POTENTIAL THREATS TO HORSESHOE CRABS ON CAPE COD, MASSACHUSETTS

by

Michelle Fabie
Dr. Bill Kirby-Smith, Advisor
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Abstract

The Atlantic horseshoe crab, *Limulus polyphemus*, is an ancient species with ecologically and economically vital roles in estuarine ecosystems. Most notably, the biomedical industry relies on an amoebocyte lysate in their blood for detecting bacterial endotoxins. Noticeable declines in the horseshoe crab population around Cape Cod, Massachusetts recently spurred a collaborative state-wide research effort. The Massachusetts Division of Marine Fisheries identifies three primary impacts as potential threats to the horseshoe crab population: direct harvest, effects of bleeding, and habitat loss. This project discusses those potential threats while explaining the human and institutional ecology involved with the horseshoe crab population around Cape Cod. Furthermore, this project pursues the idea that spawning habitat may be threatened around Cape Cod by an increase of, or poorly located, shoreline stabilization and beach nourishment projects. These activities are quantified and addressed on a spatial scale using beach nourishment permit data, personal communication with state agencies, a review of the state permitting process, and comparisons with previous research. The results show that while there are few newly constructed shoreline stabilization structures along Cape Cod, more than forty beach nourishment projects took place over the past five years. And while processes are in place to ensure the protection of coastal habitats and their species, the environmental review system is often overlooked.

Introduction

Horseshoe crabs are an important estuarine species to a number of stakeholders. They live primarily in waters from Maine to Mexico, spending most of their time on the continental shelf region and coming inshore to spawn once a year. Stakeholders, too, live along the Atlantic

coast; scientists want to know more about the biology and behavior of this 250 million years old arthropod; fishermen depend on the horseshoe crabs for bait; and the biomedical field needs their blood, which acts as the most reliable test for bacterial contamination.[1] Their habitat, trophic interactions, and use in the medical industry make this species a unique challenge in fisheries management.

Previous research shows that there are horseshoe crab spawning 'hotspots' around Cape Cod, Massachusetts.[2] These are areas which seem to attract the highest number of horseshoe crabs each spawning season. Once a year, from about May-July, hundreds and thousands of horseshoe crabs can be seen making their way up the beach at high tide during the full and new moons. The spawning season lasts approximately 2-3 months and then the horseshoe crabs return to deeper water for the remainder of the year. Starting around 1999, residents, fishermen, and scientists noticed a decline in the observed horseshoe crab population around Cape Cod, Massachusetts. In fact, the spawning population at Mashnee Dike in Bourne, Cape Cod, experienced an 80% decline and a 95% decrease in spawning activity from 1984-1999. Other population surveys, such as that in Stage Harbor, Chatham, Cape Cod, revealed the same pattern.[3] Historic numbers of the entire Cape Cod population are unknown, so there is no baseline from which to estimate the total amount of decline. However, changes such as those found at Mashnee Dike spurred the collaborative state-wide research effort of the National Park

[1] Sargent, William. Crab Wars: A Tale of Horseshoe Crabs, Bioterrorism, and Human Health. University Press of New England: New Hampshire, 2002.
[2] James-Pirri, M.J., K. Tuxbury, S. Fish Marino, S. Koch. 2005. Spawning densities, egg densities, size structure, and movement patterns of spawning horseshoe crabs, *Limulus polyphemus*, within four coastal embayments on Cape Cod, Massachusetts. Estuaries 28: 296-313.
[3] Widener, Justin and Robert B. Barlow. 1999. Decline of a horseshoe crab population on Cape Cod. Biological Bulletin 197: 300-302.

Service, U.S. Fish and Wildlife Service, Massachusetts Division of Marine Fisheries, Massachusetts Audubon Society, and University of Rhode Island.[4]

The Massachusetts Division of Marine Fisheries identifies three primary impacts as potential threats to the horseshoe crab population: direct harvest, effects of bleeding, and habitat loss. However, the state of Massachusetts has numerous harvest regulations in compliance with the Atlantic States Marine Fisheries Commission and the bleeding of crabs is thought to have minor effects. Hence, the Massachusetts Division of Marine Fisheries is pursuing the idea that spawning habitat may be threatened around Cape Cod by an increase of, or poorly located, shoreline stabilization and beach nourishment projects.[5] Such potential impacts are not only relevant to horseshoe crabs, but numerous coastal species which rely on certain sandy shorelines during their lifecycles

The Total Ecology

Part 1. Commercial Fishing

The commercial fishing industry is an invested stakeholder when it comes to horseshoe crabs. Residents initially used horseshoe crabs to feed livestock or create fertilizer on colonial farms. Fishermen developed a particular dislike for horseshoe crabs around the 1950s, due to horseshoe crabs' taste for important shellfish, such as the soft shelled clam. This resulted in the destruction of over one million crabs per year by individual fishermen and local shellfish predator control programs throughout Massachusetts. By the 1960s, crab tails were worth up to $1500 each in bounty.[6] A decade later, fishermen started using horseshoe crabs as bait for the

[4] James-Pirri, Mary Jane. Research Associate, University of Rhode Island. Personal communication. May 2008.
[5] Leschen, Alison. Marine Biologist. Massachusetts Division of Marine Fisheries. Personal communication. September 2008.
[6] "Horseshoe Crabs: Balanced management plan yields fishery and biomedical benefits." DMF News. Second Quarter, 2003. 6-8.

conch and eel pot fisheries. Not only are horseshoe crabs effective bait, they are easily accessible and the state of Massachusetts encouraged their use at the time.[7] By 1998, total horseshoe crab bait landings for coast-wide commercial fisheries reached almost three million. Since then, the Commonwealth of Massachusetts went from over 545,000 crabs harvested annually for bait to about 140,000 in recent years.[8] New gear types and bait alternatives allow the state to remain in compliance with the horseshoe crab Fishery Management Plan (FMP), but even as recently as 2000, some Massachusetts towns still required fishermen to kill all horseshoe crabs encountered while shellfishing; otherwise, they were fined.[9]

The regulating body behind this commercial fishing industry is the Atlantic States Marine Fisheries Commission (ASMFC). Congress endorsed the ASMFC in 1942 as a compact among all 15 Atlantic coast states: Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida. The mission of the ASMFC is "to promote the better utilization of the fisheries, marine, shell, and anadromous, of the Atlantic seaboard by the development of a joint program for the promotion and protection of such fisheries, and by the prevention of physical waste of the fisheries from any cause."[10] The director for the state's marine fisheries management agency, a state legislator, and a governor-appointed individual represent each member state. These representatives are the Commissioners and constitute ASMFC's delegation. Each member state has one vote for deliberations in five main policy arenas: interstate fisheries management, research and statistics, fisheries science, habitat conservation,

[7] "Horseshoe Crabs: Balanced management plan yields fishery and biomedical benefits." DMF News. Second Quarter, 2003. 6-8.
[8] "Species Profile." ASMFC Fisheries Focus. Vol 17, Issue 5. July 2008.
[9] "Horseshoe Crabs: Balanced management plan yields fishery and biomedical benefits." DMF News. Second Quarter, 2003. 6-8.
[10] Atlantic States Marine Fisheries Commission. <http://www.asmfc.org/>

and law enforcement. ASMFC holds the power to make recommendations to each member state and to Congress regarding issues relevant to the aforementioned policy arenas.

In 1998, the ASMFC developed a Fisheries Management Plan (FMP) for horseshoe crabs. The ASMFC's Interstate Fishery Management Program, whose goal is to coordinate the conservation and management of Atlantic coastal fisheries, developed the horseshoe crab FMP. This FMP mandates member states to establish comprehensive monitoring plans to include monthly reporting, benthic sampling programs, spawning surveys, post-bleeding studies, and identification of potential habitat. Therefore, in 1999, Massachusetts created fishery permits for the harvest of horseshoe crabs in compliance with the FMP. These permits require the report of monthly catch which includes number of crabs, gender, location of catch, type of gear, and subsequent use of horseshoe crabs.[11] Under the state agency, Department of Fish and Game, the Massachusetts Division of Marine Fisheries (MDMF) authorizes the permits for horseshoe crab harvest and keeps record of monthly landings and annual quotas for the Commonwealth. They also create regulations in compliance with ASMFC's horseshoe crab FMP, their mission being to manage the harvesting of state marine resources and to ensure the sustainable role of such resources in the ecosystem for the benefit of all Massachusetts citizens.[12]

One year later, the horseshoe crab FMP adopted Addendum I which set state caps at 25% below reference period landings (RPL) and required fisheries to close when the cap was reached. The biomedical industry is not subject to these regulations and their harvest does not count towards the quota since mortalities are nominal. Based on the recorded RPL, the Massachusetts state cap was set for 330,377 in 2000. The following year, the National Marine Fisheries Service

[11] "Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32 of the ASMFC. May 2001. <http://www.asmfc.org/>.
[12] Massachusetts Division of Marine Fisheries. The Official Website of the Massachusetts Department of Fish and Game. <http://www.mass.gov/dfwele/dmf/information/info_index.htm>.

established the Carl N. Shuster Jr. Horseshoe Crab Reserve under the recommendation of ASMFC. This section of 1500 square miles of federal waters adjacent to the Delaware Bay prohibits the harvest of horseshoe crabs.[13] This same year, Addendum II of the horseshoe crab FMP passed, allowing for the voluntary transfer of harvest quotas between member states and alleviating bait shortages for the eel and conch commercial fishermen.[14] Addendum III, passed in 2004, permitted horseshoe crabs caught by the fishing industry to be sold to the biomedical industry and then released back to the fishermen after bleeding. The ASMFC added this in the hopes of minimizing mortalities caused by unnecessary transport of crabs back to their original waters. They also put further harvest restrictions in place for three of the member states, but the quota for Massachusetts remained the same.[15] Two years later, Addendum IV created further bait harvest restrictions and a closed season for states around the Delaware Bay while other member states stayed at status quo.[16] Finally, Addendum V from last year extended the provisions of Addendum IV, having no direct impact on the state of Massachusetts.[17]

Part 2. The Biomedical Industry

Horseshoe crabs are also vital to the biomedical and pharmaceutical industries. A clotting component of horseshoe crab's blood, Limulus Amoebocyte Lysate (LAL), is necessary for the detection of human pathogens in drugs, patients, and intravenous devices. Since no synthetic substitute has the same accuracy as LAL, horseshoe crab blood must be used.

[13] "Species Profile." ASMFC Fisheries Focus. Vol 17, Issue 5. July 2008.
[14] "Addendum II to the Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32b of the ASMFC. May 2001. <http://www.asmfc.org/>.
[15] "Addendum III to the Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32c of the ASMFC. May 2004. <http://www.asmfc.org/>.
[16] "Addendum IV to the Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32d of the ASMFC. June 2006. <http://www.asmfc.org/>.
[17] "Addendum V to the Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32e of the ASMFC. September 2008. <http://www.asmfc.org/>.

Authorized companies harvest this blood by capturing adult (mainly female) horseshoe crabs, collecting one-third of their blood, and releasing them back into the wild.[18] The market for LAL is approximately $50 million per year at this time. The Massachusetts company responsible for the bleeding of horseshoe crabs around Cape Cod is Associates of Cape Cod, Inc. (ACC). Based out of Falmouth, Massachusetts, ACC is a global supplier of LAL and received the first license by the Food and Drug Administration for this purpose.[19]

An estimated 10-15% of the 500,000 crabs bled along the Atlantic coast do not survive this bleeding process and the long-term effects of bleeding are still unknown to scientists.[20] However, one study suggests that bleeding may affect movement patterns of horseshoe crabs.[21] Kurz and James-Pirri (2002) tracked a total of seventeen horseshoe crabs for 26 days using acoustic telemetry in a small estuary on Cape Cod. During this time, they observed 20% mortality among the eight bled horseshoe crabs and no mortality for the nine control horseshoe crabs. Furthermore, this study recorded random directions of movement among the bled horseshoe crabs, suggesting that bleeding may cause disorientation.[22]

Part 3. Biology

The species interaction between horseshoe crabs and shorebirds attracts organizations such as the National Audubon Society into horseshoe crab conservation. In fact, the Audubon Society first drew attention to changes in horseshoe crab populations around the Delaware Bay because they occurred at the same time as a noticeable decrease in shorebirds. Eleven species,

[18] Associates of Cape Cod, Inc. Nov. 2008. <http://www.acciusa.com/index.html>.
[19] Associates of Cape Cod, Inc. Nov. 2008. < http://www.acciusa.com/index.html>.
[20] "Species Profile." ASMFC Fisheries Focus. Vol 17, Issue 5. July 2008.
[21] Kurz, W. and M.J. James-Pirri. 2002. The impact of biomedical bleeding on horseshoe crab, *Limulus polyphemus*, movement patterns on Cape Cod, Massachusetts. Marine and Freshwater Behaviour Physioogy 35: 261-268.
[22] Kurz, W. and M.J. James-Pirri. 2002. The impact of biomedical bleeding on horseshoe crab, *Limulus polyphemus*, movement patterns on Cape Cod, Massachusetts. Marine and Freshwater Behaviour Physioogy 35: 261-268.

such as the more familiar red knot and the dowitcher, rely on horseshoe crab eggs for sustenance during their migration along the Atlantic Flyway. The Delaware Bay is a popular staging area, hosting over a million shorebirds for a three week stopover along the Atlantic Flyway and making the site a focal point for the Audubon Society. The Delaware Bay is also the chief spawning site for horseshoe crabs. This connection spurred the Audubon Society to play a large role in encouraging the ASMFC to create the aforementioned FMP for horseshoe crabs.[23] The Massachusetts Audubon Society, the largest conservation organization in New England, now participates in annual spawning surveys of horseshoe crabs around Cape Cod and even hosted a Horseshoe Crab Conference to raise awareness.[24]

Biologists from an assortment of groups (National Park Service, universities, National Wildlife Refuge System, and state agencies) are interested in the horseshoe crab population as well. These scientists work at state and national levels to better understand juvenile behavior, migration patterns, historical evolution, physical anatomy, development rates, and spawning success of these living fossils. They initiate research projects and make recommendations to relevant local, state, and interstate groups for the continued conservation of horseshoe crabs.

Part 4. Shoreline Change

Shoreline stabilization projects include the construction of hard shoreline structures as well as the addition of sediment to fill eroding beaches. Hard shoreline structures include bulkheads, groins, breakwaters, and jetties and are used for beach stabilization and erosion control. However, these structures can also result in destruction of beaches and erosion in adjacent areas. These structures change the longshore transport of sediment along a beach,

[23] "Interstate Fisheries Management." Atlantic States Marine Fisheries Commission. Nov. 2008. <http://www.asmfc.org/>.
[24] Nature Connection. Mass Audubon. < http://www.massaudubon.org/index.php>.

potentially altering entire shorelines.[25] The state of Massachusetts also uses beach fill, or beach nourishment, as a viable way to stabilize shorelines.

The types and magnitude of shoreline stabilization and beach nourishment projects in Massachusetts have a wide range, but the following legal mandates are relevant to most. All state shoreline projects require authorization pursuant to the Massachusetts Wetlands Protection Act and Regulations. Certification is administered by the municipal conservation commissions which are responsible for enforcing state regulations, but appeals and intervening power are under the Massachusetts Department of Environmental Protection (DEP). Shoreline projects in tidelands are also subject to the Massachusetts Public Waterfront Act and Waterways Regulations (Chapter 91).[26] A Chapter 91 license or permit is administered by DEP and is in place for the protection and promotion of public use of tidelands (Waterways, 2008). Known as the "home rule," Massachusetts towns may adopt more stringent requirements than those enforced by the Commonwealth. These fall under the Massachusetts Association of Conservation Commissions (MACC) and differ from town to town.[27]

Larger shoreline projects involving any state agency action are subject to the Massachusetts Environmental Policy Act (MEPA) which requires state agencies to explore the environmental effects of their actions and limit environmental damage. The MEPA review is not a permitting process, but rather provides an Environmental Impact Report (EIR) to ensure that permitting agencies realize the possible consequences of their decisions.[28] Projects involving dredging or filling in waters or wetlands which require a federal permit are subject to the

[25] Pilkey, O.H. and K. Dixon. 1996. The Corps and the Shore. Island Press, Washington, D.C.
[26] Public Waterfront Act. Massachusetts Office of Coastal Zone Management. Dec. 2008 <http://www.mass.gov/czm/permitguide/regs/chapter91.htm>.
[27] Stephen McKenna. CZM Cape Cod & Islands Regional Coordinator. Massachusetts Office of Coastal Zone Management. Personal communication. Nov. 2008.
[28] About MEPA-The Massachusetts Environmental Policy Act. The Official Website of the Commonwealth of Massachusetts. <http://www.mass.gov/envir/mepa/secondlevelpages/aboutmepa.htm>.

Massachusetts 401 Water Quality Certification for Dredging which ensures compliance with the Massachusetts Wetlands Protection Act, also administered by the DEP.[29] Those projects that require federal permits, issued by the Corps of Engineers-New England Division, must also abide by the Rivers and Harbors Act, Section 404 of the Federal Clean Water Act.[30]

The Massachusetts Department of Environmental Protection (DEP) is the state agency responsible for overseeing the compliance of state regulations.[31] As mentioned before, DEP and municipal conservation commissions, local environmental agencies, are both involved in relevant shoreline projects and invested in enforcing current environmental guidelines. The Commonwealth created the Conservation Commissions in the 1950s to protect natural resources at a local level. Every city and town of the Commonwealth now has a Conservation Commission and their authority comes from the Conservation Commission Act, the Wetlands Protection Act, and the 'home rule' provisions in regards to wetlands bylaws.[32]

The Massachusetts Division of Marine Fisheries (MDMF) is informed of proposed beach nourishment projects and provides local and state regulatory authorities with recommendations on how to proceed. Environmental reviewers at MDMF consult with biologists to come up with recommendations that best protect the coastal habitat and the species associated. For projects such as beach nourishment, recommendations often consist of time restrictions. Suggesting a no dumping time-of-year (TOY) helps to protect horseshoe crab spawning from May through July. Recommendations regarding other species include a "no dredging" TOY to protect winter

[29] 401 Water Quality Certification for Dredging. Massachusetts Office of Coastal Zone Management. <http://www.mass.gov/czm/permitguide/regs/dredging.htm>.
[30] Stephen McKenna. CZM Cape Cod & Islands Regional Coordinator. Massachusetts Office of Coastal Zone Management. Personal communication. Nov. 2008.
[31] State Government. The Official Website of the Commonwealth of Massachusetts. Dec. 2008. <http://www.mass.gov/?pageID=mg2topic&L=3&L0=Home&L1=State+Government&L2=Branches+%26+Departments&sid=massgov2>.
[32] "About Conservation Commissions." Massachusetts Association of Conservation Commissions. Dec. 2008. <http://maccweb.org/about_commissions.html>.

founder spawning in offshore waters. The Commonwealth encourages the Conservation Commissions and DEP to take such recommendations into consideration during the permitting process. However, the MDMF is not a regulatory authority itself and cannot demand that recommendations be addressed.[33]

Beach Nourishment on the Cape

Personal communication with, and data from, the Department of Environmental Protection provided a picture of recent shoreline stabilization and beach nourishment projects on Cape Cod. Over the past five years, the DEP permitted only a few hard shoreline stabilization structures. Seawall permits authorized during this time were all for rebuilds of already existing structures. More focus may be placed on the beach nourishment projects that were completed during the same time. Between 2003 and 2009, over forty beach nourishment projects took place on Cape Cod. These projects span eleven different towns and total more than 190,000 cubic yards of sediment—equivalent to the volume that 200,000 washing machines might fill. The highest number of projects occurred in the towns of Barnstable, Falmouth, and Mashpee while the highest displacement of sediment was in Barnstable, Dennis, and Falmouth. Of the forty-three projects permitted, five took place within water bodies surveyed for known horseshoe crab spawning populations, at the dissuasion of biologists and environmental reviewers.[34]

Beach nourishment projects can negatively impact horseshoe crab populations, particularly if the addition of sediment takes place during the spawning or hatching season. The addition of sediment affects oxygen availability for the horseshoe crab eggs and larvae,

[33] Environmental Notification Form Certificate. The Commonwealth of Massachusetts, Executive Office of Environmental Affairs. August 25, 2006.
[34] Hill, David. Department of Environmental Protection, Bureau of Resource Protection. Personal communication. March 2009.

potentially changing development rates or trapping the larvae.[35] Furthermore, horseshoe crab eggs and larvae could be depleted as a main food source for migrating bird populations.[36] Beach nourishment can also cause a change in sediment size and/or beach slope. The type of sediment is important to horseshoe crabs because their eggs are buried in sand on beaches specifically chosen by females. The grain size, amount of oxygen, and level of inundation all affect the survival of those eggs. Also, studies show that a similar degree of beach slope is found on all horseshoe crab spawning beaches. This suggests that females specifically choose those sites with a low slope. Without care to how sediment is deposited, beach nourishment projects can alter the slope of the beach, thus altering necessary spawning habitat. Finally, the time of year for beach nourishment projects can have a large impact. Horseshoe crabs begin their spawning season around the same time that tourists are beginning to vacation on Cape Cod. As horseshoe crabs are preparing to come onshore, towns are looking to improve their waterfront properties with such activities as beach nourishment. This is often the time of year when beach nourishment projects are proposed.[37] In fact, according to the Division of Marine Fisheries, some projects have taken place directly on top of spawning horseshoe crabs—buckets of sand poured over them or bulldozers driven across them. In addition, the offshore dredging process that takes place in conjunction with beach nourishment may cause its own problems.

[35] Eagle, G.A. 1983. The chemistry of sandy beach ecosystems: a review. *In* A. McLachlan and B. Erasmus (ed.), Sandy Beaches as Ecosystems, 203-224.
[36] Castro, G. and J.P. Myers. 1993. Shorebird predation on eggs of horseshoe crabs during spring stopover on Delaware Bay. The Auk 110: 927-930.
[37] Hill, David. Department of Environmental Protection, Bureau of Resource Protection. Personal communication. March 2009.

Spawning around the Cape

Monitoring of horseshoe crab spawning beaches occurred as recently as July of 2009. Since this is a state-wide effort, surveys are completed in a number of regions throughout the Cape and are administered by different organizations. These surveys are an important component to horseshoe crab conservation and evaluation of the population because they notify stakeholders of changes or patterns in spawning behavior, sex ratios, age structure, and spawning densities. The most recently published Technical Report on population demographics and spawning densities was submitted to Cape Cod National Seashore for just those purposes. Spawning densities within Cape Cod National Seashore, Cape Cod Bay, and Monomoy National Wildlife Refuge were quantified by using quadrat sampling on known spawning beaches from May through July. The results showed that spawning densities vary throughout the Cape, but the greatest amount of activity occurs from mid-May to mid-June.[38] This type of data can be used to inform organizations such as the MDMF so that their recommendations to DEP are accurate and supported by field research. The 'hotspot' spawning sites were found to be in Pleasant Bay and Monomoy NWR; beaches around these water bodies showed the highest number of horseshoe crabs during the study. Beaches of higher spawning densities were also associated with lower slope profiles[39], a noteworthy attribute when considering the affects of shoreline stabilization projects. Different age structures, sizes, and sex ratios were observed throughout the study sites.

The most significant finding may be that different age structures and sex ratio distributions were observed on different regions of the Cape. While movement patterns of

[38] James-Pirri, Mary-Jane. 2002. Population Demographics and Spawning Densities of the Horseshoe Crab, *Limulus polyphemus*, within Cape Cod National Seashore, Cape Cod Bay, and Monomoy National Wildlife Refuge, Massachusetts. Technical Report, Department of the Interior, National Park Service: Boston Support Office.
[39] James-Pirri, Mary-Jane. 2002. Population Demographics and Spawning Densities of the Horseshoe Crab, *Limulus polyphemus*, within Cape Cod National Seashore, Cape Cod Bay, and Monomoy National Wildlife Refuge, Massachusetts. Technical Report, Department of the Interior, National Park Service: Boston Support Office.

horseshoe crabs have not been well studied in this area, it may be that spawning populations in one waterbody supply recruits to another.[40] In other words, the population around Monomoy NWR may depend on the movement of juveniles from Pleasant Bay. Movement between Pleasant Bay and Monomoy NWR, a distance of approximately 15 km, was observed during the study.[41] Without knowing more about seasonal movement patterns and behavior, spawning beaches should be thought of as an inter-connected system. Therefore, changing the shoreline characteristics or dynamics of one beach may in fact impact spawning populations on other beaches. Comparing the beach nourishment projects to Cape Cod National Seashore's Technical Report shows that at least four beach nourishment projects took place adjacent to or within water bodies with known horseshoe crab spawning populations.

Policy Alternatives

The issues related to horseshoe crab conservation cannot be approached independently. Impacts of one act may very well be linked to the impacts of another act. While one act (i.e. beach nourishment) may have the most direct impact, it is likely the combination of multiple impacts that causes the most long-term damage to the horseshoe crab population. Therefore, policy alternatives should not focus merely on one potential threat, but on three (direct harvest, bleeding, and habitat loss).

All horseshoe crab conservation policy is centered on the Delaware Bay where the majority of crabs spawn each spring. This hot spot is what moved the Audubon Society into

[40] James-Pirri, Mary-Jane. 2002. Population Demographics and Spawning Densities of the Horseshoe Crab, *Limulus polyphemus*, within Cape Cod National Seashore, Cape Cod Bay, and Monomoy National Wildlife Refuge, Massachusetts. Technical Report, Department of the Interior, National Park Service: Boston Support Office.
[41] James-Pirri, Mary-Jane. 2002. Population Demographics and Spawning Densities of the Horseshoe Crab, *Limulus polyphemus*, within Cape Cod National Seashore, Cape Cod Bay, and Monomoy National Wildlife Refuge, Massachusetts. Technical Report, Department of the Interior, National Park Service: Boston Support Office.

action and gave the ASMFC reason to create an interstate FMP for horseshoe crabs. As expected, most of the Addendums to this FMP specifically refer to states adjacent to the Delaware Bay. However, Massachusetts repeatedly has the fifth highest reported horseshoe crab bait landings of all Atlantic coast states.[42] While no new regulations or policies are under consideration at this time, the following three policy alternatives could be further explored: coast-wide season closures, restricted spawning beach areas, and removal of the fishing industry.

Spawning season closures exist for states adjacent to the Delaware Bay while other states, Massachusetts included, have closed harvest days. An alternative to this state-by-state closure status is to create a spawning season closure from the beginning of May to the end of June for all Atlantic coast states. This would prohibit all commercial fisheries harvest of horseshoe crabs from state waters during a two-month span. Harvest for biomedical purposes could be included, creating a complete ban on any takes of horseshoe crabs in state waters. Furthermore, these closures could be extended to all shoreline stabilization projects. In that case, "no-dumping" and "no-dredging" TOY restrictions would be mandates rather than recommendations posed by MDMF. These restrictions would ensure that spawning season continued without direct interruption. This policy would be mandated under ASMFC's horseshoe crab FMP and put into action by each state's marine fisheries management agency. Therefore, the Commonwealth of Massachusetts would participate under the regulations and enforcement of MDMF. Enforcement efforts could be strengthened during this time to ensure compliance along the coast.

An alternative, or addition, to current shoreline projects is the identification and restriction of horseshoe crab spawning beaches. In Massachusetts, this would require the cooperation of MDMF, municipal conservation commissions, and DEP. Researchers are already

[42] "Addendum IV to the Interstate Fishery Management Plan for Horseshoe Crab." Fishery Management Report No. 32d of the ASMFC. June 2006. <http://www.asmfc.org/>.

working to identify horseshoe crab spawning beaches around Cape Cod.[43] This effort could be facilitated by requiring each conservation commission to identify spawning areas within their jurisdiction. Beaches with known spawning aggregations would then put up educational signs. Furthermore, these beaches would receive further restrictions on beach nourishment and the construction of shoreline structures. Certain hot spot areas would be deemed 'top priority conservation sites' and prohibit filling, dredging, or the construction of any hardened shoreline structures. This would have the biggest impact on beaches deemed 'top priority' which already have ongoing projects (i.e. beach nourishment).

Lastly, an alternative to the restrictions on horseshoe crab harvest for commercial fisheries is the elimination of all bait harvest. Economically speaking, the horseshoe crab is most valuable to the biomedical industry and its $50 million per year market.[44] Not only does the processed blood of crabs yield the most money, but the use of blood for the prevention of contamination in the medical field serves a global purpose and one vital to human health. Therefore, the ASMFC could decide to give highest priority to the biomedical industry and eliminate commercial fishing. This action would eliminate direct harvest, but allow for a greater incidental mortality rate due to bleeding. Furthermore, the immediate need to fully understand the effects of bleeding would be lessened. The greatest impact in this scenario would be felt by the commercial fishermen, specifically those in the conch and eel fisheries. However, alternative bait and an incentive for new gear types could alleviate this impact.

[43] "*MarineFisheries* Seeks Public Assistance to Identify Horseshoe Crab Spawning Beaches." *MarineFisheries* Advisory. Division of Marine Fisheries. April 28, 2008.
[44] "Species Profile." ASMFC Fisheries Focus. Vol 17, Issue 5. July 2008.

Recommendations

I think the most effective and justified action to take at this time is the coast-wide season closure for all direct harvest, bleeding, and shoreline stabilization projects. Horseshoe crabs are easy to harvest because they come into such shallow water, are fairly large, and slow moving. These traits are exploited during spawning season because hundreds or thousands of horseshoe crabs congregate along beaches. By prohibiting the take of crabs during this time, mature females are given the chance to lay their eggs, ensuring the continued existence of the horseshoe crab population. The biomedical industry should be included in this ban because they target large females and the long-term effects of bleeding are still not fully known. Since the peak season is only two months long, compliance with this closure should be achievable for the fisheries and the biomedical industry. With enforcement infrastructures already in place, efforts can be increased for the peak spawning season. The above recommendation needs to be done in conjunction with strictly enforced shoreline stabilization projects. Currently, it is unclear whether all recent shoreline projects around Cape Cod have abided by the mandated permitting process. Such investigations should be continued and beach nourishment projects should be banned during spawning months from known horseshoe crab spawning beaches to ensure their continued use of desirable shorelines.

Conclusion

Horseshoe crabs are an important component of estuarine ecosystems as well as coastal economies around Cape Cod. Their eggs supply fish, crabs, and migrating birds with necessary protein, their meat ensures that fishermen can continue to harvest conch and eel, and their blood enables the medical field to test for bacteria. While the uses for horseshoe crabs are well known,

the sustainability of those uses is not. To ensure the continued existence of these populations, all potential threats must be quantified and assessed as interconnected activities. Beach nourishment projects are frequent along Cape Cod and their continuation is deemed necessary by many to keep up with eroding beaches. However, the effects of sediment displacement and shoreline change to horseshoe crabs are not negligible. Horseshoe crabs require specific beach habitats to spawn successfully and maintain (or increase) their population numbers. More research needs to be conducted to realize the long-term effects of shoreline stabilization and beach nourishment projects and the Massachusetts Division of Marine Fisheries should play a more direct role in deciding when and where these projects take place. Furthermore, the movement patterns of horseshoe crabs should be better understood so that the affect of beach nourishment projects on the Cape Cod horseshoe crab population as a whole can be quantified. The science must be properly applied to the policy to ensure the conservation of this Massachusetts horseshoe crab population.

Beach Nourishment Projects from 2003-2008					
Permit #	**Applicant**	**Town**	**Waterbody**	**Description**	**Size (cy)**
9726	Town of Chatham	Chatham	Stage Harbor	dredge / beach nourish	95
9821	Town of Falmouth	Falmouth	Fresh River	dredge / beach nourish	200
9822	Town of Falmouth	Falmouth	Salt Pond	dredge / beach nourish	200
9823	Town of Falmouth	Falmouth	Little Pond	dredge / beach nourish	200
10038	Eastham / Orleans	Eastham / Orleans	Skaket Beach	dredge / beach nourish	20,000
9962	Colby/McCaffrey	Dennis	Bass River	pier / beach nourish	n/a
10153	Belkin	Mashpee	Nantucket Sound	revetment / beach nourish	300
10244	Town of Barnstable	Barnstable	Barnstable Harbor	dredge / beach nourish	20,000
10123	Seacoast Shores	Falmouth	Eel Pond	beach nourish	1095
10245	Town of Orleans	Orleans	Skaket Beach	dredge / beach nourish	2,000
10188	Waquoit Bay YC	Falmouth	Waquoit Bay	beach nourish	118
10355	Niremberg	Mashpee	Nantucket Sound	revetment / beach nourish	300
10308	Town of Barnstable	Barnstable	Centerville River	dredge / beach nourish	22,000
10309	Town of Dennis	Dennis	Sesuit Harbor	nearshore disposal	30,000
10842	Town of Harwich	Harwich	Round Cove	dredge / beach nourish	3400
11304	Hoffman	Mashpee	Nantucket Sound	beach nourish	300
11303	Bovarnick	Mashpee	Nantucket Sound	beach nourish	300
10520	Town of Wellfleet	Wellfleet	Wellfleet Harbor	dredge / beach nourish	300
10511	Town of Truro	Truro	Pamet Harbor	dredge / beach nourish	30,000
11399	Wilkens	Barnstable	Dead Neck Beach	dredge / beach nourish	508
11494	Maushop Village	Mashpee	Nantucket Sound	beach nourish	4,000
11639	Town of Harwich	Harwich	Round Cove	beach nourish	n/a
11838	Town of Falmouth	Falmouth	Nantucket Sound	dredge / beach nourish	7,500
11745	Triton Sound	Mashpee	Nantucket Sound	revetment / beach nourish	40
11970	Great Island Home	Yarmouth	Lewis Bay	dredge / beach nourish	4,000
11962	Town of Barnstable	Barnstable	Barnstable Harbor	dredge / beach nourish	n/a
11944	Town of Bourne	Bourne	Monument Beach	dredge / beach nourish	2,500
11943	Mills	Barnstable	Dead Neck Beach	dredge / beach nourish	96
11924	CMC Great Cove NT	Barnstable	Great Cove	dredge / beach nourish	1,445
11611	Save Popponesset	Mashpee	Popponesset Beach	dredge / beach nourish	2,500
11885	3 Bays Preservation	Barnstable	Dead Neck Beach	dredge / beach nourish	820
12153	Pine Acres Beach Assoc	Dennis	Nantucket Sound	beach nourish	3,350
10297	New Seabury	Mashpee	Nantucket Sound	beach nourish	1,500
10296	Town of Yarmouth	Yarmouth	Lewis Bay	dredge / beach nourish	3,500
10291	Salt Box Assoc.	Yarmouth	Bass River	beach nourish	150
12084	Kindler	Chatham	Chatham Harbor	beach nourish	6,000
12278	Goodrich Chatham RT	Chatham	Pleasant Bay	beach nourish	n/a
12278	Town of Chatham	Chatham	Ryders Cove	dredge / beach nourish	100
12246	Town of Falmouth	Falmouth	Menauhant Beach	beach nourish	20,000
11912	Town of Mashpee	Mashpee	Nantucket Sound	dredge / beach nourish	3,000
12108	Town of Mashpee	Mashpee	Popponesset Beach	dredge / beach nourish	18,000
12108	Town of Falmouth	Falmouth	Nantucket Sound	dredge / beach nourish	2,000
12097	Yasmine	Barnstable	Dead Neck Beach	dredge / beach nourish	690

Table 1. This table lists all beach nourishment projects on Cape Cod, MA between 2003-2009.[45]

[45] Hill, David. Department of Environmental Protection, Bureau of Resource Protection. Personal communication.