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The Effectiveness of Bycatch Reduction Devices on Crab Pots at Reducing Capture and Mortality of Diamondback Terrapins (*Malaclemys terrapin*) in Florida

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ABSTRACT: Diamondback terrapins (*Malaclemys terrapin*) drown in blue crab (*Callinectes sapidus*) pots throughout their range. The objectives of this study were to test if bycatch mortality of diamondback terrapins in commercial crab pots is reduced by using bycatch reduction devices (BRDs) and to determine if BRDs affect crab catch in Florida by comparing sex, size, and number of blue crabs captured in standard crab pots with those captured in pots equipped with BRDs. We fished 15 standard crab pots (controls) and 15 crab pots with bycatch reduction devices (experimentals) for 10-d periods at two sites per year from 2002 through 2005. Study sites were located in eight Florida counties with one sample period per county. Pots were checked daily and baited on alternate days. We determined sex and size of captured terrapins and blue crabs to evaluate if BRDs affected the size of either species. Thirty-seven terrapins were caught in control pots and four in experimentals. Eleven terrapins were small enough that they would not have been prevented from entering either pot treatment, but we found that 73.2% of the terrapins in this study could have been prevented from entering crab pots with functional BRDs. There were no significant differences between the sex, measurements, or number of legal-sized crabs captured in control and experimental pots at any of the study sites. We recommend that the Florida Fish and Wildlife Conservation Commission devise and adopt regulations that require the use of 4.5 × 12 cm BRDs on all commercial and recreational crab pots in Florida without delay.

Introduction

Diamondback terrapins (*Malaclemys terrapin*) are the only turtles entirely restricted to brackish water habitats of the Atlantic and Gulf coasts of the United States, ranging from Cape Cod, Massachusetts, to Corpus Christi, Texas (Ernst et al. 1994). They share this ecosystem with blue crabs (*Callinectes sapidus*), and terrapin mortality due to bycatch in crab pots has been known for over 60 years (Davis 1942). At a 2004 workshop on terrapin biology, specialists agreed that mortality due to bycatch in crab pots is the greatest threat to terrapin populations throughout their range (Butler et al. 2006).

Roosenburg (2004) provided a comprehensive review of the effect of blue crab fisheries on terrapin populations. Terrapin bycatch mortality has been reported from New Jersey (Burger 1989; Mazzarella 1994; Wood and Herlands 1996; Wood 1997), Delaware (Cole and Helser 2001), Maryland (Roosenburg et al. 1997; Roosenburg and Green 2000), South Carolina (Bishop 1983; Hoyle and Gibbons 2000), Florida (Butler 2000, 2002), Alabama (Marion 1986), Mississippi (Mann 1995), and Louisiana (Guillory and Prejean 1998). Capture rates are difficult to compare among these projects due to variation in methods, equipment, terrapin population densities, habitats, and study goals. Rates from 0.027 to 0.49 terrapins pot^{-1} d^{-1} have been reported (Bishop 1983; Mann 1995; Roosenburg et al. 1997; Wood 1997; Hoyle and Gibbons 2000). Mortality estimates due to crab pots are also difficult to compare, but they vary from 1,759 terrapins killed per year (estimated from data collected in April and May) in South Carolina (Bishop 1983) to 17,748–88,740 per year in New Jersey (Wood and Herlands 1996), and between 15% and 78% of the population per year in the Chesapeake Bay (Roosenburg et al. 1997). Terrapins exhibit a high degree of site fidelity (Lovich and Gibbons 1990), and such high capture and mortality rates can quickly reduce local populations beyond the point of recovery.

The terrapin bycatch mortality problem is sometimes compounded, as these gregarious turtles often follow one another into pots, and two to five individuals have been captured in a single active pot (Butler 2000, 2002). This situation can be further exacerbated by ghost pots, which are those pots that are either lost or abandoned by trappers but are still functional. Bishop (1983) found 28 decomposing terrapins in one ghost pot and Roosenburg (1991) discovered 49 in another.

Wood (1997) designed bycatch reduction devices (BRDs) and demonstrated their efficacy in de-

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creasing terrapin bycatch in crab pots. The devices are composed of wire or plastic rectangles attached to the inside opening of each entrance funnel of the pot. The height of the rectangle impedes the entrance of larger turtles, without significantly reducing crab capture. Roosenburg and Green (2000) refined the technique by testing a variety of BRD dimensions and determining the size that would exclude most terrapins while capturing most crabs. To date, three studies of BRDs have reported increased capture of legal-sized blue crabs in pots with BRDs, and the authors suggested that once crabs enter pots, the limited funnel size inhibits their escape (Wood 1997; Guillory and Prejean 1998; Roosenburg and Green 2000).

The coastline of Florida represents over 20% of the entire terrapin range, so the effect of crab pot mortality in this state has great significance, not only to Florida terrapins but to the conservation of the entire species. The Florida Natural Areas Inventory noted that for appropriate protection and management of terrapins in the state, it is necessary to reduce their incidental drowning deaths in crab pots (Hipes et al. 2001). The Florida Fish and Wildlife Conservation Commission (FFWCC) is concerned about terrapin bycatch, but asserts that data from Florida are necessary before management recommendations concerning the use of BRDs can be developed in the state. This project tested the efficacy of BRDs on crab pots in eight coastal counties of Florida. The objectives of the study were to test if bycatch mortality of diamondback terrapins in commercial crab pots is reduced by using BRDs and to determine if BRDs affect crab catch in Florida by comparing sex, size, and number of blue crabs captured in standard crab pots with those captured in pots equipped with BRDs.

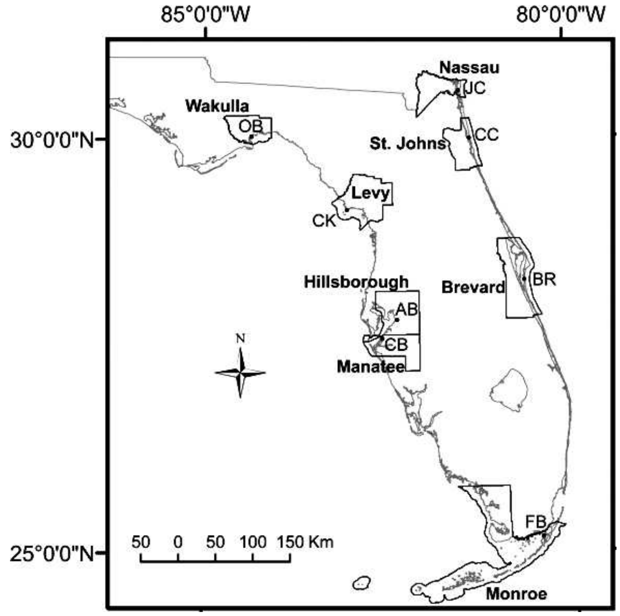

Fig. 1. Map of Florida showing sites within counties where trapping was conducted. CC = Casa Cola Creek, JC = Jackson Creek, AB = Alafia Bank, CB = Critical Bayou, OB = Oyster Bay, CK = Cedar Key, FB = Florida Bay, BR = Banana River.

Methods

Thirty-five of Florida's 67 counties have coastal borders with appropriate habitats for both diamondback terrapins and blue crabs. We chose eight counties in an attempt to represent a diversity of regions and habitats throughout the state (Fig. 1). The presence of terrapins in each study area was confirmed by prior reconnaissance. In 2002, we worked in Casa Cola and Jackson creeks (CC, JC) in St. Johns and Nassau counties, respectively. These northeastern sites were creeks emptying into the Intracoastal Waterway in typical salt marsh habitat with cordgrass (*Spartina* sp.) and black needlerush (*Juncus roemerianus*) predominating. In 2003, we trapped at Alafia Bank (AB) which includes Sunken and Bird islands at the mouth of the Alafia River in Hillsborough County, and at Critical Bayou (CB) adjacent to Terra Ceia Bay in Manatee County. Both Tampa Bay sites had red, white, and black mangrove (*Rhizophora mangle*, *Laguncularia racemosa*, and *Avicennia germinans*, respectively) along shorelines, and the CB site was populated with turtle grass (*Thalassia testudinum*). In 2004, we placed pots in Oyster Bay (OB) around Gull, Smith, and Palmetto islands in Wakulla County, and in Tyre Creek and other areas west of the causeway (SR 24) to Cedar Key (CK) between the Number 3 and 4 channels in Levy County. In both locations, cordgrass and black needlerush were present on the numerous islands, and in CK, red mangrove and the invasive nonnative Brazilian pepper (*Schinus terebinthifolius*) were present. In 2005, we set pots in Florida Bay (FB) in the Key Largo area around Pigeon Key and in the southeastern part of Lake Surprise in Monroe County, and in the Banana River (BR) near the southern end of Horti Point and on the eastern shoreline in the Thousand Islands in Brevard County. We noted the three mangrove species and Brazilian pepper at both sites, and another invasive nonnative species, Australian pine (*Casuarina* sp.), was prevalent in the Brevard County study area.

Preliminary studies between 1995 and 2000 using various modified crab pots in northeastern Florida suggested that terrapins entered the pots more frequently in May than in June or July (Butler 2000, 2002). For this project we fished 30 crab pots for 10-d periods at 2 sites per year in the month of May from 2002 through 2005. Fifteen pots were equipped with BRDs (experimentals) and 15 were left unchanged (controls). Typical commercial crab pots have dimensions of 60 × 60 × 45 cm with entrance funnels in 4 sides. Each funnel is 12.5 cm long, with the outer opening being 12.5 × 17.5 cm and the inner opening being 10 × 15 cm. The BRDs we used are 4.5 × 12 cm rectangles made of 12 gauge galvanized steel wire (about the diameter of coat hanger wire). A single wire 37.5 cm long was molded to these dimensions such that one side was formed by overlapping two 4.5 cm ends of the wire. The ends forming this side were fastened together with galvanized steel j-clips. The BRDs were affixed to the inner openings of pot entrances with stainless steel hog rings to limit the funnel dimensions. Terrapins are dimorphic with females being much larger than males, and the objective of the BRDs is to reduce the size of the opening to impede adult female terrapins and the largest males from entering pots while not decreasing crab capture. Small male terrapins and immature females would still be able to enter the pots, but because males often follow mature females into pots, this method could secondarily reduce male entrapment.

Crab pots were placed in rows of alternating experimental and control treatments approximately 20 m from one another. All pots were checked daily and baited on alternate days. We used baits recommended by local crab trappers, and at most sites (JC, CK, FB, and BR) that was pogy (menhaden, *Brevoortia* sp.). At CC we used fish market discards, at AB and CB we used shad (*Alosa* sp.), and in OB we used chicken backs. Control pot data represented the expected capture numbers and sizes of both terrapins and crabs under normal circumstances, and those values were compared to capture totals for experimental pots.

We sexed all captured terrapins, and measured shell height (SH) and carapace width (CW) with calipers (1 mm). Though not critical to this study, we also weighed the terrapins with handheld Pesola scales (5 g) and measured carapace and plastron lengths. All live specimens were released at the capture sites. To monitor whether terrapins were recaptured during the study, each was injected between the carapace and the right hind limb with a unique subcutaneous microchip (12 mm, AVID Identification Systems, Inc., Norco, California). Terrapins that died as a result of entrapment were preserved and placed in the University of North Florida Vertebrate Zoology Collection.

All captured blue crabs were sexed, and measured to the nearest millimeter between the lateral points of the carapace (point to point, PP) to determine if they were of legal size (in Florida 5 in., 127 mm PP). Crabs smaller than this were released at the capture site, but all legal-sized crabs were removed from the study area to avoid recapture. Catch per unit effort (CPUE) was calculated as crabs pot^{-1} d^{-1}. We also recorded the front to back measurement of the carapace (FB) and carapace height (CH) of most of the legal crabs.

Statistical analyses were performed using SPSS 11 (SPSS Inc., Chicago, Illinois). Numbers of legal-sized crabs captured in control and experimental pots were compared at each site using the chi-square statistic. We used MANOVA to compare measurements of legal-sized crabs with pot treatment and sex at each site. Significance level was 0.05. Means are followed by ± one standard error.

TABLE 1. Number of male and female diamondback terrapins captured in control and experimental crab pots.

Sex	Control	Experimental	Total
Male	28	2	30
Female	9	2	11
Total	37	4	41

Results

Terrapins

We captured 41 diamondback terrapins, 30 males and 11 females (Table 1) for a sex ratio of 2.7:1. Eleven males and 3 females died as a result of entrapment during the study. Fourteen other captured terrapins were unconscious or barely moving when found. These were kept overnight in buckets and all survived after up to 24 h in captivity. No terrapins were recaptured. Multiple captures in the same pot of from 2 to 4 terrapins occurred 5 times. Mean terrapin CW was 90.8 ± 1.69 mm (range = 69–118 mm), and mean SH was 48.1 ± 0.84 mm (range = 39–68 mm).

Thirty-seven terrapins were captured in control pots and 4 in experimentals (Table 1). Of the ones captured in experimental pots, 3 had SH of less than 45 mm and were not prevented from entering with the size of BRDs we used. The fourth, captured during the second season, had a SH of 48 mm, and we determined that two BRDs on that pot had become misshapen to heights exceeding 45 mm. This event prompted us to recheck BRD measurements on all experimental pots, and we found this pot to be the only one with the problem. Of the 37 terrapins captured in control pots, 5 had SH less than 45 mm, and 3 had SH exactly 45 mm high. We can say with certainty that 30 terrapins (73.2%) in this study (29 from controls and one from the nonfunctioning experimental) could have been prevented from entering crab pots with functional BRDs.

We captured no terrapins at CC, FB, or BR. At JC we captured 3 males and 2 females, all in control

TABLE 2. Number of blue crabs captured at the study sites and catch per unit effort (CPUE) in control and experimental pots.

Site	Sex	Control	Experimental	p Value
Casa Cola Creek	M	105	99	
	F	103	116	
Subtotal		208	215	0.734
CPUE		1.39	1.43	
Jackson Creek	M	164	154	
	F	90	74	
Subtotal		254	228	0.219
CPUE		1.75	1.52	
Alafia Bank	M	60	61	
	F	10	12	
Subtotal		70	73	0.802
CPUE		0.47	0.49	
Critical Bayou	M	16	16	
	F	6	4	
Subtotal		22	20	0.758
CPUE		0.15	0.13	
Oyster Bay	M	114	136	
	F	31	42	
Subtotal		145	178	0.066
CPUE		0.97	1.19	
Cedar Key	M	151	174	
	F	129	154	
Subtotal		280	328	0.052
CPUE		1.87	2.19	
Florida Bay	M	49	47	
	F	16	16	
Subtotal		65	63	0.860
CPUE		0.43	0.42	
Banana River	M	277	283	
	F	34	10	
Subtotal		311	293	0.372
CPUE		2.07	1.95	
Total		1,355	1,398	

pots. We lost one of our control pots for the last 5 d at JC, so we had 295 trap-days and our rate of terrapin capture there was 0.017 terrapins pot^{-1} d^{-1}. If we consider only control pots (145 trap-days), because large terrapins were excluded naturally from the experimental pots, then the terrapin capture rate was 0.034 terrapins pot^{-1} d^{-1}.

At AB we captured 22 terrapins in controls and one in an experimental pot (with the misshapen BRD previously described). Twenty-one were males and 2 were females. Capture rate there for 300 trap-days was 0.077 terrapins pot^{-1} d^{-1}, or considering only control pots 0.147 terrapins pot^{-1} d^{-1}. At CB we captured 8 terrapins in controls and 3 in experimentals; 4 were males and 7 were females. Capture rates there were 0.037 terrapins pot^{-1} d^{-1} overall, or 0.053 terrapins pot^{-1} d^{-1} in controls only.

We captured one terrapin at OB and one at CK; both were males in control pots. Capture rate at each of those sites was 0.003 terrapins pot^{-1} d^{-1}, or considering only control pots 0.007 terrapins pot^{-1} d^{-1}.

Crabs

We captured 2,753 legal-sized crabs, 1,906 males and 847 females. There were no significant differences between the numbers of legal-sized crabs captured in control and experimental pots at any of the study sites, and CPUEs were similar (Table 2). At six sites (JC, AB, CB, OB, FB, and BR) significantly more males were trapped than females, but this was consistent for both pot treatments.

Pot treatment had no statistically significant effect on PP, CH, or FB of the crabs at any of the 8 study sites (Table 3). Female crabs had significantly larger PP measurements than males at CC, JC, OB, and CK. Females had larger CH than males at CB and OB; and at OB female FB measurement was larger than that of males. In all cases these relationships were consistent for both pot treatments.

TABLE 3. MANOVA tests of between-subjects effects of blue crabs captured during the study. * denotes a statistically significant relationship.

Site	Independent Variable	df	Wilks' Lambda Value	p Value
Casa Cola Creek	sex	3, 394	0.6565280	<0.0001*
	pot treatment	3, 394	0.98993887	0.077
Jackson Creek	sex	3, 154	0.62795203	<0.0001*
	pot treatment	3, 154	0.99020966	0.6777
Alafia Bank	sex	3, 138	0.87694611	0.0004*
	pot treatment	3, 138	0.97145590	0.2603
Critical Bayou	sex	3, 37	0.71650452	0.0059*
	pot treatment	3, 37	0.92697348	0.4165
Oyster Bay	sex	3, 318	0.78416049	<0.0001*
	pot treatment	3, 318	0.99014736	0.3685
Cedar Key	sex	3, 428	0.78561941	<0.0001*
	pot treatment	3, 428	0.99855274	0.8917
Florida Bay	sex	3, 118	0.75698311	<0.0001*
	pot treatment	3, 118	0.99810549	0.9735
Banana River	sex	3, 392	0.84310697	<0.0001*
	pot treatment	3, 392	0.998571855	0.6405

TABLE 4. Rates of diamondback terrapin capture in crab pots without bycatch reduction devices.

Place	Diamondback Terrapins pot^{-1} d^{-1}	Source
Florida	0.007–0.147	Current study
South Carolina	0.16	Bishop 1983
	0.027	Hoyle and Gibbons 2000
Mississippi	0.163	Mann 1995
Maryland	0.17	Roosenburg et al. 1997
New Jersey	0.054–0.49	Wood 1997

Discussion

At JC, AB, OB, and CK we recorded male-biased terrapin sex ratios (1.5:1, 10.5:1, 1:0, and 1:0, respectively) in our pots. Roosenburg et al. (1997) suggested that because males are vulnerable to capture throughout their life span while females grow too large to enter, this would lead to a male bias in crab pots. Selectively removing males from a population could lead to population sex ratios skewed toward females such as those reported by Roosenburg et al. (1997) and Seigel (1984). At CB we recorded 1.75:1 female bias in our pots, which is similar to Hoyle and Gibbons (2000) in South Carolina. The overall population sex ratio in the South Carolina terrapins favored males, and this was attributed to their shorter maturation period than females. We did not attempt to assess overall population characteristics in our study, but more research is needed to determine how crab-pot-captured terrapin sex ratios influence overall population sex ratios.

Adult female terrapins have SH and CW that preclude them from entering most standard crab pots (Roosenburg et al. 1997; Butler 2002), and we captured only males and immature females. None of the terrapins captured in this study had CW that would have prevented entrance through the BRDs (i.e., > 120 mm), so the critical BRD measurement is its height of 4.5 cm. Wood (1997) tested several BRD sizes ranging from 4 × 8 to 5 × 10 cm. While all reduced terrapin bycatch to varying degrees only the largest model was clearly shown not to reduce capture of legal-sized crabs. In fact, in some of his tests crab capture was enhanced in pots with BRDs. Our data do not suggest enhancement of crab catch, but capture rates at both OB and CK were higher in experimental pots and they approached statistical significance (Table 2).

The rates of terrapin capture we recorded are similar to those of previous studies (Table 4). Based on research in northeastern Florida we know that terrapin capture rates vary throughout the year (Butler 2000, 2002), so it is difficult to estimate how many terrapins are lost to crab pots each year in this state. Our capture rates suggest that if 15 crab pots were placed in Florida waters, throughout May, where terrapins exist we could expect mortality between 3.3 and 68.4 turtles (0.007 terrapins × 15 pots × 31 d = 3.3; 0.147 terrapins × 15 pots × 31 d = 68.4). Most commercial crabbing operations deploy hundreds of pots, so in the relatively small areas where we trapped these losses could have significant detrimental effects on local populations.

Wood's (1997) experiments with the intermediate sized 4.5 × 10 cm BRD showed promising results in excluding terrapins, and, although crab sizes were similar between his control and experimental treatments, slightly fewer legal-sized crabs were captured in pots with that size BRD. Roosenburg and Green (2000) also tested a variety of BRD sizes and showed that BRDs with dimensions of 4 × 10 cm prevented all terrapins from entering pots but lowered crab capture rates. BRDs with dimensions of 5 × 10 cm did not affect crab capture and reduced terrapin bycatch by 47%. They showed that BRDs with dimensions of 4.5 × 12 cm reduced terrapin capture by 82% without affecting the number or size of crabs captured (Roosenburg and Green 2000).

We measured CH of 2,197 (79.8%) of the legal-sized crabs we captured. Although we recorded no statistically significant differences in any crab measurements due to pot treatment, 83 crabs (3.78%) had CH ranging from 46 to 51 mm and theoretically would have been excluded by the BRDs. Sixty-seven of these were captured at BR, 7 at CC, 5 at FB, and one each at AB, CB, CK, and JC. Curiously, 26 of these were collected in experimental pots, and we assume they were able to squeeze through the BRDs.

As a result of Wood's (1997) work, in 1998 the New Jersey Bureau of Marine Fisheries mandated the use of 5 × 15 cm BRDs on commercial crab pots set in any body of water less than 150 ft. wide, and they were provided free of charge to crab trappers. In 1999, the Maryland Department of Natural Resources adopted regulations requiring 4.5 × 12 cm BRDs on all recreational crab pots in that state based on the findings of Roosenburg and Green (2000). Based on studies by Cole and Helser (2001), the Delaware Department of Natural Resources followed suit.

The current study has demonstrated that diamondback terrapins enter and die in crab pots in Florida waters. The results of the current study are comparable to the others in that 73.2% of trapped terrapins would have been excluded from pots with BRDs, and use of BRDs had no significant effect on the sex, size, or number of crabs captured. We recommend that the FFWCC devise and adopt regulations that require the use of 4.5 × 12 cm BRDs on all commercial and recreational crab pots in Florida as soon as possible. The regulations should include a time frame after which all newly sold crab pots should already be equipped with BRDs at the time of purchase. BRDs should be provided free of charge by the FFWCC, so that pots currently in use can be altered to satisfy new regulations. It is our hope that all 16 states within the range of the terrapin will eventually require the use of BRDs on all crab pots.

Roosenburg and Green (2000) noted that BRDs must be constructed of materials strong enough to prevent manipulation and bending by terrapins attempting entrance, and they suggested the use of 11 gauge galvanized wire. Because we had several BRDs made of galvanized wire become misshapen, we recommend using a stronger material such as stainless steel or thick plastic. Either material would also reduce or prevent rusting. Our j-clips rusted early and required occasional replacement, so we recommend soldering or welding the stainless steel ends together in lieu of using j-clips. Additional recommendations concerning regulatory changes must include adequate enforcement with appropriate fines and penalties for noncompliance.

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