Bait, Birds and Biomedical: A Glimpse into the World of Horseshoe Crabs

Species Snapshot

Horseshoe Crab
Limulus polyphemus

Taxonomy:
- Horseshoe crabs are in the taxonomic class Merostomata, which means "legs attached to mouth"
- Their scientific name "polyphemus" alludes to a one-eyed giant in Greek mythology, due to the fact that people thought they only had one eye (they actually have ten).

Interesting Facts
- Horseshoe crabs have existed for nearly 450 million years, predating flying insects, dinosaurs and humans.
- There are 4 living species of horseshoe crabs: one inhabits the Eastern and Gulf coasts of North America, while the other three are found in Southeast Asia.
- Horseshoe crabs are more closely related to spiders, ticks and scorpions than they are to true crabs. Like other arthropods, they have a hard shell, or exoskeleton, a segmented body and jointed legs.
- Horseshoe crabs use their tails primarily to flip themselves upright if they are overturned.
- They feed by crushing up food, such as mollusks and worms, between their legs before passing the food to their mouths.

Stock Status:
Unknown

Introduction

Horseshoe crabs provide the backdrop for one of the most interesting marine resource management issues along the Atlantic coast. An ecologically important species, horseshoe crab eggs are a primary food source for red knots, a shorebird that is near threatened under the Endangered Species Act (ESA), as they pass through the Delaware Bay on their long migration from South America to the Arctic. Also economically important, horseshoe crabs provide bait for commercial American eel and conch fisheries along the coast. Their bright blue blood is also used by the biomedical industry to produce Limulus Amoebocyte Lysate (LAL), an important tool for detecting contaminants in medical devices and drugs. The challenge for fisheries managers is to ensure that horseshoe crabs are managed to meet all these diverse needs, while conserving the resource for future generations.

Life History

Horseshoe crabs are a marine arthropod found along the Atlantic coast from northern Maine to the Yucatan Peninsula and the Gulf of Mexico. Adults either remain in estuaries or migrate to the continental shelf during the winter months. Migrations resume in the spring when the horseshoe crabs move to beach areas to spawn. Juveniles hatch from the beach environment and spend their first two years in nearshore areas before moving further offshore.

Spawning usually coincides with the high tide during the full and new moon. Breeding activity is consistently higher during a full moon and is also greater during the night. Adults prefer sandy beach areas within bays and coves that are protected from surf. Eggs are laid in clusters or nest sites of about 4,000 eggs each along the beach with females laying approximately 90,000 eggs per year in different egg clusters (although only about ten eggs per breeding female will reach adulthood).

The eggs play an important ecological role in the food web for migrating shorebirds. The Delaware Bay Estuary is the largest staging area for shorebirds in the Atlantic Flyway. Up to one million migratory shorebirds converge on the Delaware Bay each year to feed and rebuild energy reserves prior to completing their northward migration, including approximately 90% of the ESA-listed red knot population (about 24,000 birds). It is estimated that red knots need to double their mass (by consuming a diet of mostly horseshoe crab eggs) before they have sufficient fuel to complete the journey north to the Arctic.

Commercial Fisheries & Biomedical Harvest

From the 1850s to the 1920s, between 1.5 and two million horseshoe crabs were harvested annually for fertilizer and livestock feed. Harvest dropped throughout the 1950s and ceased in the 1960s. Between 1970 and 1990, reported commercial harvest ranged from less than 20,000 pounds to greater than two million pounds annually. Since the mid- to late 1990s, commercial harvest has been sold primarily as bait for the American eel and whelk pot fisheries. Increased need for bait in the whelk fishery likely caused an increase in horseshoe crab harvest in the 1990s, with a peak of nearly six million pounds in 1997. Reported coastwide bait landings in 2016 remained well below the coastwide quota at 787,223 crabs.

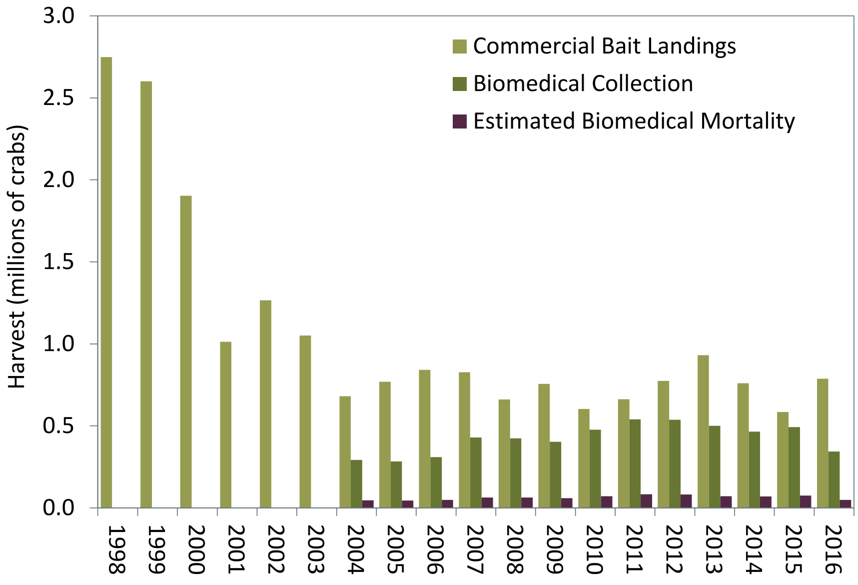
Photo (c) Dr. Rob Robinson, British Trust for Ornithology

Commercial fishermen have adopted new gear such as bait bags and cups allowing them to effectively catch eel and conch while using as little as a tenth of the previous portion of bait per pot. The majority of horseshoe crab harvest comes from the Delaware Bay Region, followed by the New York, New England, and the Southeast regions. Trawls, hand harvests and dredges make up the bulk of commercial horseshoe crab bait landings. Discard mortality occurs in various dredge fisheries and may vary seasonally with temperature, impacting both mature and immature horseshoe crabs; however, the actual rate of discard mortality is unknown.

Horseshoe crabs are also collected by the biomedical industry to support the production of LAL, a clotting agent that aids in the detection of human pathogens in patients, drugs, and intravenous devices. Blood is obtained by collecting adult horseshoe crabs and extracting a portion of their blood. Most crabs collected and bled by the biomedical industry are, as required by the FMP, released alive to the water from which they were collected; however, a portion of these crabs die from the procedure. Crabs harvested for bait are sometimes bled prior to being processed and sold by the bait industry; these crabs are counted against the bait quota. Biomedical use has increased since 2004, when reporting began, but has been fairly stable in recent years with an estimated 426,195 crabs brought to biomedical facilities in 2016. The Horseshoe Crab Management Board continues to collaborate with the biomedical industry to find ways to incorporate biomedical data into a regional stock assessment.

Horseshoe Crab Bait Landings and Biomedical Collection

Source: ASMFC State Compliance Reports, 2017



Please note the following details regarding biomedical collection numbers:
* Biomedical collection numbers, which are annually reported to the Commission, include all horseshoe crabs brought to bleeding facilities except those that were harvested as bait and counted against state quotas.
* Most of the biomedical crabs collected are returned to the water after bleeding; a 15% mortality rate is estimated for all bled crabs.

Timeline of Management Actions: FMP ('98); Addendum I ('00); Addendum II ('01); Addendum III ('04); Addendum IV ('06); Addendum V ('08); Addendum VI ('10); Addendum VII ('12)

Stock Status

The status of the stock is unknown largely due to the lack of long-term data sets for commercial landings and stock abundance. However, the 2013 stock assessment update indicates horseshoe crab abundance has increased in the Southeast (North Carolina through Florida) and remains stable in the Delaware Bay region (New Jersey through coastal Virginia). The New York and New England regions continue to see a decrease in abundance.

Horseshoe crabs are currently undergoing a benchmark stock assessment. The report and peer review are expected to be available in spring 2019.

Atlantic Coastal Management

Horseshoe crabs are managed under the Interstate Fishery Management Plan for Horseshoe Crab (1998) and its subsequent addenda (Addenda I-VII). Under Addendum I (2000), the Commission established state-by-state quotas in all Atlantic states for horseshoe crabs harvested for bait. Addendum II (2001) allows voluntary transfers of harvest quotas between states to alleviate concerns over potential bait shortages on a biologically responsible basis, with Commission approval. Addendum III (2004) reduced harvest quotas, implemented seasonal bait harvest closures, and revised monitoring components. In response to decreasing migratory shorebird populations, Addendum IV (2006) reduced quotas in New Jersey and Delaware and added additional protection in Maryland and Virginia to increase horseshoe crab and egg abundance in and around Delaware Bay. Addenda V and VI extended Addendum IV's measures through 2012.

2013 marked the first year the Horseshoe Crab Management Board used the Adaptive Resource Management (ARM) frame-work to set horseshoe crab harvest levels for the Delaware Bay area. The ARM Framework, established through Addendum VII (2012), incorporates both shorebird and horseshoe crab abundance levels to set optimized harvest levels for horseshoe crabs of Delaware Bay origin.

For the 2016, 2017, and 2018 fishing seasons, harvest in the Delaware Bay area has been limited to 500,000 male horse-shoe crabs and zero female horseshoe crabs. This total harvest is allocated among the four states that harvest horseshoe crabs from the Delaware Bay crab population (New Jersey, Delaware, Maryland, and Virginia). The allocation is based upon multiple decision options, including the proportion of horseshoe crabs harvested that originate from Delaware Bay and the allowance for additional male harvest by Virginia and Maryland to compensate for protecting females when the ARM harvest output includes a moratorium on female crabs. Since 2008, New Jersey has had a moratorium on horseshoe crab harvest despite its allocation of the Delaware Bay origin horseshoe crab quota.

In October 2017, the Board approved terms of reference, including tasks specific to the horseshoe crab stock assessment, such as assessments of regional populations of horseshoe crabs, incorporation and evaluation of estimated mortality attributed to biomedical use of horseshoe crabs for LAL production, and comparisons of assessment results with results from the ARM Framework. This assessment is expected to be presented to the Board in spring 2019. For more information, please contact Mike Schmidtke, Fishery Management Plan Coordinator, at mschmidtke@asmfc.org.

Essential Horseshoe Crab Trawl Survey Receives Needed Boost from Mid-Atlantic Congressmen & NOAA Fisheries

The Mid-Atlantic Horseshoe Crab Trawl Survey, administered by Virginia Tech since 2002, is the only survey designed to sample the horseshoe crab population in coastal waters. Its geographic scope is broad, covering the Atlantic coast from Atlantic City, New Jersey to Wachapreague, Virginia and also the lower Delaware Bay. It provides the data that allow fishery managers and scientists to optimize Delaware Bay harvest levels for the economic, ecological, and biomedical uses of horseshoe crabs.

The survey is the single most important data source to sustainable horseshoe crab management along the Atlantic coast because of its critical role in the horseshoe crab stock assessment and the Adaptive Resource Management (ARM) framework applied in the Delaware Bay region (New Jersey-Virginia). The ARM framework includes modeling that links management of horseshoe crab harvest to multispecies objectives, particularly to demographic recovery of near threatened red knots. The ARM was developed jointly by the Commission, U.S. Fish and Wildlife Service, and U.S. Geological Survey in recognition of the importance of horseshoe crab eggs to migratory shorebirds stopping over in the Delaware Bay region.

Unfortunately, the Trawl Survey was a casualty of federal cost cutting measures in the early 2010s. From 2011 to 2013, the biomedical and commercial fishing industries provided limited funding for increasingly smaller scale surveys and the survey did not occur at all in 2014 and 2015. The quality of fisheries assessments are highly dependent upon a consistent time-series in order to track abundance over time. As such, the 2011 to 2015 data gap is a major setback for horseshoe crab management and those who depend upon it.

By 2015, concern on Capitol Hill spurred action within the Mid-Atlantic delegation and appropriators subsequently restored the funding for the survey to resume in the fall of 2016. In every fiscal year since then, both the U.S. House of Representatives and Senate have used the annual appropriations bill funding NOAA Fisheries to encourage the agency to fund the survey. In turn, NOAA Fisheries has been enthusiastic in providing the needed resources to conduct the survey annually.

The efforts by Congress, NOAA Fisheries, and the states are paying dividends already. The new data collected in 2016, 2017, and 2018 have been essential to the benchmark assessment that is currently underway, allowing the use of more sophisticated models for the Delaware Bay population than any previous horseshoe crab assessment. However, the data shortfalls from 2011 through 2015 continue to challenge the Horseshoe Crab Stock Assessment Subcommittee, in large part because the most recent continuous time series of data (2016-2018) is less than the 10 years needed for horseshoe crabs to mature and reproduce. Continuation of the survey is expected to be the top recommendation of the Horseshoe Crab Technical Committee when the benchmark assessment approved.

Earlier this year, three Senators and six Representatives requested that NOAA Fisheries incorporate the survey into the agency's annual budget. This long-term funding solution would ensure the resources are in place for the survey for years to come. We are deeply grateful for the support of Senators Chris Coons (D-DE), Tom Carper (D-DE), Cory Booker (D-NJ); and Representatives Frank Pallone (D-NJ), Frank LoBiondo (R-NJ), Lisa Blunt-Rochester (D-DE), Donald Norcross (D-NJ), Chris Smith (R-NJ), and Bill Pascrell (D-NJ) for their help in restoring the Trawl Survey and their dedication to the sustainable management of this important resource.

Effects of Biomedical Bleeding on the Behavior and Physiology of Horseshoe Crab

Each year, approximately 550,000 horseshoe crabs (*Limulus polyphemus*) are captured and a portion of their blood withdrawn to make *Limulus* Amebocyte Lysate (LAL). LAL is a substance essential to ensuring the sterility of many medical products implanted or injected into humans each year. During the bleeding process, horseshoe crabs are transported to bleeding facilities, up to 30% of their blood is extracted, and then they are returned to the ocean.

Several published studies, along with other graduate theses and technical reports, have estimated how much mortality occurs during the collection and bleeding process. Methods vary among these studies, as well as among biomedical bleeding facilities; thus, values estimated in the studies are not necessarily reflective of the mortality rate for a given bleeding facility. The Commission's annual review of the fishery currently assumes a 15% mortality rate for all bled crabs, derived as an approximate midpoint of estimates from mortality studies. This rate is being further evaluated through a new benchmark stock assessment, scheduled for completion in 2019. A set of best management practices was developed in 2011 by members of the biomedical industry and has been used since then as a standard to minimize biomedical mortality (http://www.asmfc.org/uploads/file/biomedAdHocWGReport_Oct2011.pdf).

A more recent study funded by New Hampshire Sea Grant and conducted by researchers at the University of New Hampshire (UNH) and Plymouth State University has shown that bled animals also exhibit significant behavioral and physiological changes that may affect their survival and ability to spawn. While specific details of horseshoe crab handling and bleeding procedures are limited and vary among facilities, the animals appear to be exposed in some capacity to three primary stressors that may be responsible for the negative impacts of the bleeding process: warm temperatures and air exposure that occur primarily during transportation to and from the bleeding facilities, and the blood loss itself.

One of the goals of the UNH/Plymouth State research has been to determine the relative impacts of each of the stressors on the physiology and behavior of horseshoe crabs. The researchers collected crabs in the Great Bay Estuary, New Hampshire, exposed them to different combinations of air exposure, heat, and bleeding, and then measured changes in both their activity

X-ray image of two horseshoe crabs showing the difference in the distribution of blood between a bled crab (left) and an unbled crab (right). Photo (c) Seth Doane, Southern Maine Community College; Steve Jury, Saint Joseph's College; and Meghan Owings, UNH

and blood hemocyanin levels. Hemocyanin is an important respiratory pigment, similar to our hemoglobin, with additional immunological and other functions. The study revealed:

1. The full bleeding process has larger negative impacts than blood loss alone.
2. After bleeding, many animals are less active, their hemocyanin levels drop, and such effects last for weeks.
3. Mortality tends to occur in animals that have the lowest hemocyanin levels before they are bled.
4. There are large seasonal changes in hemocyanin levels, with low values in the spring and early summer, and higher values in the late summer and fall.

Thus, the study demonstrated additional sublethal impacts of the bleeding procedure which warranted further investigation of the overall effects on animals in the field.

To examine effects in the field, the research team fitted horseshoe crabs with acoustic tags that transmitted depth and acceleration data and released them back into their natural habitat. Animals that had been exposed to the full bleeding procedure, as well as a control group of crabs not bled, were tagged and released. Importantly, during the first few weeks of the mating season it appeared as if bled animals approached beaches to mate less often than controls, especially females. However, after that time, both groups of horseshoe crabs appeared to display similar daily and tidal rhythms of activity and seasonal migrations.

Study findings support continued implementation of several of the best practices established in 2011. These include practices that keep crabs from overheating and allow them to breathe, such as collecting at night, controlling temperature during transport, minimizing transport time, keeping crabs wet and covered throughout their time out of the ocean, and minimizing overall time out of the ocean. This work also supports the best practice that unhealthy individuals should be returned to the water immediately upon collection and not transported to the facility, as these crabs are more likely to die during the bleeding process. Implementation of these and other best practices is maintained through periodic audits of all stages of the biomedical process.

The researchers also believe that two additional best practices could be considered to further reduce mortality in the collection and bleeding process. First, refrain from collecting animals when they are most compromised in terms of health: before and during their spawning season. Second, provide crabs with a food supplement after being bled, prior to releasing them back into their natural habitat, as other UNH/Plymouth State lab findings indicate a faster recovery to normal levels of hemocyanin, and perhaps amebocytes as well. The recommendations, if adopted, should lead to reduced mortality of bled horseshoe crabs. This, in turn, will support the long-term health and sustainability of the horseshoe crab resource for all who depend on it – from migratory shorebirds and commercial fishermen, to patients who benefit from LAL-based medical products.

The Commission would like to thank the following individuals for their contributions to this article. Readers should contact them for more information on the new horseshoe crab study.

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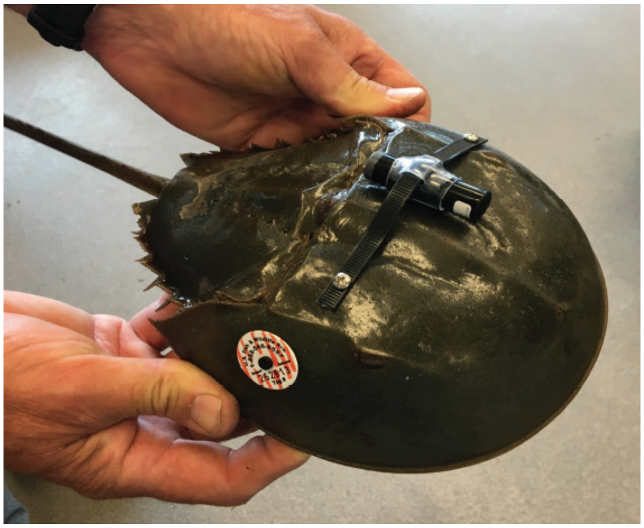

Horseshoe crab fitted with an acoustic transmitter that transmits acceleration and depth data ~ every 3-5 minutes. These transmissions are detected and logged with VR2 receivers that are moored throughout the Great Bay Estuary. As a result, it is possible to keep track of each animals position, activity and depth for almost a year. Photo (c) Seth Doane, Southern Maine Community College; Steve Jury, Saint Joseph's College; and Meghan Owings, UNH