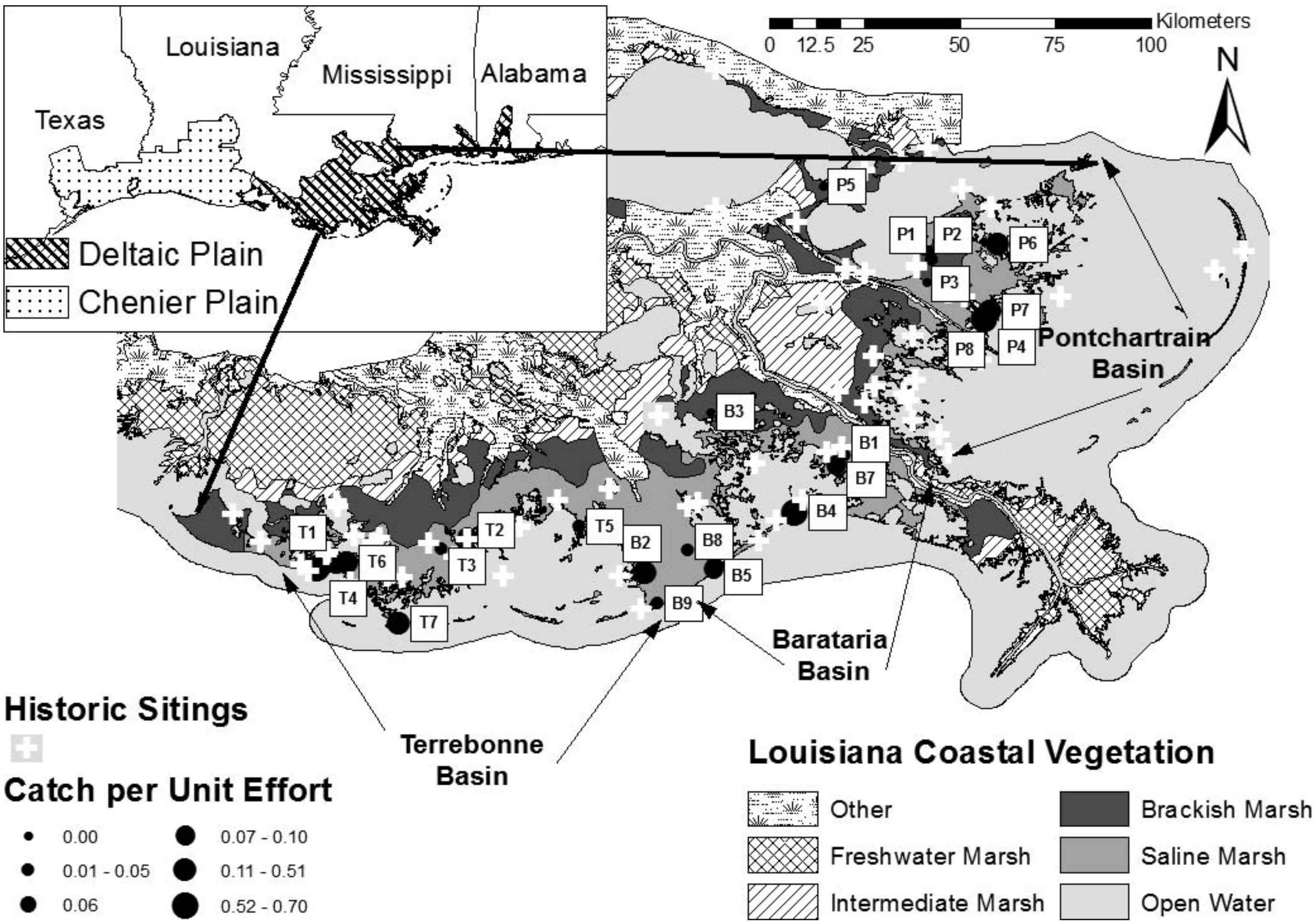

FIG. 1.—Locations of Diamond-Backed Terrapins (*Malaclemys terrapin*) from historic museum records, historic trawl sampling data (from the Louisiana Department of Wildlife and Fisheries), and surveys of the Deltaic Plain in Louisiana (inset). Locations overlay background habitat categories defined by vegetative communities (Sasser et al. 2014).

sighting locations from historic trawl sampling data from the Louisiana Department of Wildlife and Fisheries (LDWF). As the majority (70%) of Louisiana's coastal zone is privately owned, access permission was sought from both private and public landowners as well as natural resource managers. Once granted access, we conducted on-site evaluations at 27 potential sampling locations, with a subset ($n = 24$) deemed suitable for future efforts. Of note, the three locations not assessed did not have vegetative or aquatic habitats known to support terrapin populations; YSI salinity readings at these sites confirmed salinity levels below 4 parts per thousand.

Terrapin Trapping and Captures

Following Selman and Baccigalopi (2012), unbaited fyke nets ($n = 5$–10/site) with 7.6-m or 15.2-m leads were utilized to sample terrapins. The actual number of nets set within any given sampling location was limited to available habitat. The nets were anchored with poles across appropriately sized bayous, inlets, and embayments and were typically checked for terrapin captures for 4 consecutive days (weather conditions sometimes prevented daily monitoring). Trapping occurred at the 24 designated sampling locations August–November 2012 and April–November 2013. We utilized the number of turtles captured per net day (i.e., catch per unit effort [CPUE]) from the 2012 and 2013 data to select sites with the highest CPUE for more detailed study from April through June 2014. We selected two sampling locations within each of the following three LDWF fisheries management basins: (1) Pontchartrain, (2) Barataria, and (3) Terrebonne, all of which comprise the state's Deltaic Plain region (Bourgeois et al. 2014).

Straight-line plastron length (PL; $\pm$ 1 mm) was measured with calipers between the nuchal and anal notches of each captured terrapin, and sex was determined on the basis of precloacal tail length (Tucker et al. 2001). To facilitate future identification, each subject received a unique permanent mark by notching with a half-round file or by drilling holes in marginal scutes (Cagle 1939), as well as a passive integrated transponder (Biomark Inc.). Date and location of each capture were recorded using a handheld global positioning system unit. All individuals were released near their point of capture within 48 h. We used a two-way analysis of variance (ANOVA) to detect any differences in PL as a function of either sex or management basin. If differences existed ($P < 0.05$), we used Tukey's honest significant difference (HSD) test to detect differences in response means (Crawley 2013).

Table 1.—Captures of Diamond-Backed Terrapins (*Malaclemys terrapin*), including sex ratio and catch per unit effort (CPUE), on site-specific and regional scales within the Deltaic Plain region of Louisiana. Regions are organized east to west; sex ratios (♂:♀) represent the number of males per female captured within an individual region. NA = no terrapins were captured; ND = only a single sex was captured.

Region	Site name	Years trapped	No. of captures (♂/♀/?)	♂:♀	Trap days	CPUE (captures/day)
Pontchartrain Basin	Pontchartrain 1	2012, 2013	2 (1/1/0)	1.0	93	0.02
	Pontchartrain 2	2012, 2013	0	NA	37	0
	Pontchartrain 3	2012, 2013	0	NA	40	0
	Pontchartrain 4	2012, 2013, 2014	106 (74/32/0)	2.31	191	0.55
	Pontchartrain 5	2012, 2013	0	NA	24	0
	Pontchartrain 6	2012, 2013, 2014	66 (39/27/0)	1.44	375	0.18
	Pontchartrain 7	2012, 2013	10 (4/6/0)	0.66	86	0.12
	Pontchartrain 8	2012, 2013	0	NA	34	0
	Pontchartrain Basin		184 (118/66)	1.78	880	0.21
Barataria Basin	Barataria 1	2012, 2013	1 (0/1/0)	ND	63	0.02
	Barataria 2	2012, 2013	2 (1/1/0)	1.0	15	0.13
	Barataria 3	2012, 2013	0	NA	25	0
	Barataria 4	2012, 2013, 2014	189 (103/85/0)	1.21	274	0.69
	Barataria 5	2012, 2013	9 (0/7/2)	ND	78	0.10
	Barataria 6*	2012, 2013	3 (0/2/1)	ND	*	*
	Barataria 7	2012, 2013, 2014	32 (16/16/0)	1	237	0.13
	Barataria 8	2012, 2013	3 (1/2/0)	0.5	64	0.05
	Barataria 9	2012, 2013	2 (0/2/0)	ND	66	0.03
	Barataria Basin		241 (122/115/3)	1.06	812	0.30
Terrebonne Basin	Terrebonne 1	2012, 2013	3 (2/1/0)	2.0	15	0.20
	Terrebonne 2	2012, 2013	7 (1/6/0)	0.17	84	0.08
	Terrebonne 3	2012, 2013	3 (3/0/0)	NA	57	0.05
	Terrebonne 4	2012, 2013, 2014	160 (99/58/3)	1.70	276	0.58
	Terrebonne 5	2012, 2013	1 (1/0/0)	ND	70	0.01
	Terrebonne 6	2012, 2013, 2014	98 (57/41/0)	1.39	220	0.45
	Terrebonne 7	2012, 2013	1 (0/1/0)	ND	8	0.13
	Terrebonne Basin		273(163/107/3)	1.52	730	0.37

* Terrapin captured with unknown location and search effort submitted to Louisiana Department of Wildlife and Fisheries.

Results

Trapping efforts from 2012 through 2014 resulted in 667 individuals (278 female, 385 male, 4 juvenile; Table 1). Of the 667 captures, 180 were from the Ponchartrain Basin, 224 from Barataria Basin, and 263 from Terrebonne Basin. Of the 24 sampling locations, Diamond-Backed Terrapins were captured at 17 sites with a mean CPUE of 0.19 (range = 0.02–0.58, Table 1). Seven of the 17 successful sampling locations had a CPUE less than 0.10, and at least one location with a low value (<0.1) was found within each management basin (Table 1). If unsuccessful sites were included, mean CPUE was 0.16. A total of 31 recaptures was made (for a total of 698 captures for the study), occurring within all three management basins, but not within all sampling locations.

Mean Size

The mean (± 1 SD) PL of female terrapins in the Pontchartrain, Barataria, and Terrebonne basins was 166.2 ± 29.9 mm (range = 71–207 mm), 174.3 ± 18.3 mm (range = 64–210 mm), and 168.2 ± 18.8 mm (range = 84–198 mm), respectively (Fig. 2). ANOVA showed a difference in female size between basins ($F = 3.57$, df = 2, $P = 0.03$), and a post hoc Tukey HSD test showed that female terrapins in Barataria Basin were larger than females in Ponchartrain ($P < 0.05$) but were similar to females in Terrebonne. The mean male PL in Pontchartrain, Barataria, and Terrebonne basins was 107.4 ± 8.1 mm (range = 88–126 mm), 110.5 ± 6.2 mm (range = 92–126), and 110.3 ± 5.9 mm (range = 95–125), respectively (Fig. 3). ANOVA showed a difference in male size between basins ($F = 8.02$, df = 2, $P \leq 0.001$) and a post hoc Tukey HSD test showed that males in Pontchartrain Basin were smaller than males in the other two basins.

Sex Ratios

At all study sites where both sexes were captured, sex ratios ranged between 1:6 and 1:0.43 (male:female; Table 1). Sex ratios among sampling locations with larger sample sizes (2014 sampling sites) ranged from 1:1 to 2.31:1. Male-dominated sex ratios were documented throughout all management basins, although the sex ratio in Barataria Bay was near 1:1 (Table 1).

Discussion

Historic records suggest that Diamond-Backed Terrapins were found in high densities in portions of their range (Hay 1917; Cagle 1952), but harvest for consumption caused population collapses along the Atlantic and Gulf coasts (Hay 1917). As in other parts of the range, commercial terrapin harvest in Louisiana for markets in the northeastern United States and New Orleans during the late 19th and early 20th centuries likely depleted populations (Holder 1913; Cagle 1952; Davis 1973; Bishop 1983). The overharvest of terrapins in Louisiana is evidenced in two recent genetic studies of terrapins across Louisiana's coast that found low genetic diversity and potential bottlenecks in recent history (Drabeck et al. 2014; Petre et al. 2015). Our finding of a patchy distribution with local areas of abundance in Louisiana's Deltaic marshes are similar to those described in the Chenier Plain (Selman et al. 2014). In Pontchartrain and Terrebonne basins, the highest CPUE sites were within remote locations. In contrast, the site with the highest CPUE in Barataria Basin was in relative proximity to anthropogenic

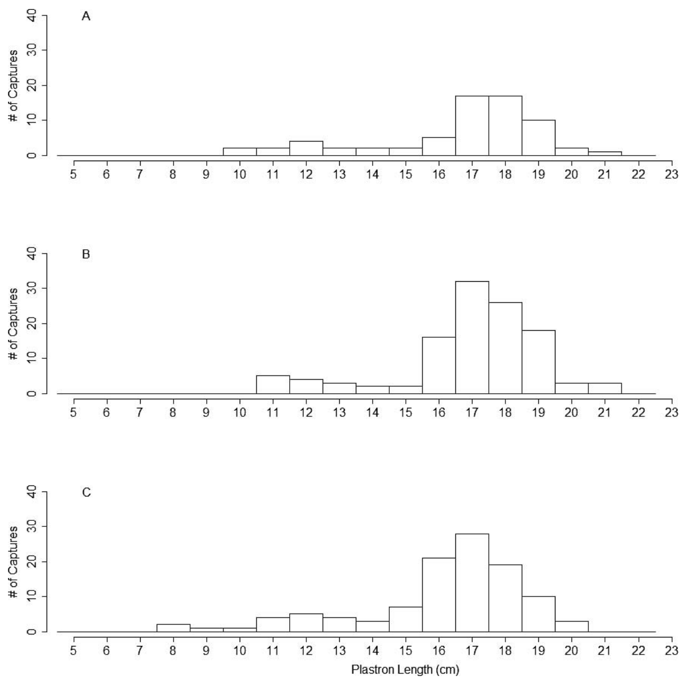

Fig. 2.—Size distribution of female Diamond-Backed Terrapins (*Malaclemys terrapin*) within Deltaic Plain management basins of Louisiana, USA. (A) Ponchartrain Basin, (B) Barataria Basin, (C) Terrebonne Basin.

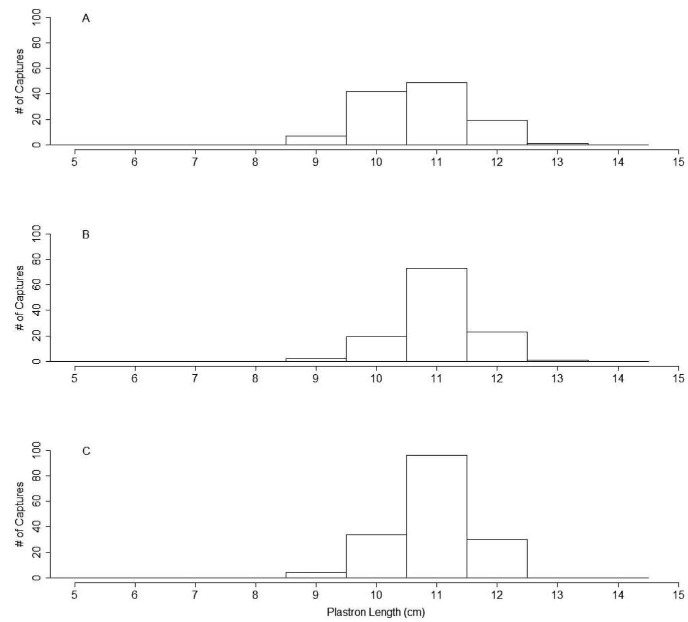

Fig. 3.—Size distribution of male Diamond-Backed Terrapins (*Malaclemys terrapin*), within Deltaic Plain management basins of Louisiana, USA. (A) Ponchartrain Basin, (B) Barataria Basin, (C) Terrebonne Basin.

development (e.g., boat launch, fishing communities); however, this site was in an area where trapping for blue crab (*Callinectes sapidus*) is prohibited. Higher CPUE at these sites is likely attributable to the improved habitat quality with higher salinity near the Gulf of Mexico, or proximity to nesting habitats. Alternatively, increased CPUE might be attributable to reduced pressure from fisheries in or around these sites. Additional research is needed to further determine the drivers of terrapin abundance within Louisiana's Deltaic Plain coastal regions. As established in other portions of the range, it is likely that areas with increased anthropogenic activity can present increased risk to the terrapin populations at those sites (Dorcas et al. 2007; Lester et al. 2013; Coleman et al. 2014). Furthermore, both foraging and nesting habitats at the marsh fringes are at risk of loss because of sea-level rise (Woodland et al. 2017).

When compared with terrapin populations from Louisiana's Chenier Plain marshes, CPUE within Deltaic Plain sites was generally lower (Selman et al. 2014). The highest CPUE for any location sampled in the Deltaic Plain was 0.69, whereas a site within the Chenier Plain had a CPUE as high as 5.19, and two additional sites that were greater than 1.0 (Selman et al. 2014). These regional differences in terrapin abundance indicate that further evaluation of potential limiting factors and sources of mortality is needed.

The mean size of adult terrapins in the Deltaic Plain indicates limited recruitment and survivorship within these populations (Dorcas et al. 2007; Coleman et al. 2014). The mean PL of female terrapins trapped in Terrebonne and Barataria basins equaled or exceeded the mean sizes of trapped terrapins within the range of the subspecies (*Malaclemys terrapin pileata* occurs from the Florida panhandle to Texas; Mann 1995; Coleman et al. 2014). Mann (1995) reported a mean PL of 158 mm for trapped terrapins in Mississippi, whereas Coleman et al. (2014) reported a mean PL of 168 mm for nesting females and trapped terrapins in Alabama. The mean size of trapped female terrapins in Pontchartrain Basin (166.2 mm) falls between the mean values reported by Mann (1995) and Coleman (2014). Trapping methods used by Mann (1995) are similar to those we used, whereas Coleman (2014) relied more on collecting nesting females on nesting beaches, which might have resulted in a larger mean size than from trapping. It is possible that the larger body sizes in Louisiana indicate that derelict fishing gear (DFG, material that is lost or discarded and is no longer under a fisherman's control; NOAA Marine Debris Program 2015), and other sources of mortality might be negatively affecting regional terrapin populations in Louisiana, as has been documented in other states within the species' range (Roosenburg et al. 1997; Dorcas et al. 2007; Coleman et al. 2014). More emphasis should be placed on determining the sources of terrapin mortalities throughout Louisiana's coastal zone. Additional research with specific focus on hatchling and juvenile terrapin habitats may refine our understanding of the structure of these populations.

The regional male-biased sex ratios documented in this study might further serve as an indicator of regional declines in terrapin populations caused by female-biased mortalities, as has been documented in other portions of the species' range. For example, Avissar (2006) noted that female turtles experience higher mortality rates during nesting activity than males, which can alter sex ratios of a population. Nesting terrapins in Louisiana generally do not contend with road mortalities on account of the remote nature of many nesting beaches (Pearson and Wiebe 2018), but might be consumed by predators such as coyotes and raccoons. Additional factors that might lead to male-biased populations include differential immigration and emigration rates, different primary sex ratios attributable to nest environments that produce more males than females, differences in maturation rates between the sexes, and trapping biases (Lovich and Gibbons 1990; Lovich 1996; Lovich et al. 2014). On account of our region-wide sampling plan, we feel confident in eliminating differential immigration and emigration as the driver of the observed male-biased sex ratio. Differential primary sex ratios might be a causal factor, but are unlikely to have contributed to our findings because surveys and characterizations of nest sites across Louisiana's deltaic plain found nesting in multiple substrates with varied surface characteristics that likely provide nest temperatures producing both male and female hatchlings (Kolbe and Janzen 2002; Pearson and Wiebe 2018). Differences in maturation age between the sexes might be a plausible contributing factor for the observed pattern (Lovich et al. 2014), but additional region-wide information would be required to exclude differential mortalities as the principal cause of the male-biased sex ratio.

Potential sources of terrapin mortality in Louisiana are habitat loss from natural and anthropogenic activities, oil spills, and DFG. Anthropogenic habitat loss has been the result of extensive oil and gas exploration/transportation across Louisiana's coastal zone and the broader northern Gulf of Mexico (Day et al. 2000; Iledare and Olatubi 2006). Extensive coastal habitat modification, in the form of canal dredging, has facilitated saltwater intrusion, causing significant coastal erosion and subsidence that further amplify sea-level rise on coastal habitats and communities (Day et al. 2007).

Habitat loss paired with increased vigilance by natural resource managers has increased our understanding of the impacts that oil spills have on coastal species such as Diamond-Backed Terrapins. Natural resource injury assessments (e.g., Chalk Point, Deepwater Horizon [DWH]) have demonstrated the deleterious nature of oiling, dispersants, and related response activities on coastal erosion, populations, and ecosystems. Although an understanding of these effects on terrapins is limited, inferences can be drawn from injury assessment information for comparable taxa and habitats (e.g., sea turtles, coastal marshes; Putman et al. 2015; Vander Zanden et al. 2016) as well as from species that utilize comparable nesting habitats (e.g., colonial nesting birds, nesting shorebirds; Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). If Diamond-Backed Terrapins sustained similar injuries as other DWH-injured taxa, then severe decreases in terrapin populations likely occurred and might be reflected in the reduced capture success within the Deltaic region compared with the adjacent Chenier region (which was not affected by DWH).

Louisiana represents the largest commercial blue crab fishery in the United States, with over half of the Gulf of Mexico's harvest from within the state's waters (Bourgeois et al. 2014). A residual of this activity is the historic and expansive presence of DFG (a known source of increased mortality for a wide variety of animals including birds, fish, invertebrates, mammals and reptiles; NOAA Marine Debris Program 2015). Within Louisiana, terrapin mortalities have been documented within organized DFG removal operations as well as incidental observations throughout the coastal zone (Anderson and Alford 2014; SHP, personal observation). Although the impact of DFG to terrapin populations in Louisiana is still unknown, the impacts attributable to DFG and crab fishery activities have been documented in other portions of the species' range (Roosenburg et al. 1997; Dorcas et al. 2007; Coleman et al. 2014). Terrapin populations heavily affected with DFG have typically been female biased (Dorcas et al. 2007). However, Coleman et al. (2014) demonstrated that large adult females are still threatened by DFG.

Our findings represent the first comprehensive evaluation of the abundance and distribution of Diamond-Backed Terrapins within Louisiana's Deltaic Plain region. Coupled with data presented by Selman et al. (2014), these data provide natural resource managers with a comprehensive understanding of the species throughout Louisiana's coastal zone. Furthermore, our study illustrates potential reductions in the abundance of Diamond-Backed Terrapins within the state's Deltaic Plain in comparison with the Chenier Plain. The data represent a relatively brief time frame given the life history of terrapins within Louisiana's Deltaic Plain, particularly among populations with robust capture rates. Therefore, we advocate for continued monitoring of Diamond-Backed Terrapins across the state of Louisiana to determine how the population is changing in response to the rapid changes among the state's coastal ecosystems.

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