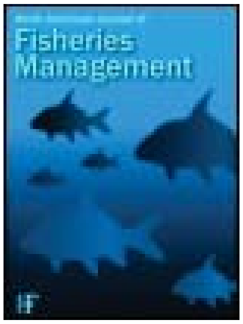

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A Test of Bycatch Reduction Devices for the Blue Crab Fishery

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Abstract

We compared two models of Bycatch Reduction Devices (BRDs), designed to maintain the catch of commercially harvestable Blue Crabs *Callinectes sapidus* while excluding Diamondback Terrapins *Malaclemys terrapin*. The "Virginia BRD" model was a thick plastic, 5.1 x 15.3 cm rectangular red frame. The "South Carolina BRD" model was a thin plastic, 6.4 x 7.3 cm rectangular red frame. Baited crab traps were fished in groups of three (No BRD, VA BRD, SC BRD) in tidal creeks in Virginia and South Carolina. In Virginia, legal-sized crabs from traps with BRDs were 2 mm smaller than from traps without BRDs. In South Carolina, significantly fewer and smaller crabs were

captured in traps with SC BRDs relative to traps without BRDs or VA BRDs. Shorter soak times in South Carolina may have reduced traffic flow of crabs into traps fitted with BRDs, an effect that was overcome by longer soak times in Virginia. Twenty-three of 29 diamondback terrapins in the Virginia study were captured in traps without BRDs, with three terrapins captured in each of the traps of the two BRD designs. BRDs are needed for the blue crab fishery to decrease terrapin mortality in hot spots where crabbing and terrapin habitat overlap.

The commercial Blue Crab *Callinectes sapidus* fishery in the U.S. extends along the Atlantic and Gulf Coasts from Connecticut to Texas (Chambers and Maerz 2018). In the southeastern U.S., some traps from the commercial crab fishery and a majority of traps from the recreational fishery are fished close to shore in shallow embayments and tidal marsh creeks. The placement of crab traps in these locations and the subsequent bycatch mortality of Diamondback Terrapins *Malaclemys terrapin* is known to affect the size and demographics of terrapin populations (Roosenburg et al. 1997; Wood 1997; Wolak et al. 2007; Grosse et al. 2009) and is a threat to their conservation (Roosenburg 2004).

Bycatch Reduction Devices (BRDs) have been promoted for 25 years as a conservation measure to reduce terrapin mortality in crab traps (Wood 1997; Chambers and Maerz 2018). Numerous BRD sizes and styles have been considered by research studies conducted across the range of terrapin and crab trap interactions, but few states require BRDs, and where required, discrepancies exist with respect to BRD size (Upperman et al. 2014; Chavez and Williard 2017). Two widely-marketed BRD designs are considerably larger than the original 5 x 10 cm design (Wood 1997). BRDs that measure 5.1 x 15.3 cm are required when crabbing in New Jersey (NJ) waters within 23 meters of shore or in New York (NY) waters under special circumstances decided by state department of environmental protection review. In Delaware (DE), Maryland (MD), and Virginia (VA), smaller BRDs (4.5 x 12.1 cm) are required on some traps fished recreationally. In states with bycatch regulations, BRDs may be constructed of wire, plastic, or other rigid materials that would maintain the BRD shape and size. No other states currently have BRD regulations, although most states promote the voluntary use of BRDs by recreational crabbers.

BRDs are effective at reducing terrapin bycatch, but may also reduce crab catch (Coleman et al. 2011; Hart and Crowder 2011; Morris et al. 2011; Upperman et al. 2014), rendering them unappealing to crabbers who must bear the cost of installing and maintaining the BRDs. Consequently, continued research is needed to improve marketable crab catch, minimize costs associated with outfitting traps with BRDs, and achieve the greatest terrapin exclusion rates possible. Prior research suggests that altering BRD placement within trap funnels, physical BRD dimensions, or BRD orientation relative to the trap entrance funnel may impact crab catch (see review by Chambers and Maerz 2018). Changing the color of BRDs from orange to red (the same color as female crab chelae) has been shown to attract the more-profitable male blue crabs (Corso et al. 2017). BRDs appear to reduce the rate of crab entry into traps, but also significantly decrease the crab escapement rate, which in turn yields a high net rate of crab capture (Corso et al. 2017).

We designed a field study in Virginia and South Carolina to compare crab catch (number, size, and sex ratio) and terrapin bycatch in traps without BRDs and in traps with two different BRD designs. One BRD design excluded terrapins based on shell height; the second BRD design excluded terrapins based on carapace width. Our goal was to compare results amongst the three BRD treatment groups within each state, using different sampling methods between states to include some of the variation in trap use by commercial and recreational crabbers.

METHODS

BRD Description

Traps with red BRDs developed in Virginia comprised the VA BRD treatment group, for which the four funnel entrances in each crab trap were fitted with 5.1 x 15.3 cm TopME Products© BRDs, secured horizontally using zipties in the far interior of the funnel openings. These BRDs, originally orange, were colored red on the outward-facing surface and white on the inward-facing surface by coating them in Performix Plasti-Dip©. Red was chosen due to a previous study showing that male crabs show a preference for traps with red BRDs (Corso et al. 2017); white was chosen as a color to which male crabs show little response (Baldwin and Johnsen 2009). The VA BRDs exclude terrapins based on shell height (i.e., 5.1 cm). Traps with narrow, red BRDs developed in South Carolina comprised the SC BRD treatment group, for which the far interior of four funnel entrances in each trap was fitted with a proprietary, fully red plastic BRD with the dimensions of 7.3 x 6.4 cm. The SC BRDs exclude terrapins based on carapace width (approximated by the diagonal of the BRD opening, 9.1 cm).

Virginia Study

The field experiment in Virginia was conducted at Indian Field Creek (37.2662 N, -76.5600 W) and Felgates Creek (37.2592 N, -76.5770 W), which are both mesohaline tidal marsh creeks in the York River, a main tributary of the lower Chesapeake Bay. In each creek we placed four groups of three standard commercial, four-funnel crab traps (60 x 60 x 45 cm), each group containing one trap of each treatment (No BRD, VA BRD, SC BRD; Table 1). Traps with no BRDs served as the control group, for which the entry funnel openings were unmodified at approximately 10 x 18 cm.

In each creek, the four groups of three traps were placed at least 50 m apart from one another. Within each group, the three traps (No BRD, VA BRD, SC BRD) were deployed in random order with ~5m of space between each trap. Traps were placed at a depth of ~165 cm at mean high water. This depth was chosen to approximate the depth of water occasionally fished by commercial operations, especially during the peeler season (Rook et al. 2010; Morris et al. 2011).

Every crab trap in the study was modified to prevent the death of captured terrapins. A 20-cm diameter hole was cut out of the top corner of each trap and a 120 cm tall “chimney” of 1-inch chickenwire was installed to allow terrapins access to the surface during prolonged trap submergence. The chimneys were secured with bungee cords to wooden stakes driven into the creek bed, which also served as markers for trap placement.

The field experiment was conducted during weekdays from 2 June until 15 July 2016. Traps were baited every other day (Monday and Wednesday) with Atlantic menhaden *Brevoortia tyrannus*, and were checked once daily (~24-hour soak time; Table 1). Crab catch and bycatch data were collected Tuesday through Friday. On Friday, the traps were left opened and unbaited to minimize capture over the weekend while not in use. On sampling days, all captured crabs were sexed and measured for carapace width (from point to point) prior to release. All captured terrapins were sexed and measured for shell height (dorso-ventral thickness), carapace width, and straight carapace length.

South Carolina Study

A complementary study was completed in tidal creeks at Hunting Island State Park, South Carolina (32.3514 N, −80.4634 W). Six standard commercial crab traps were utilized. Two were fitted with SC BRDs, two were fitted with VA BRDs, and two traps with No BRDs served as the control group (Table 1). Data collection took place between 28 July and 31 August 2016. Each morning of sampling, the six traps were baited with chicken neck/breasts and fully immersed in the tidal water off a recreational fishing dock. Traps were soaked for 2-4 hour increments and were not modified with chimneys (Table 1). After each soak period, all traps were retrieved and captured crabs were sexed and measured for carapace width prior to release away from the trapping area. Typically, traps were re-set for a second soak period each day, and captured crabs were measured. All trapping was completed during daylight hours and traps were removed from the water during the night.

Data Analysis

Box plots summarized legal crab sizes by treatment groups within each study. Because data were not normally distributed, the average crab catch per unit effort (CPUE) and average crab sizes were compared among treatment groups using a Kruskal-Wallis H test with post-hoc comparison, setting $\alpha = 0.05$. Finally, the sex ratios of crabs and number of terrapins captured from each treatment group were compared using chi-square goodness of fit tests.

RESULTS

Virginia Study

During the 24 days of data collection, a total of 2350 crabs were caught, ranging in carapace width from 7 to 18 cm (Figure 1). The mean ± SD catch per unit effort (CPUE, i.e., per 24-hour soak time) of the 1244 legal-sized crabs (carapace width ≥ 12.7 cm) was 2.2 ± 2.0 for traps with No BRDs, 2.3 ± 1.7 for traps with VA BRDs, and 2.0 ± 1.6 for traps with SC BRDs (Table 2), and was not significantly different among treatment groups (Kruskal Wallis H = 1.9, p = 0.385). The mean ± SD size of legal-sized crabs from traps with No BRDs (14.0 ± 0.9 cm) was significantly greater by 0.2 cm, relative to traps with VA BRDs (13.8 ± 0.9 cm) and with SC BRDs (13.8 ± 0.9 cm; Kruskal Wallis H = 12.9, $p < 0.01$), which were not different from each other (Table 2). The male:female sex ratio of legal-sized crabs was significantly higher for traps with VA BRDs relative to traps with No BRDs (chi-square goodness of fit $X^2 = 5.6$, $p < 0.05$, Table 3).

Significantly more terrapins (23) were captured in traps with No BRDs relative to three terrapins each in traps with VA BRDs and SC BRDs (chi-square goodness of fit $X^2 = 47.9$, $p < 0.01$, Table 3). Twenty-five of the terrapin captures were male; all four female captures were from No BRD traps. The shell heights of 12 of the 23 terrapins in traps with No BRDs were ≤ 5.1 cm and thus potentially able to fit through a VA BRD. Likewise, the carapace widths of 6 of the 23 terrapins in traps with No BRDs were ≤ 9.1 cm and thus potentially able to fit through a SC BRD.

South Carolina Study

During 22 days of data collection, a total of 518 crabs were caught, ranging in carapace width from 9 to 17 cm (Figure 1). The mean ± SD CPUE (per 2-4 hour soak time) of the 382 legal-sized crabs (carapace width ≥ 12.7 cm) was 2.0 ± 0.8 for traps with No BRDs, 1.7 ± 0.8 for traps with VA BRDs, and 1.1 ± 0.8 for traps with SC BRDs. The CPUE for traps with SC BRDs was significantly less than the CPUE for traps with No BRDs and VA BRDs (Kruskal Wallis H = 48.2, $p < 0.01$), which were not significantly different (Table 2). The average carapace width ± SD of legal crabs was significantly different amongst the three treatment groups (Kruskal Wallis H = 6.41, $p = 0.04$), although only the post-hoc comparison of crabs from VA BRDs (14.1 ± 0.7 cm) and SC BRDs (13.8 ± 0.8 cm) was significantly different ($p = 0.04$; Table 2). The male:female sex ratio of legal-sized crabs was not significantly different among treatment groups (chi-square goodness of fit $X^2 = 3.8$, $p > 0.05$), and no by-catch of terrapins occurred for any of the traps in the South Carolina study (Table 3).

DISCUSSION

Bycatch reduction devices used in the VA study reduced terrapin bycatch, a result that has been corroborated by most prior BRD studies (Chambers and Maerz 2018; Chavez and Williard 2017; McKee et al. 2016). The VA BRD that excluded terrapins based on shell height captured the same number of terrapins as the SC BRD that excluded terrapins based on carapace width. None of the terrapins captured in traps with BRDs were female, an important outcome since the morphologically larger, reproductive females contribute more to terrapin population growth and maintenance via recruitment (Mitro 2003; Gilliand et al. 2014). In some parts of the terrapin's range, however, reproductively mature females are small enough to enter crab traps fitted with BRDs and could be at risk (Coleman et al. 2014). Further, the selective loss of large numbers of smaller, adult male terrapins via drowning in crab traps also changes population demographics (Dorcas et al. 2007). Whether exclusion is based on shell height or carapace width, BRD use is a proven method for reducing the loss of juvenile and adult terrapins in commercial-style crab traps. Based on the sizes of terrapins captured in traps without BRDs in the Virginia study, more would have been excluded from traps with SC BRDs than VA BRDs.

Despite their general effectiveness, BRD use in crab traps is not regulated in most coastal states (Upperman et al. 2014). Where regulations exist, compliance tends to be poor (Radzio et al. 2013) owing to cost and perceptions of need and impact. Commercial crabbers already face hardships with rising fuel costs, bait costs, and ongoing regulations regarding when and where they are allowed to crab. Adding more gear (four BRDs per trap) takes additional time and money. Recreational crabbers may be able to assume these costs owing to the reduced number of traps they fish, but many crabbers are either unaware of the regulation or simply choose not to comply (Radzio et al. 2013).

Many crabbers also suspect that a reduction in the size of the funnel opening in BRD traps will reduce the crab catch. In the Virginia study, legal crab CPUE was not reduced relative to traps without BRDs when traps were soaked for 24 hours (Table 2), although the average carapace width of legal-sized crabs caught was 2 mm smaller. Corso et al. (2017) suggested that small differences of 1-2 mm may be statistically but not economically significant. In the current South Carolina study for which soak times were only 2-4 hours, both legal crab number and crab size were significantly lower in traps fitted with SC BRDs (Table 2). No crabs were excluded based on crab size, but fewer were captured during these shorter soak times. In addition to the sampling design features in the South Carolina study (Table 1), the lower CPUE with SC BRDs in South Carolina could have been related to sub-optimal placement of the BRDs at the funnel interior and to elevated water temperatures that could have reduced crab entry into traps with SC BRDs.

Crabs appear to have a behavioral response to BRDs, i.e., a narrowing of the funnel entry slows but does not exclude their movements into and out of traps. Given that a greater percentage of crabs entering traps with BRDs are retained (Corso et al. 2017), we suspect that BRDs can modulate crab egress to increase rates of retention. For the current study, the South Carolina data indicate that BRDs may reduce rates of crab entry over 2-4 hour soak times, but the Virginia data illustrate that this disadvantage is eliminated given enough time for crabs to enter traps (i.e., a 24-hour soak). In addition, the red BRD color may increase the capture ratio of male:female crabs over longer soak times (Corso et al. 2017; Table 3), which may provide another benefit to BRD use.

A majority of commercial crabbers place their traps in open water far away from terrapin habitat, and thus should not need to use BRDs for terrapins. Some commercial crabbers, however, do place their traps very near shore and/or within tidal creeks that are prime terrapin habitat, as approximated in the VA study. Further, almost all recreational crabbers place traps off fishing docks or in shallow embayments occupied by terrapins, as approximated in the SC study. New Jersey regulations that require

BRD use on traps fished in any water within 23 m of shore seem to address conservation at the intersection of crabbing and terrapin habitat better than any other state. Targeting “hot spot” spatial overlap of terrapin habitat and crabbing activity (sensu Harden and Williard 2012) rather than the type of crabber (commercial or recreational) seems a more direct approach to the problem of bycatch mortality.

Development and testing of BRDs specific to different regions along the Atlantic and Gulf coasts, combined with other conservation efforts (Hart and Crowder 2011) are necessary to ensure that high rates of commercial and recreational crab catch are not achieved at the expense of diamondback terrapin populations. In crabbing-terrapin hot spots, the commercial-style crab trap could be modified to benefit both the crab fishery and terrapin conservation. States or regions could require specific dimensions and colors for BRDs appropriate for their area that could be produced via 3D printing at minimal cost. The ultimate goal, of course, would be for manufacturers to simply produce crab traps with funnels satisfying the required size and color specifications. This would reduce both financial and time costs at every stage and would also prevent mistakes in installing BRDs. Perhaps most importantly, these manufactured traps would eliminate the “choice” of whether or not to use a restricted funnel entrance, thereby reducing the adverse effects of commercial and recreational crabbers on terrapin populations.

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FIGURE 1. Box plots comparing the legal sizes of crabs caught in traps in the Virginia and South Carolina studies, by BRD treatment group. **Grubbs et al. FIGURE 1**

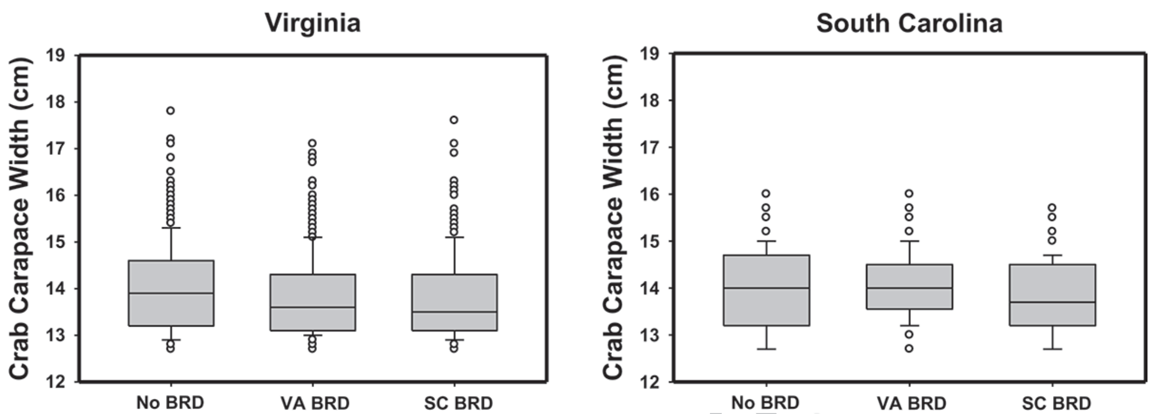

Table 1. Methods comparison between studies completed in Virginia and South Carolina in 2016 using the same BRD treatments.

	Virginia Study	South Carolina Study
Dates	2 June – 15 July	28 July – 31 August
Crabbing method	Commercial	Recreational
Number of traps	24	6
Trap placement, sampling	By boat in creek channels	From fishing pier
Soak time	24 hours	2 - 4 hours
Bait	Fish	Chicken

Table 2. Comparison of average ± S.D. legal crab catch per unit effort (CPUE) and crab carapace width (cm) from traps fitted with No BRDs, VA BRDs, and SC BRDs in Virginia (N = 1244) and South Carolina (N = 382).

Treatment	VA CPUE	VA Size (cm)	SC CPUE	SC Size (cm)
No BRDs	2.2 ± 2.0	14.0 ± 0.9	2.0 ± 0.8	14.0 ± 0.9
VA BRDs	2.3 ± 1.7	13.8 ± 0.9 z	1.7 ± 0.8	14.1 ± 0.7
SC BRDs	2.0 ± 1.1	13.8 ± 0.9 z	1.1 ± 0.8 z	13.8 ± 0.8 z

Table 3. Comparison of M:F sex ratios of legal crabs and total numbers of male and female terrapins captured from traps fitted with No BRDs, VA BRDs, and SC BRDs.

Treatment	Crabs VA study	Crabs SC study	Terrapins VA Study	Terrapins SC Study
No BRDs	40:1	41:1	23 (19:4)	0
VA BRDs	145:1 z	44:1	3 y (3:0)	0
SC BRDs	48:1	18:1	3 y (3:0)	0