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Behavioural interactions of diamondback terrapins with crab pots demonstrate that bycatch reduction devices reduce entrapment

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ABSTRACT

1. Diamondback terrapins (*Malaclemys terrapin*) have experienced declines throughout their range, and accidental mortality in crab pots is a significant conservation concern. To minimize the risk of terrapins entering crab pots, researchers have suggested the use of bycatch reduction devices (BRDs) to reduce the size of crab pot openings and thereby exclude terrapins from entering crab pots. Despite these recommendations, few studies have observed terrapin interactions with BRDs and effectively evaluated the efficacy of these devices at preventing the entry of terrapins into pots.

2. The objective of this study was to determine the effect of BRD presence and orientation on terrapin behaviour around crab pots and overall terrapin capture rates.

3. In a controlled laboratory setting, terrapins investigated crab pots more frequently when crab pots were baited with fish versus chicken. Terrapins were captured more frequently when BRDs were not installed. The presence of the BRDs also increased the length of time necessary for a terrapin to enter a crab pot and decreased the proportion of entries relative to the number of investigations. Vertically-oriented BRDs were more effective than horizontally-oriented BRDs at reducing terrapin captures.

4. To prevent the continued decline of terrapin populations due to crab fisheries, it is recommended that crabbers avoid the use of fish as bait in crab pots to reduce the attractiveness of pots to terrapins and fit all crab pots with vertically-oriented BRDs to reduce terrapin entrapment.

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KEY WORDS: behaviour; brackish; crab; estuary; fishing; recreation; reptiles; sustainability

INTRODUCTION

Wildlife harvest has the potential to alter the population demography of both target and non-target species (Lewison *et al*., 2004a). Commercial fisheries inadvertently capture thousands of non-target individuals every year (Brooke *et al*., 2012). Bycatch, or the unintentional capture or harm to non-target aquatic animals, has contributed to population declines in many species, including sharks and sea turtles (Dulvy *et al*., 2008; Žydelis *et al*., 2009). For example, sharks represented >30%

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of the total catch weight in a study on swordfish fleets in the western Mediterranean Sea, and, in another study, longline swordfish fishing captured hundreds of loggerhead sea turtles and many leatherback turtles (Lewison *et al.*, 2004b; Megalofonou *et al.*, 2005). Although all sea turtles and numerous other turtle species are protected in the United States under the Endangered Species Act, laws do not fully protect them in cases where they were not intentionally targeted (Duugan, 2011). Consequently, efforts to minimize and prevent the incidental take of these species are key to long-term conservation efforts.

Diamondback terrapin (*Malaclemys terrapin*) populations have historically been over-harvested for human consumption (Hay, 1917; Garber, 1990). Despite historical depletion, diamondback terrapins are not protected at the federal level but are listed as a CITES II species. In addition, terrapins are listed as endangered in Rhode Island, threatened in Massachusetts, and a species of concern in New Jersey, North Carolina, and Virginia (Hackney, 2010). Using the criteria set forth by the Natural Heritage Program, terrapins have been identified as critically imperilled in Rhode Island; imperilled in Alabama, Louisiana, Massachusetts, and Mississippi; and vulnerable in Connecticut, Georgia, New York, North Carolina, New Jersey and Texas (Hackney, 2010). Although most states now ban or restrict the commercial harvest of terrapins, they have experienced recent population declines consistent with accidental capture in blue crab pots (often referred to as crab traps; Gibbons *et al.*, 2001; Dorcas *et al.*, 2007; Grosse *et al.*, 2011). Blue crabs (*Callinectes sapidus*) and diamondback terrapins both inhabit estuarine tidal creeks. Terrapins, which range from Massachusetts to Texas, significantly overlap with crabs in both range and habitat type. When crab pots are placed in tidal creeks, terrapins sometimes enter them and often drown (Bishop, 1983; Grosse *et al.*, 2009). Because of the smaller size of male and juvenile terrapins (Lovich and Gibbons, 1990), they may be removed from the population at higher rates than mature females that are unable to enter some crab pots, creating terrapin populations that are both older and female-biased in areas where crabbing is common (Roosenburg *et al.*, 1997; Dorcas *et al.*, 2007). Consequently, crab pots negatively impact terrapin populations by causing mortality (Bishop, 1983; Wood, 1997; Grosse *et al.*, 2009), offsetting natural sex ratios (Wood, 1997; Roosenburg and Green, 2000; Dorcas *et al.*, 2007), and decreasing juvenile recruitment (Grosse *et al.*, 2011).

Because crabbing can potentially extirpate populations and poses a serious threat to terrapin conservation, there have been numerous studies into methods to reduce the mortality of terrapins in crab pots (Roosenburg *et al.*, 1997; Butler and Heinrich, 2007; Grosse *et al.*, 2009; Rook *et al.*, 2010; Coleman *et al.*, 2011; Hart and Crowder, 2011; Morris *et al.*, 2011). One of the most widely proposed solutions rests on the implementation of bycatch reduction devices (BRDs). BRDs are rectangular, rigid devices that can be fitted over pot openings to exclude terrapins that are either too wide or too tall to fit through the BRD. Studies conducted throughout the terrapin range have documented reductions in terrapin captures when pots are fitted with BRDs (Roosenburg and Green, 2000; Butler and Heinrich, 2007; Coleman *et al.*, 2011; Morris *et al.* 2011). However, studies on how BRDs affect crab catch have produced variable results, with some studies finding a significant decrease (Coleman *et al.*, 2011) in crab catch with BRD use but others finding no effect (Cuevas et al., 2000; Morris *et al.*, 2011) or even a slight increase in catch rates (Guillory and Prejean, 1998). In efforts to balance terrapin conservation while continuing to catch high numbers of crabs, studies have examined factors such as size (Roosenburg and Green, 2000; Cole and Helser, 2001) and orientation (Hart and Crowder, 2011) of BRDs on terrapin entry. Hart and Crowder (2011) first tested the effectiveness of vertically-oriented BRDs and found that vertically-oriented BRDs had limited effects on crab catch, yet their capture rates of terrapins limited their inferences about the efficacy of vertically-oriented BRDs on terrapin capture. Typically, horizontally-oriented BRDs act as a physical barrier with depth acting as the primary limiting dimension for terrapin entry. Because vertically-oriented BRDs require terrapins to turn sideways to enter the crab pot, terrapins may be more likely to be physically excluded from crab pots. Previous research has similarly demonstrated that small modifications in the design and implementation of turtle exclusion devices have led to reduced bycatch rates for sea turtles (Jenkins, 2012).

Field studies of BRD effectiveness are often limited by low capture rates and do not allow for determination of the mechanisms that reduce capture rates (Coleman *et al.*, 2011; Hart and Crowder, 2011). Controlled behavioural observations of terrapins with BRDs will allow a more comprehensive understanding of how they prevent terrapin entry into crab pots to design and implement the most effective BRD. This study used a controlled laboratory experiment to examine the effects of BRD presence and orientation on terrapin capture and behaviour in and around crab pots. Vertically-oriented BRDs were hypothesized to be most effective because it would require terrapins to swim sideways into the pot.

METHODS

Study animal collection and housing

Terrapins were collected from Botany Island, South Carolina by seining. Of the 70 terrapins captured during this event (30 female and 40 male), 38 were selected for inclusion in this study. All female terrapins and male terrapins with missing limbs were excluded from the study. Shell widths of the males ranged from 8.5–10.2 cm and shell depths ranged from 4.1–5.0 cm; all were physically capable of fitting through the BRD (15.24 × 5.08 cm), which is the size typically used in the Carolinas. The 38 terrapins were divided into three study groups ranging in size from 10–15 individuals per group to test terrapins at natural, observed densities. Each individual was assigned a number that was painted on the carapace to identify individuals by camera from a distance. When not being studied in the test enclosure, terrapins were housed at the Savannah River Ecology Laboratory.

Behavioural observations

Terrapins were tested in a circular, 1000 gallon brackish water experimental enclosure (2.75 m diameter and 1 m deep) at the South Carolina Aquarium. Each group of terrapins was allowed to acclimate to the enclosure for at least 2 h before trials began. Trials began when the crab pot with a chimney was introduced into the treatment tank. The chimney was mounted in the centre of the pot and allowed terrapins to access air once they became trapped. All behavioural trials were recorded using a webcam mounted above the test tank while the terrapins underwent a series of three bait treatments and three BRD treatments. Twenty-five terrapins were used to evaluate bait type while these 25 plus an additional 13 terrapins were evaluated for their behaviour around crab pots. Only one trial was run each day.

To use the most attractive bait, three potential bait options were tested: chicken, fish (thawed mackerel), or nothing (i.e. control). Twenty-five terrapins were tested for each bait type, and the order of treatments was randomly determined. The bait was installed in a crab pot without a BRD. The crab pot was subsequently placed in the centre of the enclosure. Terrapins were video recorded for 90 min for each bait type. To correct for differences in the length of the recordings resulting from a storm that interfered with the function of the webcam, each individual's entry rate per hour was compared for each bait type.

A 5.08 × 15.24 cm (2 × 6 inch) BRD, which is the size typically available to recreational and commercial crabbers in South Carolina, was used to evaluate the effects of BRDs on terrapin

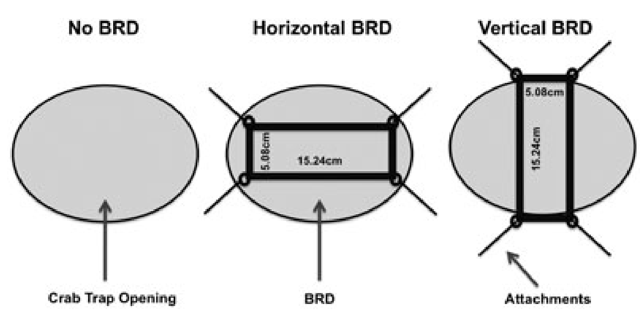

Figure 1. Diagram of the no BRD, horizontally-oriented BRD, and vertically-oriented BRD treatments.

capture (Figure 1). All four entrances to the crab pot were modified to complete the treatments. The effects of no BRDs, horizontally-oriented BRDs, and vertically-oriented BRDs on the total number of captures, the amount of time terrapins investigated the pot before entering, and the proportion of times a terrapin entered a pot per the number of times it approached the pot (i.e. investigations) were evaluated in this study. Each trial was conducted for 6 h, but because of storms that affected video capture, only 3 h of continuous footage was available for each of the BRD treatments. In cases with additional video footage, only the first 3 h of footage were evaluated to maintain temporal consistency. The order of the BRD treatments for each group was assigned randomly, and fish, the most effective bait (see study above), was used to attract terrapins to maximize observations of terrapin behaviours around BRDs. Once animals entered the pot and remained for 5 min without finding the chimney, they were removed from the pot to prevent accidental drowning and re-released into the test tank. No terrapins died during the study, and all 38 terrapins were released at their point of capture after the study was completed.

Data analysis

A power analysis was conducted in program R using pwr (Cohen, 1988) to evaluate the ability to detect a moderate to large effect of the predictors in this study. The analysis was conducted assuming a confidence level of $\alpha = 0.05$ with three treatments and 38 individuals evaluated per treatment. To determine the most effective bait type for terrapin captures, a repeated-measures ANOVA was used to analyse the effect of bait type (fish, chicken, none) on terrapin entry rates. Post hoc pairwise *t*-tests with Bonferroni corrections were used to evaluate the differences among bait type if bait was determined to be a significant factor.

Three repeated-measures ANOVAs were used to analyse the effects of BRD treatment (no BRD, horizontal BRD, and vertical BRD) on the total number of entries, the time necessary before entry, and the proportion of investigations yielding an entry. Assumptions of the repeated-measures ANOVAs were assessed by evaluating results of Mauchly's sphericity tests that indicate whether variance was equally distributed. If the Mauchly's sphericity test indicated departure from sphericity, the more conservative Greenhouse–Geisser correction was used to evaluate the significance of all tests at the α = 0.05 level. If treatment was significant in the repeated-measures ANOVA, a pairwise *t*-test was used to evaluate differences among treatments using a Bonferroni correction.

RESULTS

Bait trials

The power analysis demonstrated that this experiment had an 81–99% probability of detecting a moderate to large difference (f = 0.3–0.5) among treatments using this sample size if a difference existed. Bait type significantly affected terrapin entries into the crab pot ($F_{df=2,69} = 5.43$, $P = 0.007$). Terrapins entered pots at the rate of 1.20 entries per terrapin per h with fish as bait, 0.58 entries per terrapin per h with chicken as bait, and 0.21 entries per h with no bait (Figure 2). Fish attracted more terrapins than chicken (post hoc *t*-tests; $t = 2.40$, $P = 0.015$) and the no bait control ($t = 3.88$, $P = 0.001$). No difference was detected between chicken and the no bait control ($t = 0.035$, $P = 0.99$).

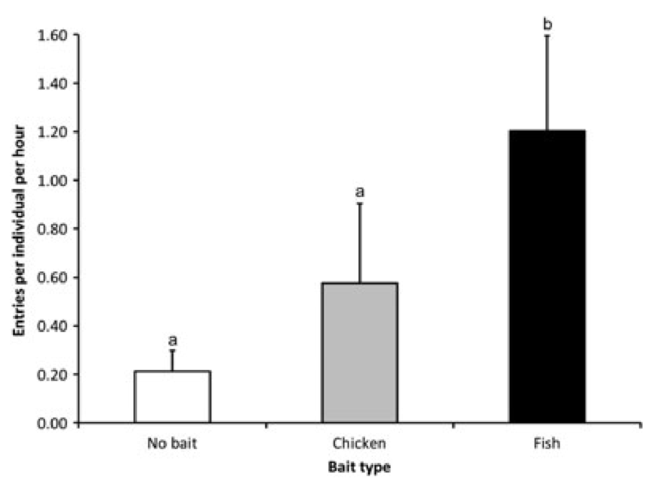

Figure 2. Fish used as bait increased terrapin entries into a crab pot with no BRD (epsilon = 0.950, $P < 0.001$). Letters denote significant differences among treatments.

BRD treatments

In total, 27 h of BRD trial video were captured and analysed (3 h per treatment per study group). The presence and orientation of BRDs significantly influenced terrapin behaviour and affected terrapin movement into crab pots. Although sphericity was met for the entry rate and the proportion of entries per investigation variables, deviation in sphericity for the time to entry variable was found (Mauchly's test statistic = 0.148, $P < 0.001$). Therefore, the Greenhouse–Geisser correction was used to account for this deviation for all tests including those that met sphericity assumptions for consistency. The BRD treatment altered the entry rates of terrapins into crab pots (epsilon = 0.99; $P < 0.001$; Figure 3). Vertically-oriented BRDs significantly reduced the number of entries into the pot, when compared with both the no BRD (post hoc pairwise *t*-tests; $t = -4.32$, $P = < 0.001$; Table 1) and horizontally-oriented BRD treatments ($t = -2.99$, $P = 0.020$; Table 1). Although 40 fewer terrapins entered the crab pot with horizontally-oriented BRDs relative to no BRD treatment, it was not significantly different ($t = -0.86$, $P = 0.94$; Table 1). Individuals entered crab pots without BRDs between 0 and 21 times whereas they entered crab pots with vertically-oriented BRDs 0 to 8 times. Three terrapins did not enter the BRD absent crab pot, seven terrapins did not enter when horizontally-oriented BRDs were applied, and eight terrapins did not enter when vertically-oriented BRDs were applied.

BRD treatment affected the length of time necessary for terrapins to enter the crab pot and the proportion of investigations that resulted in an entry (epsilon = 0.54, $P = 0.012$; epsilon = 0.94, $P < 0.001$; Figure 3). When compared with the no BRD treatment, the presence of vertically-oriented BRDs significantly increased the time spent investigating the pot before entry ($t = 2.99$, $P = 0.023$; Table 1), but the presence of horizontally-oriented BRDs did not ($t = -2.89$, $P = 0.870$; Table 1). The proportion of entries per investigation declined when BRDs were present (no BRD:horizontally-oriented BRD $t = 3.06$, $P < 0.001$; no BRD:vertical BRD, $t = 6.96$, $P < 0.001$; Table 1), but vertically-oriented BRD orientation was more effective than

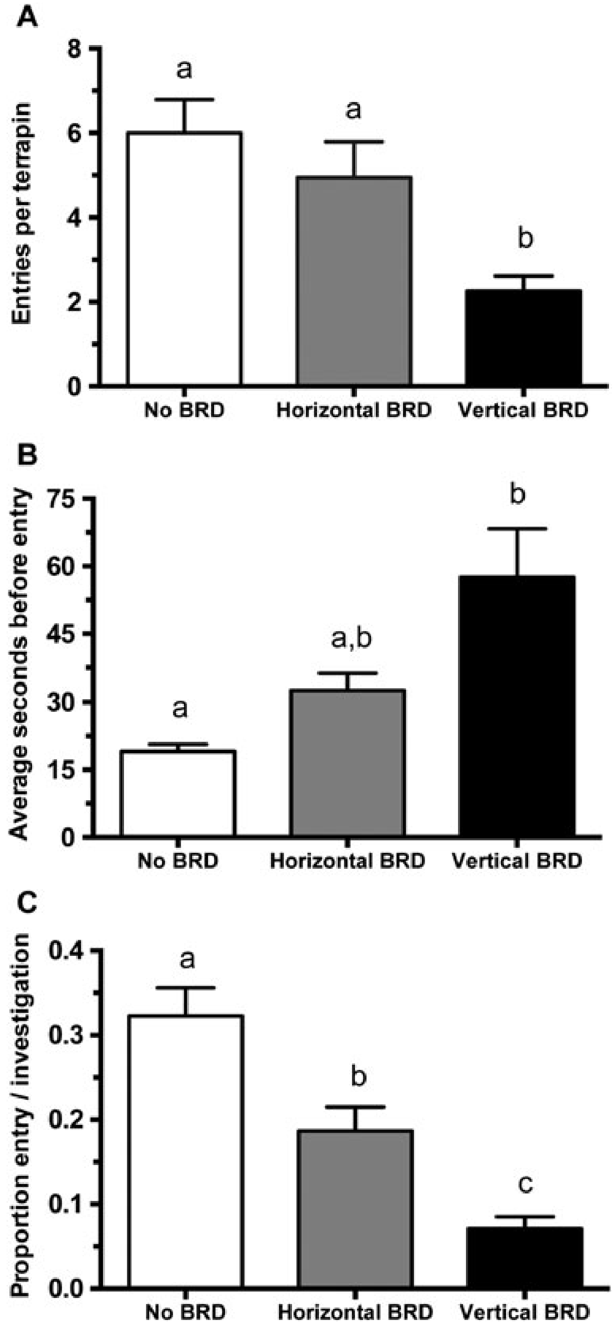

Figure 3. The use of BRDs reduces terrapin entries (A, epsilon = 0.99, $P < 0.001$), increases the time necessary for entry into crab pots (B, epsilon = 0.54, $P = 0.012$), and alters the success of terrapin entry (C, epsilon = 0.94, $P < 0.001$). Terrapin entries are expressed as entries per terrapin (A). Average time to entry refers to the time from terrapin approach to the crab pot until it passed through the entrance (B). Finally, the proportion of investigations that yielded an entry is displayed (C). Letters denote significant differences among treatments.

Table 1. Pairwise *t*-test comparisons for each significant factor identified in repeated-measures ANOVAs using Bonferroni corrections to control for family-wide error. Bold italicized values indicate significant effects

	No BRD - horizontal BRD	No BRD – vertical BRD	Horizontally-oriented BRDs-vertical BRD
Number of entries	0.941	<0.001	0.020
Number of entries per investigations	0.002	<0.001	0.007
Time to entry	0.870	0.023	0.227

horizontally-oriented BRD orientation at reducing the number of entries per investigation ($t = 3.73$, $P = 0.07$; Table 1).

DISCUSSION

During bait tests, higher entry rates of terrapins were observed when the pots were baited with fish than with chicken or with no bait. BRD presence and orientation significantly affected terrapin behaviour and capture in pots. Although horizontally-oriented BRDs decreased the percentage of investigations yielding an entry, the horizontally-oriented BRDs were less effective than the vertically-oriented BRDs at reducing overall capture rates and increasing the time to entry. These results indicate that avoiding use of fish as bait in crab pots and fitting pots with vertically-oriented BRDs offer more protection to terrapins, particularly juvenile and male terrapins which more easily enter pots because of their smaller sizes. For declining populations, preventing the disproportionate loss of males and juvenile females will be essential to successful management plans (Heppell, 1998).

Although BRDs offer some protection to male, and presumably smaller female terrapins, these results indicate that BRDs do not completely protect smaller terrapins from mortality in crab pots. During both the horizontally-oriented and vertically-oriented BRD treatments, the decreased proportion of terrapin investigations that yielded an entry into the pot was consistent with results of a field study by Hart and Crowder (2011). In the present study, both horizontally- and vertically-oriented BRDs required terrapins to approach the pot more times before entry and also required them to spend longer attempting to enter the pot. Collectively, these findings indicate that BRDs increased the difficulty of entering the pot and suggest that BRD presence could deter terrapins from entering pots even when BRDs do not physically exclude terrapins. Despite a 17.5% reduction in terrapin entries using a horizontally-oriented BRD relative to the absence of a BRD, 188 entries with horizontally-oriented BRDs were recorded. This observed reduction is lower than the reduction rates observed in other field studies that fitted pots with horizontally-oriented BRDs (Roosenburg and Green, 2000; Butler and Heinrich, 2007; Rook *et al.*, 2010, Coleman *et al.*, 2011). Reported discrepancies in horizontally-oriented BRD effectiveness may be due to several differences among studies. First, some studies have used smaller BRDs that exclude a larger proportion of the population (Roosenburg and Green, 2000; Butler and Heinrich, 2007; Rook *et al.*, 2010). Second, despite terrapins exhibiting sexual size dimorphism with females reaching larger sizes, studies do not always account for differences in entry rates among sexes (Coleman *et al.*, 2011). This may positively bias their entry reduction estimates because females are more likely to be excluded than males due to their larger size and faster growth rates (Gibbons and Lovich, 1990; Roosenburg *et al.*, 1997; Coleman *et al.*, 2011). Although BRDs reduced female terrapin entry by 96%, male entry rate was reduced by only 38% (Cole and Helser, 2001). Collectively, these results indicate that males and juveniles are still vulnerable to mortality in crab pots fitted with horizontally-oriented BRDs suggesting that modifications such as turning the BRD vertically may be necessary to effectively exclude smaller terrapins from crab pots.

Because this study was conducted in a controlled laboratory setting, BRD effectiveness could be evaluated in terms other than total terrapin catch. Because terrapin behaviour was observed around the pots, elements such as time before entry and the proportion of entries per investigation could be analysed as well. In this study, results indicated that vertically-oriented BRDs increased the length of time necessary for a terrapin to enter a crab pot, thereby decreasing the likelihood that a terrapin will enter a crab pot. By making it more difficult for terrapins to enter crab pots, vertically-oriented

BRDs may deter entries of terrapins small enough to fit through the BRD. Such behavioural data would be difficult or even impossible to obtain in a traditional field study. Understanding terrapin behaviour is imperative to the development of effective bycatch reduction technology, and future studies focusing on blue crab interactions with pots are needed to gain a full understanding of factors that increase crab interest in pots without increasing terrapin mortality.

Bait type is a rarely considered factor in terrapin entrapment, but these results indicated that bait type could play a significant role in terrapin entrapment in crab pots. Although no other studies have explicitly tested bait type and terrapin attraction, a previous study on bait type and blue crab catch showed that an alternative bait (shrimp alginate) resulted in a crab catch comparable with that using traditional bait (fish, specifically menhaden); however, bycatch rates were substantially lower in pots baited with the alternative bait (Anderson, 2014). The present study underscores the importance of considering bait as a factor in reducing the inadvertent mortality of all non-target species. Other studies examining terrapin entrapment in crab pots have used a variety of baits. Although the species may vary, fish appears to be almost exclusively used as bait across terrapin field studies (Wood, 1997; Butler and Heinrich, 2007), with the exception of the Hoyle and Gibbons (2000) study that used chicken to simulate the bait used by recreational crabbers (Bishop, 1983; Roosenburg *et al*., 1997; Hoyle and Gibbons, 2000; Coleman *et al*., 2011). In the present study, the most attractive bait for terrapins was fish. Prohibiting the use of fish in pots placed in terrapin habitat could reduce terrapin interest in the pots and thereby reduce mortality. In some cases, alternatives to fish might not be financially viable, and further research on the feasibility and limitations of alternative bait types is warranted.

Although results indicate that bait type can affect terrapin attraction to the pots, it is important to pair bait selection with BRDs. A recent study used unbaited crab pots and observed 70 terrapins and 40 fish captured in the pots (Upperman *et al*., 2014). Anecdotally, terrapins were observed to follow one another into pots, and pots are often found with multiple captured terrapins suggesting that entry of one individual may encourage entry of others (Grosse *et al*., 2009; Dorcas, unpublished data). It should also be noted that terrapins continued to enter the crab pot in this study despite the absence of bait. Consequently, other means of bycatch prevention are essential even when pots are left unbaited or employed with bait alternatives that are less attractive to terrapins.

Additional research into factors that reduce the attractiveness of crab pots to terrapins should be conducted to reduce the conflict between the need for terrapin conservation and high capture rates of blue crabs. Previous bycatch studies on sea turtles have highlighted the importance of recognizing differences in the behavioural factors that attract target and non-target species to fishing gear (Swimmer and Brill, 2006; Wang *et al*., 2010). Collectively, these results suggest that understanding the behaviours of non-target organisms may improve the design and implementation of BRDs while maintaining fishery profitability. Terrapin bycatch in crab pots is one factor threatening the stability of terrapin populations (Dorcas *et al*., 2007). We recommend avoiding the use of fish for bait in crab pots and the implementation of vertically-oriented BRDs on all crab pots to reduce terrapin bycatch in the blue crab fishery. Future field studies examining the effect of bait type and vertical BRD presence on crab behaviour are needed to assess whether these practices are also economically viable for crabbers.

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REFERENCES

Anderson AN. 2014. Development of an alternative bait for the Lousiana commercial blue (*Callinectes sapidus*) fishery, Louisiana State University, USA: MS thesis.

Bishop JM. 1983. Incidental capture of diamondback terrapin by crab pots. *Estuaries* **6**: 426–430.

Brooke SG, Desfosse LL, Karp WA. 2012. Estimating overall fish bycatch in US commercial fisheries. *Marine Fisheries Review* **74**: 1–5.

Butler JA, Heinrich JL. 2007. The effectiveness of bycatch reduction devices on crab pots at reducing capture and mortality of diamondback terrapins (*Malaclemys terrapin*) in Florida. *Estuaries and Coasts* **30**: 179–185.

Cohen J. 1988. *Statistical Power Analysis for the Behavioral Sciences*, 2nd edn.Hillsdale, NJ: Laurence Erlbaum.

Cole RV, Helser TE. 2001. Effect of three bycatch reduction devices on diamondback terrapin *Malaclemys terrapin* capture and blue crab *Callinectes sapidus* harvest in Delaware Bay. *North American Journal of Fisheries Management* **21**: 825–833.

Coleman AT, Wibbels T, Marion K, Nelson D, Dindo J. 2011. Effect of by-catch reduction devices (BRDs) on the capture of diamondback terrapins (*Malaclemys terrapin*) in crab pots in an Alabama salt marsh. *Journal of the Alabama Academy of Science* **82**: 145–157.

Cuevas KJ, Buchanan MJ, Perry WS, Warren JT. 2000. Preliminary study of blue crab catch in pots fitted with and without a diamondback terrapin excluder device. *Proceedings of the Annual Southeast Association of Fish and Wildlife Agencies* **54**: 221–226.

Dorcas ME, Willson JD, Gibbons JW. 2007. Crab trapping causes population decline and demographic changes in diamondback terrapins over two decades. *Biological Conservation* **137**: 334–340.

Dulvy NK, Baum JK, Clarke S, Compagno LV, Cortés E, Domingo A, Fordham S, Fowler S, Francis MP, Gibson C, *et al*. 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**: 459–482.

Duugan P. 2011. Incidental extinction: how the endangered species act's incidental take permits fail to account for population loss. *Environmental Law Reporter: News and Analysis* **41**: 10628–10640.

Garber SD. 1990. The ups and downs of the diamondback terrapin. *Conservationist* **44**: 44–47.

Gibbons JW, Lovich JE. 1990. Sexual dimorphism in turtles with emphasis on the slider turtle (*Trachemys scripta*). *Herpetological Monographs* **4**: 1–29.

Gibbons JW, Lovich JE, Tucker AD, Fitzsimmons NN, Greene JL. 2001. Demographic and ecological factors affecting conservation and management of diamondback terrapins (*Malaclemys terrapin*) in South Carolina. *Chelonian Conservation and Biology* **4**: 66–74.

Grosse AM, Van Dijk JD, Holcomb KL, Maerz JC. 2009. Diamondback terrapin mortality in crab pots in a Georgia tidal marsh. *Chelonian Conservation and Biology* **8**: 98–100.

Grosse AM, Maerz JC, Hepinstall-Cymerman JA, Dorcas ME. 2011. Effects of roads and crabbing pressures on diamondback terrapin populations in coastal Georgia. *Journal of Wildlife Management* **75**: 762–770.

Guillory V, Prejean P. 1998. Effect of a terrapin excluder device on blue crab, *Callinectes sapidus*, pot catches. *Marine Fisheries Review* **60**: 38–40.

Hackney AD. 2010. *Conservation biology of the Diamondback Terrapin in North America: policy status, nest predation, and managing island populations*, Clemson University, USA: MS thesis.

Hart KM, Crowder LB. 2011. Mitigating by-catch of diamondback terrapins in crab pots. *Journal of Wildlife Management* **75**: 264–272.

Hay WP. 1917. Artificial propagation of the diamond-back terrapin. *Bulletin of the US Bureau of Fisheries* **24**: 1–20.

Heppell SS. 1998. Application of life-history theory and population model analysis to turtle population. *Copeia* **2**: 367–375.

Hoyle ME, Gibbons JW. 2000. Use of a marked population of diamondback terrapins (*Malaclemys terrapin*) to determine impacts of recreational crab pots. *Chelonian Conservation and Biology* **3**: 735–737.

Jenkins LD. 2012. Reducing sea turtle bycatch in trawl nets: a history of NMFS turtle excluder device (TED) research. *Marine Fisheries Review* **74**: 26–44.

Lewison RL, Crowder LB, Read AJ, Freeman SA. 2004a. Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology and Evolution* **19**: 598–604.

Lewison RL, Freeman SA, Crowder LB. 2004b. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecology Letters* **7**: 221–231.

Lovich JE, Gibbons JW. 1990. Age at maturity influences adult sex ratio in the turtle *Malaclemys terrapin*. *Oikos* **59**: 126–134.

Megalofonou P, Yannopoulos C, Damalas D, De Metrio G, Deflorio M, De la Serna JM, Macias D. 2005. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. *Fishery Bulletin* **103**: 620–634.

Morris AS, Wilson E, Dever EF, Chambers RC. 2011. A test of bycatch reduction devices on commercial crab pots in a tidal marsh creek in Virginia. *Estuaries and Coasts* **34**: 386–390.

Rook MA, Lipcius RN, Bronner BM, Chambers RM. 2010. Bycatch reduction device conserves diamondback terrapin without affecting catch of blue crab. *Marine Ecology Progress Series* **409**: 171–179.

Roosenburg WM, Green JP. 2000. Impact of a bycatch reduction device on diamondback terrapin and blue crab capture in crab pots. *Ecological Applications* **10**: 882–889.

Roosenburg WM, Cresko W, Modesitte M, Robbins MB. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. *Conservation Biology* **5**: 1166–1172.

Swimmer Y, Brill RW (eds). 2006. *Sea turtle and pelagic fish sensory biology: developing techniques to reduce sea turtle bycatch in longline fisheries*. Pacific Islands Fisheries Science Centre, Honolulu, HA.

Upperman AJ, Russell TM, Chambers RM. 2014. The influence of recreational crabbing regulations on diamondback terrapin bycatch. *Northeastern Naturalist* **21**: 12–22.

Wang JH, Fisler S, Swimmer Y. 2010. Developing visual deterrents to reduce sea turtle bycatch in gill net fisheries. *Marine Ecology Progress Series* **408**: 241–250.

Wood RC. 1997. The impact of commercial crab pots on northern diamondback terrapins, Malaclemys terrapin. Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles – an International Conference. New York Turtle and Tortoise Society, New York, USA.

Žydelis R, Wallace BP, Gilman EL. 2009. Conservation of marine megafauna through minimization of fisheries bycatch. *Conservation Biology* **23**: 608–616.

