4-2024

Ecology and Conservation of Diamondback Terrapins in Virginia

Cypress Ambrose
William & Mary

Ecology and Conservation of Diamondback Terrapins in Virginia

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Biology from William & Mary

by

Cypress M. Ambrose

Accepted for HONORS
(Honors)

Dr. Randolph Chambers, Director

Dr. Matthias Leu

Dr. Robert Hicks

Williamsburg, VA

April 25th, 2024

Abstract

The diamondback terrapin (*Malaclemys terrapin*) is the only turtle species native to North America with specific morphological and physiological adaptations to estuarine environments. Along with many other pressures contributing to population declines, terrapins frequently become trapped and drown as bycatch in crab pots used in the commercial and recreational blue crab (*Callinectes sapidus*) fishery. A wealth of evidence supports the use of inexpensive bycatch reduction devices (BRDs) that can be attached to the entrances of these traps, which leads to a marked decrease in terrapin bycatch while not reducing crab catch dramatically. Virginia is the only mid-Atlantic state with a prominent crabbing fishery but without legislation requiring the use of BRDs, owing largely to pushback from a strong lobby of commercial crabbers. To examine potential alternatives to BRDs, we designed three prototypes of a "terrapin release hatch," constructed to allow terrapins to escape traps and to retain crabs. Each prototype used different diameter elastic cords (3/32", 3/16" and 1/4/") to cover openings on the tops of crab pots. Based on results of an eight-week field study completed in Yorktown, Virginia, the 3/16" prototype allowed 50% of trapped terrapins to escape while retaining 88% of the commercial crab catch. Further tests will be required to develop a more effective terrapin release hatch that approaches the functionality of BRDs. An important focus moving forward will be the ongoing absence of BRD legislation in Virginia, and the possible pursuit of federal legislation to promote terrapin conservation via BRD use, to ensure that all crabbers in all states are held to the same standard.

Introduction

Diamondback terrapins (*Malaclemys terrapin*) occupy a pivotal place at the intersection of ecology, conservation, and legislative action that is representative of the intricate challenges faced by coastal ecosystems worldwide. The only turtle species in North America native to the estuarine environments of the Atlantic and Gulf coasts of the United States, these resilient turtles thrive along salinity gradients characteristic of their brackish habitats. Here I explore the physiology and ecology of the species, highlighting their unique ability to survive in habitats unused by other turtles. The survival of this species is endangered by the influence of a variety of anthropogenic pressures, which include historical and current exploitation, habitat degradation and loss, and increased predation pressure due to human facilitation. One major source of terrapin population decline is bycatch mortality as part of the fishing industry, especially within the blue crab (*Callinectes sapidus*) fishery. The blue crab fishery overlaps with terrapin habitat along much of the Atlantic coast of the United States, and many states have implemented legislation to protect the terrapins through the use of bycatch reduction devices (BRDs) affixed to crab pots. In Virginia, progress towards the implementation of meaningful legislation requiring the use of BRDs on crab pots has so far been unsuccessful for a variety of reasons. In the summer of 2023, I carried out a field test of a novel gear modification for the blue crab fishery as a possible alternative to the traditional bycatch reduction devices currently shunned by commercial and recreational crabbers in Virginia. This paper also discusses variations in legislation that protect terrapins in states along the Atlantic coast. Ideally, I hope to develop a recommendation for improved management of the blue crab fishery that also promotes terrapin conservation.

Terrapin Biology and Ecology

Diamondback terrapins are the only species of turtle known to live obligately in brackish water (Roosenberg and Kennedy, 2018). Living in these estuarine environments is especially impressive because of the constant variation in salinity due to tides, rainfall, and position within the body of water. Many organisms that live in marine environments have complex osmoregulation processes, but this constant variation in estuaries makes maintaining the balance of salinity in the body that much more difficult. Terrapins employ several types of strategies to maintain their blood salt concentration, broadly categorized as evasive and compensatory (Harden et al., 2015). Evasive strategies are those that reduce the metabolic cost to the animal of maintaining this salinity balance. These include having skin that is not permeable to water, reducing food intake when needed, burying themselves in the mud over the winter to estivate, and retaining water by reducing the frequency of urination. A recent study of terrapins during their overwintering showed that there was not significant urea accumulation during their period of dormancy (Harden et al., 2015). This contradicts the result obtained in a groundbreaking study of terrapin osmoregulation in 1970 (Gilles-Baillien). These results likely differed because the 2015 study used blood samples from turtles in the field whereas the 1970 study used a controlled lab environment. The mud that the terrapins choose to bury themselves in to overwinter in the wild likely decreases the amount of water and salt exchange that occurs between the environment and the body of the turtle. Terrapins are also known to significantly decrease their rate of urination during dormancy. In combination, these factors significantly reduce the effect of urea (Harden et al., 2015). The amount of prey that the terrapins are eating seems to play a large role in osmoregulation, because estuarine invertebrates, the regular prey of terrapins, are high in salt and other ions like potassium. The operation of salt glands requires a lot of energy, and many have hypothesized that salt glands function mostly to remove excess salt ingested by terrapins during foraging. If this is true, the salt glands are unlikely to be used at all by the terrapins during dormancy, since evidence suggests that they do not eat during this time. The field study found that terrapins do not become dehydrated during winter dormancy, and they do not store extra water during this time, as was previously believed (Harden et al., 2015). Terrapins also do not rely on anaerobic metabolism as some other turtles do, and surface for air during their period of dormancy (Harden et al., 2015). Some relatives of terrapins in the genus *Graptemys* use aquatic respiration during their period of estivation, but this is unlikely for terrapins due to the salt water and mud in which they winter usually being very poorly oxygenated or even anoxic. Terrapins may also choose the location of their winter burial in intertidal flats, allowing them to be exposed to air at low tides without movement (Harden et al., 2015).

Compensatory strategies are those used by the turtles to maintain the salinity balance using methods involving active transport of ions and water, such as the uptake or secretion of water or salts and active ion exchange across cell membranes. These methods include secretion of salt out of the body and into the environment through the lachrymal salt gland (Harden et al., 2015). Terrapins are also able to sense differences in water salinity, and use this information to drink water of salinities that will help them to maintain homeostasis. When the terrapins are in a “salt-loaded” state, they avoid drinking water of high salinity altogether, drink small amounts of water with salinity slightly higher than their blood, and drink a large amount of water that is low salinity. (Davenport and Macedo, 1990). The adaptations and strategies used by diamondback terrapins to navigate the constantly fluctuating salinity levels in estuarine environments demonstrate their exceptional ability to maintain homeostasis in challenging conditions.

In comparison, other organisms that obligatorily live in water, like fish, will drink saltwater and use excretion mechanisms like the kidney to produce the correct levels of tissue salinity (Cuesta et al 2019). When diamondback terrapins are in full sea water conditions, they have been experimentally shown to have the ability to rehydrate themselves in less than 15 minutes when able to access fresh water. Terrapins are able to drink fresh water from thin freshwater films found on top of seawater, from surrounding substrates, the shells of other turtles during rainfall, drink dew off of leaves of marsh plants, and have even been shown to drink water directly from the air during experimentally simulated heavy rain conditions (Davenport and Macedo, 1990).

Diamondback terrapins are sexually dimorphic, which plays a pivotal role in their ecological dynamics, influencing resource partitioning, male and female reproductive strategies, sexual selection and the choice of a mate, and species recognition and communication. In the case of terrapins, males reach sexual maturity at three to four years old, whereas females reach maturity between six and eight years. This delayed sexual maturity, seen in many species of turtles, coupled with a naturally high mortality in early life stages due to a lack of parental care of hatchlings, severely limits the ability of turtle populations to recover from the loss of reproductive-age individuals (Brooks et al., 1991). As adults, females reach an average carapace length of 24 cm relative to males at only 14 cm (Florida Fish and Wildlife Conservation, 2021). This difference in size likely functions to allow the females to use their increased body mass to have enough energy to produce eggs, but also results in female terrapins having a stronger bite force than males, allowing them to consume larger prey and expand their diets beyond that of males of the species (Underwood et al., 2013).

The first studies of diamondback terrapin reproduction in the field observed that mating behavior generally only occurred in “quiet canals and ditches,” where groups of 6-75 terrapins were observed congregating in late March and early April in South Carolina (Seigel, 1979). Congregations in small, shallow areas increase the probability of a successful mating event, since open water is not advantageous for this due to its exposed nature. All mating observed in this study happened during the day (Seigel, 1979), but more recent studies suggest that nesting times may depend more on the air temperature than on other factors, and therefore vary based on the local weather and climate (Feinberg and Burke, 2023). Copulation and courtship behaviors were found to be relatively uncomplicated, with male turtles approaching a female, mounting if the female does not move away, and copulating while floating at the surface. The entire process takes around two minutes (Seigel, 1979). Other closely related species of emydid turtles are known for their complex and specific mating behaviors. For example, another species of emydids, *R. incisa,* mating is a complex three stage process involving vibration of the head and neck by the male turtle, nose to nose contact initiated by the female, and eventual mounting and copulation (Hidalgo, 1982). Complex reproduction behaviors likely function to assist in species recognition in freshwater environments, where the diversity of turtle species is high. Diamondback terrapins do not exhibit such complex behaviors, because contact with other species of related turtles is very rare in their brackish environment, resulting in no selective evolutionary pressure to evolve these behaviors (Seigel, 1979).

Early studies of the nesting behavior of diamondback terrapins reported that females lay one to three clutches of eggs per year. Studies have shown differences in clutch sizes between more northern nesting regions, where more eggs were laid per clutch, and more southern nesting regions, where eggs and hatchlings were larger in size (Seigel, 1979). These studies also found that the size of the female turtles is correlated to clutch size, and that the plastron length specifically is positively correlated to greater numbers of eggs per clutch. No correlation was found between the size of the female and size of the eggs themselves, or between number of eggs per clutch and the size of the eggs (Seigel, 1979). Although this early study is well respected as an authority on terrapin ecology, other studies in the 1980s and 1990s documented many variations in nesting ecology, including differences in clutch size, nesting time, and preferred substrates (Feinberg and Burke, 2003). Terrapins, like many other turtle species, return to the same nest sites to lay their eggs each nesting season (Baldwin et al., 2005). Studies on the shell patterns of terrapins have shown that markings on the mother terrapins are passed down to her offspring (Reid, 1955). Juvenile terrapins usually emerge from their eggs in late summer, but if the hatchlings emerge later in the season, they have been known to overwinter within their nest and not emerge at the surface until the following spring (Muldoon and Burke, 2012). Although some studies have noted that terrapins seem to prefer sandy soils as a choice for nesting substrate, a survey by Seigel (1979) found no evidence of terrapin nesting on sandy embankments even when readily available. Seigel hypothesized that there must be something about the sand dunes in his study areas that made them somehow unsuitable for nesting, but was unable to find evidence to support this. This lack of nesting in sandy soil was something that we also noticed in our field work in the summer of 2023, and were similarly surprised by. Terrapins seem to prefer loosely packed dirt in a location where the canopy is open, which is usually found at the sides of roads in habitats that have been disturbed by humans. (Seigel, 1979; C. Ambrose pers. obs.). In studies conducted in warmer climates, nesting in sandy substrates was frequently observed (Feinberg and Burke, 2003), indicating that the choice of substrate is likely influenced by air and ground temperatures. The length of the nesting season seemingly varies based on latitude, with shorter seasons observed in the north and longer seasons observed in the south (Seigel, 1979). There are varying reports of the timing of nesting in regards to the day night cycle, even in studies conducted in the same areas, but the general consensus is that terrapins prefer to nest during daylight (Seigel, 1989; Feinberg and Burke, 2003). Rainfall in a terrapin habitat, which causes a quick decrease in air temperature, causes marked decreases in nesting activity (Feinberg and Burke, 2003), and terrapins seem to prefer nesting during clear sunny weather, a trend that is also seen in many species of turtles (Seigel, 1979).

The importance of terrapins to the ecosystems in which they reside cannot be overstated. As keystone predators in tidal marsh ecosystems, terrapins greatly influence the balance of these environments. Due to their role as predators to snails and other invertebrates, terrapins regulate the population densities of these herbivores, preventing the overgrazing of marsh grasses (Brennessel, 2006). This top-down control mechanism is crucial for the maintenance of health and diversity of marsh grass communities (Upperman, 2014). Dense populations of grazing snails have been shown to contribute to the loss of diversity of marsh grass communities in salt marshes. Studies have demonstrated that declining populations of terrapins correlate with decreases in marsh grass diversity, which upsets the stability of the ecosystem as a whole (Petrov, 2014). As such, the conservation of terrapins is not only important for the survival of the species, but also for the resilience of the marsh ecosystems that they inhabit. These coastal wetlands provide many important ecosystem services, including extremely high productivity and carbon sequestration. They also act as protection of the coasts from flooding and other dangers to coastal communities like hurricanes and tsunamis, making their conservation imperative for more than just the organisms that live within them (Li et al., 2018).

Threats to Terrapins

Throughout history, terrapins have been under constant pressure from both natural predators and, more recently, anthropogenic impacts. In early American history, terrapins were overexploited as a food source, first by native Americans and then by colonists (Roosenberg and Kennedy, 2018). "Turtle soup" eventually became so popular in the late 1800s that stewed terrapin was included in President Grover Cleveland's White House Cookbook, creating a very high demand for terrapins. This exploitation eventually progressed to the point that there was local commercial extinction of terrapins in several estuaries along the Atlantic coast. The advent of prohibition in the 1930s helped to limit the demand for turtle soup as another important ingredient of the soup was sherry. This decline in popularity as a food item allowed terrapin populations to recover (Diamondback Terrapin Working Group). Due to their bright colors, attractive patterns, and calm demeanor, diamondback terrapins have long been targeted in the pet trade. Individuals have been known to poach both adult turtles and nests from the wild and illegally sell the hatchlings to people seeking pets. Many coastal states have laws prohibiting this activity, and have programs to help rehabilitate pet terrapins so that they can be released back into the wild (Wurst, 2023).

Another major and well documented danger to female terrapins is their tendency to cross roadways in search of nest sites, causing many turtles to be killed by vehicles. Studies of terrapin mortality have found that around 9% of total adult terrapin mortality can be attributed to road kills (Szerlag and McRobert, 2006). Because mature female turtles are the main demographic crossing roads in search of nest sites, loss of these individuals can have a huge impact on reproduction and growth for a population of terrapins. Terrapins take many years to reach sexual maturity, making it very difficult for many turtle populations to recover from the loss of reproductive individuals (Brooks et al., 1991). While within the water terrapins are at risk for injuries from vehicles as well, with observances of injuries from watercraft increasing significantly in areas with more boating traffic (Cecala et al., 2008).

Natural predators to terrapins include crows, raccoons, hogs, and rats, all of which dig up terrapin nests and consume the eggs. Although many of these animals are native to the same places as terrapins, they are somewhat facilitated by human presence in an area. Especially animals who consume human trash like crows, raccoons, and rats are able to move into coastal areas when humans do, increasing their predation pressure on terrapin nests (Cecala et al., 2008). Nests can also be invaded by the roots of marsh plants, which is well documented as a cause of nest mortality in many species of turtles, who are especially susceptible due to their soft shelled eggs laid in sandy soils (Redding et al., 2024).

Another pressure adding to the decline of terrapin populations in the United States is habitat loss. Estuaries, the habitat of diamondback terrapins, are regions of restricted exchange, and therefore especially susceptible to damage from sea level rise due to inundation and flooding (Simas, 2001). Rising temperatures also contribute to an increase in pelagic production, which in turn leads to an increase to levels of photosynthesis and respiration in the marsh. This increase contributes massive amounts of carbon dioxide into the atmosphere, facilitating a positive feedback loop that continues to exacerbate the problem. Salt marshes will sometimes work against sea level rise through a negative feedback loop where longer soil submersion times lead to increases in mineral deposition and decreases in soil compaction due to organic matter not being able to readily decompose when submerged. Rapid sea level rise counteracts these mechanisms by reducing the productivity of the marsh so much that organogenesis sedimentation is no longer possible (Simas, 2001). Invasive species pose another threat to the health of salt marshes. *Phragmites australis*, a common marsh reed has expanded into marshes in the United

States and is able to outcompete native plants in these areas, causing decreases in plant diversity, breakdown of native vegetation structures, and changes in the soil and water in the areas (Cook et al., 2018). These plants impact diamondback terrapins specifically by invading areas that the terrapins historically have used to nest, preventing terrapins from nesting in their preferred sites. The plant also causes a significant change in temperature in the soils where it grows densely, affecting the sex ratios of hatched turtles in those areas (Cook et al., 2018). More severe than the impacts of climate change are direct anthropogenic impacts on salt marshes. As technology has advanced, wetlands have increasingly become a target for development of shorelines, with more than 80% of wetlands lost to this development in some southeastern states (Li et al., 2018). The damming of rivers and creation of reservoirs also contributes to the loss of wetlands by preventing sediments from reaching the shore. This causes "sediment starvation" in some estuaries and leads to erosion and further loss (Syvitski et al., 2009). Beyond the direct loss of marshland to development, terrapins can be affected by development further inshore due to their choice of nest sites usually away from the marsh itself. Movement of females through the area in search of nest sites can be blocked by sea walls or other development, even when intended to protect the habitat from sea level rise or other factors (Wass and Wright, 1969). Setting aside the importance of marshlands to global ecosystem functioning, the preservation of these areas is imperative for the conservation of the species that live within them. Terrapins, like many other obligately estuarine species, have unique physiological needs that can only be facilitated by these marsh habitats.

Loss of Terrapins in the Blue Crab Fishery

Diamondback terrapins, both male and female, are frequently trapped and drowned as bycatch in crab pots used in the blue crab fishery, which extends along the Atlantic and Gulf coasts of the U.S. Crab pot mortality contributes to the removal of fecund adult individuals from the population and may also skew sex ratios. Smaller male terrapins are caught more frequently than females that often avoid getting caught in pots because of their larger size, which prevents them from fitting through the entrance funnels of the traps (Wolak et al., 2010). A bycatch reduction device (BRD), is defined by the National Oceanic and Atmospheric Administration as “a tool designed to minimize unintended capture of marine animals.” A turtle exclusion device (TED) is a specific type of BRD intended for turtles. The first industry to be targeted in the push for the use of bycatch reduction devices was the shrimp fishery, due to the indiscriminate nature by which shrimp trawls gather their catch. Implementation of bycatch reduction measures was very successful at excluding sea turtles, in part because reducing bycatch benefitted the fishery by decreasing damage to shrimps and by lowering fuel costs and sorting times. The devices also reduce the impact of trawling on marine environments and sustains non-target species (Boopendranath, 2009).

For diamondback terrapins specifically, tests of a 4.5×12 cm BRD reduced terrapin bycatch by 82%, and showed no change in the size or number of crabs caught (Roosenburg and Green, 2000). Mortality of terrapins in crab pots has been reported in 13 of 14 states on the Atlantic coast where crabbing is allowed (Chambers and Maerz, 2018). Many tests of BRDs on recreational crab pots have been carried out, but it is challenging to draw comparisons between these studies due to differences in geographic area and size/type of BRD used (Upperman et al., 2014). In order for BRDs to be implemented in the blue crab fishery, the devices must not only prevent terrapin mortality, but also maintain the capture of crabs in pots fitted with the devices (Chambers and Maerz, 2018).

Terrapin mortality in the crab fishery arises from three types of crab pots: recreational, commercial, and derelict pots. Recreational crabbers have long raised concerns that it is unfair to regulate the use of BRDs on their pots while leaving commercial pots unregulated, but there is less concern about bycatch mortality in commercial crab pots because they are generally checked more frequently than recreational pots (Upperman et al., 2014). Additionally, although commercial crab pots are much more numerous than recreational, with numbers in the millions along the Atlantic and Gulf coasts, they are primarily placed in open waters within estuaries (Upperman et al., 2014). In contrast, recreational crab pots, although likely fewer in number, are all placed in shallow waters in tidal creeks and lagoons, directly overlapping with the habitat of terrapins (Chambers and Maerz, 2018).

The third, and arguably most concerning, type of crab pots are the ones that have been lost because of cut lines or displacement by storms, but remain unchecked in the water, continuously catching animals. These pots, known as derelict pots, are of special interest to many conservationists. A study on terrapin bycatch was completed with unbaited pots, to mimic conditions in derelict pots (Morris et al., 2011). In a single summer, the investigators caught what amounted to nearly 75% of an estimated terrapin population, all in unbaited pots (Morris et al., 2001). The conversion of active pots to derelict pots in the Chesapeake Bay fishery (i.e., lost pots) are conservatively estimated at 15% (Bilcovic et al., 2012), and studies show that traps do not decrease their catch rate as they age (Upperman et al., 2014). Additionally, these pots continue catching fish, essentially self-baiting for crabs, terrapins, and other fish-eating organisms (Havens et al., 2008). In one instance, a derelict crab pot was pulled up that contained 94 dead terrapins (Grosse et al., 2009).

Turtle Learning and Cognition

In general, little research has been done in the field of turtle learning and cognition. Study of turtles is made more difficult in part because there is still some controversy surrounding their phylogeny, and without this base, deeper understanding of the species is restricted. The most recent evidence indicates that turtles may be diapsids, the group which includes birds, crocodilians, snakes, lizards, and tuatara (Iwabe et al., 2004). It is also difficult to observe turtle behavior in the wild due to the nature of their habitats, and as such most studies of turtle interactions focus on basking interactions and competition for basking locations. Davis (2009), set out to study social behavior of emydid turtles, the group to which diamondback terrapins belong. She found that turtles are known to train for food rewards more readily than other reptiles, and that they are also able to distinguish between colors and shapes very well. These two traits make them good candidates for studies of learning in turtles. In Davis's study of social interactions, she found that turtles display dominance hierarchies, especially in males, as well as offensive and defensive behaviors commonly occurring between turtles. Turtles also showed changes in their social behaviors between different contexts, e.g., if they were interacting with members of their own species vs members of another species. The study also found that courtship behavior and play behaviors were often occurring in the same contexts. These findings and some of the behaviors themselves mimic what is seen in the study of behavior in mammals and birds. Turtles are one of few species that do not care for their offspring after they hatch. Because of this, the presence of social behaviors in the species is somewhat surprising - turtles cannot learn behaviors from their parents, which is the route that most species learn social behaviors. These behaviors therefore must arise from some combination of genetics and learning from interactions with other turtles in the population. There is a significant knowledge gap in the understanding of the behavior of hatchlings and young turtles, so it is still unknown how these early-life interactions affect the way that turtles interact with each other. Overall, the results of this study support a push for further study of turtles as a model group for the study of the development of social behavior without parental care. Additionally, an understanding of learning and color differentiation in turtles can be used for the development of methods to help exclude terrapins from trapping gear in the blue crab fishery.

Test of a Novel Gear Modification for the Blue Crab Fishery

Many states along the Atlantic coast of the United States have enacted legislation in the blue crab fishery in order to limit bycatch of terrapins, fish, mammals and other species. Some states have banned the use of “Maryland-Style” pots altogether, while others, including New York, New Jersey, Delaware, and North Carolina, have implemented regulations that mandate the use of bycatch reduction devices on crab pots. Of all the mid-Atlantic states, only Virginia has been unable to enact meaningful legislation to promote terrapin conservation in the crab fishery. The group responsible for this legislation, the Virginia Marine Resources Commission, has been unsuccessful in this for a variety of reasons, including arguments that the fishery is already over-regulated” (VA Watermen’s Association, 2022), concerns that the use of BRDs will limit the catch of blue crabs, and that it is not fair to regulate only the recreational and not commercial crab pots in the state. As a result, the current regulatory environment in Virginia is that BRDs are not required for either recreational or commercial crabbing (Virginia Marine Resources Commision, 2023).

Given that both crabs and terrapins are able to easily enter crab pots when BRDs are not present, research at William & Mary has focused on testing alternatives to BRDs that allow captured terrapins to escape from crab pots, but simultaneously keep crabs in the pots. In the summer of 2022, researchers at the Keck Environmental Field Lab conducted experiments with funding from the Morris Animal Foundation to test a variety of prototypes for a device to allow captured diamondback terrapins to escape from crab pots as an alternative to a traditional BRD which prevents turtles from entering the traps in the first place. The goal was to come up with a device that allows turtles to escape without allowing blue crabs to escape, as a small but significant decrease in crab catch has prevented requisite BRD use in Virginia. Thirteen potential release hatches were designed and tested with terrapins in and crab pots in saltwater pools at the Virginia Institute of Marine Science in Yorktown, Virginia. Designs that required terrapins to push a physical hatch open revealed that even though terrapins have strong enough legs to do so, terrapins behaviorally were unable to orient themselves correctly in the trap and were not able to open any of the hatch designs. The most promising design tested by the group was an opening cut into the top of the pot covered by parallel elastic bands. In the seawater pools at VIMS, terrapins were observed pushing their way through the elastic, whereas crabs tended to stay in the pots. At the end of the summer, a brief field study was completed in Felgates Creek in Yorktown, VA. In the 10-day study, no terrapins were caught in either control pots without elastic openings or pots with elastic openings, but crab catches between experimental and control pots were identical, and significantly fewer sublegal crabs were caught in pots with the escape hatch (Figure 1).

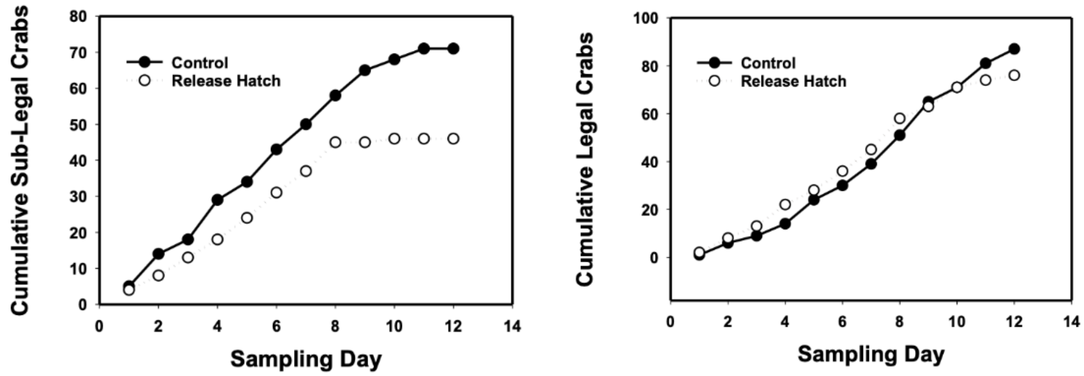

Figure 1: Results of pilot study from summer 2022. Legal crab catch remained consistent in pots fitted with a release hatch when compared to control pots. Sublegal crab catch decreased in pots fitted with release devices, suggesting small crabs escaped through the hatch.

From here, I continued investigations of this escape hatch design, testing the efficacy of different widths of elastic bands on the release of terrapins and retention of marketable blue crabs. My objective was to determine the width of elastic cord that was best able to release terrapins while simultaneously retaining blue crabs, especially those of legal size (over 12.7 cm). I also hoped the trend observed in the pilot study of sublegal sized crabs escaping would continue in my study, ideally replacing the function of cull rings in pots fitted with the escape hatch.

Methods:

Further studies of the elastic bycatch release device were conducted in the summer of 2023 at Felgates Creek, a tributary of the York River located on the Yorktown Navy Weapons Station in Yorktown, Virginia, USA (37.267°N, 76.585°W). Sixteen crab pots were fitted with "chimneys"–cylinders of coated chicken wire (height = 120 cm) attached to the top of the pots and protruding over the surface of the water–installed to prevent turtle mortality (Figure 2).

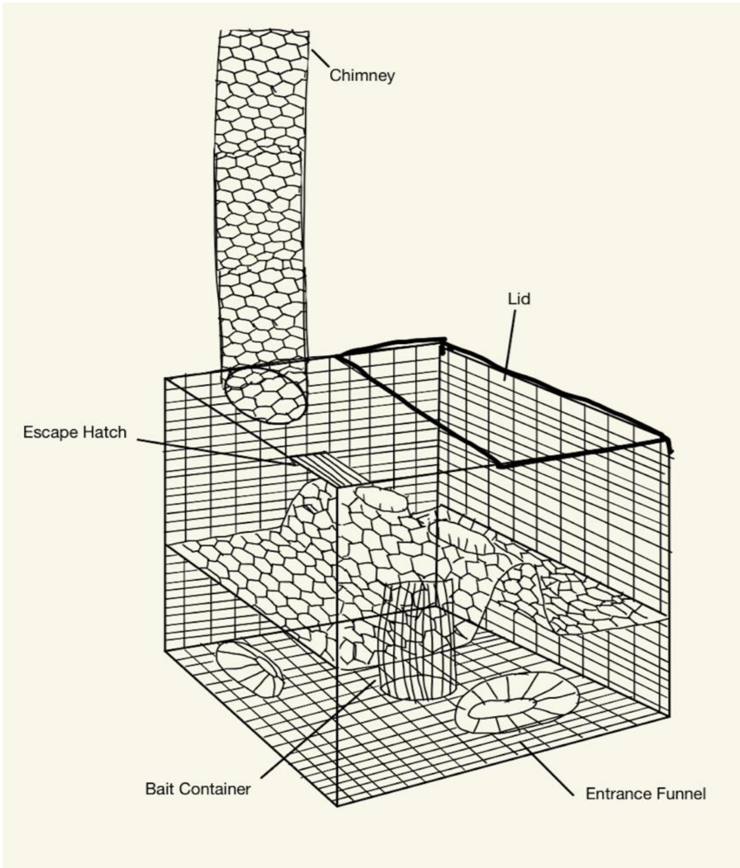

Figure 2: Illustration of the "Maryland-Style" Crab pots used in the experiment. Location of "Chimney" and escape hatch noted.

The bycatch release device tested was an "escape hatch" - a 2 inch by 6 inch hole cut into the top of the pot and covered with elastic cords of differing widths stretched and secured with hog rings. Three different sizes of elastic were tested, and the pots differentiated in four treatments to the "escape hatch;" These treatments were 1/4 inch elastic at 50% tension (Labeled "Yellow"), 3/16 inch elastic at 50% tension (Labeled "Orange"), 3/32 inch elastic at 50% tension (Labeled "Green"), and control pots with no escape hatch (Labeled "Blue"). Traps were placed at four sites within Felgates Creek at close proximity to an embankment where terrapins had been observed nesting in past years (Figure 3).

Figure 3: Map of Felgates Creek showing locations of 16 experimental crab pots. Blue = Control, Yellow = ¼ inch elastic, Orange = 3/16 inch elastic, Green = 3/32 inch elastic

At each site, one trap of each experimental treatment was placed, at random, in a line parallel to the bank of the creek. Ideal pot placement was a location where the entire pot would stay submerged at low tide, and the chimney would remain at least partially emersed at high tide. This placement ensures the lowest mortality for captured turtles and crabs. The traps must never be so far emersed that crabs overheat and suffocate, but never completely submerged so that turtles are unable to surface for air and do not drown. Due to these constraints, pots were distributed relatively close to the shore of the creek.

Pots were anchored in place using stake poles with color coded bungees to ensure that the chimneys remained upright and the pots remained in place, and to allow for easier differentiation between treatments in the field. Operationally, turtles and crabs entered the trap through either of two cones of wire in the lower level of the trap in search of frozen fish placed in the bait compartment of the trap. Once inside the trap, turtles and crabs are unable to find their way out. The chimney installed on top of the trap ensures that turtles are able to surface for air without escaping the trap. In theory, I hoped that turtles would be able to push their way out of the trap through the elastic installed over the escape hatch, while crabs would not be able to.

Between June 12th and August 1st, 2023, bait was added to traps on Monday and Wednesday mornings, and traps were kept closed and operational Monday-Friday, with the exception of a few days where weather caused higher than usual tides, causing the chimneys to be submerged, so traps were left open. Traps were left open over weekends to prevent mortality as much as possible. When checked, all captured organisms were removed from the traps. Crabs were measured and point-to-point lengths recorded, as well as sex. Crabs were then released at the site of capture. Terrapins, when present, were measured for carapace length, width, and height. Terrapins were sexed using tail length and cloacal location, with male turtles having longer tails and cloacal openings that extend past the base of the shell. Turtles were not weighed and no measurements of maturation were made. The terrapins were then marked using a base two notching pattern originally described by Cagle (1939), and released at the site of capture. Bycatch in traps were also released at the site of capture. Common bycatch included jellyfish and white perch, which were often dead and partially consumed.

With the data collected throughout the summer, I determined the retention of terrapins and legal sized crabs in pots fitted with different-sized elastic release devices, and compared retention to the control pots. I also compared the sizes of legal crab catch between the control pot and experimental pots. Bar charts were used to visualize this data. For analysis of terrapin data, I used a binomial cumulative distribution function to compare the counts of catches in experimental pots with the total caught in the control pot. I chose this test because it can be used to determine the probability of observing the same number of successes as the control. I used a chi-square goodness of fit test to analyze crab capture. For the analysis of crab size, I used a t-test to compare the experimental sizes to the control.

Results:

Over the eight week study, there were a combined total of 340 trap days (100 each of control, 3/16 inch, and 3/32 inch elastic and 40 of 1/4 inch elastic). Total captures included 383 legal crabs, 611 sublegal crabs, and 35 terrapins over the course of the field study. Out of the 35 terrapins, 32 were male and 3 were female. One female terrapin caught was excluded from analysis of the success of the release device, because her carapace height would have prevented her from leaving the opening regardless of elastic width. The 1/4 inch elastic treatment was removed after 40 trap days because it was clear by that time that it was not successful in releasing terrapins, with the same rate of capture as the control. Significantly fewer terrapins were caught in pots fitted with 3/16" and 3/32" elastic ($p = 0.04$, $df=1$), but not in 1/4" elastic ($p = 0.45$, $df=1$). The significance of these data were checked using a binomial cumulative distribution function. Significantly fewer legal size crabs were caught in 3/32" elastic ($p \ll 0.05$, $df=1$), but differences in catch between the control and 3/16" elastic were not significant ($p = 0.212$). Relative to control pots, sublegal crab catch between groups was not significantly different (3/32" $p = 0.608$, $df=1$, 3/16" $p = 0.207$, $df=1$). The significance of these data was interpreted using a goodness-of-fit chi square test. Catch numbers for the 1/4" elastic have been extrapolated to provide an estimate for what they would have been if they had been in the water for all 100 trap days. The average size of crabs in the pots fitted with 3/16" elastic and 3/32" elastic were insignificant (3/16” p=0.634, df=276, t=0.47, 3/32” p=0.902, df=121, t= -0.12), but were slightly significant between 1/4” elastic and the control (p=0.0496, df=49, t= -2.01).

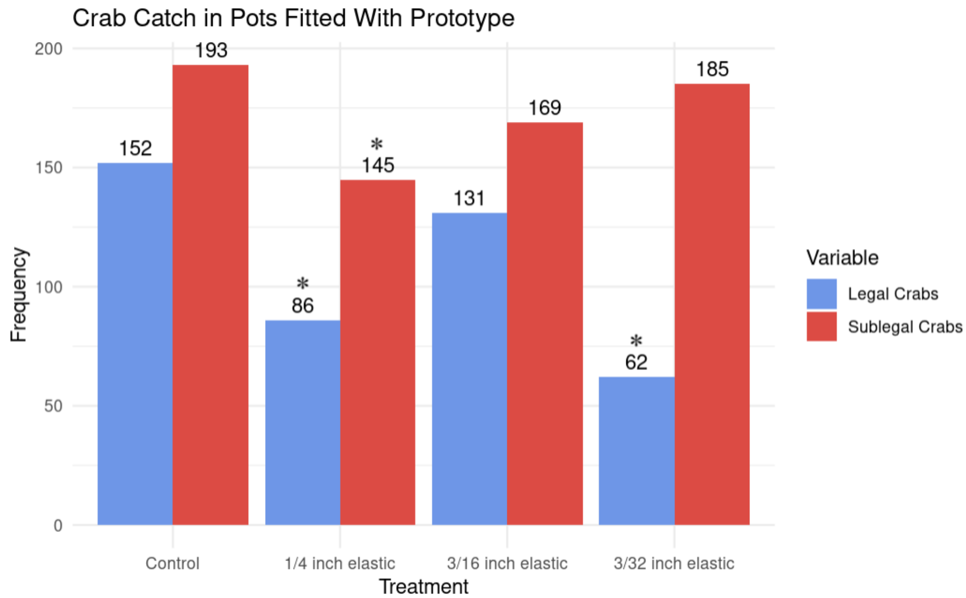

Figure 4: Bar chart displaying legal and sublegal crab catch totals in control and three experimental pots. Asterisk (*) denotes significance using a chi-square goodness of fit test.

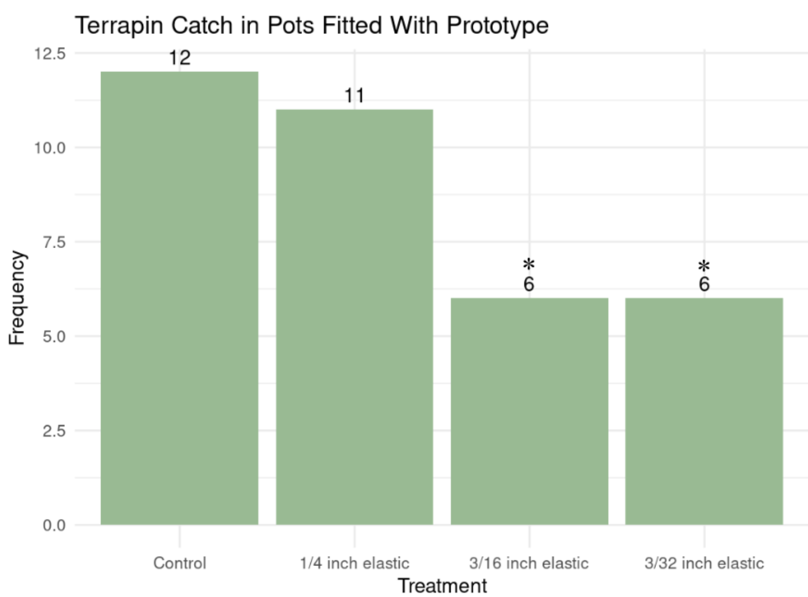

Figure 5: Bar chart displaying total terrapin catch in control and three experimental pots. Asterisk (*) denotes significance using a binomial cumulative distribution function.

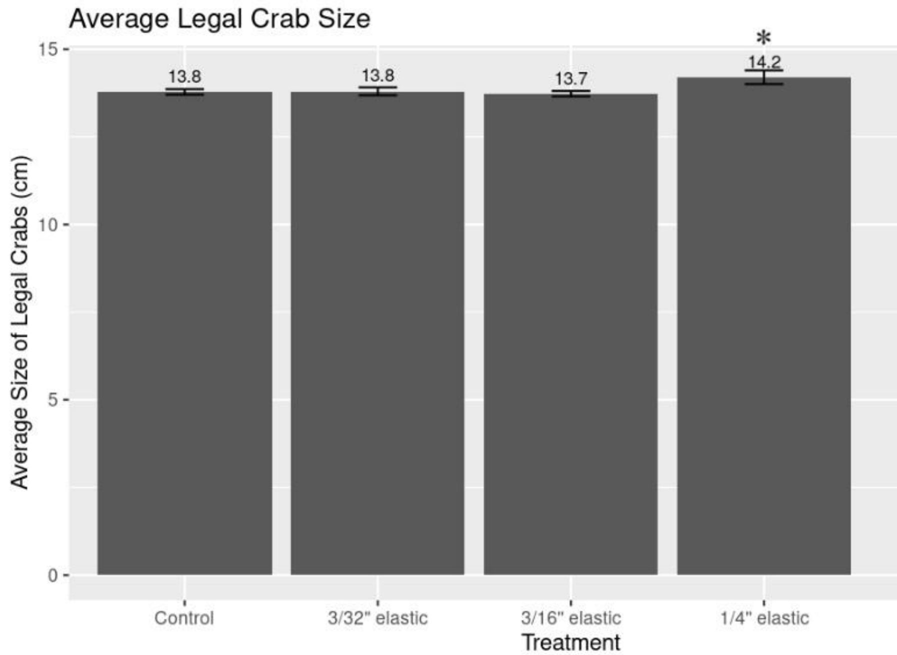

Figure 6: Bar chart comparing sizes of legal crabs in control pot and three experimental pots. Asterisk (*) denotes significance using a t-test.

Discussion

Based on these analyses, terrapins appear able to escape from both 3/16" and 3/32" elastic release devices, but not from 1/4" elastic. When examined alongside the crab catch data, this provides a promising result: 3/16" elastic is successful in both releasing terrapins and maintaining legal size crabs. 3/32" elastic, although equally successful at releasing terrapins, also demonstrated a large decrease in legal crab catch, indicating that crabs are also able to escape through this release device. Differences in size between legal crabs were generally minimal, which is encouraging and consistent with previous studies. The slight increase in size in the 1/4" elastic is likely due to the fact that the 1/4 inch treatment was removed from the study early, and crabs earlier in the season may have been slightly larger.

Overall, I was not especially encouraged by the results of this study of a bycatch release device. Although the two smaller elastic sizes did show a 50% reduction in terrapin bycatch, the 3/32" elastic also showed a 60% reduction in legal sized crab catch. Previous studies at the same site reported dramatically higher catches of legal size crabs closer to the mouth of the stream, about 1.5 km upstream of where my study took place (Upperman et al., 2014). Different results may be obtained if the same study was replicated in an area where more crabs were present. If the Virginia Marine Resources Commission continues to allow commercial and recreational crabbing without the use of bycatch reduction devices, then further research into alternative designs of release hatches is warranted.

It is my belief that the next direction for improvement of the device is to utilize turtles' ability to differentiate between colors. As discussed above, terrapins in a previous study were captured most often in pots fitted with a green BRD, indicating that they may be attracted to that color (Figure 7). Crabs in this study were attracted to red, but specific tests of crab's attraction to other colors were not specifically tested (Corso et al., 2017). On tests of color differentiation and choice in crawfish, which have a very similar visual range to crabs, the crustaceans strongly preferred red over green (Suryanto et al., 2023) (Figure 8).

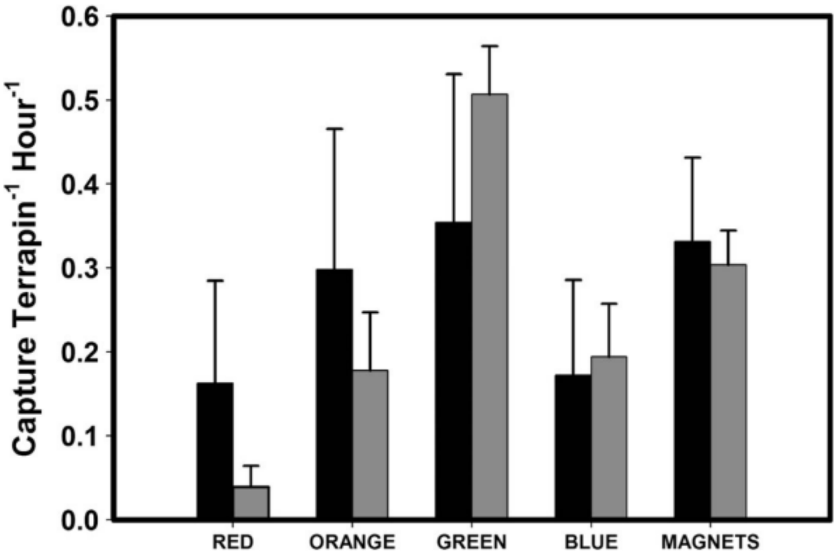

Figure 7: Color choice by terrapins, displaying a preference for green. (Corso et al., 2017)

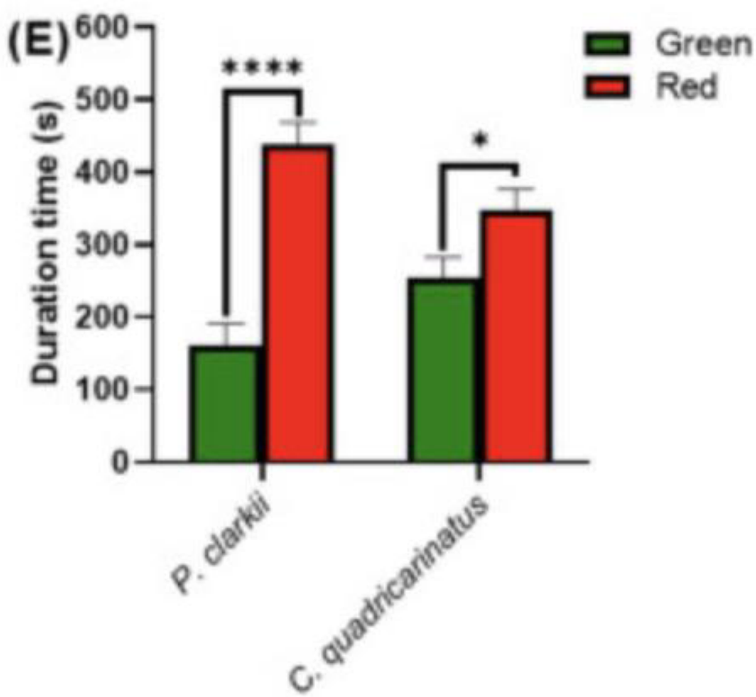

Figure 8: Color choice between red and green of two species of crawfish, displaying a preference for red. (Suryanto et al., 2023)

Knowing this, and also knowing that turtles are able to learn and remember visual discrimination behaviors, and even teach those behaviors to other turtles (Davis, 2009), I believe that the next prototype to be tested is an escape hatch made up of 3/16" elastic marked with a green border, hopefully making it more visible and enticing to terrapins while not alerting crabs of its presence. It is a well-documented problem of crab traps to become dirty or fouled in the water due to the growth of algae on the traps, which may become problematic when attempting to use visual cues to guide terrapins out of the pots. Further research should explore options to help mitigate this issue. Future studies may also benefit from observation of turtle behavior inside the traps when no chimney is available, as this may provide additional motivation for the turtles to attempt to find an escape route. To avoid terrapin mortality, experiments without a chimney would need to be performed in a controlled and monitored environment, which is obviously labor intensive, as well as stressful for the turtles. Although it is exciting to see a significant reduction in terrapin catch in two of the elastic treatments, the reduction in crab catch is not promising for its use in the blue crab fishery. Because this release device was developed in an attempt to create an alternative option to the traditional funnel-narrowing BRDs, I believe that the bulk of future terrapin conservation efforts should focus not on developing a new release device, but rather on strengthening the legislation surrounding the BRD designs that we already know are very effective at limiting terrapin bycatch.

Policy Considerations in the Blue Crab Fishery

Blue crabs have been harvested on the Atlantic coast of the United States since colonial times. The fishery today is made up of many (hundreds to thousands) of fishers running crabbing operations (Stagg and Whildren, 1997). This model of a large fishery made up of many small operations is relatively unique in modern times and is not seen often in other fisheries. Crab pots have been the most commonly used method of trapping crabs since the 1950s (Stagg and Whildren, 1997). The use of commercial-style or “Maryland-style” crab pots and crabbing is not allowed in Connecticut, Rhode Island, and Massachusetts (Upperman et al., 2014). These states instead require the use of constantly-monitored trapping techniques, like nets, as they lead to lower bycatch mortality (Connecticut Marine Fisheries Division, 2022).

Tests of bycatch reduction devices for the blue crab fishery that aim to specifically exclude terrapins have been carried out since the 1990s. Although many of these results provide compelling data showing that these devices effectively prevent terrapin capture without decreasing the capture of crabs (Table 1), the wide variety of tests done in many separate locations makes it difficult to assimilate the information. Existing data have convinced some state legislatures to pass BRD regulation into law, but for other states, confusion in comparing different study results has proven to be a roadblock to successful legislative outcomes.

(standard hardshell or peeler pots) and BRD pots (pots fitted with bycatch reduction devices)

State	BRD type	Dim Dimensions (cm)	Terrapin bycatch, control : BRD	Change in crab size	Change in crab number	Reference
AL	Wire	5×15	22:2	N/A	31% decrease	Coleman et al. 2011
DE	Wire	5×10	97:40	No change	No change	Cole & Helser 2001
DE	Wire	3.8×12	106:0	No change	~26% decrease	Cole & Helser 2001
DE	Wire	4.5×12	106:36	No change	~14% decrease	Cole & Helser 2001
DE	Wire	5×12	106:93	No change	No change	Cole & Helser 2001
FL	Wire	4.5×12	37:4	No change	No change	Butler & Heinrich 2007
GA	Plastic	5×15	136:5	No change	~14% decrease	Belcher et al. 2007
LA	Wire	5×10	0:0	N/A	38% increase	Guillory & Prejean 1998
MD	N/A	4.5×12	1:0	N/A	29% decrease	Lukacovic et al. 2005
MD	Wire	4.5×12	105:19	No change	No change	Roosenburg & Green 2000
MD	Wire	5×10	105:56	No change	No change	Roosenburg & Green 2000
MS	Wire	5×15	0:0	No change	No change	Graham et al. 2011
MS	Wire	5×10	0:0	No change	No change*	Cuevas et al. 2000
NJ	Wire	5×10	40:3	No change	No change	Mazzarella 1994
NJ	Wire	4.5×10	3:0	No change	12% increase	Wood 1997
NJ	Wire	5×10	25:4	No change	10% increase	Wood 1997
NJ	Wire	5×10	46:5	No change	49% increase	Wood 1997
NC	Wire	4×15; 5×15	13:1	No change	No change	Chavez 2014
NC	Wire	5×16	7:0	N/A	No change†	Hart & Crowder 2011
NC	Wire	4×16; 4.5×16	1:0	N/A	23% decrease†	Hart & Crowder 2011
SC	Plastic	5×15	30:0	N/A	N/A	Powers et al. 2009
SC	Plastic	4.5×12	75:3	N/A	21% decrease	Powers et al. 2009
TX	Plastic	4.5×12	2:0	No change	No change	Baxter 2014
VA	Plastic	4.5×12	2:0	Slight decrease	~25% decrease	R. Lipcius, VIMS, pers. comm.
VA	Plastic	4.5×12	69:2	No change	53% decrease‡	Upperman et al. 2014
VA	Plastic	5×15	69:0	No change	No change‡	Upperman et al. 2014
VA	Plastic	4.5×12	9:0	N/A	17% decrease	Morris et al. 2011
VA	Plastic	4.5×12	42:0	N/A	47% decrease‡	Morris et al. 2011
VA	Plastic	4.5×12	46:2	No change	No change	Rook et al. 2010

*Based on total crab catch data.
†Legal male captures in hard crab pots only.
‡Unbaited pots.

Table 1: a summary of studies of BRD use on crab pots on the east coast in the past 30 years. (Chambers and Maerz, 2018)

With the help of the Wetlands Institute, a nonprofit organization that advocates for diamondback terrapins, New Jersey was the first state to implement this type of legislation. Beginning in 1989, the Wetlands Institute launched the "Terrapin recovery and conservation project" in response to a serious decline in terrapin populations. The Wetlands Institute is cited as developing the first terrapin excluder device, which is attached to the inner narrow end of the entrance funnel on crab traps and prevents terrapins from entering the traps. The effectiveness of this device was studied by the Wetlands Institute, the New Jersey Division of Fish, Game, and Wildlife, and commercial crabbers. These studies showed that BRDs are very effective at preventing terrapins from entering the traps, and that there is no significant decrease in the number or size of legal-sized crabs that are caught in the traps equipped with an excluder. Some studies even showed an increase of legal-sized crabs, which is thought to be due to the fact that the exclusion devices further decrease the size of the inner opening of the funnel in the trap, making it more difficult for large crabs to find their way out once they have entered. The research results convinced legislators in New Jersey to pass the first terrapin exclusion device regulation into law in 1998, making New Jersey the first state to regulate the use of BRDs on crab traps. The regulation, which is still in place, applies to commercial crab pots placed in bodies of water that are less than 150 feet wide and in man-made lagoons, which are common habitats for terrapins. The exclusion devices must be attached to the inside of all pot entrance funnels, and the rule also applies to recreational crabbers who use "commercial-style" crab pots. Estimates suggest that 10,000 or more traps are used recreationally by recreational crabbers in New Jersey, highlighting the importance of the regulation applying to these pots (Terrapin Conservation at the Wetlands Institute, 2022).

Maryland became the next state to begin mandating the use of BRDs on recreational crab pots in 1999. This regulation specifically targets recreational crabbing at waterfront properties, likely because owners of these properties are legally allowed to use two crab pots without a license. The requirement states that a BRD must be attached to each funnel or entrance to the lower chamber of the crab pot. To enforce this requirement, Maryland has begun requiring recreational waterfront property owners to register their crab pots if they wish to set them along the Chesapeake Bay. This registration process is free, and is also used as an opportunity to educate recreational crabbers about the steps that they can take to preserve the terrapin, the state reptile of Maryland. The state currently does not require BRDs to be used on commercial crab pots, but commercial crabbing is restricted specifically in tributaries to Chesapeake Bay (Maryland Department of Natural Resources, 2022). Delaware began implementing BRD regulations in 2001, which apply only to recreational crab pots. Delaware's legislation states that it is illegal for an owner to place a non-commercial pot in tidal waters unless the pot is equipped with BRDs. Violation of this legislation is considered to be a class D environmental violation, punished by a $50-100 fine, revocation of the fishing license, and court and prosecution costs when applicable. Delaware has a significant history of prosecuting violations of its crab pot violations as a strategic deterrence mechanism to mitigate concerns about enforceability of BRD regulations. One notable case in 2016 occurred when a recreational crabber was arrested and pleaded guilty to violating the regulation. They were fined $2,558, had to pay court costs, and had their crabbing license revoked for one year. This strategy of punishing violators to the fullest extent of the law encourages crabbers to seriously consider the possible costs of non-compliance with the state's BRD requirements (Delaware Department of Natural Resources, 2017).

New York State was the next to implement regulations on crab traps. In 2018, the New York Department of Environmental conservation implemented a regulation that required recreational crabbers to use BRDs on all non-collapsible crab pots or traps in specified areas only. These areas included the Long Island Sound, the Hudson River, and other designated harbors and bays. This regulation was enacted to ensure that exclusion devices were used in places that are ideal habitats for terrapins, like creeks and harbors, while not requiring them in areas where terrapins are not present. Over 60 scientists in the state were publicly in support of a ban on commercial crab harvests, which helped to highlight the risk that crabbing posed to New York State's terrapins. The director of the NY State Department of Environmental Conservation's Marine Crustacean unit, headed at the time by Carl LoBue, played a key role in advocacy for the use of BRDs. Open dialogue was held with crabbers, with some admitting to accidentally catching terrapins in their crab pots in the past. A pivotal moment in proceedings occurred when a crabber testified about his positive experiences while using the exclusion device, including an increase in Blue Crab catches (Bennett, 2019). Next, the state of North Carolina implemented regulations to protect terrapins in 2020 through its Marine Fisheries Commission. Two Diamondback Terrapin Management Areas have been designated in the state, within which all crabbers must use BRDs on their crab pots. These areas are decided based on extant populations of Diamondback Terrapins, depth, and distance from shore. The measures came into effect in early 2021, and coincided with the closed season of crabbing to allow fishermen time to make modifications to their gear. The state plans to introduce additional Management Areas in the future (Smith, 2020). Finally, Florida's coastline makes up 20% of the total terrapin habitat in the United States (Butler and Heinrich, 2007) and therefore was an early target for bycatch reduction measures. Still, BRD regulations in Florida were not enacted until 2022. The only Atlantic coast states without requirements for BRDs are Georgia, South Carolina, and Virginia.

The state of Virginia has struggled to implement meaningful BRD legislature. The Virginia Marine Resources Commission (VMRC) proposed an amendment to license regulations for recreational crabbers that would require the use of BRDs, but the vote was sent to the Crab Management Advisory Committee (CMAC) before it came to a vote before the VMRC. At the CMAC meeting, recreational crabbers in attendance raised questions about the fairness of imposing a regulation on recreational crabbers but not on commercial crabbers, and asked about differences in terrapin mortality between the two groups. In Virginia, recreational crabbers are legally permitted to place up to two crab pots at a time without registration or a license. Using more than two pots requires the purchase of a $36 license, and at that price, the use of BRDs on traps is required. Crabbers can pay $10 more to bypass this BRD requirement, however, and records of license sales indicate that close to 60% of licenses sold do not require the use of exclusion devices. In addition to resistance to legislation from recreational crabbers, Virginia State Governor Glenn Youngkin has operated on a platform that emphasizes regulatory reductions as a route for economic growth and job creation. In an executive order in January of 2022, Youngkin's office directed that processes be initiated that will "reduce by at least 25% the number of regulations not mandated by federal or state statute," (Exec. Directive No. 1, 2022). This reduction of regulations further limits the ability of the VMRC or any other legislative entity to implement BRD legislation.

Although often left out of scientific conversations, it is important to remember that watermen, defined as anyone who earns a living by working on the water harvesting seafood, are also directly impacted by this legislation (VA Watermen's Association, 2024). To understand the impact that these regulations have on watermen, it is imperative that the crabbers themselves are not excluded from the conversation. It is unfair to assert that watermen are not educated about crabs, terrapins, and the waters that many of them have been working for generations. In many walks of science, researchers are quick to discount the voices and opinions of blue collar workers, impoverished people, and other historically marginalized groups, especially when two or more of these groups overlap. Examples of this can be found throughout many scientific journals and publications. In a paper about coral reef destruction, researchers write "However, many reserves have failed to prevent ongoing overfishing because of a lack of support from impoverished local people, poor compliance and inadequate resources for education and enforcement" (Hughes et al., 2010). This assertion that a lack of compliance with recommendations to prevent overfishing is due to a simple lack of support from impoverished local people is misleading and does not provide the reader with a comprehensive understanding of the factors at play.

Watermen of the middle peninsula, the stretch of land between the Rappahanock and York Rivers in Virginia, when interviewed by researchers, recounted stories of using skills and values that they learned growing up in the fishing industry to navigate economic and environmental uncertainty, especially in situations where the two are inseparably connected to one another. Watermen both historically and today have used fishing technologies and their own knowledge of the environments in which they work in order to work hard toward the goal of economic independence. As development continued in coastal cities in the late nineteenth century, watermen profited as the fish industry boomed. As fishing technologies advanced in the late nineteenth century and on, these ideals of hard work and physical labor struggle to keep up with mechanization. Coupled with fluctuations in fish populations, increases in harvesting efficiency and an extreme demand for product, watermen faced a disappointing end to a time of prosperity (Taylor, 2022).

Watermen are regarded by some as an example of the tragedy of the commons, participating in the declines of the fish that they harvest via overharvesting and participating in and reinforcing problematic inequities in the workforce, including a lack of respect for women and non-white watermen (Taylor, 2022). Racialized labor regimes existed in the 1950s where Black men were employed as crew members on boats owned by white men, which were some of the only jobs available in these areas. Wages on ships were generally raised based on skill level, but this was really only true for white men on vessels captained by white men. Although the ideals of hard work have been passed down through generations of watermen, many children of watermen have also moved out of the areas in search for more consistent work and education. For many families, generations of men have been working the same docks for four generations or more (Taylor, 2022).

There is a long history of tension between watermen and policymakers. Taylor argues that the tension is between the multiple ways that you can get to know a place. Watermen, for example, say that "it is only through experiential knowledge that one can learn what can be learned about the blue crab" (Taylor, 2022). Doubtless, many researchers would disagree with this assertion and may even claim the opposite, that knowledge gained through scientific research is the only way to learn the full truth about an organism or ecosystem. In fact, Francis Putz of the University of Florida claims that "rednecks" may even be "the unsung heroes of ecosystem management." He asserts that through traditional practices like recreational burns and hunting, poor people in rural communities should get at least some recognition for their role as ecosystem managers (Putz, 2003). This idea can be applied wider to the idea that, like anyone who has lived and worked in the same place for an extended period of time, the perspectives of poor, rural, and blue collar workers should not be discounted simply because they lack a formal education about the ecosystems in which they live and work.

In the 1970s a push for regulations began as crab populations struggled to maintain healthy numbers. Limits were placed on the number of hours crabbers were allowed to work and the number of pots that they could put in the water. Not only did these limits decrease revenue for the crabbers, they also caused tension between marine officers and crabbers. The crabbers felt that the nature of their work should allow them to be their own boss, especially since this had been the case for so long. Steve Pope, a marine resource officer at the time, said “I was probably reviled more than the regular law enforcement here because what I did affected somebody’s livelihood,” (Taylor, 2022). In the 1990s, as conservation became more of a concern, the VMRC limited the total number of crab pots that could be placed in certain waters and shortened the dredging season in an effort to help crab populations return to what they once were. These regulations caused the number of crab landings to significantly decrease, and crabbers who needed the work for monetary reasons were able to be granted “hardship licenses” which worked against previous limits on pot numbers, but allowed crabbers to earn a living. There was significant disagreement about what the root cause of the decline in crab catch was. Some scientists cited weather patterns, some watermen said it was due to the lack of enforcement of crabbing regulations that had been in place even before the declines. Other watermen felt as though these changes were a natural part of the industry, saying that hard work and changing tactics had always been a part of crabbing. The tactic necessary at this time required crabbers to work less, which was not possible if they wanted to make enough money to support themselves and their families. Environmental changes in Virginia further hinder the success of watermen who are already struggling. Sea level rise, declines in water quality, and more frequent red tides have permanently changed the coastline and the fishing industry in the area (Taylor, 2022).

Studies have shown that recreational fishing can have a much more profound effect on shoreline dynamics than was previously believed, with the removal of predators by fishermen causing large-scale trophic dysfunction and shifting community structure in those areas (Altieri et al., 2012). Although this issue is relatively well-documented in areas with pressure from commercial fisheries, this data further emphasizes the need for legislation and management solutions that include recreational and small-scale fisheries. Diamondback terrapins provide an excellent example of this need, due to their higher mortality in recreational pots than in commercial pots. Although it may seem counterintuitive, all impacts on these ecosystems must be considered in order to implement functional management strategies that will best be able to mitigate harm to these important areas.

These struggles between industry, science, and the world we live in are nothing new, and are not likely to go away any time soon. Beyond the crab fishery, the issue of convincing the general public to care about conservation at times seems insurmountable. Especially for species like the diamondback terrapin, with limited contact or obvious benefit for humans, it is difficult to convince the casual observer that these turtles are worth devoting resources to. In studies on sea turtle conservation, Hannah Henry found that there is a direct link between a person's knowledge of a species and their willingness to change their behaviors to conserve that species (H. Henry unpublished data, 2023). This study focused on sea turtles, but I believe this pattern also applies widely to many issues. Although a federal mandate requiring the use of BRDs on all crab pots would undeniably significantly reduce terrapin mortality in the crab fishery, perhaps education of watermen about the terrapins could accomplish this goal with less strife between scientists, lawmakers, and watermen. If watermen were more aware of the terrapin and its ecosystem services, perhaps a federal mandate would be able to be passed into law with less resistance. The information from my field work in 2023 provides evidence to support the idea that the path forward for terrapin conservation is through mandating the use of the BRDs, that we already have proven to be functional, in Virginia, where they are not yet required, and strengthening existing legislation in other states. Although it is exciting that a release hatch may be feasible, the release of blue crabs at higher rates than the current BRD does not bode well for its success in implementation in Virginia. Perhaps increasing outreach and understanding of the importance of the diamondback terrapin as a species could aid in the endeavor to pass this legislation into law.

Overall, the diamondback terrapin serves as a model organism for demonstrating the intricate challenges facing coastal ecosystems globally. Through an exploration of their physiology and ecology, as well as a knowledge of the many anthropogenic threats they face, the urgent need for comprehensive conservation strategies is clear. By addressing the complexities of habitat degradation, historical exploitation, and fishing industry bycatch, novel solutions such as gear modifications within the blue crab fishery offer new ideas for mitigating terrapin mortality. The analysis of terrapin protection legislation across eastern U.S. states emphasizes the importance of cohesive management approaches to ensure the species' long-term survival, and underscores the fact that existing research on BRDs can prove their efficacy in the blue crab fishery. Moving forward, concerted efforts from scientists, policymakers, and stakeholders are imperative to safeguarding diamondback terrapins and preserving the ecological integrity of coastal habitats for generations to come.

Works Cited

Altieri, A.H., Bertness, M.D., Coverdale, T.C., Herrmann, N.C. and Angelini, C. (2012), A trophic cascade triggers collapse of a salt-marsh ecosystem with intensive recreational fishing. Ecology, 93: 1402-1410. https://doi.org/10.1890/11-1314.1

Arnold, K., & Neumeyer, C. (1987). Wavelength discrimination in the turtle Pseudemys scripta elegans. *Vision research*, *27*(9), 1501–1511. https://doi.org/10.1016/0042-6989(87)90159-3

Baldisserotto, B., Miguel, M. R. J., & Kapoor, B. G. (2019). *Fish osmoregulation*. CRC Press.

Baldwin, J. D., Latino, L. A., Mealey, B. K., Parks, G. M., & Forstner, M. R. (2005). The diamondback terrapin in Florida Bay and the Florida Keys: insights into turtle conservation and ecology. *Amphibians and reptiles: status and conservation in Florida*, 180-186.

Bennett, E. (2019, March 29). *New York Rule Will Prevent More Turtles From Drowning in Coastal Crab Traps*. Www.biologicaldiversity.org. https://www.biologicaldiversity.org/news/press_releases/2018/diamondback-terrapin-03-29-2018.php

Bilkovic, D. M., Chambers, R., Leu, M., Havens, K. J., & Russell, T. (2012) Diamondback Terrapin Bycatch Reduction Strategies for Commercial and Recreational Blue Crab Fisheries. Virginia Institute of Marine Science, William & Mary. https://dx.doi.org/doi:10.25773/v5-e181-h936

Brennessel, Barbara. *Diamonds in the Marsh : A Natural History of the Diamondback Terrapin*. Hanover: University Press of New England, 2006. Print.

Brooks, R.J., Brown, G.P., and Galbraith, D.A. (1991). Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (Chelydra serpentina). *Canadian Journal of Zoology*. 69(5): 1314-1320. https://doi.org/10.1139/z91-185

Butler, J. A., & Heinrich, G. L. (2007). The effectiveness of bycatch reduction devices on crab pots at reducing capture and mortality of diamondback terrapins (Malaclemys terrapin) in Florida. *Estuaries and Coasts*, *30*(1), 179–185. https://doi.org/10.1007/bf02782978

Cairns, N.A., Stoot, L.J., Blouin-Demers, G., Cooke, S.J. (2013). Refinement of bycatch reduction devices to exclude freshwater turtles from commercial fishing nets. *Endangered Species Research. 22*, 251-261. Doi: 10.3354/esr00549

Cecala, K.K., Gibbons, J.W. and Dorcas, M.E. (2009), Ecological effects of major injuries in diamondback terrapins: implications for conservation and management. Aquatic Conserv: Mar. Freshw. Ecosyst., 19: 421-427. https://doi.org/10.1002/aqc.999

Chambers, R.M, and Maerz, J.C. Bycatch in Blue Crab Fisheries. In V.S. Kennedy & W.M oosenburg, *Ecology and Conservation of the Diamond-backed Terrapin.* (231-244). Baltimore: Johns Hopkins University Press., https://doi.org/10.1353/book.62773.

Cole, R., & Helser, T. E. (2001). Effect of Three Bycatch Reduction Devices on Diamondback Terrapin Capture and Blue Crab Harvest in Delaware Bay. *North American Journal of Fisheries Management*, *21*(4), 825–833. https://doi.org/10.1577/1548-8675(2001)021%3C0825:eotbrd%3E2.0.co;2

Cook, C.E., McCluskey, A.M. & Chambers, R.M. Impacts of Invasive *Phragmites australis* on Diamondback Terrapin Nesting in Chesapeake Bay. *Estuaries and Coasts* **41**, 966–973 (2018). https://doi.org/10.1007/s12237-017-0325-z

Davenport, J. and Macedo, E.-.-A. (1990), Behavioural osmotic control in the euryhaline diamondback terrapin *Malaclemys terrapin*: responses to low salinity and rainfall. Journal of Zoology, 220: 487-496. https://doi.org/10.1111/j.1469-7998.1990.tb04320.x

Feinberg, J. A., & Burke, R. L. (2003). Nesting Ecology and Predation of Diamondback Terrapins, Malaclemys terrapin, at Gateway National Recreation Area, New York. *Journal of Herpetology*, *37*(3), 517–526. http://www.jstor.org/stable/1566055

Grubbs, S. P., Funkhouser, H., Myer, P., Arendt, M., Schwenter, J., & Chambers, R. M. (2018). To BRD or Not to BRD? A Test of Bycatch Reduction Devices (BRDs) for the Blue Crab Fishery. *North American Journal of Fisheries Management*, *38*(1), 18–23. https://doi.org/10.1002/nafm.10017

Harden, L.A., Midway, S.R., and Williard, A.S. (2015). The blood biochemistry of overwintering diamondback terrapins (Malaclemys terrapin)*, Journal of Experimental Marine Biology and Ecology, 466*, 34-41. https://doi.org/10.1016/j.jembe.2015.01.017.

Havens, K.J., D.M. Bilkovic, D. Stanhope, K. Angstadt and C. Hershner. 2008. The effects of derelict blue crab traps on marine organisms in the lower York River, Virginia, North American Journal of Fisheries Management 28:194-1200.

Henry, H. 2023. Sea Turtle - Angler Dynamics. Unpublished data.

Hidalgo, H. (1982). Courtship and Mating Behavior in Rhinoclemmys pulcherrima incisa (Testudines: Emydidae: Batagurinae). *Transactions of the Kansas Academy of Science (1903-)*, *85*(2), 82–95. https://doi.org/10.2307/3628429

Hughes, T. P., Graham, N. A. J., Jackson, J. B. C., Mumby, P. J., & Steneck, R. S. (2010). Rising to the challenge of sustaining Coral Reef Resilience. *Trends in Ecology & Evolution*, *25*(11), 633–642. https://doi.org/10.1016/j.tree.2010.07.011

Installing a Turtle Bycatch Reduction Device (TBRD) on a crab pot. (2017). https://documents.dnrec.delaware.gov/fw/Fisheries/Documents/2019%20Turtle%20Brochure%20-%20FINAL.pdf

Iwabe, N. & Hara, Y. & Kumazawa, Y. & Shibamoto, K. & Saito, Y. & Miyata, T. & Katoh, K. (2005). Sister Group Relationship of Turtles to the Bird-Crocodilian Clade Revealed by Nuclear DNA-Coded Proteins. Molecular biology and evolution. 22. 810-3. 10.1093/molbev/msi075.

Li. X., Bellerby, R., Craft, C., and Widney, S.E. 2018. Coastal wetland loss, consequences, and challenges for restoration. Anthropocene Coasts. 1(1): 1-15. https://doi.org/10.1139/anc-2017-0001

Louisiana Fisheries - Bycatch Reduction Device (BRD). (n.d.). Www.seagrantfish.lsu.edu. Retrieved December 27, 2023, from https://www.seagrantfish.lsu.edu/management/TEDs&BRDs/brds.htm

Legal Complaint in Turtle Excluder Device Lawsuit, (United States District Court for the District of Columbia April 6, 2021). https://www.biologicaldiversity.org/programs/oceans/pdfs/Gulf-of-Mexico-TEDs_Complaint-for-Declaratory-and-Injuctive-Relief-4-6-21.pdf

McRobert, & Szerlag. (2006). Road occurrence and mortality of the northern diamondback terrapin. *Applied Herpetology*, *3*(1), 27-37. https://doi.org/10.1163/157075406775247058

Morris, A.S., Wilson, S.M., Dever, E.F. *et al.* A Test of Bycatch Reduction Devices on Commercial Crab Pots in a Tidal Marsh Creek in Virginia. *Estuaries and Coasts* **34**, 386–390 (2011). https://doi.org/10.1007/s12237-010-9330-1

Muldoon, K.A. & Burke, Russell. (2012). Movements, overwintering, and mortality of hatchling Diamond-backed Terrapins (Malaclemys terrapin) at Jamaica Bay, New York. Canadian Journal of Zoology. 90. 651-662. 10.1139/z2012-032.

No license required. Legal Blue Crab Capture Methods. (2022) Connecticut Marine Fisheries Division. https://portal.ct.gov/-/media/DEEP/fishing/saltwater/BLUECRABFACTSHEETpdf.pdf

Petrov, Tandy Dolin, "Biology, Ecology, And Conservation Of Hatchling And Post-Hatchling Diamondback Terrapin (Malaclemys Terrapin Pileata)" (2014). All ETDs from UAB. 2715. https://digitalcommons.library.uab.edu/etd-collection/2715

Putz, F. E. (2003). Are Rednecks the Unsung Heroes of Ecosystem Management? *Wild Earth. 13*(2/3), 10-14.

Recreational Crab Pot Requirements. (n.d.). Maryland Department of Natural Resources. https://dnr.maryland.gov/fisheries/pages/regulations/crabpot.aspx

Recreational Crabbing Rules. Virginia Marine Resources Commission. (2023). https://www.mrc.virginia.gov/regulations/VA-recreational-crabbing-rules.shtm

Redding, O. T., Castorani, M. C. N., & Lasala, J. (2024). The effects of dune plant roots on loggerhead turtle (caretta caretta) nest success. *Ecology and Evolution, 14*(4), 1. doi:https://doi.org/10.1002/ece3.11207

Reid, G.K. (1955). Reproduction and Development in the Northern Diamondback Terrapin, malaclemys terrapin terrapin. *Copeia 4*, 310-311. https://www.jstor.org/stable/1440314

Roosenburg, W. M., & Green, J. P. (2000). Impact of a Bycatch Reduction Device on Diamondback Terrapin and Blue Crab Capture in Crab Pots. *Ecological Applications*, *10*(3), 882–889. https://doi.org/10.1890/1051-0761(2000)010[0882:ioabrd]2.0.co;2

Sea Turtle Conservation; Shrimp Trawling Requirements. (2021, March 31). Unblock.federalregister.gov; Federal Register. https://www.federalregister.gov/documents/2021/03/31/2021-06594/sea-turtle-conservation-shrimp-trawling-requirements

Segelson, C. (2021, December 16). *FWC approves diamondback terrapin conservation measures*. Florida Fish and Wildlife Conservation Commissio

Seigel, R.A. (1979). "The Reproductive Biology of the Diamondback Terrapin, Malaclemys Terrapin Tequesta." *Retrospective Theses and Dissertations*. 445. https://stars.library.ucf.edu/rtd/445

Smith, P. (2020, May 15). *Marine Fisheries Commission establishes first two state diamondback Terrapin Management Areas*. Marine Fisheries Commission establishes first two state diamondback terrapin management areas. https://www.deq.nc.gov/news/press-releases/2020/05/15/marine-fisheries-commission-establishes-first-two-state-diamondback-terrapin-management-areas

Stagg, Cluney & Whilden, Marguerite. (1997). The history of Chesapeake Bay's blue crab (Callinectes sapidus): Fisheries and management. Investigaciones marinas. 25. 10.4067/S0717-71781997002500007.

Suryanto, M. E., Audira, G., Roldan, M. J. M., Lai, H. T., & Hsiao, C. D. (2023). Color Perspectives in Aquatic Explorations: Unveiling Innate Color Preferences and Psychoactive Responses in Freshwater Crayfish. *Toxics*, *11*(10), 838. https://doi.org/10.3390/toxics11100838

Syvitski, J., Kettner, A., Overeem, I. *et al.* Sinking deltas due to human activities. *Nature Geosci* 2, 681–686 (2009). https://doi.org/10.1038/ngeo629

Taylor, J., & Daglaris, P. (2022). Labor, Landscape, and Four Virginia Watermen. *Journal of Southern History 88*(2), 257-290. https://doi.org/10.1353/soh.2022.0055.

Terrapin Conservation at the Wetlands Institute. (n.d.). Nytts.org. Retrieved December 27, 2023, from http://nytts.org/terrapinconservation/home.htm

Underwood, E.B., Bowers, S., Guzy, J.C., Lovich, J.E., Taylor, C.A., Gibbons, J.W., Dorcas, M.E. (2013) "Sexual Dimorphism and Feeding Ecology of Diamond-backed Terrapins (*Malaclemys terrapin*)," Herpetologica, 69(4), 397-404.

Upperman, A.J., Russell, T.M., and Chambers, R.M. (2014). The influence of recreational crabbing regulations on diamondback terrapin by-catch. *The Northeastern Naturalist 21*(1), 12-22. https://doi.org/10.1656/045.021.0103

Virginia Waterman's Association. VIRGINIA WATERMAN'S ASSOCIATION. (2024). https://vawaterman.weebly.com/

Wass, M. L., & Wright, T. D. (1969) Coastal Wetlands of Virginia: Interim Report of the Governor and General Assembly. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No. 10. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5715S

Wilson, L., Romano, S., & Williard, A. S. (2022). Efficacy of Fisheries-Sourced Bycatch Reduction Solutions in Preventing Capture of Diamond-backed Terrapins (Malaclemys terrapin) in Blue Crab Pots. *Herpetological Conservation and Biology*, *17*(1), 76–84.

Wurst, B. (2023, June 21). *The Black Market for Terrapins is thriving*. Conserve Wildlife Foundation of New Jersey. https://www.conservewildlifenj.org/blog/2023/06/21/the-black-market-for-terrapins-is-thriving/

Younkin, G. (2022, January 15). *Laying a Strong Foundation for Job Creation and Economic Growth Through Targeted Regulatory Reductions.* https://www.governor.virginia.gov/executive-actions/executive-ordersdirectives/executive-action-title-918545-en.html