Diamondback terrapin mortality in eel pots and evaluation of a by-catch reduction device

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Study Objectives:

1. Quantify the by-catch of cloth-funnel eel pots

2. Assess the impact of the eel pot fishery on a local terrapin population

3. Test the effect of a prototype by-catch reduction device (BRD) by-catch and catch

TABLE OF CONTENTS

Project Summary	1
Background and Objectives	2
Methods and Materials	4
Experiment 1: BRD and Habitat Effects on By-catch and Catch	4
Experimental Gear	4
Study Area and Fishing Protocol	4
Data Analysis	5
Experiment 2: Entrance Funnel Size and BRD Effects on By-catch	6
Experimental Gear and Fishing Protocol	6
Data Analysis	6
Fishery Impacts on Terrapins	6
Results	7
Experiment 1: BRD and Habitat Effects on By-catch and Catch	7
Terrapin By-catch	7
Fish By-catch	7
Blue Crab By-catch	9
Eel Catch	9
By-catch Mortality	9
Experiment 2: Entrance Funnel Size and BRD Effects on By-catch	9
Terrapin By-catch	11
Fish and Crab By-catch	12
Eel Catch	12
Fishery Impacts on Terrapins	12
Conclusions	13
Management Recommendations	16
Acknowledgments	16
Literature Cited	16

LIST OF FIGURES AND TABLES

Figure 1: Eel pot by-catch reduction device (BRD) 4
Figure 2: Study site 5
Figure 3: BRD and habitat effects on blue crab captures 10
Figure 4: BRD and habitat effects American eel captures 10
Figure 5. Survey of commercial eel potting effort 12

Table 1: BRD effects on by-catch fish captures 8
Table 2: Habitat effects on by-catch fish captures 8
Table 3: BRD effects on by-catch fish and blue crab size 9
Table 4: Mortality rates of by-catch species 10
Table 5: Pot type effects on by-catch and American eel captures 11
Table 6: Pot type effects on by-catch and American eel size. 12

PROJECT SUMMARY

We address the issue of diamondback terrapin (*Malaclemys terrapin*) by-catch in the commercial American eel (*Anguilla rostrata*) pot fishery. Although terrapin by-catch in commercial and recreational blue crab (*Callinectes sapidus*) pot fisheries has received considerable attention from scientists, conservation workers, and resource managers, terrapin by-catch in the commercial American eel pot fishery has gone largely unaddressed. To address terrapin by-catch in the eel pot fishery, we carried out a field study with the following objectives: 1) Quantify the by-catch of cloth-funnel eel pots, 2) Assess the impact of the eel pot fishery on a local terrapin population, and 3) Test the effect of a prototype by-catch reduction device (BRD) on by-catch and catch.

During spring and summer 2002, we carried out two experiments in the Patuxent River, MD and several of its creek tributaries designed to simulate commercial eel fishing. In the first experiment (May-August 2002), we fished cloth-funnel eel pots with and without BRDs for a total of 5,256 pot days. By-catch in this experiment consisted of seven fishes, three crab species, and diamondback terrapins. Terrapin captures were lower than expected based on past observations of the commercial fishery. Eel pots captured two (0.005 terrapins per 48-hr set) terrapins in creeks and no terrapins in the river. Although we purchased our pots from two commercial suppliers, the entrance funnels of our pots were relatively small compared to many homemade and old, worn pots that are used in the commercial fishery. We hypothesized that pots with large entrance funnels capture more terrapins than pots with small entrance funnels and carried out a second field experiment (August-September 2002) to test this hypothesis. In this experiment, we fished pots with small entrance funnels, large entrance funnels, and large entrance funnels with BRDs for a total of 360 pot days. By-catch in this experiment consisted of three fishes, blue crabs, and diamondback terrapins. Pots with large entrance funnels captured a strikingly greater number (55 terrapins or 0.458 terrapins per 24-hr set) of terrapins than pots with small entrance funnels (1 terrapin or 0.008 terrapins per 24-hr set). Using the terrapin by-catch rates generated in these two experiments, along with an estimate of commercial eel potting effort in the study area, we estimated combined spring and summer by-catch mortality in the study area to be up to 192 terrapins, or 3% of the study area population. However, we list several reasons why we may have underestimated actual terrapin mortality in the fishery. Based on the results of this study and direct observations of terrapin mortality in the commercial fishery, we conclude that by-catch in eel pots may lead to large terrapin kills and have adverse effects on local terrapin populations.

The BRD effectively eliminated terrapin by-catch in our study. Eel pots with BRDs did not capture terrapins. The BRD had no effect on the size or number of eels captured in either experiment. Additionally, it is easy to install on new and existing pots and does not increase pot handling time. Thus, we conclude that the BRD represents an economically viable solution to the problem of terrapin by-catch mortality in eel pots.

Based on the findings of this study we recommend that BRDs be required on all eel pots fished and sold in Maryland.

BACKGROUND AND OBJECTIVES

By-catch and subsequent death in fishing gear of non-target species and size-classes is a problem that confronts many fisheries. Annual global by-catch has been estimated at 27 Mt, or 27% of the catch (Alverson et al. 1994). Examples of fisheries with recognized by-catch problems include, but are not limited to, trawl (Northridge 1991), gillnet (Perrin et al. 1994), driftnet (Northridge 1991), longline (Brothers 1991), and pot (Wood 1997) fisheries. The negative ecological and economic consequences of fisheries by-catch are well documented. By-catch may lead to decreases in the population sizes of vulnerable species (e.g., albatross: Inchausti and Weimerskirch 2001; sea turtles: Magnuson et al. 1990; pinnipeds: Wickens 1995; diamondback terrapins: Burger 1989, Roosenburg et al. 1997). Additionally, by-catch discards may provide subsidies to species that learn to utilize fishing operations as feeding opportunities (Furness et al. 1988), and large accumulations of by-catch discards may disrupt nutrient dynamics leading to anoxia and other problems (Dayton et al. 1995). Non-selective fishing practices have also been blamed for decreased harvests of target species. This realization, along with recognition of the need to protect vulnerable species, has led to many changes in fishing gear design and practices in many fisheries.

Often substantial by-catch reduction can be achieved via minor adjustments in gear design or utilization with little or no reduction in target fishing efficiency or additional operating expense. For example, simple measures such as lowering the point of release and use of seabird scarers have been shown to reduce seabird by-catch in longline fisheries (Løkkeborg 1998). Establishment of vessel mortality limits and use of techniques such as the backdown maneuver have resulted in dramatic decreases in dolphin mortality in purse seine fisheries (Hall et al. 2000). Escape rings reduce undersize blue crab capture in crab pot fisheries (Guillory and Hein 1998). Nordmøre grids (Graham 2003, Broadhurst et al. 2002), square-mesh panels (Broadhurst et al. 2002), and modified footrope settings (Hannah and Jones 2000) are a few examples of the many innovative approaches to reducing by-catch in trawl fisheries. Turtle excluder devices (TEDs), originally used by Georgia shrimp trawlers to exclude jellyballs (*Stomolophus meleagris*), are now required in coastal shrimp trawl fisheries, and their use has been credited with declines in sea turtle mortality rates (Crowder et al. 1995). The list of technologies and fishing practices associated with reducing by catch is long and reflects the importance of by-catch reduction as a central theme in sound fisheries management.

Although considerable progress has been made to reduce fisheries by-catch, by-catch remains a problem in many fisheries. Recently, diamondback terrapins have been reported to become by-catch in cloth-funnel pots used in the American eel fishery (Roosenburg in press). Terrapin by-catch in another economically important fishery, the blue crab pot fishery (Bishop 1983, Wood 1997, Roosenburg et al. 1997, Roosenburg and Green 2000), has been recognized as a major conservation issue (Burger 1989, Siegel and Gibbons 1995, Roosenburg et al. 1997) and has received considerable attention from fishery managers with several states adopting legislation requiring the use of by-catch reduction devices (BRDs) in recreational and commercial crab pot fisheries. Given recent observations of terrapin mortality in eel pots (Roosenburg in press) and the similarity between eel and crab pot fisheries (pots are often baited with same baits, passively fished, and heavily fished in terrapin habitats), there is reason to believe that eel potting may also have adverse effects on local terrapin populations.

Maryland supports a moderate-sized commercial eel pot fishery with a mean annual reported harvest of just under 130,000 kg (1990-99, MD DNR 2003). Cloth-funnel eel pots are the main gear type used to harvest eels in this fishery, as well as the Virginia and North Carolina eel pot fisheries. Pots are usually baited with razor clams (*Tagelus plebeuis*) or peeler blue crabs. These baits not only attract eels, but also attract terrapins which may become entrapped and drown in eel pots. Unlike commercially-fished crab pots, which are not permitted in Maryland rivers and creeks, large numbers of eel pots are fished in these habitats. Terrapins primarily inhabit the shallow waters of tidal rivers and creeks. Thus, high overlap exists between the commercial eel pot fishery and terrapin habitat creating the potential for large numbers of terrapins to be lost in eel pots. One of us (WMR) has documented more than 60 terrapins in the by-catch of eel pots fished in the Patuxent River, MD. This includes 20 individuals captured in a single creek in a one-month period. Such capture rates are similar to those that have been reported for terrapin by-catch in crab pots (Roosenburg in press). This is alarming given that by-catch mortality in crab pots has been identified as the major cause of terrapin declines throughout their range (Burger 1989, Seigel and Gibbons 1995).

To address terrapin by-catch in the eel pot fishery, we conducted a field study with the following three objectives:

1. Quantify the by-catch of cloth-funnel eel pots

2. Assess the impact of the eel pot fishery on a local terrapin population

3. Test the effect of a prototype by-catch reduction device (BRD) on by-catch and catch

We implemented these objectives by carrying out two fishing experiments and a survey of commercial eel potting effort in a section of the Patuxent River. In the first experiment, eel pots captured relatively few terrapins. Although we purchased our pots from two commercial vendors, the entrance funnels of our pots were relatively small compared to many homemade or old pots that are used in the commercial fishery. We hypothesized that pots with large entrance funnels capture more terrapins than pots with small entrance funnels and carried out a second experiment to test this hypothesis. We combined the terrapin by-catch rates that were generated in these two experiments with an estimate of commercial eel potting effort in the study area to estimate eel pot mortality rates of terrapins during the spring and summer eeling seasons.

Materials and Methods

Experiment 1: BRD and Habitat Effects on By-catch and Catch

Experimental Gear

Figure 1. Cloth-funnel eel pot with a BRD. The BRD is designed to reduce terrapin by-catch without affecting eel catch.

We purchased pots used in this study from two commercial suppliers (Shady Lane Seafood in Montrose, Virginia and Eddie Heath Pots in Crisfield, Maryland). Pots were 25 cm in diameter, 70 cm in length, and were constructed from 1 cm square mesh wire. Each pot had a cloth entrance funnel measuring approximately 21 cm in perimeter at the narrow end.

We developed a simple BRD for cloth-funnel eel pots (Figure 1). The BRD is a 77-mm (inside diameter) PVC ring that is designed to physically exclude terrapins when rigged around the narrow end of the flexible eel pot entrance funnel. We selected a 77-mm BRD for this study because previous demographic work suggested that this size would exclude most terrapins. Additionally, we reasoned that a BRD of this size would have little or no effect on eel catches because it would not greatly alter the dimensions of the entrance funnel opening.

We fitted one-half of our pots with BRDs. Pots with and without BRDs are referred to as BRD and control pots, respectively.

Study Area and Fishing Protocol

During spring and summer 2002, we conducted a fishing experiment to evaluate the effects of habitat, BRD, and their interaction on the by-catch and catch of cloth-funnel eel pots. Our study took place in the Patuxent River, MD and several of its creek tributaries. We selected a section of the river from Horse Head Landing to Long Point, including portions of adjacent Washington, Persimmon, and Buzzard’s Island creeks (38°26′ N, 76°38′ W), as the study site because this area supports a large eel pot fishery that overlaps with a terrapin population that is the subject of an ongoing demographic study (Roosenburg 1991, 1994, 1996, Roosenburg and Place 1995, Roosenburg and Kelly 1996, Roosenburg et al. 1997, Roosenburg and Niewiarowski 1998, Roosenburg et al. 1999).

We fished an equal number of BRD and control pots among three habitat types: offshore river, nearshore river, and creek. Habitat types exhibited distinct depth regimes (creek: 1-2 m, nearshore river: 2-4 m, and offshore river: 4-9 m). At each fishing, we baited pots with approximately 300 ml of crushed fresh razor clams and allowed pots to fish for 48-hr periods (with the exception of one, three-day period, 5-8 June 2002, when we fished pots an additional day due to bad weather). Within each habitat type, we fished BRD and control pots in pairs (approximately 30 m apart) at approximately 100-m intervals along fixed transects. Although the number of BRD and control pot sets was balanced within and among habitat types during each fishing period, the number of sets per period and their locations within habitat types varied. From 4 May to 3 June 2002, we fished up to 48 pots among a southern offshore transect, a northern nearshore transect, and Washington and Persimmon creeks. From 3 to 28 June 2002 and, again from 11 July to 14 August 2002, we fished 72 pots among a southern offshore transect, a northern offshore transect, a northern nearshore transect, a southern nearshore transect, and Washington, Persimmon, and Buzzard's Island creeks (Figure 2).

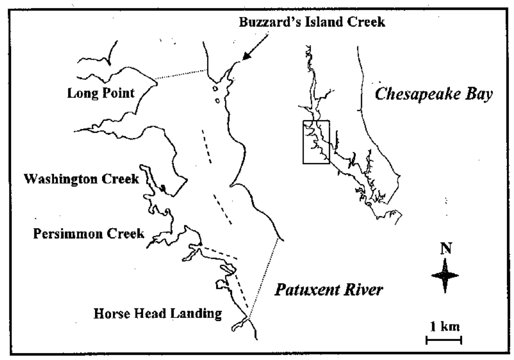

Figure 1. Patuxent River study site. Dashed lines are river transects. Dotted lines delineate study area.

At the end of each fishing period, we hauled pots and sorted their contents to species. We recorded straight-line carapace length, shell width, mass, sex, and age for diamondback terrapins. We recorded carapace width, sex, and molt stage for crabs, and total length for fish. We processed and released all by-catch, except for terrapins, at their location of capture. We processed terrapins at a field station on the shore and did not release terrapins captured in this experiment because the two terrapins captured in this experiment were dead at the time pots were fished. For other by-catch we also noted whether individuals were alive or dead at the time of release. We placed the eel catch of each pot into a zippered-mesh bag and transported eels to the shore in an aerated tub where mass was recorded for each individual. After all animals were removed from a pot, we replaced bait and alternated BRD and control pots at random.

Data Analysis

A small number of sets (29 of 2700) did not follow protocol (mostly lost or improperly set pots) and were removed from the dataset prior to statistical analysis. We randomly removed additional sets from the data so that the number of sets was balanced with respect to pot and habitat type. This resulted in 2628 successful sets (438 of each pot type in each habitat) that provided data for by-catch and catch comparisons.

We performed statistical analyses using Number Cruncher Statistical Software (Hintze 2001) with alpha levels set to reject H_0 at $P = 0.05$. We used chi-square analysis of log-linear model to analyze habitat, BRD, and interaction effects on by-catch and catch frequencies. When Chi-sqaure analysis of log-linear model detected significant habitat effects, we performed multiple comparisons (G-tests with a William's correction factor (G_{adj}) and Bonferroni-adjusted alpha values) to identify exact differences. For ease of presentation, we only presented significant habitat comparisons and main effect interactions. We used one-tailed independent sample t-tests to analyze BRD effects on by-catch mean size when data met parametric assumptions of normality and homogeneity of variances. We used Mann-Whitney U-tests to test BRD effects on median size only when data transformation failed to produce parametric distributions.

Experiment 2: Entrance Funnel Size and BRD Effects on By-catch

We captured a surprisingly low number of terrapins in Experiment 1. We hypothesized that differences in entrance funnel size between the pots used in our experiment and those that we had observed to capture terrapins in the commercial fishery (pots with larger entrance funnels) could explain why we did not capture more terrapins in Experiment 1. We compared the by-catch and catch of pots with small entrance funnels to that of pots with large entrance funnels.

Experimental Gear and Fishing Protocol

We modified pots from Experiment 1 to simulate pots with large entrance funnels. We shortened the entrance funnels to the dimensions (27 cm in perimeter at the narrow end) of pots with large entrance funnels that we had observed to be used in the commercial fishery. We refer to these pots as "large-funnel" pots.

We selected Buzzard's Island Creek and an adjacent nearshore area of the Patuxent River as the study site. We selected this area because we observed large numbers of terrapins in the area in addition to many eel pots earlier in the spring. We fished 10 small-funnel pots without BRDs and 20 large-funnel pots, 10 with and 10 without BRDs. We fished pots for twelve, 24-hr periods from 25 August to 6 September 2002. We fished pots in groups of 3 (1 of each pot type) and alternated the positions of pots between sets. We quantified pot contents in the same manner as in the first experiment. To avoid drowning terrapins, we checked pots 2-3 times daily to remove terrapins, but we removed other contents only once a day.

Data Analysis

One-hundred twenty sets of each pot type provided data for by-catch and catch comparisons. We used G-tests to test for differences in by-catch and eel catch frequencies among pot types. If overall differences were detected, we performed multiple comparisons (G-tests with Bonferroni-adjusted alpha values) to identify exact differences. We used Kruskal-Wallis analysis of variance (ANOVA; for non-parametric distributions) tests to analyze pot type effects on median fish total length, blue crab carapace width, and eel mass.

Fishery Impacts on Terrapins

We conducted 9 visual surveys at approximately bi-weekly intervals from 19 April to 4 September 2002 to estimate commercial eel fishing effort in the study area. During each survey, we counted all eel pot floats in the study area and took longitude and latitude readings for each using a Garmin eTrex® global positioning system, with the exception of the 19 April survey, when only the western shore was surveyed. We estimated the number of pots fished between surveys to be the mean of counts from the preceding and following survey period. Number of sets between surveys was estimated as:

$$\text{Sets} = (\text{number of pots} \times \text{number of days}) / \text{an assumed 2-day set period}$$

We estimated spring and summer terrapin eel pot-mortality (M) in each habitat type (offshore river, nearshore river, and creek) in the study area using the following equation:

$$M = m(n_s r_s + n_l r_l),$$

where n_s and n_l are the estimated number of sets for pots with small and large entrance funnels, respectively, r_s and r_l are the corresponding terrapin capture rates, and m is the estimated proportion of terrapins that do not survive entrapment. We calculated an upper bound terrapin mortality (M_u) estimate by assuming that 100% of eel pots used in the study site have large entrance funnels and that 0% of captured terrapins survive entrapment. We calculated a lower bound mortality (M_l) estimate by assuming that 0% of the eel pots used in the study site have large entrance funnels and 50% of captured terrapins survive entrapment.

RESULTS

Experiment 1: BRD and Habitat Effects on By-catch and Catch

In 2628 sets, we caught 3822 American eels and captured 2 diamondback terrapins, 1767 blue crabs, 239 white perch (*Morone americana*), 211 oyster toadfish (*Opsanus tau*), 79 striped bass (*Morone saxatilis*), 38 hogchoker (Trinectes maculatus), 29 Atlantic croaker (*Micropogonias undulatus*), 27 mummichog (*Fundulus heteroclitus*), 1 Norfolk spot (*Leiostomus xanthurus*), 1 white-fingered mud crab (*Rithropanopeus harrisii*), and 1 black-fingered mud crab (*Panopeus herbstii*).

Terrapin By-catch

Control pots captured 2 male terrapins, 1 terrapin in Washington Creek (carapace length = 124 mm, age = 6 years old) and 1 terrapin in Buzzard's Island Creek (carapace length = 145 mm, age = undetermined). Control pots captured no terrapins in river habitats, and BRD pots did not capture terrapins in any habitat type.

Fish By-catch

The BRD reduced the total number of Atlantic croaker and white perch captures, but had no effect on the number of oyster toadfish, striped bass, hogchoker, or mummichog captures (Table 1). Habitat type had an effect on total number of captures for all 6 major by-catch fish species (Table 2). The BRD reduced the size of captured Atlantic croaker and hogchoker, but had no effect on the sizes of other by-catch fish species (Table 3).

Table 1. Effect of the BRD on total number of by-catch fish by species. Parentheses denote captures per 48-hr set.

Species	Control Pots	BRD Pots	χ^2	df	*P*
White perch	146	93	11.82	1	< 0.001
	(0.11)	(0.07)			
Oyster toadfish	114	97	1.37	1	> 0.1
	(0.09)	(0.07)			
Striped bass	36	43	0.62	1	> 0.1
	(0.08)	(0.03)			
Atlantic croaker	22	7	7.97	1	< 0.01
	(0.03)	(0.01)			
Mummichog	14	13	0.04	1	> 0.1
	(0.01)	(0.01)			
Hogchoker	16	22	0.94	1	> 0.1
	(0.01)	(0.02)			

Table 2. Effect of habitat type on total number of by-catch fish by species. Parentheses denote captures per 48-hr set. Different superscripts indicate differences in total number between groups. We identified differences between groups using G-tests with a William's correction factor and Bonferonni-adjusted alpha values.

Species	Offshore	Nearshore	Creek	χ^2	df	*P*
White perch	51 ^{a}	29 ^{b}	159 ^{c}	115.34	2	< 0.0001
	(0.06)	(0.03)	(0.18)			
Oyster toadfish	84 ^{a}	127 ^{b}	0 ^{c}	177.49	2	< 0.0001
	(0.10)	(0.15)	(0.00)			
Striped bass	2 ^{a}	10 ^{a}	67 ^{b}	94.44	2	< 0.0001
	(0.00)	(0.01)	(0.08)			
Atlantic croaker	14 ^{a}	14 ^{a}	1 ^{b}	15.62	2	< 0.0001
	(0.02)	(0.02)	(0.00)			
Mummichog	0 ^{a}	0 ^{a}	27 ^{b}	55.91	2	< 0.0001
	(0.00)	(0.00)	(0.03)			
Hogchoker	36 ^{a}	2 ^{b}	0 ^{b}	65.46	2	< 0.0001
	(0.04)	(0.00)	(0.00)			

Blue Crab By-catch

The BRD reduced blue crab captures (χ^2 = 21.12, df = 1, *P* < 0.0001; Figure 3), but had no effect on median crab carapace width (Table 3). Habitat type also had an effect on crab captures (χ^2 = 128.31, df = 2, *P* < 0.0001; Figure 3). A greater number of captures occurred in creek habitat than in river habitat (multiple comparisons). Within the river, a greater number of captures occurred in offshore than nearshore habitat (multiple comparisons; Figure 3).

Table 3. Effect of BRD on median blue crab carapace width (mm) and mean (or median) by-catch fish total length (mm). Parentheses denote one standard error.

Species	Control Pots	BRD Pots	Test	df	*P*
Blue crab	106	106	Z = -0.67	1759	> 0.1
White perch (< 150 mm)	114	117	t = -1.15	110	> 0.1
	(1.4)	(1.9)			
White perch (≥150 mm)	194	188	t = 1.64	125	> 0.1
	(2.4)	(2.5)			
Oyster toadfish	201	202	t = -0.32	219	> 0.1
	(2.7)	(2.9)			
Striped bass	184	186	t = -0.34	76	> 0.1
	(4.6)	(3.5)			
Atlantic croaker	331	310	Z = -1.81	27	< 0.05
Mummichog	99	98	t = 0.26	25	> 0.1
	(2.1)	(2.6)			
Hogchoker	104	89	t = -2.32	36	< 0.05
	(5.5)	(3.5)			

Eel Catch

The BRD had no effect on the total number (χ^2 = 0.15, df = 1, *P* > 0.1; Figure 5) or mean (92 g for both groups) and median (77 g for both groups) mass (Table 1) of American eels. Habitat had an effect on the total number of eels caught (χ^2 = 173.99, df = 2, *P* < 0.0001; Figure 3). Pots caught a greater number of eels in offshore river habitats than in nearshore river or creek habitats (multiple comparisons).

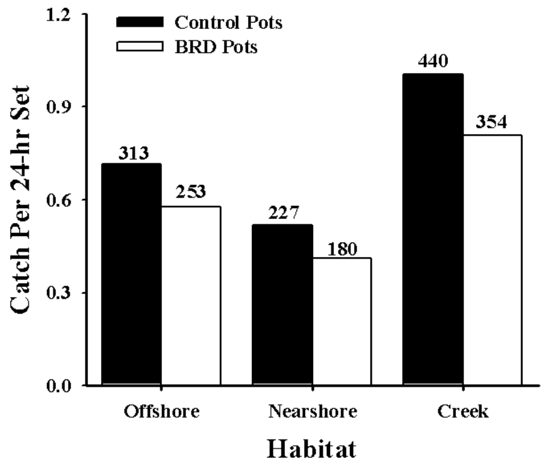

Figure 3. Blue crab by-catch per 24-hr set of BRD and control pots fished in different habitats. Numbers above bars are number of crabs captured. The BRD reduced blue crab captures by 19.7%.

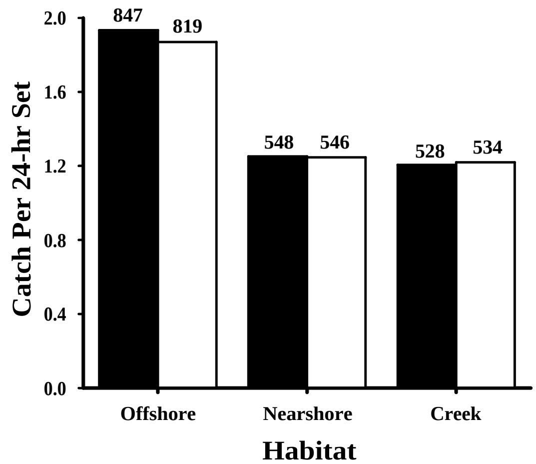

Figure 4. American eel catch per 24-hr set of BRD and control pots fished in different habitats. Numbers above bars are number of crabs captured. The BRD had no effect on eel catch.

Table 4. Number of captures, number dead in pot, and percent in-pot mortality of eel pot by-catch.

Species	Captures	Number Dead	Percent Mortality
Diamondback terrapin	2	2	100.0
White perch	239	9	3.8
Oyster toadfish	211	0	0.0
Striped bass	79	6	7.6
Atlantic croaker	29	5	17.2
Norfolk spot	1	0	0.0
Mummichog	27	0	0.0
Hogchoker	38	2	5.3
Blue crab	1767	25	1.5
Black-fingered mud crab	1	0	0.0
White-fingered mud crab	1	0	0.0

By-catch Mortality

Terrapin mortality in this experiment was 100% (2/2). In-pot mortality of all other by-catch species was low and ranged from 0.0 to 17.2% (Table 4).

Experiment 2: Entrance Funnel Size and BRD Effects on By-catch

In 360 sets, we caught 50 American eels and captured 56 diamondback terrapins, 204 blue crabs, 137 white perch, 65 striped bass, and 32 oyster toadfish.

Terrapin By-catch

Pot type had an effect on terrapin captures (Table 5). Large-funnel pots without BRDs captured more (55 and 3 re-captures) terrapins than small-funnel pots without BRDs (1) or large-funnel pots with BRDs (0) terrapins. We removed most (41) terrapins from pots between 1000 and 1500 hrs on the first day of fishing. We removed 13 terrapins after 1500 hrs on the day of fishing, and 5 terrapins were removed the following morning. Pots captured a greater number of male (55) than female (1) terrapins ($G_{adj} = 67.00$, df = 1, $P < 0.0001$). Terrapins ranged from 114 to 164 mm in carapace length and 92 to 128 in shell width. Only 12 (21.4%) terrapins could be accurately aged by counting plastral scute annuli or by recognition of previously aged, marked individuals. Aged terrapins ranged from 3 to 18 years old.

Table 5. Effect of pot type on the total number of by-catch and American eels caught. Parentheses denote catch per 24-hr set. Different superscripts indicate differences in total number between groups. We identified differences between groups using G-tests with a William's correction factor and Bonferonni-adjusted alpha values.

Species	**Small No BRD**	**Large No BRD**	**Large BRD**	**G**	**df**	***P***
Terrapin	1 [a]	55 [b]	0 [a]	113.01	2	> 0.0001
	(0.01)	(0.46)	(0.00)			
Blue crab	67	64	73	0.61	2	< 0.1
	(0.56)	(0.53)	(0.61)			
White perch	40	53	44	1.92	2	< 0.1
	(0.33)	(0.44)	(0.37)			
Oyster toadfish	8	13	11	1.22	2	< 0.1
	(0.07)	(0.11)	(0.09)			
Striped bass	7 [a]	34 [b]	24 [b]	19.73	2	> 0.05
	(0.06)	(0.28)	(0.20)			
American eel	14	16	20	1.10	2	> 0.1
	(0.12)	(0.13)	(0.17)			

Fish and Crab By-catch

Pot type had an effect on striped bass captures, but had no effect on white perch or oyster toadfish captures (Table 5). A greater number of striped bass were captured in large-funnel pots than in small-funnel pots. Pot type had no effect on the size of by-catch fish or blue crabs (Table 6).

Table 6. Effect of pot type on median fish total length (mm) and blue crab carapace width (mm).

Species	Small No	Large No BRD	Large BRD	H	df	*P*
Blue crab	132	132	132	0.32	2	> 0.1
White perch	192	188	186	0.23	2	> 0.1
Oyster toadfish	225	220	225	0.79	2	> 0.1
Striped bass	172	182	177	0.18	2	> 0.1
American eel	83	102	90	2.98	2	> 0.1

Eel Catch

Pot type had no effect on the total number (Table 5) or median mass of eels (Table 6).

Fishery Impacts on Terrapins

We estimated r_s and r_l for creek sets to be 0.005 and 0.458 terrapins per 48-hr set, respectively. We estimated r_s for all river sets to be 0.000 terrapins per 48-hr set and assumed that pots with large entrance funnels do not capture terrapins in river habitats. Commercial eeling activity was highest in late spring but continued throughout the summer (Figure 6). We estimated fishing effort in the study area from 19 April to 4 September 2002 to be 4973.5 river and 418.3 creek sets. Using these values, we estimated M_l for all habitats combined to be 1 terrapin and M_u for all habitats combined to be 192 terrapins.

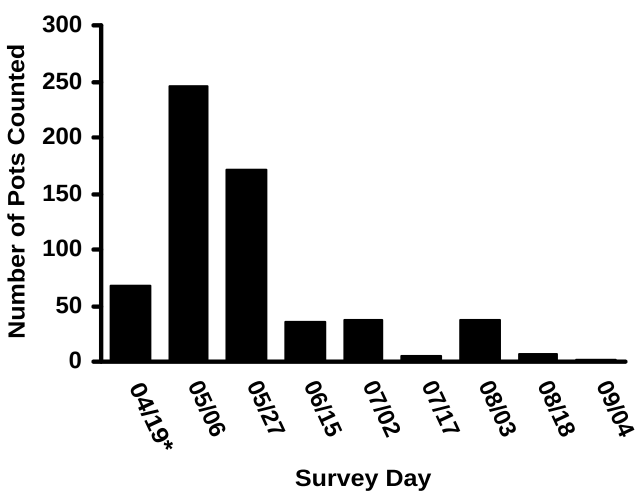

Figure 5. Number of eel pot floats observed in the study area during nine surveys of commercial fishing effort conducted in spring and summer 2002. *Only the western side of the river was surveyed on this day.

CONCLUSIONS

The findings of this study, along with direct observations of terrapin by-catch in the commercial eel pot fishery, indicate that by-catch in eel pots has the potential to negatively impact local terrapin populations. We found terrapin by-catch rates to vary with eel pot entrance funnel size. In our experiments, pots with small entrance funnels rarely (0.005 terrapins per 48-hr set and 0.008 terrapins per 24-hr set) captured terrapins, whereas pots with large entrance funnels frequently (0.458 terrapins per 24-hr set) captured terrapins. Therefore, it is likely that actual terrapin by-catch rates in the commercial fishery also vary, and are largely dependent on the fishing effort and habitat placement of pots with large entrance funnels. The proportion of the fishery that uses eel pots with large entrance funnels is unknown. We have observed some fishermen to almost exclusively fish pots with large entrance funnels whereas others mostly fish pots with small funnels. We estimated that if the fishery only used pots with large entrance funnels, then spring and summer terrapin eel pot mortality in our study area would be as high as 192 terrapins, or 3% of the study area population (Roosenburg et al. 1997). There are several reasons why we may have underestimated actual terrapin mortality. First, we did not account for potential terrapin eel pot mortality in river habitats. Although eel pots captured terrapins in nearshore river habitat in the second experiment, we did not use these captures to develop nearshore river capture rate estimates because river sets in this experiment were in shallow (< 1.5-m deep) water near the mouth of Buzzard's Island Creek and several nearby islands, areas where terrapins aggregate. It is likely, however, that eel pots capture terrapins in nearshore river habitats throughout our study area as, in the past, we have captured terrapins in experimental crab pots set in other nearshore areas of the river. Thus, given the large number of eel pots fished in nearshore river habitat, terrapin eel pot mortality in the river may be comparable to eel pot mortality in creeks. Second, our pots were purchased new at the beginning of this study, and it is possible that older eel pots with worn-out, enlarged entrance funnels may capture more terrapins than pots that are in new condition. Third, by-catch in ghost eel pots may represent an additional source of terrapin mortality that we did not account for. Thus, annual terrapin eel pot mortality may be much greater than 3% when these additional sources of mortality and the fall potting season are included. Based on our direct observations of terrapin by-catch in the commercial fishery, the high terrapin capture rates of eel pots with large entrance funnels, and the large number of pots fished in terrapin habitat by the fishery, we conclude that the commercial eel pot fishery can have an adverse impact on local terrapin populations.

Although all terrapins survived entrapment in the second experiment, we believe that this was because we checked pots 2-3 times daily and removed terrapins shortly after they were captured. Both terrapins that were captured in the first experiment, in which pots were not checked for terrapins, drowned. Most (68%) terrapins captured in the second experiment were captured within 7 hrs of baiting. We removed all captured terrapins within approximately 3 hrs of capture. Even after less than 3 hrs of submersion, many terrapins showed signs of hypoxic stress. Based on these observations, mortality of the 2 terrapins captured in the first experiment, and the fact that commercially-fished pots are usually checked every 24-48 hrs, we conclude that mortality of by-caught terrapins in commercially-fished eel pots is high. We have observed fishermen to let their pots fish for several days. In these cases, mortality of by-caught terrapins may be even higher. Mortality of by-caught terrapins is probably low in the early spring and late fall when water temperatures are low and terrapin metabolic rates and associated oxygen demands are also low. However, we have observed terrapins to drown in commercial eel pots in early May, the period when the eel fishery is most active.

Aside from reducing the population size, terrapin mortality in eel and crab (Roosenburg et al. 1997, Roosenburg and Green 2000) pots may contribute to the female-biased sex ratio observed in the Patuxent River population. The sex ratio in the study area is female-biased (Roosenburg unpublished data), but only 1 (1.7%) of 58 terrapins captured in this study was female. This is not surprising given that terrapins exhibit sexual size dimorphism with females growing faster (Roosenburg and Kelly 1996) and attaining larger body sizes than males (Gibbons and Lovich 1990). Mature females are too large to enter eel pots, whereas many mature males were captured in our study. Female immunity is not obtained until the approach of reproductive maturity at approximately 8 years of age (Roosenburg et al. 1997). The removal of sub-adults from the population with potentially high reproductive value can have a major impact on the viability of the population.

Long-term observations suggest that the Patuxent River terrapin population is in decline (Roosenburg, unpublished data). However, many factors other than eel pot mortality may be responsible for this trend. By-catch mortality in recreational crab pots (Roosenburg et al. 1997, Roosenburg and Green 2000), loss and degradation of nesting habitat, and collisions with motorboats (Roosenburg 1991) all increase terrapin mortality above natural background rates. Still, the Patuxent River terrapin population is large compared to what is found in many other areas of the Chesapeake Bay estuary. Wide availability of nesting beaches and prohibition of commercial crab potting in Maryland Rivers are helping to sustain this population. If the Patuxent River population is indeed in decline, then maintaining it at current levels will require reduction in anthropogenic sources of terrapin mortality. The most effective way to do this would be through a comprehensive approach that addresses all known anthropogenic sources of terrapin mortality. While it is unclear how large a role eel pot mortality plays in the decline of the Patuxent River population, we have demonstrated that eel pots have the potential to kill large numbers of terrapins in a short period of time. Therefore, it is important to seek approaches to reduce this threat and the impact of the fishery on terrapin populations.

Use of BRDs

Our data suggest that the BRD represents an economically viable solution to the problem of terrapin by-catch in eel pots. Eel pots without BRDs captured a total of 58 terrapins whereas pots with BRDs did not capture terrapins. Just as importantly, the BRD had no effect the size or total number of eels caught. This is very important, because in order for solutions to by-catch to be accepted, their economic impact on the fishery must be minimal. Aside from having no impact on eel catches, the BRD is inexpensive to produce, can be easily installed on existing eel pots, and does not increase pot handling time. Thus, pots that once captured terrapins can be easily retrofitted with BRDs for “turtle-safe” fishing with little cost or effort. Retrofitting existing pots with BRDs represents a better alternative to the problem of terrapin by-catch than banning the use of cloth-funnel eel pots altogether, which would result in unacceptable costs to fishermen. Regulating entrance funnel size could potentially reduce terrapin by-catch in eel pots, but this option would probably be difficult to enforce. Furthermore, the BRD would prevent terrapin captures for the lifetime of the pot, whereas older pots may develop enlarged entrance funnels and capture terrapins. Restricting eel potting to deeper waters where terrapins do not frequent would reduce terrapin mortality. However, this is not a feasible management option because it would reduce commercial eel harvests. For these reasons the BRD appears to be the best solution to terrapin by-catch mortality in the eel pot fishery.

Reactions of several fishermen to the BRD have been positive. We installed BRDs on two fishermen's pots in late summer 2002. One fisherman suggested that a smaller-diameter BRD would be useful for reducing unwanted catfish and toadfish by-catch. Catfish may damage eel pot funnels with their pectoral barbs, and toadfish eat bait and take up space in pots. A smaller BRD would have the additional benefit of reducing ghost pot mortality of fish and blue crabs in lost or abandoned eel pots. Pots are frequently lost in the fishery and it is likely that they continue to fish for many seasons as has been demonstrated to occur in several pot fisheries (e.g., Guillory 1993, Stevens et al. 2000). Smaller BRDs would reduce ghost fishing mortality in eel pots. However, it is unknown what impact a smaller BRD would have on eel harvests. The BRD tested in this study may reduce blue crab, white perch, and Atlantic croaker by-catch. In the first experiment, pots with BRDs captured fewer blue crabs, white perch, and Atlantic croaker. However, the BRD had no effect on blue crab and white perch captures in the second experiment. Atlantic croaker were not captured in the second experiment. It is unclear why blue crabs and white perch responded differently to the BRD in these two experiments. Reduction in blue crab, white perch, or Atlantic croaker captures would not have a negative economic impact on the fishery as it is not legal to harvest species other than American eels from eel pots fished in Chesapeake Bay.

Our study suggests that by-catch in eel pots results in the loss of large numbers of terrapins each year and contributes to population declines in the Patuxent River. Maintaining and restoring this population will require a comprehensive effort to reduce anthropogenic sources of terrapin mortality. Terrapin mortality in eel pots can be effectively reduced, if not eliminated, through the use of BRDs. Our BRD represents an economically viable solution to terrapin mortality in eel pots because it has no effect on eel catch, is inexpensive to produce, can be easily installed on existing eel pots, and does not increase pot handling time. Thus, we believe that the conservation benefits of the BRD far outweigh the minimal cost associated with constructing pots with BRDs and fitting existing pots with the device. Unfortunately, the use of devices that reduce by-catch is frequently strongly resisted because of the fear of increased equipment cost or loss of revenue. As with our by-catch solution, the successful implementation of management practices relies on the education and recognition of the value of non-commercial species as important and integral components of global biodiversity.

MANAGEMENT RECOMMENDATIONS

In response to the issue of terrapin by-catch in eel pots, we make the following management recommendations:

1. Require BRDs for all cloth-funnel eel pots fished in Maryland

Requiring the use of BRDs on all eel pots fished in Maryland would dramatically reduce terrapin by-catch mortality in the fishery. This would be an important step towards reversing declines in terrapin populations and promote stewardship a valuable Chesapeake Bay resource. The findings of this study indicate that the BRD would have no negative effect on target fishing efficiency of eel pots, and the cost of fitting new or used pots with BRDs would be minimal.

2. Require BRDs for all new cloth-funnel eel pots sold in Maryland

Requiring eel pot manufacturers to install BRDs on eel pots as they are constructed would eliminate time and effort on the part of fishermen to install BRDs and would make use of BRDs easier to enforce.

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