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ISSUES RELATED TO ENTRAINMENT OF HORSESHOE CRABS (*LIMULUS POLYPHEMUS*) BY HOPPER DREDGES

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ABSTRACT

Horseshoe crabs, *Limulus polyphemus*, are estuarine and coastal bottom-dwelling arthropods with habits similar to true crabs and other marine crustaceans. Although not officially designated as either threatened or endangered, declining populations have sparked concern due to the importance of horseshoe crab eggs and larvae in the diets of migratory shorebirds. A number of factors have detrimentally affected crab numbers over time including loss of spawning habitat and harvest for fertilizer, livestock feed, use as bait by the eel and whelk fishing industries, and biomedical applications. Recently concern has been raised that hydraulic dredging of navigation channels may inadvertently contribute to the observed declines in horseshoe crab populations.

Horseshoe crabs are found from northern Maine to the Yucatan peninsula, but are most abundant between North Carolina and New Jersey. Adults spend most of their lives in the deeper portions of estuaries and the continental shelf at depths less than 30 m. They migrate from these habitats to sandy, sheltered estuarine beaches to spawn in late spring. Eggs hatch in 3-4 weeks and the larvae settle onto nearby intertidal flats. Juveniles remain in the vicinity of the spawning beaches, migrating to greater depths and further from shore as they mature. Little else is known about crab movements and depth preferences, consequently assessment of their vulnerability to entrainment by hydraulic dredges in general or in specific locations poses a difficult challenge. Some evidence exists that they may be locally abundant in inlets and navigation channels during their seasonal migrations and therefore may be susceptible to entrainment. Anecdotal evidence suggests that on occasion substantial numbers of horseshoe crabs have been observed in hopper dredges. This paper proactively examines relevant life history information and existing dredging records to evaluate the extent of the problem and identify critical data gaps.

KEYWORDS: Hydraulic **d**redge, environmental impact, environmental resources, commercial species, sand mining

INTRODUCTION

The horseshoe crab, *Limulus polyphemus*, is not a true crab, but a bottom-dwelling chelicerate arthropod (Class Merostomata) more closely related to spiders than marine crustaceans (Lochhead 1950, Barnes 1987). It is also one of the few marine invertebrates that spawns in the intertidal zone. Although not officially designated as either threatened or endangered, declining populations have sparked increased concern especially because of the importance of horseshoe crab eggs and larvae to the diets of migratory shorebirds (Castro and Myers 1993, Tsipoura, N. and J. Burger 1999, Widener and Barlow 1999, Shuster et al. 2003, Botton 2009). Between the early nineteenth and mid-twentieth century horseshoe crabs were harvested intensively for fertilizer and livestock feed. Although the activities have since ceased, populations are still suffering from loss of spawning habitat while some harvest continues for eel and whelk bait and biomedical applications (Atlantic States Marine Fisheries Commission (ASMFC) 1998, Graham et al. 2009). Recently concern has also been raised that hydraulic dredging of navigation channels may inadvertently contribute to the decline in horseshoe crab populations. Concern over entrainment of arthropod populations is not unusual and recent examples include the Dungeness crab (*Cancer magister*) on the Pacific coast (Wainwright et al. 1992, Pearson et al. 2003) and the blue crab (*Callinectes sapidus*) along the Atlantic and Gulf of Mexico coasts (Reine et al. 1998).

In this report the biology and ecology of the horseshoe crab are briefly reviewed with emphasis on potential impacts from dredging and dredged material disposal. The life history and ecology of this species has been described by a

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number of authors including Shuster (1982), ASMFC (1998), Walls et al. (2002), and Shuster et al. (2003). The following summary is derived from these sources and others as indicated in the text.

Found from northern Maine to Mexico's Yucatan peninsula, *Limulus* is most abundant along the Mid-Atlantic coast (North Carolina and New Jersey), where it also reaches its greatest size (Shuster 1982, ASMFC 1998, Anderson and Schuster 2003). Sexes are separate with adult females reaching prosomal (carapace) widths up to 327 mm while males are typically smaller with prosomal widths of 232 mm or less (Shuster 1979, Shuster 1982). Adults of populations south of the North Carolina or north of New Jersey tend to be somewhat smaller; for instance, Plum Island Sound (Massachusetts) populations have an average prosomal width of 156 mm for females and 118 mm for males (Shuster 1982), while in Sarasota Bay males average only 141 mm (no data for females) (Shuster 1979).

Limulus has an estimated lifespan of 14-19 years (Ropes 1961, Botton and Ropes 1988) and may require 9-10 years to reach sexual maturity (Shuster 1950). Crabs generally move by walking along the bottom and feed by burrowing several centimeters into the sediment or more deeply (8-20 cm) to lay their eggs. They can also swim if the water is relatively quiescent (Shuster 1979)**.** *Limulus* feeds on a wide range of benthic invertebrates including polychaetes, amphipods, barnacles, copepods, snails, and bivalves (Botton 1984a, Botton and Haskin 1984, Botton and Ropes 1989, Botton 2009). Botton (1984 a,b) has demonstrated that feeding is not indiscriminate and when feeding on juvenile bivalves, crabs will actively avoid species whose shells are relatively hard to crush such as the gem clam *Gemma gemma* in favor of thinner shelled forms like the soft clam (*Mya arenaria*) or dwarf surf clam (*Mulinia lateralis*). In turn, *Limulus* is a significant prey item for a number of different species. Eggs and larvae are known to represent an important forage resource to migratory shorebirds as well as finfish and macroinvertebrates (Shuster 1982, Castro and Myers 1993, Botton 2009). Juvenile horseshoe crabs are thought to be prey for finfish and macroinvertebrates, but the extent of this mortality is presently unknown (Botton 2009). Adults are known to be fed upon by loggerhead sea turtles (*Caretta caretta*) and occasionally by the American alligator (*Alligator mississippiensis*). Herring Gulls (*Larus arentatus*) and Laughing Gulls (*L. marinus*) can be significant predators of stranded horseshoe crabs.

Horseshoe crabs migrate from deeper estuarine or shelf habitats to sandy, wave-sheltered, estuarine beaches to spawn. In the Delaware Bay and Chesapeake Bay region they begin their migration in late spring and begin to appear on spawning beaches in April or May. Spawning peaks in May and June when high tides coincide with the full and new moon (Cohen and Brockman 1983, Barlow et al. 1986, ASMFC 1998, Smith et al. 2002a, Botton et al. 2003). New England populations spawn between March and July (Barlow et al. 1986, Carmichael et al. 2003), while North Florida populations have been reported to spawn from March through November (Brockman 1990). Ehlinger et al. (2003) report that crab populations in Indian River Lagoon (Florida) reproduce year-round, but peak spawning occurs in spring. Based on size frequency distributions of Delaware Bay populations, Smith et al. (2009a) suggest that migrations may be sex-specific: females undergo offshore migrations around age 8 while males remain within the estuary to mature. Data from Widener and Barlow (1999), Moore and Perrin (2007), Watson et al. (2009) suggest that part or all of some populations do not migrate out of the natal estuary and simply reside in relatively deep bay waters during overwintering.

Horseshoe crabs are capable of spawning on a variety of different habitats including mud, salt marsh, sandy shoals, and peat, but are more plentiful and more successful on well aerated sandy beaches in areas where the salinity ranges between 20 and 30 (ASMFC 1998, Shuster and Sekiguchi 2009). Development of the resulting larvae is most rapid under these same salinity conditions (Jegla and Costlow 1982). Characteristics of the spawning beaches have been examined by Botton et al. (1988), Penn and Brockman (1994), Smith et al. (2002b), and Jackson et al. 2008). Botton et al. (1988) noted that spawning success differed substantially between two Delaware Bay beaches located within 1 km of each other. The beach exhibiting the lowest success consisted of a 10 cm layer of sand underlain by peat. They hypothesized that reduced sediments with high levels of hydrogen sulphide discouraged spawning. Comparing egg development on Delaware Bay and Florida beaches, Penn and Brockman (1994) found that in Delaware Bay horseshoe crabs nested higher and over a wider range of the intertidal zone than Florida crabs. They suggested that differences in tidal range (Delaware Bay range = 2 $\pm$ 1 m; Florida range = 1 m $\pm$ 0.5 m) and sediment grain size (Delaware Bay – very coarse sand; Florida – medium sand) were responsible. Higher development rates were attributed to higher sediment porosity and oxygenation on the Delaware Bay beaches. Smith et al. (2002b) also examined spawning beaches in Delaware Bay and found that horseshoe crabs preferred relatively narrow (low foreshore width) beaches presumably due to lower wave energy in these areas. They also suggest that the relative steepness of these beaches promotes drainage and therefore higher oxygenation levels than less steep beaches. The importance of beach steepness is reinforced by the fact that post-spawning crabs relocated to areas with less than 6-10^{o} slope become disorientated, whereas those in areas of steeper slope move towards the waterline after spawning (Botton and Loveland 1987).

Eggs take 3-4 weeks to fully develop and hatch and larvae tend to disperse during periods with strong offshore winds (Botton and Loveland (2003). The trilobite larvae settle onto nearby intertidal flats after only a few days in the plankton (Shuster 1982). After settling to the bottom the larvae grow and mature into juvenile crabs. Carmichael et al. (2003) reported that juveniles in Pleasant Bay, Cape Cod, reached an average prosomal width of almost 17 mm within the first year. Mortality estimates of this population indicated that only 0.001% of the eggs laid survived to be juveniles by the end of the first year, but approximately 78% of the resulting juveniles survived into adulthood. Leschen et al. (2006) measured the fecundity of females in this same population (Pleasant Bay) and found that although large females laid more eggs, the higher abundance of mid-sized females resulted in this size class being the most important with regard to the total number of eggs laid.

Little is known about the preferred habitat of juveniles except that they remain in the vicinity of the spawning beaches and as they mature they tend to migrate into deeper waters and further from shore (Rudloe 1981). Adult *Limulus* are believed to spend most of their lives in the deeper portions of estuaries and on the continental shelf at depths less than 30 m, although specimens have been collected as deep as 290 m off Cape Hatteras, North Carolina. There is an order of magnitude difference in abundance and biomass between inshore (<27 m) and offshore (>27 m) populations (Botton and Haskin 1984, Botton and Ropes 1987). Smith et al. (2009a) estimated that juveniles of both sexes remain in the Delaware Estuary for the first 8 years after which migrations are initiated.

Tagging studies have shown that Delaware Bay horseshoe crabs (the largest single population in the U.S.); although capable of migrating over long distances, tend to remain within 30-50 km of their spawning beaches (Swan 2005). Brousseau et al. (2004) found that spawning females would retreat offshore between spawning events, but only moved a distance of 50 to 715 m from the beach. Watson et al. (2009) monitored movements of *Limulus* in the Great Bay estuary (New Hampshire) and found that the crabs move from the deepest part of the estuary (10-11 m), which they inhabit during the coldest months, to shallow water approximately one month before spawning. Similar results were reported by Moore and Perrin (2007) for crabs in the Tauton Estuary (Maine). In this case tagged animals overwintered in channels and shallow flats, beginning to move onto spawning beaches in April and May. The peak of crab movement occurred in June and July, after which animals began to migrate off the beaches and back into deeper water. By the October-November time period most animals had begun to overwinter. During overwintering crab movement was restricted: to approximately 41 m 2003-2004 and 173 m in 2004-2005. Mean home and overwinter ranges were estimated in two embayments to be 61 to 64 hectares (ha) and overwintering ranges of 5.7 to 5.9 ha. Baptist et al. (1957) reported that crabs in Plum Island Sound, Massachusetts seasonally migrate in and out of the bay. Crab abundances declined over the winter and increased in the spring. Outward migrations were detected in September and inward migrations in March. In Cape Cod, Massachusetts James-Pirri et al. (2005) tagged crabs and recovered approximately 70% within 2 km of their spawning beaches. Rudloe (1980) studied the movement of tagged crabs away from spawning beaches in North Florida, and found that that they moved between 3.5 and 40.7 km with an average migration distance of 7.6 km.

DREDGING RECORDS

While there have been no prior studies specifically addressing the potential impacts of hydraulic dredging on horseshoe crab populations, it is clear from descriptions of bycatch by endangered species observers that the crabs are commonly entrained during dredging operations. Hopper dredge load sheets recording bycatch are available for many dredging projects at the USACE Sea Turtle Data Warehouse. The warehouse website can be found online at http://el.erdc.usace.army.mil/seaturtles/index.cfmhttp://el.erdc.usace.army.mil/seaturtles/index.cfm. Although dredging records are incomplete, an initial assessment of the existing database has identified several projects representing a range of geographic locations, times of year, and dredge plants (Table 1). Conclusions from this analysis are preliminary pending a more systematic examination of the bycatch data.

Characteristics of the dredges in these example projects varied widely (Table 1). Load size (hopper volume) ranged from 3058 m^3 for the dredges R. N. Weeks and Newport to 10,320 m^3 for the dredge Glenn Edwards. Larger vessels generally are equipped with large dragheads (Glenn Edwards – 4.3 X 4.3 m and McFarland -3.7 X 3.7 m). Smaller vessels generally employed 2.4 X 2.4 m dragheads. Most projects used a California style draghead and all utilized 2 dragheads fitted with sea turtle deflectors.

Table 1. Project summary statistics and dredge information

			Draghead Specifications			
Project	**Dredge**	**Hopper Volume (m^3)**	**Number**	**Size (m)**	**Type**	**Deflector**
Savannah	Glenn Edwards	10320	2	4.3 X 4.3	Vosta	Yes
Buttermilk Channel	McFarland	2401	2	3.7 X 3.7	California	Yes
Brunswick Harbor	Bayport	3712	2	2.4 X 2.4	Unknown	Yes
Brunswick Harbor	Newport	3058	2	2.4 X 2.4	California	Yes
Atlantic Channel	Padre Island	3364	2	2.4 X 2.4	California	Yes
Assateague Island	R. N. Weeks	3058	2	Unknown	Unknown	Yes

Project	**Dredge**	**Total Crabs**	**Total Loads**	**Crabs/Load**	**Crabs/m^3**	**Time of Year**
Savannah	Glenn Edwards	5521	138	40.01	0.003890	Jan-Feb
Buttermilk Channel	McFarland	102	75	1.36	0.000057	Jun-Jul
Brunswick Harbor	Bayport	384	276	1.39	0.000037	Mar
Brunswick Harbor	Newport	77	52	1.48	0.000048	Dec-Jan
Atlantic Channel	Padre Island	10	94	0.11	0.000003	Mar-Apr
Assateague Island	R. N. Weeks	272	40	6.80	0.002224	Sept

Observer bycatch data were available for the dredge Glenn Edwards which dredged the Savannah Harbor Entrance Channel during January and February of 2007. Entraining a total of over 5,500 crabs in 138 loads, this operation collected the largest number of horseshoe crabs and had the highest catch rate (40.01 crabs/load) of the five projects reported herein. Catch rates were converted to crabs/m^3 as a more accurate measure of catch per unit effort (CPUE) to adjust for different load sizes. The Savannah Harbor Entrance project had the highest value CPUE (0.00389 crabs/m^3). Catches were comparatively high in the first few days of dredging, and then declined (Figure 1). Absolute numbers of crabs entrained generally reflected the number of loads.

In 2005, the USACE hopper dredge McFarland 2005 dredged the Buttermilk Channel in New York Harbor. Operating between mid-June and late July a total of 75 *Limulus* were entrained in 102 loads (average = 0.74 crabs/load) (Table 1). Catch varied over time with most crabs being caught in late June and relatively few from mid- to late July (Figure 2). Peaks in the number of crabs entrained to a large extent reflect the number of hopper loads although the catch rate declined substantially over time.

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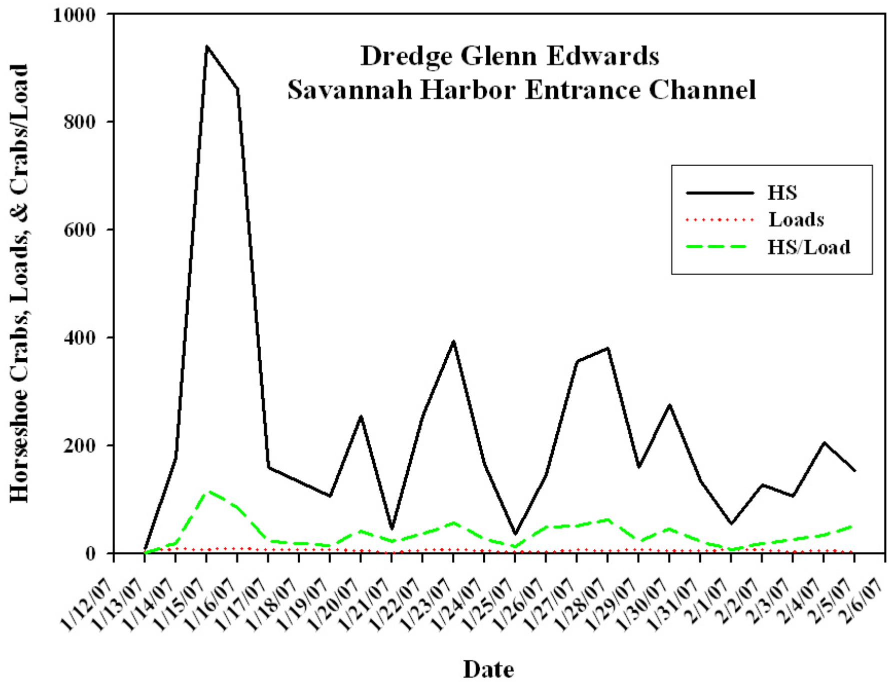

Figure 1. Catch Data for Savannah Harbor Entrance Channel

The dredges Newport and Bayport were used to dredge Brunswick Harbor, Georgia. The Newport dredged for 23 days between December 20, 2006 and January 11, 2007, while the Bayport dredged for five days in late March. As in the Buttermilk Channel and Savannah Harbor Entrance Channel cases greater numbers of crabs were entrained early in (December-January) followed by declining numbers. Entrainment rates rose again during operations in March (Figure 3). Catch rates expressed as crabs/load were similar (Bayport- 1.39 and Newport – 1.48), but after conversion to catch/m^3 the CPUE of the Newport was higher than that of the Bayport.

The dredge R. N. Weeks was used for a beach nourishment project at Assateague Island State Park, Virginia, from early to mid-September 1998. Total catch of horseshoe crabs increased over the period of the operation falling only during a short interval when dredging was suspended (Figure 4). Although a relatively small dredge, it had the second highest catch rate calculated either as crabs/load or crabs/m^3 (Table 1).

The dredge Padre Island was used to dredge of the Chesapeake Bay entrance channel during the Atlantic Ocean Channel Deepening Project. This operation was conducted from December 2005 to April 2006 and reported the lowest total number of crabs, crabs/load, and crabs/cy of any of the five projects (Figure 5). Only ten crabs were entrained in 94 loads.

To facilitate comparison, all catch rates have been converted to CPUE in order to adjust for hopper volume. However, results must be interpreted with recognition of the small number of examples. Perhaps the most obvious pattern emerging from the data is the importance of dredging locality, as evidenced by the vastly different catch rates between projects such as the Savannah Entrance Channel and the Atlantic Ocean Channel (Figure 6). The Catch rate at Savannah Harbor Entrance Channel was far greater than that at the Atlantic Channel Deepening Project despite the fact that the latter occurred during a period (March-April) when crabs may have been actively migrating (Table 1). Another pattern appears to be a decline in catch over time as seen in three of the five cases: Savannah, Buttermilk, and Brunswick. These operations occurred at different times of the year suggesting that operational characteristics were more important than seasonal migrations especially since two of the three projects occurred during the overwintering period. Declining catch rates may reflect progressive removal of a finite number of crabs occupying a given project channel reach.

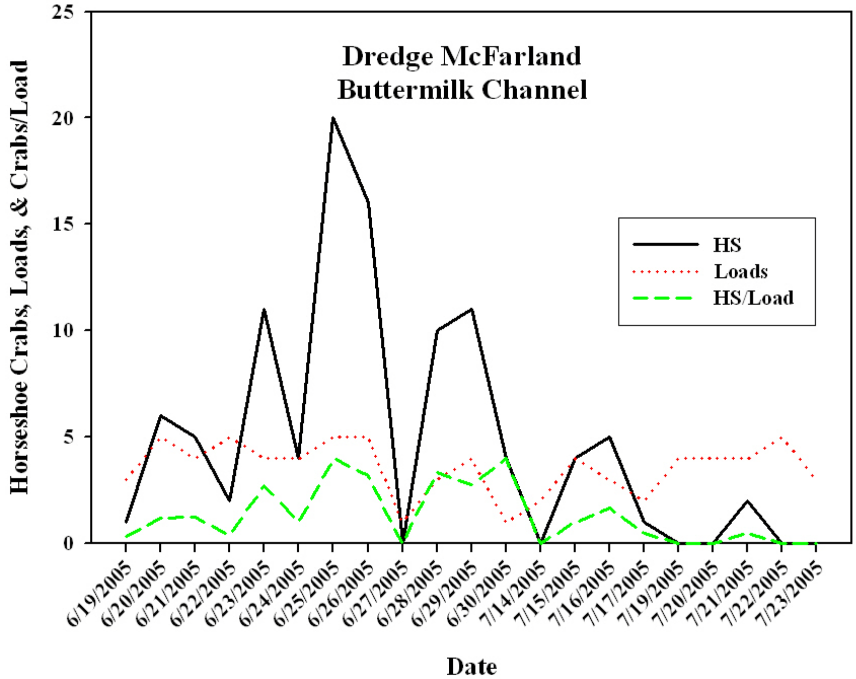

Figure 2. Catch Data for Buttermilk Channel

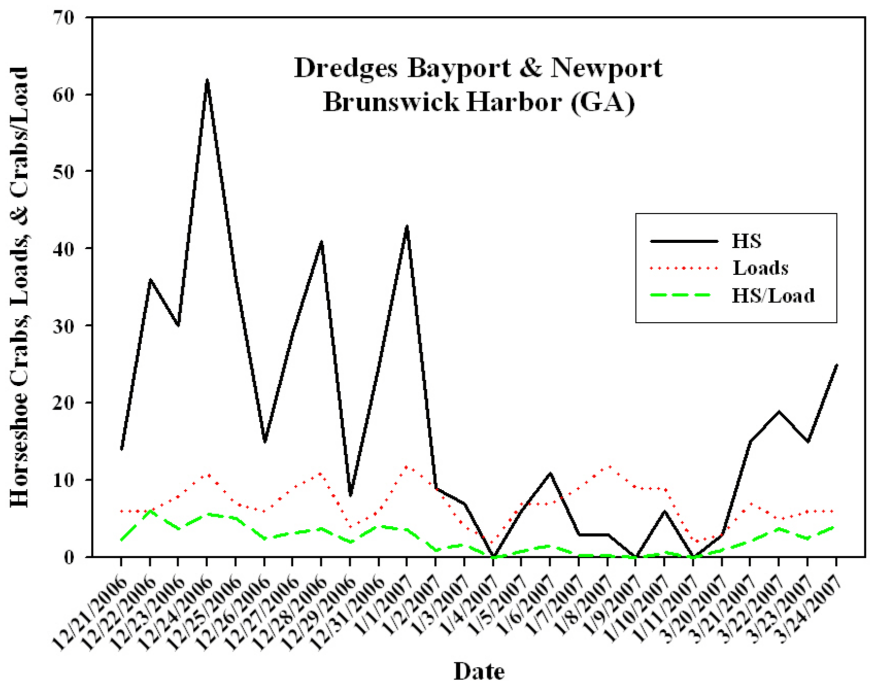

Figure 3. Catch Data for Brunswick Harbor (Georgia)

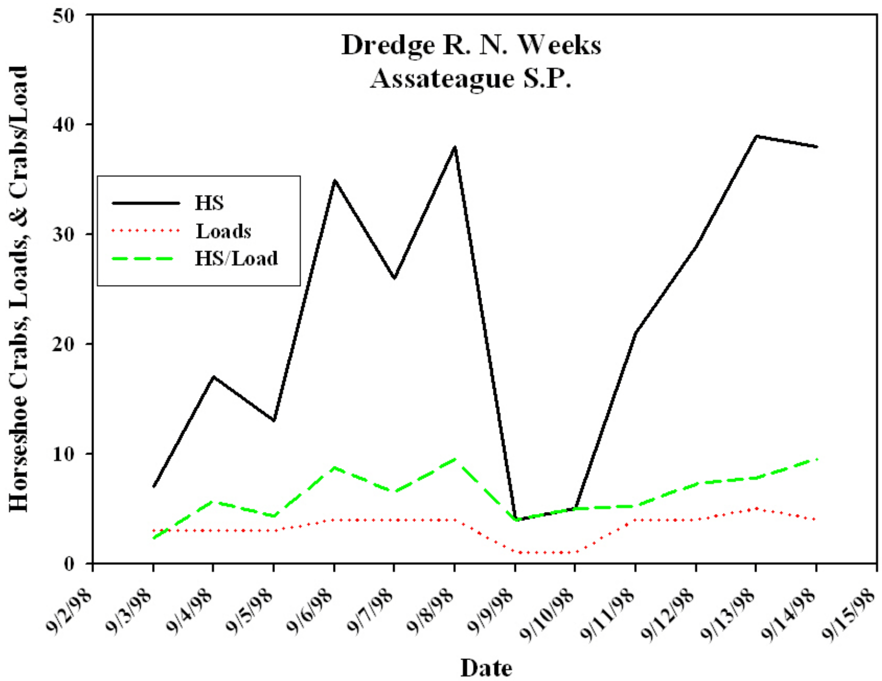

Figure 4. Catch Data for Assateague Island State Park

While it might be assumed that larger dragheads would catch greater numbers of crabs, there is conflicting evidence in this regard. While the highest catch rate was seen for the largest draghead size, a high rate was also found in the Assateague Island (Dredge R. N. Weeks) example and moderate rate for the second largest equipment (Dredge McFarland). Information on draghead size of the R. N. Weeks was unavailable. However, it seems likely that a vessel of that size employed an 2.4 X 2.4 m draghead. Seasonal fluctuations in abundance would also seem a likely factor in the results, yet similar catch rates were encountered in projects occurring in spring (dredge Newport), summer (dredge McFarland), and winter (dredge Padre Island).

BEACH NOURISHMENT

Several studies have pointed out the potential importance of beach nourishment projects in providing suitable spawning habitat for horseshoe crabs (Jackson and Nordstrom 2009). Smith et al. (2002c) have reported stable or increased spawning on recently nourished beaches with mean sediment grain sizes of 0.35 mm to 0.50 mm. Jackson et al. (2007) evaluated a small nourishment project where gravel had been added to coarsen beach sediments and report that while the pebble fraction of the sediment can be important, finer grains are also necessary to insure moisture retention. The importance of moisture retention was also pointed out by Jackson et al. (2008) during an experimental transplantation of newly laid eggs to different tidal positions on a beach. Eggs developed faster at higher temperatures associated with sites in the upper half of the foreshore as long as the sediments were able to retain enough moisture. Avissar (2006) developed a Habitat Suitability Model of horseshoe crab spawning habitat with a specific emphasis on beach nourishment operations and indicated that proper selection of sediments for fill material is absolutely essential to successfully construct crab habitat. Botton et al. (2006) examined crab spawning habitats in Jamaica Bay, New York in order to assist in ecological restoration of the area. They recommended that multiple efforts be considered including removal of debris fields and pilings and installation of breakwaters as well as beach nourishment.

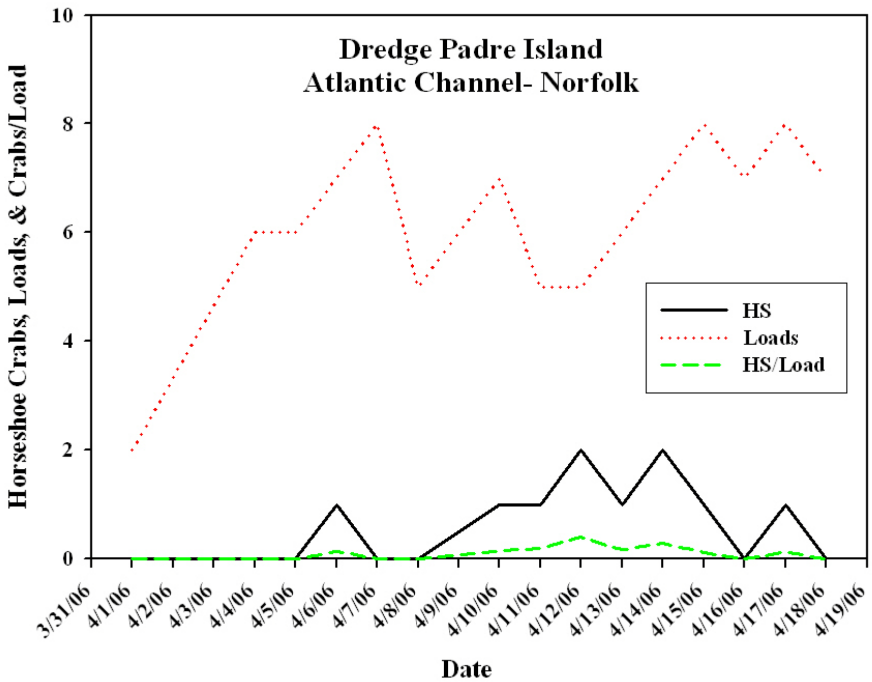

Figure 5. Catch Data for Atlantic Ocean Channel

CONCLUSIONS

The preliminary examination of the available hopper dredging bycatch records conducted in this study indicates that horseshoe crabs are routinely entrained in the course of dredging operations, and that a variety of factors may influence the number of crabs taken. At a minimum, these factors include dredging location, time of year, type of equipment, and manner of operation. Such factors may individually or collectively result in different entrainment rates in different environments (e.g., offshore borrow areas, inlet entrances channels). Comparison of the five projects presented in this report lends qualified support for several of these possibilities.

Evaluation of potential dredging impacts on horseshoe crabs requires an understanding of their location within the estuary and adjacent continental shelf waters at any given time. The relationship between crab distribution and depth is clear for juveniles and spawning adults, which are abundant in relatively shallow water from spring to mid summer. There is also a tendency for the adults to migrate into deeper estuarine or shelf waters with the onset of fall. Abundance of adults in shelf waters is generally highest in depths less than 30 m (Botton and Ropes 1987). The relative importance of location to the scale of potential dredging impact is evidenced by the large differences in catch between projects. Some sites such as the Savannah Entrance Channel may represent “hot spots” of crab abundance on either a year round basis or at certain times of the year. Determining these locations however, would not be a trivial exercise because relatively little is known about the precise distribution of the crabs except during the spawning periods. Complicating the problem is the fact that crab populations may exhibit different behavior patterns with all or only part of some populations migrating out of the natal estuaries while other populations may spend their entire lives within a specific estuary.

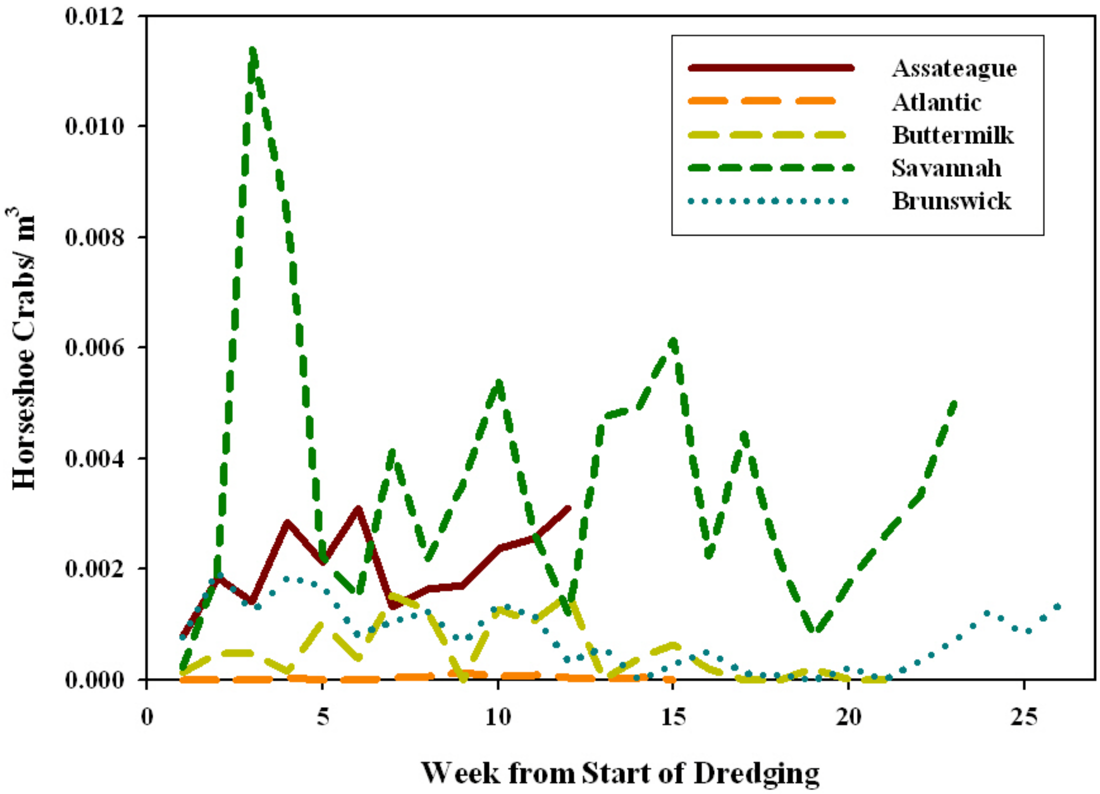

Figure 6. Comparison of catch rates over time

Seasonal patterns of crab abundance are relatively well known, but can differ among locations. In New England populations begin to migrate toward spawning beaches in early spring and spawn between March and July. By August and September they have moved off the beaches into deeper water. In the Mid-Atlantic inward migration occurs in March-April and followed by spawning between March and July. Outward migration occurs in September and October. In Florida, spawning occurs over a longer period of time, and in some cases may be year-round. Nonetheless, peak spawning occurs in spring. It is generally assumed that crabs are most vulnerable to dredging during the migration periods. In a manner similar to that reported by Schaffner and Diaz (1988) for blue crabs (*Callinectes sapidus*), horseshoe crabs may overwinter in large numbers in deeper waters that could include navigation channels. In the projects examined in this report two occurred during probable periods of inward migration (March-April). These were the Brunswick Harbor Channel and Atlantic Ocean Channel projects, and in both cases abundances appeared to be relatively high (Figures 3 and 5). Total catch during the Brunswick Harbor Channel project was, in fact, the second highest of the five projects. The Assateague Island State Park project occurred during a likely period of outward migration and had the third highest catch. Identifying data gaps such as the spatial and temporal distribution of migrating and overwintering crabs would assist in planning projects to avoid potential impacts.

The characteristics of the dredge plant (e.g., hopper volume, draghead size) and manner of operation may also affect the catch rate of horseshoe crabs. Evidence gleaned from our preliminary examination is inconsistent in some respects, perhaps reflecting the small number of cases studied. For instance, an accurate comparison of catch rates associated with different sized dragheads would require a much larger data set encompassing different localities and seasons. Likewise, the decline in catch over time as seen in three of the five cases (i.e. Savannah Entrance Channel, Buttermilk Channel, and Brunswick Harbor Channel) suggests that temporal and spatial scales may be important. For example, if horseshoe crab movements are relatively slow, that segment of the population that occurs in a navigation channel may be considered to be a finite number over the span of time dredges operate in that channel reach. Therefore the dredge would be "sampling" a progressively smaller number of crabs through the duration of the project. Consequently, the observed drops in catch rates may simply reflect removal from a progressively smaller number of vulnerable crabs present in the channel.

The relative importance of horseshoe crab entrainment by hopper dredges should be placed into context with other anthropogenic factors and sources of mortality acting on the population. Among the cases examined, with the exception of the Savannah Harbor Entrance Channel project, fewer than 900 crabs were taken during dredging of over 2.3 million m^3 of dredged material. Compared to this total, harvesting of crabs as bait for eel and whelk fisheries alone accounted for more than 500,000 takes in each year from 2004 to 2006 (Smith et al. (2009b). Mortality due to bleeding for biomedical purposes is estimated at 57,000 horseshoe crabs per year (ASMFC 2007). It is import to note that evidence from the Savannah Harbor Entrance Channel project, where 5,500 crabs were taken does indicate that certain individual projects may represent a substantial source of mortality for local horseshoe crab populations. High hopper dredge bycatch rates such as in Savannah may be interpreted in two ways. First, the dredge may have removed a significant number of crabs from a finite local population that had congregated in the channel. Second, the dredge may have removed an insignificant number of crabs from a much larger population that inhabited a much larger area. If the former case is real, then the project should obviously be examined for potential ways to minimize future impacts. Further investigation of the status of the horseshoe crab population in the vicinity of Savannah Harbor would be needed.

As stated at the outset of this review, these conclusions must be considered preliminary in nature. Additional relevant information in existing dredging records is being sought for a more comprehensive evaluation. In particular, compilation of knowledge pertaining to the affinities of local horseshoe crab populations for navigation channels, and efforts to fill gaps in that knowledge, should be pursued. It does appear that entrainment by hopper dredges represents a minimal "take" in contrast to other sources of mortality across most of the relevant geographic range of horseshoe crabs. In the event that horseshoe crab protection is identified as a priority concern for management of hopper dredging operations, we recommend that a full evaluation be completed of lessons learned on the Pacific Coast for protection of Dungeness crabs. Studies by Dinnel et al. (1986a, b), Armstrong et al. (1987), McGraw et al. (1988), Larson and Patterson (1989), Larson et al. (1994), Woolley et al. (1996), and Pearson et al. (2003, 2006) provide valuable insights into monitoring and mitigation strategies that may be applicable to horseshoe crab protection.

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