The Impact of Crab Pot Fisheries on Terrapin (*Malaclemys terrapin*) Populations: Where Are We and Where Do We Need to Go?

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Abstract: *In the Atlantic and Gulf states, the crab pot fishery overlaps with much of the habitat of the diamondback terrapin,* Malaclemys terrapin. *The exclusively estuarine terrapin can be found throughout the coastal bays and creeks of the eastern and Gulf coasts of the United States. Terrapin populations can incur considerable mortality of males and juveniles when crab pots are fished in terrapin habitat. Terrapin catch rates in crab pots vary from 0.0 to 0.49 terrapins/crab pot/day. Depending on the extent of the fishery and the assumed mortality rates, between 15% and 78% of a local terrapin population may be removed annually (Roosenburg et al. 1997). Several solutions have been tested with varying degrees of success and feasibility as techniques to reduce terrapin mortality in both recreational and commercial crab pot fisheries. The most feasible mechanism is a by-catch reduction device (BRD) developed by Wood (1997), a rigid rectangular structure placed in the funnel entrance to the crab pot that prevents terrapins from entering but has no effect on the size or number of crabs caught. Several studies have evaluated different BRD sizes throughout the terrapin's range resulting in different size requirements and use regulations in different states. Herein, I review studies of crab pots, terrapins and BRDs, I summarize the current terrapin safe technologies for crab pot fisheries, and I suggest future research needs for terrapins and their interaction with crab pots and other similar fisheries.*

The capture of turtles and other non-target species as by-catch in fishing gear is a tremendous problem that confronts both fisheries managers and conservationists. Determining the impact of fishing practices and developing techniques to reduce by-catch mortality without affecting fishing effectiveness has recently attracted considerable legal, political and environmental attention. One widespread example of a by-catch problem is the capture of diamondback terrapins, *Malaclemys terrapin*, in commercial and recreational crab pots. Davis (1942) first identified the potential problem of terrapin mortality in crab pots when they were introduced as a commercial fishing gear. This concern prompted the Maryland Department of Natural Resources, at that time, to restrict the use of crab pots to a commercial fishery in deeper water areas where the impact on shallow water by-catch species such as terrapins would be minimal.

Over the years, the use of crab pots has become more widespread throughout the Atlantic and Gulf coasts, and many states have permitted their use by recreational crabbers. The conflict between crab pots and terrapin populations has been reported in several states including New York (Garber 1988, 1990a, 1990b), New Jersey (Burger 1989, Burger and Garber 1995, Wood 1995a, 1997a and 1997b), Delaware (Wood 1995b), Maryland (Davis 1942, Roosenburg et al. 1997, Roosenburg and Green 2000), North Carolina (Grant 1997, Hart, 1999), South Carolina (Bishop 1983, Hoyle and Gibbons 2000, Gibbons et al. 2001), Florida (Seigel 1993, Butler 2000), Louisiana (Guillory and Prejean 1998) and Mississippi (Mann 1995). Additionally, a diamondback terrapin workshop in August of 1994 concluded that terrapin mortality as by-catch in crab pots is the single largest threat to terrapin populations throughout their range (Seigel and Gibbons 1995, Nemec 1995).

The diamondback terrapin is an obligate estuarine species that lives in coastal and brackish bays and inlets along the eastern seaboard and the Gulf of Mexico of the United States (Carr 1952). Throughout much of its range, its habitat overlaps with that of the blue crab, *Callinectes sapidus*. The blue crab is an important commercial and recreational species throughout coastal regions of the Atlantic and Gulf States and is the primary commercial fishery in inland waters of the mid-Atlantic region. Crab pots are the primary method used to catch crabs in both the commercial and recreational fisheries. Crab pots are 60 cm by 60 cm by 60 cm wire mesh structures with four funnel-like openings that allow crabs to enter. Crabs are attracted to the pots by bait (usually menhaden, chicken or razor

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clams) and enter through one of the four funnels. The openings of the funnels vary in size and are flexible. In addition to blue crabs, a variety of other animals are caught in crab pots including spider crabs, conch, various species of fish, muskrat, otter and diamondback terrapins. Because crab pots remain submerged while set and are checked every 24 hours or less frequently, the air-breathing animals that get caught in the pots frequently drown. Several states including New Jersey, Maryland, Delaware, North Carolina, South Carolina, Florida, Mississippi and Louisiana have recognized that terrapins are caught in crab pots, and most of these states have indicated that substantial decreases in terrapin populations are the result of drowning in crab pots (Seigel and Gibbons 1995).

Because of the pervasive habitat overlap between terrapins and blue crabs, research has been undertaken to determine both the impact of crab pots on terrapin populations and potential solutions to reduce terrapin and other by-catch in crab pots. Bishop (1983) first studied the problem and estimated that 285 terrapins died daily in South Carolina crab pots, concluding that the impact on terrapin populations was minimal. However, more recent work has suggested that the impact of crab pot mortality on terrapin populations is substantial and could quickly result in extirpating local populations (Roosenburg et al. 1997). Interestingly, the catch rates of terrapins per crab pot in these two studies were very similar.

Two viable solutions to the crab pot by-catch problem have been developed and tested to various degrees. In this manuscript, I review the studies that to date have investigated the impact crab pots have on terrapin populations and the potential mechanisms for reducing by-catch in crab pots. I summarize the current BRD regulations and suggest the research needed to further reduce terrapin mortality in crab pots and other fisheries that drown terrapins.

Methods

Data were collected from the various studies that either reported terrapin catch rates in crab pots or tested mechanisms to exclude or prevent terrapins from drowning. These data are summarized in Table 1. I tried to collect data from studies that were both published and in the grey literature and unpublished reports. Additional reports of terrapin entrapment in crab pots are cited in the introduction to this paper. Finally, I summarize the regulations concerning the use of BRDs throughout the terrapin's range and make suggestions for future research.

Results and Discussion

The Impact of Crab Pots on Terrapin Populations—Terrapin catch rates in crab pots that are not equipped with a BRD ranged from 0.0 to 0.49 terrapins/crab pot/day depending on the state where the study was conducted (Table 1). The wide range in terrapin catch rates observed among these studies (Table 1) may be due to several reasons. First, the area or habitat where the pots were set may not have had high terrapin densities. For example, I can avoid catching terrapins by setting crab pots in deeper water (>5 m); thus, estimates of catch rates of terrapins averaged across several depths might underestimate the actual catch rates in prime terrapin habitat. Second, some of the studies may have been conducted at times when terrapins were not as active or were not using the habitat where the pots were set. Finally, the crab pot fishery may have removed most of the terrapins in the study area. For example, the low catch of 0.027 terrapins/crab pot/day reported in South Carolina occurred in a creek where the terrapins had been exposed to extensive crab pot fishing (Hoyle and Gibbons 2000) and the population already had been significantly reduced (Gibbons et al. 2001). Variation in the catch rates of terrapins suggests that there may be behavioral, spatial and temporal habitat differences between crabs and terrapins that could be exploited to reduce terrapin mortality. However, it is clear that crab pots can catch terrapins at high rates, increasing the mortality of both adult and juvenile age classes.

Two studies have estimated the effect of crab pot mortality on terrapin populations. Roosenburg et al. (1997) estimated that a 25% mortality rate for terrapins caught in recreational crab pots would result in killing 15% of the population annually. If the mortality rate is raised to 100%, as occurs during the warm-water summer months, 78% of the population could die each year. Additionally, the small entrance into crab pots resulted in a 2:1 male bias in crab pots that selectively removed males and juvenile female terrapins from their population. The differential mortality could contribute to the skewed sex ratios observed in some terrapin populations where mature female terrapins become too large to enter into crab pots. Hoyle and Gibbons (2000) estimated that during their two-year South Carolina study they captured from 6% to 11% of the terrapin population in crab pots. Additionally, the absence of terrapins in some creeks of this long-studied population was attributed to the commercial crab pot fishery (Gibbons et al. 2001). In the South Carolina population, adults of both sexes were caught because females do not reach the large body size that provides immunity to crab pots in Maryland. Geographic variation in terrapin body size and sexual dimorphism warrant regional studies to determine the vulnerable sex and age classes and the effect of crab pots on

Table 1. Studies of the catch rates of terrapins in crab pots and evaluations of various methods to reduce terrapin catch rates and mortality in crab pots. (t/cp/d = terrapins/crab pot/day)

State and Study	Terrapin Catch Rate without BRD T/cp/d	Gear Tested (units in cm)	Terrapin Catch Rate with BRD	Change in Crab Catch Due to Gear Modification
South Carolina (Bishop 1983)	0.16–0.24 t/cp/d	—	—	
(Hoyle and Gibbons 2000)	0.027 t/cp/d			
Louisiana (Guillory and Prejean 1998)	None Caught	5 X 10 BRD	None Caught	14.5–32.9% increase in number
Maryland (Roosenburg et al. 1997)	0.17 t/cp/d	Tall Crab Pot	0.17 t/cp/d - 0 mortality	No effect - slight increase depending on grade of crab
(Roosenburg and Green 2000)	0.044– 0.23 t/cp/d	4 X 10 BRD	0 t/cp/d	Decreased size and number
		4.5 X 12 BRD	0.043 t/cp/d	No effect
		5 X 10 BRD	0.126 t/cp/d	No effect
New Jersey (Mazzarella 1994)	0.0054 t/cp/d	5 X 10 BRD	0 t/cp/d	No effect on size, 2.5% decrease in number
	0.06 t/cp/d	5 X 10 BRD	0.0049 t/cp/d	No effect on size, 14% increase in number
(Wood 1997a)	0.071–0.49 t/cp/d	Floats	—	Decreased size and number
		4 X 8 BRD	0 t/cp/d	Decreased size and number
		4.5 X 10 BRD	0 t/cp/d	No effect on size, decreased number
	—	5 X 10 BRD	0.015 t/cp/d	No effect on size, 11 – 49% increase in number
(Wood, 1997b)		5 X 10 BRD	—	No effect on size, 11% increase in number
		5 X 15 BRD	—	No effect on size, 11% increase with in number
Delaware (Cole and Helser 2001)	—	3.2 X 12 BRD	- 100 %	Decreased size and number
		3.8 X 12 BRD	- 100%	Decrease size and 25.9% decrease in number
		4.5 X 12 BRD	- 66%	No effect on size, 12.3% decrease in number
		5 X 10 BRD	- 59%	No effect on size, 2.4% increase in number
		5 X 12 BRD	- 12%	No effect on size, 0.0% increase in number
Mississippi (Cuevas et al. 2000)	None Caught	5 X 10 BRD	None Caught	No effect of size or number
North Carolina (Grant 1997)	0.15 t/cp/d	5 X 10 BRD	0.037 t/cp/d	Decreased size males and 13% decrease in number
		4 X 12 BRD	0 t/cp/d	Decreased size males and 15% decrease in number

terrapin populations. Clearly, detailed studies of crab pot fisheries need to overlap with terrapin population studies to determine vulnerable age and size classes and estimate the impact of changes in mortality on population growth and sex ratio.

The increases in mortality caused by crab pots could result in declining terrapin populations. Several studies have conducted feasible demography analyses of turtle populations with survival and fecundity rates similar to terrapins, pointing out that turtle population stability depends on high sub-adult and adult survivorship (Congdon et al. 1993, 1994). Elasticity analysis applied to a 16-year data set of a Massachusetts terrapin population revealed that population growth is most sensitive to changes in juvenile survivorship (Hart 1999). Juvenile female age and size classes have the highest mortality in the crab pot fishery (Roosenburg et al. 1997). Mortality increases of 15% were sufficient to reduce population size by 49% within fifteen years (Hart 1999). A final conclusion from these modeling approaches is that half-way technologies such as head-starting and hatcheries (Fraser 1992 and 1997, Seigel and Dodd 2000) cannot offset the decline in terrapin populations that results from increased juvenile mortality caused by crab pots. These findings reveal the dramatic effects that crab pot mortality can have on terrapin populations, particularly that local populations can be extirpated in a few years. Perhaps more alarming is the false conclusion that terrapins do not occur in certain areas because the crab pot fishery eliminated them before efforts to find terrapins were undertaken.

Techniques to Reduce Terrapin Catch Rates and Mortality—Two unsuccessful solutions for reducing terrapin mortality in crab pots were floating crab pots and trap doors. Wood (1997) used floats on crab pots to prevent submergence at high tide and concluded that this technique was unsuccessful because crabs will enter a crab pot only while it sits on the bottom. Thus, the crab harvest was reduced when floats were attached to crab pots. The second technique tested by my colleagues and I was a trap door that would allow terrapins to escape while retaining crabs. We tried several different escape panel designs on different locations of the pot, and none were effective (Roosenburg unpub. data). As a matter of fact, our observations concluded that crabs escaped more readily through the trap doors than did terrapins. Once again, this is an unfeasible solution because the crab catch was adversely affected.

There are two techniques that are effective in reducing terrapin mortality in crab pots with a minimal, if any, effect on the crab catch. The first is a tall crab pot (Roosenburg et al.1997) that maintains a permanent air space above the high tide. Tall crab pots use the standard 60 cm by 60 cm design, however are 180 cm tall (see Roosenburg et al. 1997 for details). Tall crab pots continue to catch terrapins. However, because they maintain a permanent air space, there is no mortality when they are checked daily. The use of the tall crab pots is restricted to shallow waters in areas where the tidal amplitude is less than 75 cm so the pots will not be submerged at high tide. Additionally, they are prohibitively expensive for a commercial crab pot fishery because they require considerable additional material and their increased size takes up considerable space on board a boat. Tall crab pots can be useful to estimate terrapin catch rates in crab pots without increasing terrapin mortality in future crab pot studies that are conducted in shallow waters with low tidal amplitude.

The second effective technique for reducing terrapin mortality is the use of a by-catch reduction device (BRD) or turtle excluder device (Wood 1997). The BRD is a simple rectangular device that is inserted into each of the four funnel entrances of a crab pot (Wood 1997). The BRD restricts the opening of the funnel so that terrapins cannot enter the pot. Furthermore, the size of the BRD can be tested locally to ensure maximum protection for terrapins without affecting the size or number of crabs that are caught (Roosenburg and Green 2000, Grant 1997, Cole and Hesler in review). BRDs have been tested in several states (Table 1) and their effectiveness and impact on the crab fishery varies among geographic regions. For example, in New Jersey a 5 cm by 10 cm BRD (Wood 1997) effectively reduced terrapin capture, however in Maryland (Roosenburg and Green 2000) and Delaware (Cole and Hesler 2001) a 4.5 by 12 cm BRD is more effective than the 5 cm by 10 cm or 5 cm by12 cm BRD at reducing terrapin entrapment. These findings suggest that the geographic variation of terrapin body size requires local investigation to evaluate the use of the BRD in different regions. Most studies have discovered that both the 4.5 cm by 12 cm and the 5 cm by 10 cm BRD have a minimal effect on crab catch.

Seven studies have tested BRDs in various states, and the impact of the BRD on the crab catch varies among states (Table 1). In general, BRDs that are less than 4.5 cm high tend to reduce the number of legal-sized crabs that are caught and therefore also reduce the average size of crabs caught. BRDs greater than 4.5 cm tall have no effect on the size of the crabs that are caught, but in some studies they reduced the number of the crabs that were caught (Table 1). Interestingly, in some of the studies the 5 cm BRD increased the number of crabs that were caught relative to control pots without BRDs (Wood 1997). Grant (1997) reported the only decrease in both size and number of crabs caught in pots with a 5 cm by 10 cm BRD. There are two possible explanations for the decrease. First, the size of crabs in North Carolina where the study was conducted may have been larger than in other states where BRDs have been tested. Second, the experiment paired and placed pots with and without BRDs adjacent to each other. Thus, crab pots without BRDs may have offered slightly less resistance, and the proximity of a more accessible food may have affected the behavior of the crabs. Behavioral studies that evaluate crab feeding and entrance into crab pots might provide an understanding of the reduction in crab catch in Grant's study.

Unfortunately, little is known about the behavior and habitat use of terrapins. However, this information can be extremely valuable for reducing terrapin mortality in crab pots. Grant (1997) noted in North Carolina that terrapin capture rates decreased dramatically as the distance from shore increased. These findings are consistent with the observation that juvenile and male terrapins tend to remain in near-shore shallow areas (Roosenburg et al. 1999). This is one of the reasons why both Maryland and Delaware currently require the use of a BRD in the recreational crab pot fishery where their use overlaps most dramatically with terrapin habitat. Consistent with this, New Jersey now requires that both commercial and recreational crab pots within 150 ft of the shoreline are required to have BRDs (Wood pers. comm.). Because the commercial crab pot fishery is restricted to deeper channel areas in Maryland and Delaware, terrapin populations may have avoided the overwhelming mortality that has been reported in Florida (Seigel 1993) and South Carolina (Hoyle and Gibbons 2000, Gibbons et al. 2001). Thus, requirements that crab pots be a minimum distance from shore and not be allowed in smaller tidal creeks could considerably reduce terrapin mortality.

Clearly, the BRD represents the best and most feasible solution to reducing terrapin mortality in crab pots. Many studies to date have indicated that the use of the BRD will have no effect on the recreational take of crabs. However, these crabbers normally use less than 10 pots. The impact of the BRD has not been effectively studied in large scale commercial operations that fish more than 100 pots. Anecdotal reports from watermen who use BRDs in large-scale operations claim that they see no effect and maybe an improvement in their crab catch (Wood pers. comm.).

Where Do We Need To Go?—Crab pots are a significant threat to terrapin populations, and the BRD is the most economically feasible solution. Crab pots that are fished in near-shore, shallow water throughout the terrapin's range should be required to have BRDs installed, particularly recreational crabbers who have a high probability of catching terrapins. It seems prudent that all states allowing the recreational use of crab pots implement regulations requiring the use of BRDs. New Jersey, Maryland and Delaware have already implemented such regulations. The new regulations requiring BRDs should be accompanied by education and enforcement programs. I consistently have observed crab pots without BRDs in areas where they are required by law. One effective method to ensure compliance is to mandate that all pots sold for recreational use be equipped with BRDs. Pots without BRDs could be sold only to individuals who hold a valid commercial harvesting license.

Commercial crab pots in near-shore shallow waters also should be required to have BRDs. Currently, New Jersey is the only state in which BRDs are required in the near-shore commercial fishery. Despite the growing number of studies that have tested BRDs in various regions of the United States, none have tested the BRD in the context of a large-scale commercial fishery. All of the studies have used 10 or fewer pots in each of the test groups. What is needed is a season-long study that is done in collaboration with commercial crab potters using 100 or more pots to test the BRD. The large number of pots in the study is necessary because small differences in crab catch multiplied over the 300 to 600 pots used by a commercial crabber could have an economic impact. In such a study, depth of water, time of year and other habitat variables need to be carefully tracked in order to accurately identify the extent of the overlap between terrapin habitat use and the crab pot fishery. For example, I have spoken with several commercial crabbers that claim that in the spring and fall they catch terrapins in water 4 m to 5 m deep. This overlap in the fishery will have been missed in most of the BRD studies to date because of the studies' overlap with the academic summer field season.

Crab pots are not the only commercial gear threatening terrapin populations. Eel pots and fyke nets pose a similar problem. Round eel pots with cloth funnels are easily entered by terrapins; I have captured more than 60 terrapins in eel pots and have documented catch rates as high as 0.2 terrapins/eel pot/day. Additionally, this fishery uses one of the preferred foods of terrapins as bait, contributing to potentially high turtle catch rates. The eel pot fishery is a strong candidate for a BRD to reduce terrapin mortality. Fyke net fisheries also can result in the drowning of turtles. I have successfully captured thousands of turtles with negligible mortality rates by simply placing a float in the cod end of the net. A float requirement during the summer months could reduce turtle mortality by providing a permanent air space. When water temperatures are below 10°C, a permanent air space may not be necessary because the turtles can remain submerged for extended periods of time. I have observed turtles in fyke nets that have remained submerged for up to three days when the water temperatures were cold. Because of the reduced oxygen demand of terrapins at cool temperatures, regular fishing of fyke nets (every 2 to 3 days) can prevent mortality during cold water seasons. BRDs or other technologies can be applied to these and other fisheries to minimize the impact on turtle populations.

A confounding factor for terrapin death due to drowning is the length of time that animals can remain submerged. Because terrapins are ectotherms and their metabolic physiology is temperature-dependent, the amount of time that they can remain submerged varies throughout the year. When water temperature is below approximately 10° C terrapins can remain submerged for prolonged periods of time; indeed, terrapins submerged in fyke nets for up to three days at these lower temperatures had no adverse effects. However, as the water temperature increases, the length of time that individuals can remain submerged decreases, and by mid-summer, when temperatures go above 20° C terrapins drown in 2 to 4 hours. Further study of terrapin aerobic capacity while forcibly submerged is needed and could be used to establish seasonal restrictions on gear use to protect terrapins.

One final issue that threatens terrapins and other by-catch species is ghost fishing gear. Ghost gear is equipment that is abandoned and continues to catch. Ghost crab and eel pots occur when buoys are severed from the pots or the pots are not properly disposed. Ghost pots can be a problem for terrapins because they are frequently carried by current and waves into shallow waters (Bishop 1983). Bishop reported a ghost pot with 28 dead terrapins and Roosenburg (1991) found one with 49 dead terrapins along with the partial remains of others. Curiously, the 49 terrapins were in various states of decay, suggesting that some had been in the pot for long periods while others had recently entered the pot and died. Although the impact of ghost crab and eel pots on terrapin populations is unknown, the anecdotes of large numbers of terrapins found in some ghost pots suggests that the impact can be considerable. Additionally, the number of ghost pots in some areas can be high (David Lee and Kevin Smith pers. comm.). Some states require a panel of rapidly corroding wire that will result in a large opening in the pot after some period of time. These panels combined with BRDs represent the best solution. However, in pots without BRDs, many terrapins may die before the panel corrodes. Additionally, the panel must be large enough to allow for the escape of terrapins. Its original intent was for the release of crabs, and thus it may not be large enough to let terrapins escape. Clean-up efforts also are needed to remove ghost pots from terrapin habitat. The impact of ghost gear on terrapin populations is poorly understood and requires further study from both a demographic and a behavioral perspective.

Conclusions

Clearly, crab pots have an overwhelming effect on terrapin population dynamics that can quickly result in the extirpation of local populations. Fortunately, the technologies exist to reduce terrapin mortality in crab pots with the use of the BRD and tall crab pots. However, to assume that preventing mortality in crab pots alone will restore terrapin populations is naive. To restore and maintain terrapin populations throughout their range will require protecting all age classes and nesting areas. In many areas where nesting areas are threatened by development and the introduction of exotic species, terrapin populations face the challenge of both reduced survivorship and recruitment. Therefore, effective management and conservation will require protecting all stages of the terrapins' life cycle and their habitats so that natural recruitment and longevity can be attained.

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