Impact of a Bycatch Reduction Device on Diamondback Terrapin and Blue Crab Capture in Crab Pots
Author(s): Willem M. Roosenburg and Jason P. Green
Source: *Ecological Applications*, Vol. 10, No. 3 (Jun., 2000), pp. 882-889
Published by: Ecological Society of America
Stable URL: http://www.jstor.org/stable/2641052
Accessed: 29/10/2013 14:03

Ecological Applications, 10(3), 2000, pp. 882–889

IMPACT OF A BYCATCH REDUCTION DEVICE ON DIAMONDBACK TERRAPIN AND BLUE CRAB CAPTURE IN CRAB POTS

WILLEM M. ROOSENBURG[1,3] AND JASON P. GREEN[2]

[1]*Department of Biological Sciences, Ohio University, Athens, Ohio 45701 USA*
[2]*Department of Environmental Studies, Ohio University, Athens, Ohio 45701 USA*

Abstract. Bycatch in fisheries is receiving attention because of its impact on ecological diversity and resource sustainability. Male and juvenile female diamondback terrapins, *Malaclemys terrapin,* frequently drown as bycatch in crab pots, removing individuals with high reproductive value from the population and possibly skewing sex ratios. We tested a wire bycatch reduction device (BRD) to determine its ability to reduce terrapin entrapment and to examine any effects the BRD has on the size and number of blue crabs, *Callinectes sapidus,* caught in crab pots. We tested three sizes of BRDs, a 4 × 10 cm BRD in 1996, and 4.5 × 12 cm and 5 × 10 cm BRDs in 1997. We equipped both standard crab pots and modified (tall) crab pots with BRDs, the latter were used to prevent terrapin mortality in areas of high terrapin density. Traps were checked and baited daily. In 1996, we caught no terrapins in 14 crab pots equipped with the 4 × 10 cm BRDs and 21 terrapins in 14 crab pots without BRDs. In 1997, the 4.5 × 12 cm BRD reduced terrapin bycatch by 82%, whereas the 5 × 10 cm BRD reduced terrapin bycatch by 47%. The 4 × 10 cm BRDs, however, reduced the size and number of large "Number One" and mature female crabs. Catch rate for standard crab pots with 4 × 10 cm BRDs was 2 crabs·pot^{-1}·day^{-1} lower than standard crab pots fished without BRDs in 1996. Neither the 5 × 10 cm BRD nor the 4.5 × 12 cm BRD affected crab size or the number of crabs caught in crab pots. Standard crab pots with a 4.5 × 12 cm BRDs had the highest catch per unit effort (2.69 crabs·pot^{-1}·day^{-1}), followed by standard crab pots without BRDs (2.55 crabs·pot^{-1}·day^{-1}) and standard crab pots with 5 × 10 cm BRDs (2.39 crabs·pot^{-1}·day^{-1}). The largest crab caught in 1997 was in a crab pot with a 4.5 × 12 cm BRD. We stress the importance of using the 4.5 × 12 cm BRD on crab pots fished commercially and recreationally to reduce terrapin mortality and the need to integrate the use of BRDs on crab pots with other conservation practices such as protection of critical terrapin habitat, particularly nesting beaches.

Key words: blue crab; bycatch reduction device; Callinectes; *diamondback terrapin; fisheries;* Malaclemys; *resource sustainability; TED, turtle excluder device.*

INTRODUCTION

Bycatch consists of nontarget size classes or species caught in nonselective commercial fishing and trapping equipment. The loss of species unsuitable for consumption and juveniles of target species too small for consumption can result in reduced recruitment, biomass, yield, and other ecological impacts on local diversity (Saila 1983). Thus, techniques developed to reduce the impact of nonrestrictive gear on bycatch must simultaneously minimize the effect on the number and size of target species captured. Attempts to reduce bycatch has pitted scientists, fisherman, and policy makers against one another, each attempting to balance the economic concerns of equipment cost, economic efficiency, revenue loss, and the environmental concerns of diversity, sustainability, and conservation. Therefore, effective mechanisms to reduce bycatch must be inexpensive and minimize the impact on target species.

The effects of bycatch on population dynamics of nontarget species has not been well documented; however, the species affected are well established. Northern right whale dolphin (*Lissodelphis borealis;* Mangel 1993), dolphin (*Coryphaena hippurus*; Massuti and Morales 1995), squid (Loliginidae; Pierce et al. 1994), yellowtail kingfish (*Seriola lalandi*; Moon et al. 1996), sea turtles (Magnuson et al. 1990, Stabenau et al. 1991, Crowder et al. 1995, Robins 1995, sensu Klima et al. 1988), southern kingfish (*Menticirrhus americanus*; Smith and Wenner 1985) and diamondback terrapins (*Malaclemys terrapin*; Bishop 1983, Roosenburg 1991, Roosenburg et al. 1997) are among species captured as bycatch of nonselective fishing equipment. Although the ratio of bycatch to target species can be small, large numbers of recreationally and commercially important species are frequently killed and discarded (Liggins and Kennelly 1996). On the other hand, bycatch ratios can be as high as 12 : 1, thereby overexploiting nontarget species (Yáñez-Arancibia et al. 1985).

Recent studies have demonstrated that bycatch mortality can be reduced by making minor technological changes in fishing gear or altering the manner in which gear is deployed (Perra 1992). Turtle excluder devices

Manuscript received 25 September 1998; accepted 3 May 1999; final version received 14 June 1999.
[3] E-mail: roosenbu@ohiou.edu

(TEDs) on trawl nets (Crowder et al. 1995, Hillsted et al. 1982), BRDs on crab pots (Guillory and Prejean 1998, Wood 1997), and modification of crab pots (Roosenburg et al. 1997) are examples of technological changes that have reduced or eliminated the impact on nontarget species. Changes in fishing practices, such as the depth at which trotlines are fished (McEachron et al. 1988) and the closure of fisheries (e.g., deep sea drift netting in 1991) have also reduced bycatch mortality (Richards 1994). Management restrictions, however, are often controversial because of their potential economic impact (Rulifson et al. 1992). In this study, we evaluate the ecological impact of a bycatch reduction device (BRD), developed by Roger Wood at Stockton State College, that reduces the capture of turtles in commercial crab pots. The device is a simple wire rectangle that decreases the size of the funnel entrance into crab pots, preventing bycatch species from entering the crab pot.

Terrapin life history and crab pots

Diamondback terrapins (*Malaclemys terrapin*) range from Cape Cod, Massachusetts to the Gulf Coast of Texas, inhabiting salt marshes, bays, and lagoons (Carr 1952). Terrapins mature late, are slow growing, and have low reproductive rates (Carr 1952). The range, habitat, and diet of the terrapin overlap with the that of blue crab (*Callinectus sapidus*). One of the most popular mechanisms utilized to catch blue crabs is the crab pot, a 60 × 60 × 60 cm wire cage with two or four funnel openings that allow animals to enter. The capture and drowning of terrapins in crab pots is a major threat to terrapin populations throughout their range (Burger 1989, Seigel and Gibbons 1995, Wood 1997). The problem is exacerbated by recreational crab pots fished in shallow, nearshore areas where terrapins are more common, particularly when these pots remain unchecked for several days (Roosenburg et al. 1997). Estimates of terrapin capture rates in crab pots have ranged from 0.16 (Bishop 1983) to 0.17 terrapins·pot^{-1}day^{-1}, the latter catch rate resulting in the death of 15–78% of the local population annually (Roosenburg et al. 1997).

The small entrance into crab pots and the sexual dimorphism of terrapins result in the capture of males and smaller, juvenile females (Roosenburg et al. 1997). Terrapins are sexually dimorphic (Gibbons and Lovich 1990, Lovich and Gibbons 1990) and Chesapeake Bay females are 3–4 times larger than males (Roosenburg 1991). Once females grow larger than 15.5 cm plastron length, at ~8 years of age, they are too large to enter crab pots (Roosenburg et al. 1997). This results in a 3 : 2 male bias in capture rates of terrapins in crab pots and may contribute to the 1 : 2 female biased sex ratio observed in the Patuxent River, a tributary of Chesapeake Bay (Roosenburg et al. 1997). Lovich and Gibbons (1990) proposed that because male terrapins mature earlier, they should dominate numerically, thus the sex ratio of the Patuxent population may be shifted from the normal operational sex ratio due to terrapin mortality in crab pots. A 2.3 : 1 male bias terrapin capture in crab pots has been observed in the Ashley River estuary population of South Carolina, however, the natural sex ratio of this population was unknown (Bishop 1983). Furthermore, because the female terrapins killed in crab pots are of age classes with high survivorship but have not reproduced yet, their loss can have a considerable impact on the population sustainability (Roosenburg et al. 1997)

We had two objectives in our study. First, to determine the dimensions of a BRD that would be most effective at preventing terrapins from entering crab pots. Second, to evaluate the impact of the BRD on the number and size of crabs that were caught to minimize impact on the crab fishery. Wood (1997) tested three BRD sizes on crab pots fished in the Great Bay of New Jersey and found that a 4 × 8 cm BRD successfully excluded terrapins, but also the commercially, more valuable (i.e., larger) crabs. The 4.5 × 10 cm and 5 × 10 cm BRDs dramatically reduced terrapin bycatch without reducing the number of crabs caught (Wood 1997). Similarly, in Louisiana, crab catch per unit effort was higher in pots with 5 × 10 cm BRDs than in pots without BRDs (Guillory and Prejean 1998). Unfortunately, in both these studies the size of crabs caught was not examined and thus the effect on larger, more valuable crabs was not evaluated. In this study, we tested the effect of three sizes of BRDs, 4 × 10 cm, 4.5 × 12 cm, and 5 × 10 cm, on the size and number of both terrapins and crabs caught in crab pots to determine the optimal size of the BRD to be used on crab pots fished in the Chesapeake Bay.

Materials and Methods

During the summers of 1996 and 1997, we fished standard (60 × 60 × 60 cm) and modified (tall; 60 × 60 × 180 cm) crab pots (Roosenburg et al. 1997) with and without BRDs in the Patuxent River, a tributary of the Chesapeake Bay. We fished standard crab pots in areas of low turtle density (open river, 1–4 m deep), and tall crab pots in areas of high turtle density (shallow creeks, <1 m deep). We checked all crab pots daily and baited them with fresh white perch (*Morone americana*). To avoid drowning turtles, we checked standard crab pots three times a day, however, we replaced bait and removed crabs only once a day.

In 1996, we fished 12 tall crab pots, six with 4 × 10 cm, 11-gauge galvanized wire BRDs attached to the funnel entrances and six without BRDs. We fished 16 standard crab pots: eight with 4 × 10 cm BRDs and eight without BRDs. We fished crab pots for a total of 50 d, although the number of days each crab pot type was fished varied. In 1997, standard and tall crab pots were fished for a total of 42 d. We equipped five of both tall and standard pots with 4.5 × 12 cm, 11-gauge galvanized wire BRDs, and five with 5 × 10 cm, 11-

TABLE 1. Number of turtles and crabs caught in 1996 in height and width classes used to determine BRD sizes tested in 1997.

	Height <4 cm	Height <4.5 cm	Height <5 cm	Width >10 cm	Height >4.5 cm	Total
Turtles	2	**28**	77	47	103	131
Crabs	1095	1251	0	0	**7**	1258

Note: Bold numbers indicate critical values used to determine the size of excluders tested in 1997.

gauge galvanized wire BRDs, and five of each with no BRDs as controls.

We recorded the number of turtles and crabs caught in each type of crab pot and culled crabs into standard commercial grades: Number One males (>5.5 inches [14.3 cm] from point to point), Number Two males (5.0–5.5 inches [13–14.3 cm] point to point), legal (i.e., mature) females, buckrams (recently molted crabs), and peelers (crabs at the onset of ecdysis). We collected size, sex, and age data from turtles captured. We measured mass, straight-line plastron, and carapace length of all terrapins caught in crab pots. Turtles were sexed by determining the position of the anus relative to the edge of the carapace (Carr 1952). Age of turtles was determined by counting the annuli on the plastral scutes (Halliday and Alder 1986). All crabs were measured for length (front to back), height (top to bottom), and width (point to point), and sexed.

During 1996 we realized that the 4 × 10 cm BRD had an effect on the crab catch. To determine how changing the BRD size would impact terrapins captured, we measured the heights, greatest distance between the bottom of plastron and top of carapace, and widths, greatest left to right distance, of turtles either caught in crab pots or by other methods (i.e., in bank traps and in fyke nets) that were small enough to get caught in crab pots (<15.5 cm plastron length, Roosenburg et al. 1997). The mean width of turtles caught by all methods, 9.86 cm, indicated that the BRD did not exclude terrapins based on their width. However, comparing the height of terrapins, we determined that 58% of the turtles had heights <5 cm, while 21% of the turtles had heights <4.5 cm (Table 1). This suggested a 79% decrease in terrapins caught in crab pots with the 4.5 × 12 cm BRD, but only a 42% reduction using the 5 × 10 cm BRD (Table 1). Furthermore, only 0.6% of the crabs caught had a height >4.5 cm (Table 1). Thus, we hypothesized that the 4.5 × 12 cm BRD would be the most effective. We expanded the width of the BRD to 12 cm because terrapin width did not restrict their entry into crab pots. In 1997, we also tested a 5 × 10 cm BRD expecting that terrapin bycatch would be higher in crab pots with these BRDs than in those with 4.5 × 12 cm BRDs. The 5 × 10 cm BRD was chosen because it is commercially available and is currently required in the New Jersey commercial crab pot fishery.

We used PROC GLM (SAS Institute 1990) to analyze the effect of the BRDs on terrapin and crab size. PROC CATMOD in SAS version 6.12 (SAS Institute 1990) was used to analyze the impact of the BRD on the number of crabs caught. All significance levels were set to reject H_0 at $P < 0.05$.

RESULTS

Terrapin captures

During 1996, no terrapins were caught in crab pots with 4 × 10 cm BRDs, whereas 21 terrapins were caught in crab pots without BRDs. We observed a 2 : 1 male bias of terrapins in crab pots during 1996. The mean height and width of terrapins caught in crab pots was 9.86 cm and 4.94 cm, respectively, similar to terrapins caught in fyke nets and in bank traps.

During 1997, we caught 180 terrapins in crab pots, 105 in pots without BRDs, 56 in crab pots with 5 × 10 cm BRDs, and 19 in crab pots with 4.5 × 12 cm BRDs. Similar to what we predicted based on height measurements of turtles in 1996, the 5 × 10 cm BRD reduced terrapin bycatch by 47% and the 4.5 × 12 cm BRD reduced terrapin bycatch by 82%. Turtles caught in crab pots with 4.5 × 12 cm BRDs were significantly smaller (mean plastron length = 8.60 cm, SE = 0.15) than those caught in crab pots with 5 × 10 cm BRDs (mean plastron length = 9.68 cm, SE = 0.212) and crab pots without BRDs (mean plastron length = 10.11 cm, SE = 0.143; ANOVA, $F_{2,177} = 9.14$, $P < 0.0002$, Fig. 1). We observed a 1 : 1.36 female bias in crab pots without BRDs, a 1 : 2.8 female bias in modified crab pots with 4.5 × 12 cm BRDs and a 1:1 ratio of males to females in modified crab pots with 5 × 10 cm BRDs.

Crab captures

We calculated the catch per unit effort (CPUE) as crabs·pot^{-1}·day^{-1} of traps with each BRD type because they were not fished an equal number of days in 1996. The 4 × 10 cm BRDs reduced the CPUE considerably

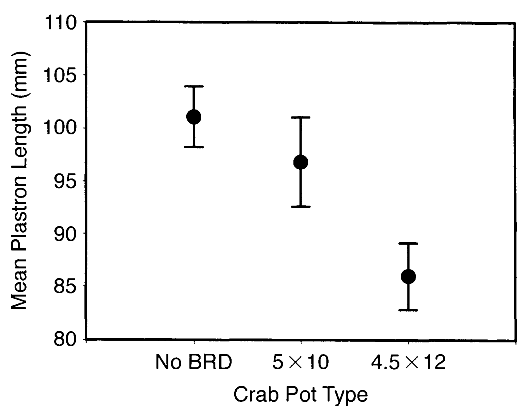

FIG. 1. Differences in mean plastron length (±2 SE) of terrapins caught in crab pots fished with 5 × 10 cm BRDs, 4.5 × 12 cm BRDs, and without BRDs, in 1997.

TABLE 2. Number of crabs caught, total number of days fished, crab pot days, and crab catch rate as crabs·pot^{-1}·day^{-1} (CPUE) of standard and modified crab pots fished with and without BRDs during 1996 and 1997.

	1996				1997					
	Standard pots		Tall pots		Standard pots			Tall pots		
BRD Type	None	4 × 10 cm	None	4 × 10 cm	None	4.5 × 12 cm	5 × 10 cm	None	4.5 × 12 cm	5 × 10 cm
Crabs caught	1013	637	532	331	522	509	490	240	273	220
Days fished	37	44	36	29	42	42	42	48	48	48
Crab pot days	263	289	220	172	205	189	205	240	240	240
CPUE	3.85	2.20	2.42	1.92	2.55	2.69	2.39	1.00	1.14	0.92

in both the standard and modified (tall) crab pots (Table 2). The CPUE also was lower in the tall pots, however we anticipated this because of the different habitats where tall pots were fished. The 4 × 10 cm BRD had a significant effect on the width and height of crabs caught because the larger Number Ones and large females were excluded (Table 3, Fig. 2). Hence, we also observed a BRD size by crab type interaction during 1996 (Table 3). Interestingly, some crabs with a height >4 cm still entered pots equipped with 4 × 10 cm BRDs, however Fig. 2 illustrates how height of the excluder, and not width, was the restricting factor for larger crabs. We expected the pot type and the pot type by crab type interaction effect on the crab size because tall pots were fished in shallow water with fewer Number Ones, and more Number Twos, females, peelers, and turtles (Table 3). We also anticipated a crab type effect because of size differences among the commercial grades of crabs (Table 3).

Despite minor differences in the total number of crab pot days for each pot type in 1997, we found no difference in the number of crabs caught among pots with either no BRD, the 4.5 × 12 cm BRD, or the 5 × 10 cm BRDs (Table 4, Fig. 3). Standard crab pots with 4.5 × 12 cm BRDs had the highest CPUE, followed by standard crab pots without BRDs and standard crab pots with 5 × 10 cm BRDs (Table 2). Again tall crab pots in 1997 had lower catch rates compared to standard crab pots (Table 2) due to the different habitats in which tall and short crab pots were fished. Although tall pots caught fewer crabs overall, the 4.5 × 12 cm and 5 × 10 cm BRDs were equally effective in allowing crabs to enter standard and tall crab pots, as indicated by the lack of BRD by pot type effect (Table 4). We also observed a significant pot type effect and a significant pot type by crab type interaction effect on the number of crabs caught in 1997 (Table 4), again as a result of the different localities in which standard and tall crab pots were fished.

We found that neither the 4.5 × 12 cm or 5 × 10 cm BRDs had any effect on the size of crabs caught (Table 5, Fig. 4). In fact, the largest crabs caught during the 1997 season was caught in a pot with a 4.5 × 12 cm BRD (Fig. 4). We expected a significant crab type, pot type, and pot type by crab type interaction due to the manner we culled crabs and the different localities where the different pots were fished (Table 5). The

TABLE 3. ANOVA analyzing the effect of BRD (4 × 10 cm vs. no BRD), pot type (PT), and crab type (CT) on the sizes of crabs caught in crab pots in 1996.

Source	df	MS	*F*	*P*
BRD	1	402.9	4.89	0.0272
Pot type (PT)	1	1410.9	17.11	0.0001
Crab type (CT)	2	73 004.9	885.45	0.0001
BRD × PT	1	34.7	0.42	0.5166
BRD × CT	2	437.5	5.31	0.0050
PT × CT	2	599.4	7.27	0.0007
BRD × PT × CT	2	1.8	1.8	0.9784
Error	2040	82.4		

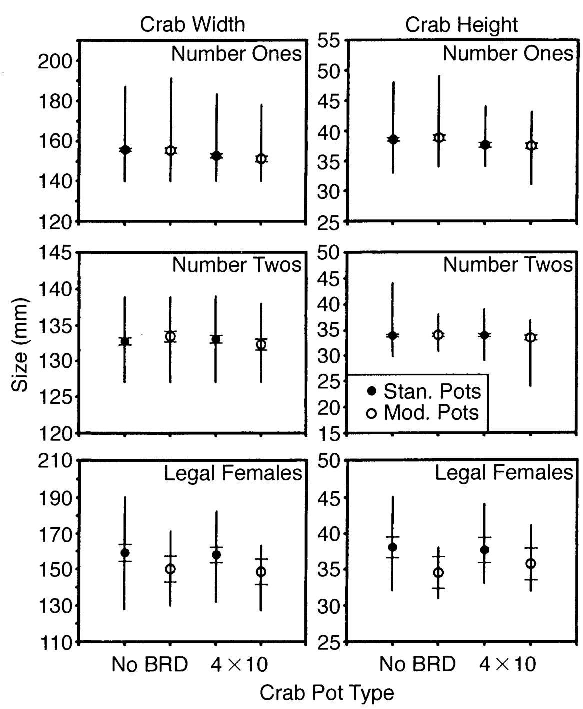

FIG. 2. Differences in crab width and height of Number Ones, Number Twos, and legal female crabs (LF) caught in standard and modified crab pots fished without BRDs and with 4 × 10 cm BRDs in 1996. The symbols indicate means, horizontal lines identify ±2 SE, and the vertical lines identify the range of crabs in each class. The presence of the 4 × 10 cm BRD reduced the size of crabs entering pots (Table 3), primarily because the opening was too short, as indicated by the reduction in crab height for Number One crabs.

TABLE 4. Chi-square analysis of log-linear model using a maximum likelihood estimation to test the influences of BRD size (4.5 × 12 cm vs. 5 × 10 cm vs. no BRD), pot type (PT), and crab type (CT) on number of crabs caught in crab pots in 1997.

Source	df	Chi-square	P
BRD	2	0.30	0.8614
Pot type (PT)	1	79.90	0.0001
Crab type (CT)	3	617.37	0.0001
BRD × PT	2	2.89	0.2359
BRD × CT	6	9.93	0.1278
PT × CT	3	113.09	0.0001
Likelihood ratio	6	10.47	0.1062

significant BRD by crab type interaction (Table 5) arose from the inclusion of a considerably larger (12.8 cm in width) peeler in a modified crab pot without a BRD (Fig. 4). When we removed peelers from our analysis, the BRD size by crab type and pot type by crab type effects became nonsignificant and the marginal P value for BRD effect increased considerably (Table 5).

DISCUSSION

Our results indicate that the 4.5 × 12 cm BRD represents the most feasible solution for preventing turtles and other bycatch from entering crab pots. Both the 4.5 × 12 cm and 5 × 10 cm BRDs did not reduce the number or size of crabs caught. However, the 4.5 × 12 cm BRD was considerably more effective at reducing the number of turtles than the 5 × 10 cm BRD. Interestingly, Guillory and Prejean (1998), Wood (1997), and we have shown that crab pots with BRDs can have a higher CPUE than crab pots without BRDs (Table 2). The smaller, fixed opening created by a BRD may increase effectiveness by keeping crabs trapped inside the pot. The wire funnel entrance into crab pots also is flexible, such that crabs may be able to move the wire and escape, installation of a BRD rigidly fixes the aperture of the funnel. Furthermore, the BRD excludes other bycatch, such as conchs and spider crabs, that have been shown to reduce crab catch (Wood 1997).

Finally, the largest crab we caught in 1997, a 7.75 inch (20.15 cm) Number One, was caught in a crab pot with 4.5 × 12 cm BRDs (Fig. 4).

The success of the 4.5 × 12 cm BRD to reduce terrapin capture in crab pots (and thus reduce terrapin mortality) suggests that this is the optimal size BRD for crab pots fished in Chesapeake Bay. Given the latitudinal variation in terrapin size (Carr 1952), the optimal BRD size may vary throughout their range. For example, Wood (1997) found that the 5 × 10 cm and the 4.5 × 12 cm BRD were equally effective at reducing terrapin entrapment in New Jersey; we caught three times more terrapins in crab pots with 5 × 10 cm BRDs than in those with 4.5 × 12 cm BRDs. Therefore, additional studies are needed to determine the optimal size, i.e., height, BRD that will exclude the maximum number of terrapins without affecting crab catch for a particular region. Additionally, our findings demonstrate that the height of the BRD is the restriction that prevents crabs and turtles from entering crab pots. Therefore changes in the width of the excluder should not alter its effectiveness, however the material must be rigid enough so that increasing the length does not increase flexibility of the height. We found that 11-gauge galvanized wire met this criteria and could work well for BRDs up to 15 cm wide.

There are many benefits associated with BRDs. They can be easily manufactured and distributed to fisheries in numerous states. Currently, 4.5 and 5 cm tall BRDs are commercially available and implementing their use would increase the price approximately U.S. $1.50 for a four funnel pot or $0.75 for a two funnel pot. The increase in crab capture of the pots with BRDs, sometimes as high as 46% (Wood 1997), would easily cover the increase in cost of the crab pot. The installation is quick and requires few tools. Once in place, the excluders need not be removed or adjusted, furthermore the excluders outlast a typical crab pot and thus can be reused. The tall crab pots are one way to decrease the impact of crab pots on terrapin populations, par-

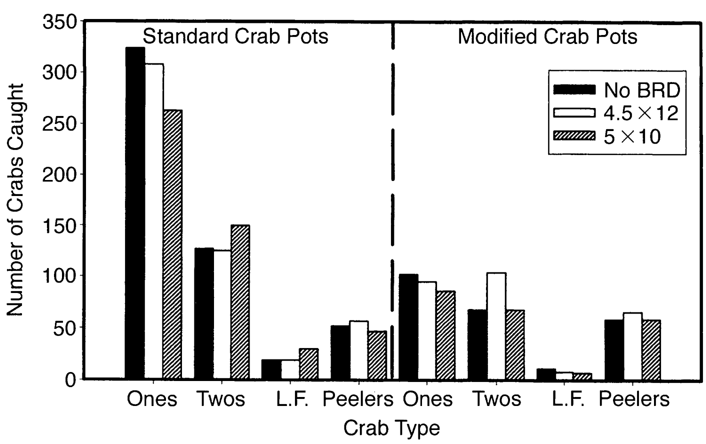

FIG. 3. Total number of Number Ones, Number Twos, legal female crabs (LF), and peeler crabs caught in standard and modified crab pots without BRDs and with 4.5 × 12 cm and 5 × 10 cm BRDs in 1997. We found no effect due to the presence of the excluder on the number of crabs caught for either pot type (Table 4).

TABLE 5. ANOVA analyzing the effects of BRD size (4.5 × 12 cm vs. 5 × 10 cm vs. no BRD), pot type (PT), and crab type (CT) on (A) the sizes of all crab types caught in pots during 1997 and (B) with peelers removed from the analysis.

Source	A) With Peelers				B) Peelers Removed			
	df	MS	*F*	*P*	df	MS	*F*	*P*
BRD	2	360.4	2.79	0.0617	2	144.4	1.52	0.2184
Pot type (PT)	1	3232.4	25.01	0.0001	1	541.5	7.21	0.0073
Crab type (CT)	3	98 847.8	764.97	0.0001	2	66 008.2	878.32	0.0001
BRD × PT	2	59.4	0.46	0.6317	2	24.5	0.33	0.7219
BRD × CT	6	328.8	2.54	0.0186	4	123.5	1.64	0.1609
PT × CT	3	1676.6	12.97	0.0001	2	115.1	1.53	0.2166
BRD × PT × CT	6	214.9	1.66	0.1261	4	146.5	1.95	0.0999
Error	2035	129.2			1738	75.2		

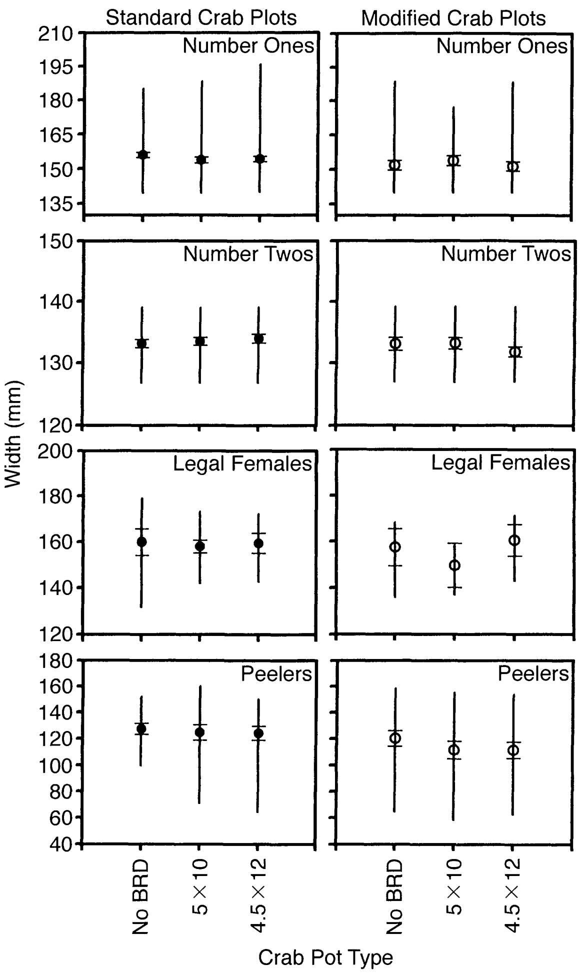

FIG. 4. Differences in crab widths of Number Ones, Number Twos, legal female crabs, and peeler crabs caught in standard and modified crab pots fished without BRDs and with 4.5 × 12 cm and 5 × 10 cm BRDs in 1997. The symbols indicate means, horizontal lines identify ± 2 standard errors, and the vertical lines identify the range of crabs in each class. There was no effect of BRD on crab size (Table 5).

ticularly in recreational fisheries where a household is usually restricted to 2 pots (Roosenburg et al. 1997). In most recreational fisheries, pots are set in shallow water and left unattended for several days, here the best solution would be tall pots with BRDs. This would prevent entrapment of most turtles, yet would insure that the smaller individuals would survive. The tall crab pots are not a viable option to reduce terrapin bycatch in commercial fisheries; their bulky size, increased cost, and the depth at which commercial crabbers fish prevents their use (Roosenburg et al. 1997). The BRD would be the most appropriate technique to reduce bycatch in the commercial crab fishery, particularly in the near shore areas frequented by terrapins.

A near two-fold reduction in the number of crabs caught in pots with a 4 × 10 cm BRD suggests that this size BRD does not provide a suitable solution, particularly for commercial crabbers whose financial loss would be considerable when fishing as many as 600 pots, Maryland's maximum license. The reduction in the size of the crabs caught in pots equipped with 4 × 10 cm BRDs would be a further burden to commercial watermen because the larger crabs are considerably more valuable than smaller crabs. Our results agree with those of Wood (1997), who found that a 4 × 8 cm BRD limited the catch of large crabs. Although the use of a 4 × 10 cm BRD on crab pots to reduce terrapin bycatch does not represent a viable option for commercial crabbers, its utility for recreational crabbers that set pots in shallow waters should be considered because this size BRD was 100% effective at reducing terrapin bycatch.

Bishop (1983) suggested that the capture rate of terrapins in crab pots was unlikely to threaten terrapin populations in South Carolina, however the demographic consequences of the losses could not be determined because there was no size estimate for the terrapin population he studied. When combined with local population estimates, crab-pot-caused mortality rates of terrapins in the Patuxent River indicated a significant impact on local terrapin populations and extirpation could occur in 3–4 yr if crab pot use was intense (Roosenburg et al. 1997). Interestingly, the terrapin catch rates in crab pots in these two studies were almost identical (0.16 terrapin·pot^{-1}·day^{-1} in South Carolina vs. 0.17 terrapin·pot^{-1}·day^{-1} in Maryland [Bishop 1983, Roosenburg et al. 1997]). Terrapins drowning in crab pots is now the biggest threat to sustainable terrapin populations throughout their range and thus must be directly addressed (Burger 1989, Seigel and Gibbons 1995). Neither the extent of mortality in crab pots, nor the natural mortality rates of terrapin populations have been thoroughly investigated in other parts of their range. However, a general decrease in terrapin populations throughout their range has been observed (Seigel and Gibbons 1995).

Although terrapins are an important part of the marsh food web (Tucker et al 1995), they have been overlooked and exploited for decades without the implementation of comprehensive conservation strategies (Hurd et al. 1979). During the early 1900s, diamondback populations of the East Coast were overexploited by the food industry (Montevecchi and Burger 1975). Recent development, resulting in the alteration of East Coast salt marshes, has decreased suitable terrapin habitat and is likely to have increased predation rates of nests (Roosenburg 1991, 1994, Seigel and Gibbons 1995). Since the decline of the fur trade, populations of foxes and raccoons have increased, posing a larger threat to terrapins through predation of terrapin nests, hatchlings, and females coming ashore to nest (Burger 1976; Seigel 1980). Human-made barriers to nesting habitat such as bulkheads and riprap also impede females from nesting on beaches (Roosenburg 1991, 1994). When coupled with the protection of key terrapin habitat, particularly nesting beaches, the implementation of the BRD represents a viable component of a terrapin conservation strategy by protecting adult and juvenile terrapins. Already, New Jersey has adopted a law mandating the use of 5 × 10 cm BRDs on crab pots fished commercially (R. C. Wood, *personal communication*). Other states should follow suit when more scientific evidence reveals the effectiveness of optimally sized BRDs to limit terrapin catch, but not crab catch.

Turtle conservation programs should protect all age cohorts, because the coevolved life history traits of late age of maturity, low reproductive rates, and high adult survivorship limit their ability to respond to increases in mortality of any age group, especially adult and older juvenile mortality (Congdon et al. 1993, Congdon et al. 1994, Spotila et al. 1996). Reductions in adult survivorship of long-lived species requires an increase in juvenile survivorship, which may already be high (Congdon et al. 1994). Life table elasticity analyses indicate that decreasing adult and subadult survivorship will have the largest impact on population growth rate in various turtle populations (Heppell 1998). These are exactly the terrapin age classes most severely affected by crab pots and our results indicate that the BRD will increase adult and subadult survivorship. Furthermore, head start and hatchery programs impact age classes that have low elasticity and thus cannot be as effective as a conservation strategy (Heppell et al. 1996). Instead of simply releasing turtles or other species from hatcheries into an already degraded or dangerous environment, technologies that directly prevent problems of exploitation and extirpation, incidental or otherwise, should be stressed (Fraser 1992).

Fisheries are crucial to the economy of the United States, but their productivity need not be weakened in order to preserve wetland biodiversity. Commercial crabbing is the most important fishery in the southern U.S. (Rulifson et al. 1992) and is a main source of income for many eastern fishermen, particularly in Chesapeake Bay. Virtually all fisheries result in the capture of nontarget species. Only recently have technological innovations, such as TEDs and BRDs been suggested as mechanisms to reduce bycatch. Implementing these devices represents a sound management and conservation strategy in order to sustain fisheries and regional diversity (Perra 1992). As the human population increases, the development of critical habitats and higher production demands on crab fisheries will place greater strains on fish stocks and the diversity of associated bycatch, emphasizing the need for effective conservation and management strategies. Closing fisheries is one option, however integrating technologies such as BRDs poses no threat to either commercial or recreational fisheries.

Acknowledgments

We are grateful to Dr. and Mrs. Norton Dodge and the staff of Cremona Farm for the use of facilities and their cooperation in this study. This study would not have been successful without the assistance of the following people in the field: P. Daly, M. Daly, S. Glinski, K. Haley, S. Kacir, K. Kelley, S. Korte, S. "Ritz" McGuire, J. Richardson, J. Reiger, K. Strafford, and S. Todd. We thank M. Keifer, S. Moody, and K. Kelley, and two reviewers for helpful comments on this manuscript. This study was funded in part by start-up funds to W. M. Roosenburg from Ohio University and conducted under scientific collecting permits issued to W. M. Roosenburg by the Maryland Department of Natural Resources, Tidewater Fisheries. Finally, we are grateful to the Maryland Department of Natural Resources that in April 1999 adopted a regulation requiring the use of the 4.5 × 12 cm BRD in all recreational crab pots based primarily on the outcome of this study.

Literature Cited

Bishop, J. M. 1983. Incidental capture of diamondback terrapins by crab pots. Estuaries **6**:426–430.

Burger, J. 1976. Behavior of hatchling diamondback terrapins (*Malaclemys terrapin*) in the field. Copeia **76**:742–748.

Burger, J. 1989. Diamondback terrapin protection. Plastron Papers **19**:35–40.

Carr, A. 1952. The handbook of turtles. Cornell University Press. New York, New York, USA.

Congdon, J. D., A. E. Dunham, and R. C. van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. Conservation Biology **7**:826–833.

Congdon, J. D., A. E. Dunham, and R. C. van Loben Sels. 1994. Demographics of common snapping turtles (*Chelydra serpentina*): implications for conservation and management of long-lived organisms. American Zoologist **34**: 397–408.

Crowder, L. B., S. R. Hopkins-Murphy, and J. A. Royle. 1995. Effects of turtle excluder devices (TEDs) on loggerhead sea turtle strandings with implications for conservation. Copeia **95**:773–779.

Fraser, N. B. 1992. Sea turtle conservation and halfway technology. Conservation Biology **6**:224–460.

Gibbons, J. W., and J. E. Lovich. 1990. Sexual dimorphism in turtles with emphasis on the slider (*Trachemys scripta*). Herpetological Monographs **4**:1–29.

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

Halliday, T., and K. Adler. 1986. The encyclopedia of reptiles and amphibians. Facts on File Inc., New York, New York, USA.

Heppell, S. S. 1998. Application of life-history theory and population analysis to turtle conservation. Copeia **98**:367–375.

Heppell, S. S., L. B. Crowder, and D. T. Crouse. 1996. Models to evaluate head-starting as a management tool for long-lived turtles. Ecological Applications **6**:556–565.

Hillsted, H. O., J. I. Richardson, C. McVea, Jr., and J. M. Watson. 1982. Worldwide incidental capture of sea turtles. Pages 489–497 *in* K. A. Bjorndal, editor. Biology and conservation of sea turtles. Smithsonian Press, Washington, D.C., USA.

Hurd, L. E, G. W. Smedes, and T. A. Dean. 1979. An ecological study of a natural population of diamondback terrapins (*Malaclemys t. terrapin*) in a Delaware salt marsh. Estuaries **2**:281–233.

Klima, E. F., G. R. Gitschlag, and M. L Renaud. 1988. Impacts of explosive removal of offshore platforms on sea turtles and dolphins. Marine Fisheries Review **50**:33–42.

Liggins, G. W., and S. J. Kennelly. 1996. Bycatch from prawn in the Clarence River estuary, New South Whales, Australia. Fisheries Research **25**:347–367.

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

Magnuson, J. J., K. A. Bjorndal, and W. D. Dupaul. 1990. Decline of the sea turtles. Causes and prevention. National Academy Press, Washington, D.C., USA.

Mangel, M. 1993. Effects of high-seas drift net fisheries on the northern right whale dolphin *Lissodelphis borealis.* Ecological Applications **3**:221–229.

Massuti, E., and N. B. Morales. 1995. Seasonality and reproduction of dolphin-fish (*Coryphaena hippurus*) in the Western Mediterranean. Scienta Marina **59**:357–364.

McEachron, L. W., J. F. Doerzbacher, G. C. Matlock, A. W. Green, and G. E. Saul. 1988. Reducing the bycatch in a commercial trotline fishery. U.S. National Marine Fisheries Service Fishery Bulletin **86**:109–118.

Montevecchi, W. A., and J. Burger. 1975. Aspects of the reproductive biology of the northern diamondback terrapin *Malaclemys terrapin terrapin.* American Midland Naturalist **94**:166–178.

Moon, D. Y., J. U. Lee, and J. B. Kim. 1996. On the log-associated school fishery of Korean tuna purse seiners. Bulletin of the Korean Fisheries Society **29**:197–207.

Perra, P. 1992. Bycatch reduction devices as a conservation measure. Fisheries **17**:28–29.

Pierce, G. J., P. R. Boyle, L. C. Hastie, and A. M. Shanks. 1994. Distribution and abundance of the fished population of *Loligo frobesi* in UK waters: analysis of fishery data. Fisheries Research **21**:193–216.

Richards, A. H. 1994. Problems of drift-net fisheries in the South Pacific. Marine Pollution Bulletin **29**:106–111.

Robins, J. B. 1995. Estimated catch and mortality of sea turtles from the east coast otter trawl fishery of Queensland, Australia. Biological Conservation **74**:157–167.

Roosenburg, W. M. 1991. The diamondback terrapin: habitat requirements, population dynamics, and opportunities for conservation. Pages 227–234 *in* J. A. Mihursky and A. Chaney, editors. New perspectives in the Chesapeake system: a research and management partnership. Proceedings of a conference. Chesapeake Research Consortium, Solomons, Maryland, USA.

Roosenburg, W. M. 1994. Nesting habitat requirements of the diamondback terrapin: a geographic comparison. Wetland Journal **6 (2)**:8–11.

Roosenburg, W. M., W. Cresko, M. Modesitte, and M. B. Robbins. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. Conservation Biology **11**: 1166–1172.

Rulifson, R. A., J. D. Murray, and J. J. Bahen. 1992. Finfish reduction in South Atlantic shrimp trawls using three designs of bycatch reduction devices. Fisheries **17**:9–19.

Saila, S. B. 1983. Importance and assessment of discards in commercial fisheries. FAO Fisheies Circular. **765**:1–62.

SAS Institute Inc. 1990. SAS/STAT Users Guide, Version 6, Fourth Edition. Cary, North Carolina, USA.

Seigel, R. A. 1980. Predation by raccoons on diamondback terrapins, *Malaclemys terrapin tequesta.* Journal of Herpetology **14**:87–89.

Seigel, R. A., and Gibbons, J. W. 1995. Workshop on the ecology, status, and management of the diamondback terrapin (*Malaclemys terrapin*), Savannah River Ecology Laboratory, 2 August 1994: final results and recommendations. Chelonian Conservation and Biology **1**:240–243.

Smith, J. W., and C. A. Wenner. 1985. Biology of the southern kingfish (*Menticirrhus americanus*) in the South Atlantic Bight. Transactions of the American Fisheries Society **114**: 356–366.

Spotila, J. R., A. E. Dunham, A. J. Leslie, A. C. Steyermark, P. T. Plotkin, F. V. Paladino. 1996. Worldwide population decline of *Dermochelys coriacea*: are leatherback turtles going extinct? Chelonian Conservation and Biology **2**:209–222.

Stabenau, E. K., T. A. Heming, and J. F. Mitchell. 1991. Respiratory, acid-base and ionic status of Kemp's ridley sea turtles (*Lepidochelys kempi*) subjected to trawling. Comparative Biochemistry and Physiology **99A**:107–111.

Tucker, A. D., N. N. FitzSimmons, and J. W. Gibbons. 1995. Resource partitioning by the estuarine turtle *Malaclemys terrapin*: trophic, spatial, and temporal foraging constraints. Herpetologica **51**:167–181.

Wood, R. C. 1997. The impact of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin.* Pages 21–27 *in* J. Van Abbema, editor. Proceedings: conservation, restoration, and management of tortoises and turtles--an international conference. New York Turtle and Tortoise Society, New York, New York, USA.

Yáñez-Arancibia, A., P. Sánchez-Gil, M. Tapia García, and M. de la C. García-Abad. 1985. Ecology, community structure, and evaluation of tropical demersal fishes in the southern Gulf of Mexico Cahiers de biologie marine **26**:137–163.