

## Size-Based Mortality of Adult Female Diamond-Backed Terrapins (*Malaclemys terrapin*) in Blue Crab Traps in a Gulf of Mexico Population

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**ABSTRACT.** – Mortality incidental to trapping for blue crabs is a primary threat to diamond-backed terrapin (*Malaclemys terrapin*) populations. Due to sexual size dimorphism in this species, crab-trap mortality is believed to be biased toward smaller adult males and juvenile females. However, a comparison of commercial trap funnel openings and adult female size from a Gulf Coast population suggested that crab-trap mortality is a larger threat than previously thought to adult female terrapins in this population and possibly others.

**KEY WORDS.** – Reptilia; Testudines; *Malaclemys terrapin*; Cedar Point Marsh; Alabama; bycatch; crab trap

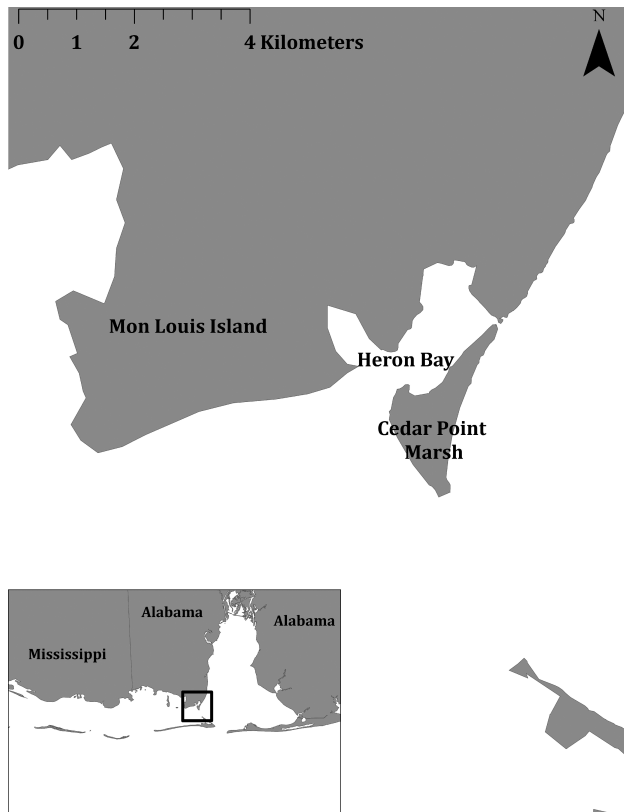
The diamond-backed terrapin (*Malaclemys terrapin*) is an obligate estuarine turtle that inhabits salt marshes, bays, and estuaries along the Atlantic and Gulf of Mexico coasts of the United States (Carr 1952). It is a potential keystone predator in salt marsh habitats (Silliman and Bertness 2002), which are experiencing high rates of erosion, especially in the Gulf of Mexico (Stedman and Dahl 2013). Formerly abundant terrapin populations were depleted due to historical commercial overharvest (Carr 1952; Hart and Lee 2006). Additionally, a variety of current threats are reducing terrapin populations and preventing their recovery. These threats include habitat degradation (Roosenburg 1991), nest predation (Butler 2002; Feinburg 2004; Coleman 2011), and road mortality (Wood and Herlands 1997; Szerlag and McRobert 2006). However, mortality of terrapins that enter and drown in submerged crab traps represents the paramount threat (Butler et al. 2006; Dorcas et al. 2007; Grosse et al. 2011). The habitats of terrapins and blue crabs (*Callinectes sapidus*) overlap widely (Roosenburg 2004), and this source of mortality has long been known to be detrimental to terrapins (Davis 1942).

Crab-trap mortality and potential mitigation strategies have been extensively studied in many populations (Alabama: Coleman et al. 2011; Florida: Butler and Heinrich 2007; Georgia: Grosse et al. 2009, 2011; Louisiana: Guillory and Prejean 1998; Maryland: Roosenburg et al. 1997; Roosenburg and Green 2000; Mississippi: Mann 1995; Cuevas et al. 2000; New Jersey: Mazzarella 1994; Wood 1997; North Carolina: Hart and Crowder 2011; South Carolina: Hoyle and Gibbons 2000; Gibbons et al. 2001; Dorcas et al. 2007; Texas: Baxter 2013; Virginia: Rook et al. 2010; Wolak et al. 2010; Morris et al. 2011; Upperman et al. 2014). Because of

sexual size dimorphism in this species, the general consensus is that crab-trap mortality is biased toward the smaller adult males and juveniles of both sexes (Roosenburg et al. 1997; Gibbons et al. 2001). Males do not reach a size that prevents their entry into crab traps, but Roosenburg et al. (1997) suggested that females reach that size (155 mm plastron length) by age 8. Dorcas et al. (2007) documented the long-term decline of a terrapin population in South Carolina and attributed the decline to crab-trap mortality. Analyses of 21 yrs of mark-recapture data indicated a demographic shift in the population toward larger and older individuals, with a female-biased sex ratio (Dorcas et al. 2007).

In addition to demographic shifts, crab-trap mortality was shown to influence an increase in sexual size dimorphism in a Chesapeake Bay terrapin population (Wolak et al. 2010). Current Chesapeake Bay terrapins in Virginia were compared to historical Chesapeake Bay specimens, collected prior to large-scale commercial crabbing, and to current specimens from the Long Island Sound, which has no commercial crabbing. The authors noted a significant increase in female growth rate and terminal size in the current Chesapeake Bay population without a concomitant increase in adult male size. Although this increase in female size may decrease the time they are vulnerable to crab-trap mortality, it may also result in fitness trade-offs, such as delayed maturity or diminished fecundity, because limited resources are devoted to growth rather than reproduction (Wolak et al. 2010).

Roosenburg et al. (1999) suggested that differential terrapin mortality may also be due to differential habitat use. In the sampled Maryland population, adult females exploited deeper, more open-water habitats than did smaller adult males and juvenile females. Large numbers



**Figure 1.** Map of study area along the Gulf coast of Alabama. Cedar Point Marsh supports the largest population of diamond-backed terrapins in Alabama.

of recreational crab traps were located in the same upper marsh habitats used by smaller terrapins (Roosenburg et al. 1999). However, habitat use may be location specific, as adult females exploited the same upper marsh habitats as did smaller terrapins in South Carolina (Tucker et al. 1995), potentially making them vulnerable to crab-trap mortality.

Terrapin bycatch in Gulf coast populations has not been studied as thoroughly as in Atlantic coast populations (but see Butler and Heinrich 2007; Coleman et al. 2011; Baxter 2013). These Gulf coast studies had limited sample sizes (41, 24, and 23 terrapins, respectively), so the susceptibility of adult female terrapins in Gulf coast populations to commercial crabbing remains unclear. The present study evaluated the size of adult females in a Gulf coast population, relative to the size of commercial crab-trap funnel openings, to assess the potential impact of crab-trap mortality in this population.

## METHODS

A long-term mark–recapture study of a diamond-backed terrapin population in Alabama was initiated in 2004 (Coleman 2011; Coleman et al. 2011). This population is composed of several isolated aggregations, with the largest inhabiting Cedar Point Marsh, located just north of Dauphin Island, Alabama (Fig. 1). At the end of the 19th Century, Cedar Point Marsh supported one of the

world’s largest terrapin farms. However, the current population is greatly depleted because of high levels of nest predation and putative crab-trap mortality (Coleman 2011).

Various types of surveys were used to sample terrapins. Drift fences with pitfall traps sampled only adult females on the nesting beach from late April or early May to early August. Otter trawls and modified crab traps (Roosenburg et al. 1997) sampled all sexes in the marsh channels and were used from March to September. For all captured terrapins, straight-line plastron length (PL), straight-line carapace width (CW), and shell depth (SD) were measured to the nearest 1 mm. Terrapins were also marked using a passive integrated transponder (PIT) tag inserted subcutaneously in the left leg and a zip-tie tag attached through a hole in a marginal scute, both with unique identification numbers. Ages were estimated, when possible, based on the number of carapacial scute or plastral scute annuli (Gibbons et al. 2001).

For the crab trap–adult female size comparison, the most recent morphological data for recaptured terrapins were analyzed. Commercial crab traps measuring  $60 \times 60 \times 50$  cm ( $W \times L \times H$ ) were purchased from a local trap manufacturer (Jimbo’s Crab Traps, 10008 Road 560, Bay St. Louis, MS 39520). The outer and inner openings of the funnels measured approximately  $12 \times 22$  cm and  $12 \times 15$  cm ( $H \times W$ ), respectively.

## RESULTS

The smallest female captured on the nesting beach during the mark–recapture study was 14.6 cm PL, similar to the smallest nesting female captured by Mann (1995) in a Mississippi population. Therefore, all females that measured  $\geq 14.6$  cm PL were considered adult females and included in this comparison, even though this threshold could be a conservative size estimate of female maturity. At Cedar Point Marsh, we captured 133 adult female terrapins (including both nesting beach and in-water captures) with 49 recaptures. On the nesting beach, 104 terrapins were captured in pitfall traps and 14 were captured by hand. For in-water captures, 8 were captured in crab traps, 6 were caught using an otter trawl, and 1 was incidentally captured by a recreational fisherman at an adjacent fishing pier. The mean PL of sampled adult females was 16.8 cm (0.11 standard error [SE];  $n = 84$ ; Table 1). The mean CW was 14.0 cm (0.10 SE;  $n = 84$ ) and the mean SD was 7.65 cm (0.06 SE;  $n = 77$ ). Age was estimated for 81 adult females, and 52 (64.2%) were estimated to be 10 yrs of age or older. Based on the height and width of the crab-trap funnel openings, funnel height rarely limits terrapin entry. Terrapin females that had a  $CW > 15$  cm would theoretically be too wide to enter crab traps (Fig. 2), but only 13 of the 84 sampled adult female terrapins (16%) had CWs that measured greater than 15 cm. None of the females would fit into a trap that was fitted with a  $5 \times 10$ -cm ( $H \times W$ ) bycatch reduction device (BRD).

**Table 1.** Mean straight-line plastron length (PL) of adult female terrapins, smallest PL of adult female captured on nesting beach or found gravid, and range of PL measurements in the Alabama populations compared with other populations.

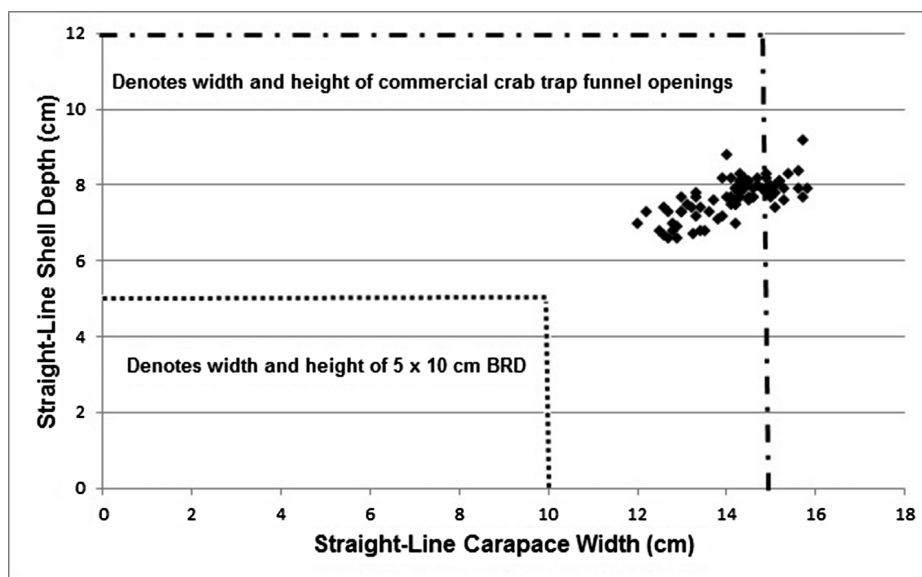
Location	Subspecies	<i>n</i>	Mean PL (cm)	Range of PL (cm)	Source
Alabama	<i>Malaclemys terrapin pileata</i>	89	16.8	14.6–19.3	Present study
Mississippi	<i>M. t. pileata</i>	27	16.4	14.7–18.8	Mann 1995
Texas	<i>M. t. littoralis</i>	45	15.8	13.1–17.4	Hogan 2003
Florida	<i>M. t. tequesta</i>	113	15.4	13.5–?	Seigel 1984
South Carolina	<i>M. t. centrata</i>	40	15.7		Zimmerman 1989
Maryland	<i>M. t. terrapin</i>		19.2	17.3–21.6	Roosenburg 1990
New Jersey	<i>M. t. terrapin</i>	180	17.3	14.2–19.6	Wnek 2010
New Jersey	<i>M. t. terrapin</i>	221	15.4	13.2–18.4	Montevecchi and Burger 1975
New York	<i>M. t. terrapin</i>	124	17.3	14.5–19.8	Feinburg 2000
Rhode Island	<i>M. t. terrapin</i>	85	20	17.5–22.5	Goodwin 1994

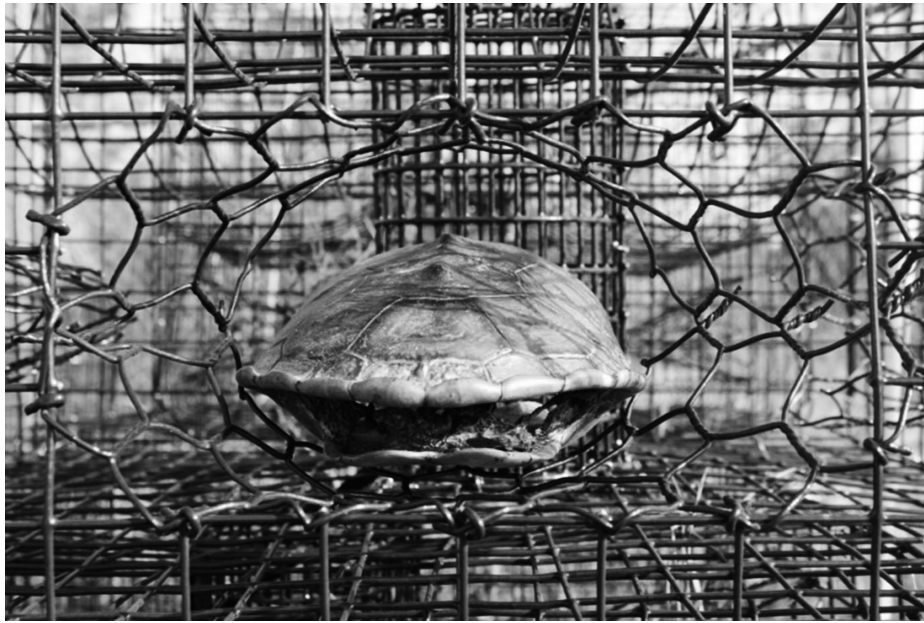
## DISCUSSION

It is generally accepted that males and juvenile females are more vulnerable to crab-trap mortality than are adult females (Roosenburg et al. 1997; Roosenburg and Green 2000; Gibbons et al. 2001; Butler and Heinrich 2007; Dorcas et al. 2007; Hart and McIvor 2008; Rook et al. 2010; Wolak et al. 2010; Coleman et al. 2011; Hart and Crowder 2011; Baxter 2013). However, Roosenburg (2004) suggested that regional studies should determine which sex and life-history stages are susceptible to crab-trap mortality. In Maryland, females reach the size that prevents crab-trap entry (15.5 cm PL) by age 8 (Roosenburg et al. 1997); however, adult females from the Maryland population are, on average, larger than most other terrapin populations. This difference cannot be explained by differences in average adult female age between the Maryland and Alabama populations. The majority of adult females sampled at Cedar Point Marsh were over 10 yrs of age, similar to the Maryland population (Roosenburg 1991). Based on both the current

long-term mark–recapture study in Alabama and the crab traps measured for this study, 84.5% of sampled adult females were capable of entering and drowning in commercial-style crab traps. By comparing the CW to the PL of adult females, adult female terrapins from this Alabama population need to grow to approximately 18 cm PL before they are too large to enter these traps. In a previous study examining the effectiveness of BRDs in Alabama, almost 30% of females captured in control crab traps were of adult female size (Coleman et al. 2011).

The practices of the blue crab fishery in the vicinity of Cedar Point Marsh may influence crab-trap mortality on adult female terrapins in Alabama. Few crab traps, if any, are placed in Cedar Point Marsh channels; instead, Heron Bay (Fig. 1), which is outside of Cedar Point Marsh, is more heavily fished for crabs (Coleman et al. 2011). If adult females venture out in deeper waters, as observed by Roosenburg et al. (1999), they would be more susceptible to crab-trap mortality than are adult males and juvenile females, which are more likely to stay within the marsh channels. Additionally, adult

**Figure 2.** Comparison of straight-line carapace width and straight-line shell depth of 77 adult female diamond-backed terrapins sampled from Cedar Point Marsh, Alabama. The majority of these terrapins (64) would fit in commercial crab-trap funnel openings (outer dashed lines), but all would be too large to fit in funnel openings of crab traps fitted with 5 × 10-cm bycatch reduction devices (BRDs) (inner dotted lines).



**Figure 3.** Adult female terrapin shell (recovered from a Mississippi nesting beach) placed inside a set funnel opening of a commercial crab trap measured for this study. The straight-line carapace width of the shell measured 14.5 cm and its shell depth measured 8.1 cm. Based on carapacial and plastral scutes, the turtle was 10 yrs of age or older at death. The shell fit easily through the set funnel opening.

females from neighboring marshes have been tracked via radiotelemetry to move to and from Cedar Point Marsh on migrations to the nesting beach (Roberge 2012). Most of these females are small enough to enter crab traps encountered during nesting movements.

The crab-trap funnel openings measured in this study could be larger than those of traps used in other areas. Recreational crab-trap funnel openings in the traps used by Hoyle and Gibbons (2000) were  $11.7 \times 7.5$  cm (H  $\times$  W), which would have prevented entry of all sampled adult females from the Alabama population. In contrast, the funnel openings of the crab traps used by Butler and Heinrich (2007) were similar ( $10 \times 15$  cm) to those measured in the present study. Roosenburg et al. (1997) and Hart and Crowder (2011) did not state the size of the funnel openings of the crab traps used in those studies, but the overall size of the traps ( $60 \times 60 \times 60$  cm) was similar to those measured in the present study.

Because crab-trap mortality poses a greater threat to adult male and juvenile terrapins, the fewer traps placed in marsh channels at Cedar Point Marsh could still remove a significant proportion of the population, especially in the case of derelict crab traps (Bishop 1983; Roosenburg et al. 1997; Grosse et al. 2009). Previous studies observed a male bias in terrapin bycatch rates (Bishop 1983; Roosenburg et al. 1997; Butler and Heinrich 2007; Morris et al. 2011). However, Roosenburg et al. (1997) argued that the loss of juvenile females is more damaging to population viability due to the loss of greater long-term reproductive potential.

Based on the present study's results and the geographical comparison of adult female sizes, the risk of crab-trap mortality to adult female terrapins is present in other

populations (e.g., Mississippi, Texas, Florida, South Carolina, and New Jersey) given comparable traps. In Mississippi (from an area also sampled by Mann 1995), whole specimens and shells of suspected drowned adult females have been recovered during a recently initiated mark-recapture study (A.T. Coleman, unpubl. data, 2014; Fig. 3). Further, 8 of 23 terrapins captured in commercial crab traps that were modified for the Baxter (2013) study conducted in Texas met the adult female size threshold used for this study (A. Baxter, *pers. comm.*, April 2014). Additionally, 18 of 41 females captured in commercial crab traps from a 2010 study conducted in the same Texas population also met this threshold (A. Baxter, *pers. comm.*, April 2014). However, in the study by Wood (1997) in New Jersey, no adult females were captured in the commercial crab traps used.

Various mitigation strategies have been proposed to reduce terrapin bycatch, including gear placement, soak time, and time-of-year regulations (Grosse et al. 2011; Hart and Crowder 2011), but the strategy that has received the most attention is requiring BRDs in crab-trap funnel openings. Numerous studies have shown that BRDs reduce terrapin bycatch while not significantly depressing blue crab catch (Mazzarella 1994; Roosenburg et al. 1997; Cuevas et al. 2000; Roosenburg and Green 2000; Butler and Heinrich 2007; Rook et al. 2010; Hart and Crowder 2011; Morris et al. 2011; Baxter 2013; Upperman et al. 2014), perhaps even increasing it (Wood 1997; Guillory and Prejean 1998). Guillory and Prejean (1998) suggested that BRDs might provide rigidity to funnel openings, thus reducing crab egress. While the normal orientation of BRDs within openings has been lateral, others have argued that vertical orientation may be more effective

(Hoyle and Gibbons 2000; Cole and Helser 2001; Dorcas et al. 2007). Although a large percentage of adult female terrapins in Alabama would fit into an unmodified commercial crab trap, all would be excluded with the use of a 5 × 10-cm BRD.

Roosenburg et al. (1997) estimated that up to 78% of a terrapin population in Maryland could be captured in crab traps per year. In addition, the extirpation of a terrapin population in South Carolina was attributed to unsustainable crab-trap mortality (Gibbons et al. 2001; Dorcas et al. 2007). Some individual traps can remove large number of terrapins from a population (Bishop 1983; Roosenburg et al. 1997; Grosse et al. 2009). The commercial crab fishery was shown to select for larger adult female terrapins (i.e., carapace width and length and body mass) in a Chesapeake Bay population (Wolak et al. 2010), but the fishery in Alabama may not be large enough to influence such a change in this sampled population. Therefore, although crab-trap mortality selectively removes more of the smaller adult males and juvenile females, adult female diamond-backed terrapins in this and other populations are susceptible to entering and drowning in crab traps. Thus, in addition to the loss of future reproductive potential with the loss of juvenile females, current reproductive output from mature females may be dwindling due to trap mortality. As such, capture of adult females in crab traps endangers the survival status of certain terrapin populations, including protected populations that have declined drastically from historic levels. For instance, the current estimate of nesting females that utilize the nesting beach at Cedar Point Marsh—the largest aggregation in Alabama—suggests that it consists of < 100 individuals (Coleman 2011).

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