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Efficacy of Fisheries-Sourced Bycatch Reduction Solutions in Preventing Capture of Diamond-backed Terrapins (*Malaclemys terrapin*) in Blue Crab Pots

Laura Wilson[1], Sam Romano[2], and Amanda Southwood Williard[1,3]

[1]Department of Biology and Marine Biology, University of North Carolina Wilmington, 601 South College Road, Wilmington, North Carolina 28403, USA
[2]Seaview Crab Company, 1515 Marstellar Street, Wilmington, North Carolina 28401, USA
[3]Corresponding author, e-mail: williarda@uncw.edu

Abstract.—**The Diamond-backed Terrapin (*Malaclemys terrapin*) is an estuarine turtle found along the East and Gulf coasts of the U.S. Diamond-backed Terrapins are a Species of Concern in North Carolina where population declines are due to a variety of threats, including incidental mortality in commercial and recreational Blue Crab (*Callinectes sapidus*) pots. One strategy to mitigate fisheries bycatch of Diamond-backed Terrapins is the use of plastic or wire bycatch reduction devices (BRD) that narrow the dimensions of the entrance funnels of the crab pots to prevent terrapin entry. Crab fishermen are resistant to many BRD designs due to concerns that BRDs reduce crab catch, and they have proposed alternative BRD shapes, or the use of crab pots manufactured with narrowed funnel dimensions (NFD) instead of BRD inserts to help reduce bycatch. Our primary goal was to determine the effectiveness of fisheries-sourced bycatch reduction solutions at excluding Diamond-backed Terrapins from crab pots. We conducted trials with captive Diamond-backed Terrapins to compare the number of entries into standard crab pots, crab pots with oval BRDs inserted in entrance funnels, and crab pots manufactured with an NFD design. Pots with smaller entrance funnel dimensions, either through insertion of oval BRDs or the NFD design, had significantly fewer Diamond-backed Terrapin entries compared with standard crab pots. Our results illustrate the effectiveness of fisheries-sourced gear modifications for preventing bycatch of Diamond-backed Terrapins in crab pots. Additional field studies to assess the effects on crab catch will determine the feasibility of incorporating these gear modifications into commercial crab fisheries.**

Key Words.—BRD; conservation; fisheries; North Carolina; turtle

Introduction

The Diamond-backed Terrapin (*Malaclemys terrapin*) is an estuarine emydid turtle that inhabits shallow water environments, including bays, lagoons, creeks, and marshes along the East and Gulf coasts of the U.S. (Ernst and Lovich 2009). This species is experiencing population declines in multiple locations throughout its range (Roosenburg et al. 2019). Although it has not been afforded federal protection, many states have listed Diamond-backed Terrapins as either Endangered, Threatened, or a Species of Concern (Kennedy 2018). The International Union for Conservation of Nature (IUCN) lists Diamond-backed Terrapins as Vulnerable with a decreasing population trend (Roosenburg et al. 2019). Diamond-backed Terrapin population decline is caused by multiple threats including habitat degradation, nest predation, and road mortality; one of the main threats they experience in the southeastern portion of their range is entering and drowning in recreational and commercial crab pots (Butler et al. 2006; Dorcas et al. 2007; Grosse et al. 2011).

The Blue Crab (*Callinectes sapidus*) pot fishery is thought to have a substantial impact on Diamond-backed Terrapin populations, as shifts in population demography and declines in Diamond-backed Terrapin numbers have been documented in creeks that experience high levels of commercial or recreational crab fishing effort (Dorcas et al. 2007; Chambers and Maerz 2018; Roosenburg et al. 2019). Blue Crabs and Diamond-backed Terrapins overlap in estuarine habitats and the Blue Crab fishery extends throughout much of the Diamond-backed Terrapin range (Harden and Williard 2012; Grubbs et al. 2017). Crab pots are boxes constructed of wire mesh with 2–4 funnel openings through which crabs and other species may enter the pot and crab pots are typically baited with Menhaden (*Brevoortia tyrannus*) or other fish species (Kennedy et al. 2007). Diamond-backed Terrapins that enter regularly fished pots or ghost pots, which are pots that are abandoned and no longer actively checked by crab fishermen, may drown if the pot is fully submerged and the entrapped terrapin cannot reach the surface to breathe (Roosenburg et al. 2003; Hart and Crowder 2011). Ghost pots are particularly dangerous as a single pot can capture many Diamond-backed Terrapins over time (Bishop 1983; Grosse et al. 2009). The estimated mortality rate for Diamond-backed Terrapins captured in crab pots is 10–78% and depends on body size of captured individuals and the time of year (Hart and Crowder 2011).

Smaller Diamond-backed Terrapins, such as juveniles of both sexes and adult males, are at higher risk of entrapment in Blue Crab pots because they can easily enter the funnel openings (Hart and Crowder 2011; Morris et al. 2011; Dorcas et al. 2007). Over time, selective removal of smaller individuals can alter the demographics of Diamond-backed Terrapin populations such that there is a higher proportion of larger, older females (Dorcas et al. 2007). Because of the negative impacts of fisheries bycatch on Diamond-backed Terrapin population size and demographics, addressing this issue is a key component of conservation efforts for this species.

Various strategies to reduce Diamond-backed Terrapin bycatch have been implemented, including spatial and temporal restrictions on gear placement and limitations on soak time (Harden and Williard 2012; Chambers and Maerz 2018; North Carolina Division of Marine Fisheries [NCDMF] 2020); however, the strategy that has gained the most traction is the use of bycatch reduction devices (BRD) in the funnel openings of the crab pots. Bycatch reduction devices are plastic or wire excluder devices inserted into the funnel openings to narrow the entrance and prevent Diamond-backed Terrapins from entering the pot (NCDMF 2020). Several states in the USA, including New York, New Jersey, Delaware, and Maryland, require the use of BRDs on recreational crab pots or conditionally on commercial crab pots. Ideally, the use of BRDs would decrease the number of Diamond-backed Terrapins caught in pots with minimal impact on the catch of commercially valuable Blue Crabs. Several studies have indicated that BRDs are effective at preventing Diamond-backed Terrapin bycatch, but effects of BRDs on Blue Crab catch vary between studies and with the dimensions of the BRD (Chambers and Maerz 2018). Many crab fishermen are resistant to using BRDs due to a perceived impact on Blue Crab catch. Furthermore, BRD installation and maintenance requires an investment of money and time on the part of the fishermen (Grubbs et al. 2017). Buy-in from fishermen is essential to implement BRDs or other types of bycatch reduction technology in the Blue Crab fisheries on a broad scale and ensure maximum compliance with bycatch mitigation measures. Studies to identify additional effective bycatch reduction technologies that exclude Diamond-backed Terrapins are warranted, especially as more states introduce bycatch reduction regulations in the commercial and recreational fisheries.

In North Carolina, the Blue Crab fishery is one of the most valuable commercial fisheries in the state (NCDMF 2013). The Diamond-backed Terrapin is listed as a Species of Concern by the North Carolina Wildlife Resources Commission and efforts to assess the impacts of Diamond-backed Terrapin bycatch in the Blue Crab fisheries of North Carolina are on-going (NCDMF 2013, 2020). Based on previous research (NCDMF 2020), NCDMF has established two Diamond-backed Terrapin Management Areas (DTMA) in the southeastern region of the state; the DTMAs encompass in-shore waters adjacent to Masonboro Island and Bald Head Island (NCDMF 2020). Crab pots fished in the DTMAs must be equipped with NCDMF-approved BRDs. In response to the establishment of DTMAs and the BRD restrictions, crab fishermen have proposed the use of alternative BRD designs and novel bycatch reduction solutions to meet the criteria for Diamond-backed Terrapin exclusion, while maintaining high levels of crab catch. Some fishermen have indicated that modifications to the shape of BRD inserts may alleviate their concerns regarding negative impacts on Blue Crab catch; specifically, oval BRDs are perceived as more acceptable than the conventional rectangular BRDs, as the oval shape is similar to the shape of the unaltered standard crab pot funnel. Furthermore, some crab fishermen are supportive of crab pots constructed with narrowed funnel dimensions (NFD) rather than the use of separate wire or plastic BRDs installed in standard size funnel openings.

Our primary goal was to determine the effectiveness of fisheries-sourced bycatch reduction solutions for excluding Diamond-backed Terrapins from crab pots. An assessment of the efficacy of bycatch reduction technologies under controlled laboratory conditions provides the proof of concept needed to proceed with broad scale field experiments and, ultimately, incorporation of a given design into the fishery. We conducted trials with captive Diamond-backed Terrapins to compare their ability to enter pots with standard size funnels (Control), pots with standard size funnels equipped with a fisheries-sourced oval plastic BRD, and pots with a fisheries-sourced narrow funnel design (NFD). We hypothesize that modifications to funnels will affect the number of Diamond-backed Terrapins excluded from crab pots; specifically, we predict that use of fisheries-sourced bycatch reduction solutions to decrease the dimensions of crab pot funnels would result in fewer Diamond-backed Terrapin entries into crab pots compared with unaltered funnels.

Materials and Methods

Terrapin capture and husbandry.—We captured 17 female Diamond-backed Terrapins in tidal creeks within the Masonboro Island Reserve, part of the North Carolina Coastal Reserve and National Estuarine Research Reserve system, during July and August 2020. We caught 15 Diamond-backed Terrapins in crab pots modified with a chimney that permitted air access throughout the tidal cycle (Chavez and Williard 2017). We caught two additional Diamond-backed Terrapins using a seine net. We assigned each Diamond-backed Terrapin a unique identity code that corresponded to notches filed on their marginal scutes (Cagle 1939; Sexton 1959). We collected straight carapace length (SCL), straight carapace width (SCW), carapace height (CH), and body mass for each Diamond-backed Terrapin prior to trials (Table 1). We calculated a theoretical diagonal dimension of turtles using SCW and CH and the Pythagorean Theorem for each Diamond-backed Terrapin for comparison with the diagonal dimension of funnel entries of crab pots with and without bycatch reduction technologies. Previous studies have found that the diagonal dimension of BRDs are predictive of the effectiveness of a given design in excluding Diamond-backed Terrapins from crab pots (Arendt et al. 2018). Diamond-backed Terrapin body mass prior to initiation of trials ranged between 171.5–850.1 g (Table 1).

Table 1. Morphometric and body mass data of individual Diamond-backed Terrapins (*Malaclemys terrapin*) captured at Masonboro Island, North Carolina, USA, in July and August 2020. Data were recorded 18 September 2020. The abbreviations SCL = straight carapace length, SCW = straight carapace width, and CH = carapace height. The symbol † indicates successful entry into Control pot, ‡ indicates successful entry into BRD pot, and * indicates excluded from statistical analysis due to camera malfunctions during a trial.

Terrapin ID	SCL (cm)	SCW (cm)	CH (cm)	Diagonal (cm)	mass (g)
†BKN	13.7	10.9	6.1	12.5	525.8
†BKO	16.1	12.0	6.6	13.7	703.8
BKP	17.3	12.6	7.4	14.6	850.1
†BKQ	12.1	9.4	5.4	10.8	321.2
†‡BKV	9.7	7.8	4.2	8.9	171.5
†BKW	12.9	9.6	5.1	10.9	334.8
†BKX	14.5	11.0	5.6	12.3	465.4
*BLM	14.0	10.2	5.5	11.6	425.0
†‡BLN	10.4	8.4	4.3	9.4	196.4
†BLO	13.8	9.9	5.6	11.4	438.1
†BLP	14.9	10.7	6.9	12.7	478.9
†BLQ	14.1	10.9	5.9	12.4	492.2
†BLV	13.7	10.4	5.6	11.8	436.7
BLW	12.2	9.7	5.2	11.0	283.9
BLX	13.0	9.7	5.4	11.1	378.6
BMN	13.5	10.9	5.8	12.3	484.3
†BMOP	15.7	11.5	6.1	13.0	646.2

We housed Diamond-backed Terrapins in three partially shaded circular outdoor tanks (2 m diameter) with flow-through water at a depth of 30 cm at the University of North Carolina (UNCW) Center for Marine Science. Each tank housed five or six Diamond-backed Terrapins. Water was pumped in from the Intracoastal Waterway and filtered to 60 microns prior to flowing into the holding tanks. During the period in which we conducted experiments, water temperature was within the range of 21.8°–31.5° C and salinity was within the range of 23–37 psu. We placed cinderblocks in the tanks to provide basking platforms and sheltering sites. We fed Diamond-backed Terrapins a ration of shrimp (7% body mass) every other day (Williard et al. 2019). We drained and rinsed tanks with freshwater for at least 10 min every day to keep tanks clean and provide Diamond-backed Terrapins with an opportunity to drink freshwater. We acclimated Diamond-backed Terrapins to captivity for 5–9.5 weeks prior to initiation of behavior trials.

Behavior trials.—We used commercial crab pots (61 cm length × 61 cm width × 50 cm height) with four funnel entries constructed of hexagonal (hex) wire to assess the efficacy of bycatch reduction technologies. The funnel size is typically expressed by crab fishermen as the number of hex openings along the ellipse circumference of the funnel. We exposed each Diamond-backed Terrapin to three treatments (Control, BRD, and NFD) in a randomized order. The Control treatment was a standard crab pot with 14 hex funnel entries that narrowed to 12 hex at the base of funnel (Fig. 1). The maximum width and height of the funnel base were 15.0 cm and 7.4 cm, respectively, with a calculated diagonal dimension of 16.7 cm. The BRD treatment was a standard crab pot with 14 hex funnel entries that narrowed to 12 hex at the base of funnel, but each funnel was fitted with an oval plastic (PVC) BRD insert to reduce the dimensions at the base of the funnel (Fig. 1). The maximum width and height of the BRD insert were 9.4 cm and 5.3 cm, respectively, with a calculated diagonal dimension of 10.8 cm. The NFD treatment was a standard crab pot manufactured with smaller funnel entries of 11 hex that narrowed to 9 hex at the base of the funnel (Fig. 1) with a maximum width and height of the funnel base 12.3 cm and 4.8 cm, respectively, with a calculated diagonal dimension of 13.2 cm.

We conducted behavior trials from 21 September to 28 October 2020. Trials occurred between 1000–1700 and we fasted Diamond-backed Terrapins for 40–48 h before the onset of a trial. We recorded water temperature and salinity before each trial. We tested Diamond-backed Terrapins individually in a separate circular tank (2 m diameter) with flow-through water at a depth of 30 cm.

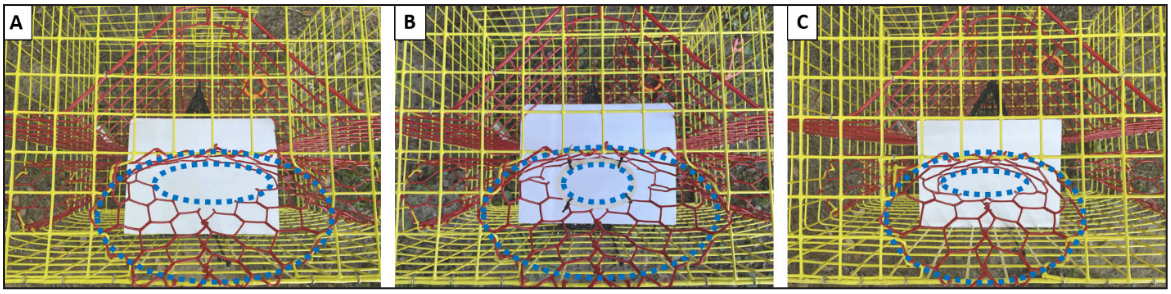

Figure 1. Entrance funnels of the three types of crab pots used in experiments with the exterior entrance and base of funnel highlighted in blue. The white backdrop highlights the base of the funnel. Once Diamond-backed Terrapins (*Malaclemys terrapin*) completely passed through the base of the funnel, they were trapped inside the pot. The Control treatment (A) was a standard crab pot with maximum dimensions of 15.0 cm width × 7.4 cm height (16.7 cm diagonal) at the base of the funnel. The BRD treatment (B) was a standard crab pot with fitted with an oval plastic insert with maximum dimensions of 9.4 cm width × 5.3 cm height at the base of the funnel (10.8 cm diagonal). The NFD treatment (C) was a standard crab pot with a narrow funnel dimensions of 12.3 cm width × 4.8 cm height at the base of the funnel (13.2 cm diagonal).

Social interactions may contribute to Diamond-backed Terrapin interactions with crab pots (Carpenter et al. 2020), so we tested subjects individually to avoid this confounding effect during trials. Water level in the tank was deep enough to cover the four funnel entries of the crab pot but left approximately 20 cm of airspace at the top of the crab pot so that terrapins that entered would be able to surface and breathe. We baited crab pots with Mackerel (*Scomber scombrus*) and shrimp (*Litopenaeus* spp. and Brown Shrimp, *Farfantepenaeus aztecus*) to maximize motivation for Diamond-backed Terrapins to enter (McKee et al. 2016). We recorded trials with a GoPro Hero 3+ (Go-Pro, Inc., San Mateo, California, USA) mounted to a PVC pipe and positioned approximately 60 cm above the crab pot. Trials started when a Diamond-backed Terrapin was introduced into the experiment tank and ended after a 70 min monitoring period or when the Diamond-backed Terrapin entered the crab pot. Diamond-backed Terrapins that entered the crab pot during the course of the trial were immediately removed and the trial was ended. We returned all Diamond-backed Terrapins to holding tanks at the completion of trials.

We reviewed video footage of each trial to document specific behaviors. We quantified attempted entries and successful entries into the crab pot. We defined an attempted entry as the Diamond-backed Terrapin entering the funnel but not passing through the funnel base to fully enter the crab pot. A successful entry was defined as the Diamond-backed Terrapin completely passing through the funnel base so that its entire body was within the crab pot.

***Statistical analyses*.**—We used the R package MCMCglmm (Hadfield 2010) to fit Generalized Linear Mixed Models (GLMM) to the data. This approach allowed us to account for the repeated measures design of our experiment (each terrapin was exposed to all three treatments) and non-normal count and binary data. For fixed effects, we used a flat, weakly informative prior with the assumption of a normal posterior distribution with high variance. The inverse Wishart prior (V = 1, nu = 0.002) was used for variances of the random effects. For the model of attempted entries, we used a GLMM fitted with the Poisson family function to account for count data. The diagonal dimension of the funnel base (FunnelDiagonal), temperature at the start of the trial (Temperature), and the diagonal dimension of cross section as a general measure of Diamond-backed Terrapin size (TerrapinDiagonal) were used as fixed effects in the model. Individual Diamond-backed Terrapin ID (TerrapinID) was included as a random effect to account for repeated measures. For successful entries, we used a GLMM fitted with the categorical family function to account for binary data. FunnelDiagonal, Temperature, and TerrapinDiagonal were used as fixed effects in the model and TerrapinID was included as a random effect. Markov chain Monte Carlo settings for both models included 70,000 iterations, 20,000 burn-in samples, and a thinning rate of 3, which resulted in a final posterior sample of n = 16,667 for each model (Williard et al. 2019). Model convergence was evaluated with traceplots and density plots. We considered an effect to be significant if the 95% credible intervals for the estimate excluded zero.

Results

We collected data for Control, BRD, and NFD pots from 16 of the 17 Diamond-backed Terrapins. A camera malfunction prevented us from obtaining a full set of data for one Diamond-backed Terrapin, so this individual was excluded from further analysis. The FunnelDiagonal covariate had a significant effect on the number of attempted entries (-0.35190 [-0.65990, -0.03429], posterior mean [95% credible intervals]). There were a greater number of attempts to enter the pots equipped with bycatch reduction technologies that

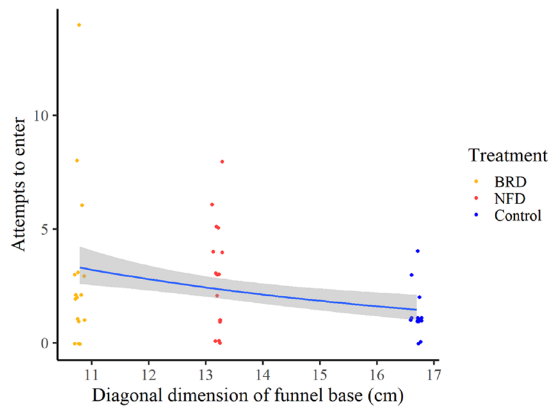

Figure 2. The number of attempts by Diamond-backed Terrapins (*Malaclemys terrapin*) to enter standard crab pots (Control) and crab pots modified with bycatch reduction technologies (BRD and NFD) that reduced the dimensions of the funnel base.

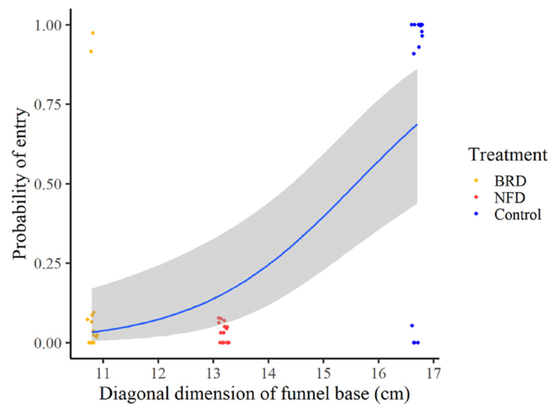

Figure 3. The probability of a Diamond-backed Terrapin (*Malaclemys terrapin*) successfully entering standard crab pots (Control) and crab pots modified with bycatch reduction technologies (BRD and NFD) that reduced the dimensions of the funnel base.

reduced the size of the funnel entry 3.0 ± 3.6 (mean ± standard deviation) attempts for BRD, 2.8 + 2.4 attempts for NFD) compared with Control pots (1.3 + 1.0 attempts; Fig. 2). Temperature (-0.12734 [-0.41126, 0.16760]) and TerrapinDiagonal (0.17284 [-0.14977, 0.48060]) covariates did not have a statistically significant effect on attempted entries.

The FunnelDiagonal covariate had a significant effect on successful entries into crab pots (304.68 [94.62, 526.86]). Significantly fewer Diamond-backed Terrapins entered pots equipped with bycatch reduction technologies that reduced the size of the funnel entry (two entries in BRD, zero entries in NFD) compared with Control pots (12 entries; Fig. 3). Temperature was not a significant factor in the model (-128.15 [-297.72, 14.08]). TerrapinDiagonal had a significant effect on entries with smaller Diamond-backed Terrapins more likely to successfully enter the crab pots (-158.82 [-323.55, -20.69]). The diagonal dimension of the Control funnels was 16.7 cm and the diagonal dimension of Diamond-backed Terrapins that entered the Control pot ranged between 8.9–13.7 cm. The two Diamond-backed Terrapins that entered the BRD pot had diagonal dimensions of 8.9 and 9.4 cm; the diagonal dimension for the BRD funnels was 10.8 cm. No Diamond-backed Terrapins entered the NFD pot, which had a funnel diagonal dimension of 13.2 cm.

Discussion

Our primary goal was to determine the effectiveness of fisheries-sourced bycatch reduction solutions for excluding Diamond-backed Terrapins from crab pots. We found that the reduction of entry funnel dimensions with the BRD and NFD designs resulted in a greater number of attempted entries and fewer successful entries into crab pots. These results suggest that novel gear modifications proposed by fishermen, such as oval-shaped BRDs and modifications to funnel dimensions at the manufacturing stage, may offer effective, alternative means of Diamond-backed Terrapin bycatch reduction. Other experiments have found that various configurations of BRDs are effective at Diamond-backed Terrapin exclusion and there is consensus that use of BRDs reduces the number of Diamond-backed Terrapins that enter Blue Crab pots (Chambers and Maerz 2018). Our study is novel in that our NFD design was a fisheries-sourced narrow funnel entry instead of a separate wire or plastic BRD insert. Crab fishermen are more likely to voluntarily adopt bycatch reduction solutions that are pre-built into the design of the crab pot and do not require additional cost and effort on the part of fishermen to install the BRDs (Grubbs et al. 2017).

The Diamond-backed Terrapins used in this study generally were within a size range that permits entry into crab pots with standard size funnels. Indeed, all but two of the study animals were collected in the wild using crab pots with standard size funnels and 12 of the 14 entries that we documented during experimental trials occurred in the Control pot. Unsurprisingly, previous studies have shown that smaller Diamond-backed Terrapins are more likely to successfully enter crab pots (Dorcas et al. 2007; Hart and Crowder 2011; Morris et al. 2011), and our results support this observation. We found that the calculated TerrapinDiagonal covariate, a single metric of Diamond-backed Terrapin size that incorporates maximum carapace width (SCW) and height (CH), had a significant effect on entries into crab pots. Our study sample was limited to adult females, as we did not capture adult males or juveniles during field collections. Additional tests of the BRD and NFD designs with smaller Diamond-backed Terrapins would refine assessments of the efficacy of these bycatch reduction technologies in excluding Diamond-backed Terrapins from crab pots.

Interestingly, although the plastic oval BRD had a smaller funnel diagonal dimension (10.8 cm) compared with the NFD design (13.2 cm), we documented two Diamond-backed Terrapin entries in the BRD pot and no entries in the NFD pot. The two Diamond-backed Terrapins that entered the BRD pot were the smallest Diamond-backed Terrapins used in the study. Evidence from earlier studies of BRD efficacy indicates that the BRD height dimension is more important than the BRD width dimension in terms of Diamond-backed Terrapin exclusion (Roosenburg and Green 2000; Chavez and Williard 2017; Arendt et al. 2018), and this is supported by a comparison of differences in the height the dimension of the BRD and NFD designs. Although the diagonal of the oval BRD was smaller than that of the NFD design, the oval BRD had a larger height dimension (5.3 cm) compared with the NFD design (4.8 cm). Even so, the two Diamond-backed Terrapins that entered the BRD pot had CH of 4.2 cm and 4.3 cm and should have been able to enter the NFD pot if funnel height was the only design feature to play a role in exclusion. Additional research into the effects of funnel shape and texture on Diamond-backed Terrapin interactions with crab pots is warranted.

Although BRDs with smaller dimensions are most effective at excluding Diamond-backed Terrapins (Arendt et al. 2018), these designs may also reduce the catch of some portion of legal sized Blue Crabs. Crab fishermen are resistant to using BRDs due to the extra investment of money and time required and the perception that BRDs reduce crab catch (Grubbs et al. 2017). It is clear that BRDs are effective at reducing Diamond-backed Terrapin bycatch in crab pots, but the impacts of BRDs on crab catch varies between studies. Some studies have found little to no change in Blue Crab catch in pots equipped with BRDs compared with standard crab pots with no BRDs (Roosenburg and Green 2000; Butler and Heinrich 2007; Rook et al. 2010; Chavez and Williard 2017; Grubbs et al. 2017). Other studies, however, have documented a significant reduction in Blue Crab catch, as well as catch of commercially valuable bycatch species, such as Stone Crab (*Menippe mercenaria*), in pots equipped with BRDs (Cole and Hesler 2001; Coleman et al. 2011; Hart and Crowder 2011; Morris et al. 2011; Upperman et al. 2014). Interestingly, Wood (1997) and Guillory and Prejean (1998) found that BRDs actually increased Blue Crab catch as Blue Crabs that entered a pot were less likely to be able to exit the pot when a BRD was installed. The impacts on Blue Crab catch for the bycatch reduction designs used in our study have not been tested. Fisheries-independent and fisheries-dependent field trials will be necessary to determine the efficacy of these designs in preventing Diamond-backed Terrapin entry while maintaining commercially viable levels of Blue Crab catch.

It is important to consider feasibility of enforcement and level of compliance with regulations when implementing BRD requirements in Blue Crab fisheries. In Maryland, BRDs are required on all recreational Blue Crab pots, but researchers found that fewer than 35% of recreational Blue Crab pots had a BRD installed (Radzio et al. 2013). Low compliance and difficulty in enforcing regulations, along with an absence of economic incentive for crab fishermen, could contribute to delays in creating and effectively implementing Diamond-backed Terrapin bycatch reduction regulations (Roosenburg et al. 2008). Both commercial and recreational fishermen compliance is critically important for BRDs or other types of bycatch reduction technologies to effectively halt Diamond-backed Terrapin population declines and restore populations. The bycatch reduction solutions tested in this study were developed by commercial crab fishermen and thus may be more accepted within the fishery.

Diamond-backed Terrapin mortality in crab pots has an impact on the abundance of Diamond-backed Terrapins in a population and the demographics of the population. Smaller Diamond-backed Terrapins, such as juveniles and adult males, are at higher risk of entrapment in Blue Crab pots because they can easily enter the funnel openings (Dorcas et al. 2007; Hart and Crowder 2011; Morris et al. 2011). Over time, selective mortality of smaller individuals can skew the demographics of the Diamond-backed Terrapin population towards a higher proportion of larger, older, females (Dorcas et al. 2007). All of the Diamond-backed Terrapins we used in this study were adult females captured in tidal creeks adjacent to Masonboro Island, North Carolina. We caught 15 of the 17 Diamond-backed Terrapins in crab pots with standard size funnel entries and the other two were caught in a seine. The fact that we captured only females through our trapping efforts is a worrisome observation and suggests that the Diamond-backed Terrapin population in this area could already be experiencing a shift in population demographics. There is an active commercial Blue Crab fishery that operates in the waters of Masonboro Sound, but because there are no long-term data on Diamond-backed Terrapin distribution and abundance in this area, it is unknown whether the fishery has had a significant impact on Diamond-backed Terrapin populations. Population models developed for Diamond-backed Terrapins in Felgate Creek, Virginia, USA, indicate that the annual removal of 12% of juveniles and adult males can ultimately lead to local population extirpation (Carolyn Ayers, unpubl. report). Addressing the issue of fisheries bycatch of Diamond-backed Terrapins is a key component of management strategies for this species.

The establishment of DTMAs in southeastern North Carolina is an important step towards addressing bycatch issues for Diamond-backed Terrapins in this region. The two DTMAs encompass in-shore waters adjacent to Masonboro Island and Bald Head Island and the use of NCDMF-approved BRDs is required within the DTMA boundaries. The development and size of these DTMAs were based on Diamond-backed Terrapin home range size and movement patterns and the potential for interactions with the Blue Crab pot fishery (NCDMF 2020). Radio-telemetry studies conducted in North Carolina illustrated that Diamond-backed Terrapins are typically located in shallow water close to the marsh edge during the active season, which extends from April through October (Harden and Williard 2012). Blue Crab pots were found to co-occur with Diamond-backed Terrapins in waters up to 30 m from the shoreline in depths < 2.8 m. Given the overlap between Diamond-backed Terrapin habitat and distribution of Blue Crab pots, there is great potential for interactions between Diamond-backed Terrapins and the Blue Crab pot fishery, especially during the warmer months when Diamond-backed Terrapins are active (Harden and Williard 2012). The implementation of DTMAs will hopefully help in the restoration of local Diamond-backed Terrapin population as BRDs will be required in areas known to harbor terrapins. Coordination with crab fishermen and effective communication regarding bycatch reduction regulations will be critical to the success of the DTMAs. Our study provides data on the efficacy of two fisheries-sourced solutions to reduce bycatch of Diamond-backed Terrapins that may be acceptable to both fisheries managers and crab fishermen operating within the DTMAs. Continued cooperation between researchers, managers, and fishermen will be necessary to ensure the success of Diamond-backed Terrapin management plans and conservation of the species.

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Laura Wilson received a B.S. in Marine Biology from the University of North Carolina Wilmington (UNCW), USA. Her interest in herpetology, especially with Diamond-backed Terrapins, began when she worked as a volunteer in the Williard Lab at UNCW. Laura also pursued work in herpetology as an intern at the Karen Beasley Sea Turtle Rescue and Rehabilitation Center in Surf City, North Carolina, where she assisted in the care and rehabilitation of sea turtles. (Photographed by Laura Wilson).

Sam Romano received his B.S. in Environmental Science from the University of North Carolina Wilmington, USA. He is a commercial fisherman and Co-Owner of Seaview Crab Company in Wilmington, North Carolina. (Photographed by Joe Romano).

Amanda Southwood Williard is a Professor in the Department of Biology and Marine Biology at the University of North Carolina Wilmington, USA. She received a B.S. in Marine Biology from Auburn University (Auburn, Alabama, USA) and M.S. and Ph.D. degrees in Zoology from the University of British Columbia (Vancouver, British Columbia, Canada). Her research addresses aspects of reptile physiological ecology and implications for conservation and management of protected species. (Photographed by Michael Williard).