BEFORE THE SECRETARY OF COMMERCE

PETITION TO LIST THE AMERICAN HORSESHOE CRAB (*Limulus polyphemus*) UNDER THE U.S. ENDANGERED SPECIES ACT AS AN ENDANGERED OR THREATENED SPECIES AND TO CONCURRENTLY DESIGNATE CRITICAL HABITAT

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CENTER FOR BIOLOGICAL DIVERSITY

FEBRUARY 12, 2024

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Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. § 1533(b); Section 553(e) of the Administrative Procedure Act, 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14(a), the Center for Biological Diversity (Center, Petitioner) and its partners submit to the Secretary of Commerce and the National Oceanographic and Atmospheric Administration (NOAA) through the NOAA Fisheries a petition to list the American horseshoe crab (*Limulus polyphemus*) as threatened or endangered and to concurrently designate critical habitat.

NOAA Fisheries has jurisdiction over this petition. Section 3(16) of the Endangered Species Act states that "the term 'species' includes any subspecies of fish or wildlife or plants." *Limulus polyphemus* is a species eligible and warranted for protection under the Endangered Species Act.

The Center and its partners are presenting the best available scientific information, which demonstrates that listing the American horseshoe crab as threatened or endangered throughout all or a significant portion of its range may be warranted. The American horseshoe crab is threatened by habitat loss, sea level rise, and climate change across the entirety of its range, and overharvest threatens the American horseshoe crab across a significant portion of its range. Populations have declined across the entirety of the horseshoe crab's range, and their numbers continue to decline or remain at historically low levels across nearly all of their range.

This petition sets in motion a specific process requiring NOAA Fisheries to make an initial finding as to whether the Petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." (16 U.S.C. § 1533(b)(3)(A).) NOAA Fisheries must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." (*Id.*)

The Center for Biological Diversity and its partners also request that critical habitat be designated for the American horseshoe crab concurrently with the subspecies being listed, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12. Critical habitat is essential to protecting the American horseshoe crab from further harm, population decline, and possible extinction. American horseshoe crab critical habitat consists of coastal areas, bays, beaches, estuaries, continental shelf waters, and open marine habitat which are essential to the species' long-term genetic health and survival.

The Center for Biological Diversity is the lead petitioner.

The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats. The Center has more than 1.7 million members and online activists worldwide. The Center and its members seek to conserve imperiled species like the American horseshoe crab through science, policy, and effective implementation of the ESA.

Additional signatories and supporters of the petition include the following organizations:

American Bird Conservancy is a non-profit dedicated to conserving wild birds and their habitats throughout the Americas. With an emphasis on achieving results and working in partnership, American Bird Conservancy takes on the greatest problems facing birds today, innovating and building on rapid advancements in science to halt extinctions, protect habitats, eliminate threats, and build capacity for bird conservation.

The **American Littoral Society** is a membership-based coastal conservation organization which promotes the study and conservation of marine life and habitat, defends the coast from harm, and empowers others to do the same. The Society

maintains its headquarters in Highlands, N.J., with offices in New York City and Millville, N.J. It has been a long time advocate for the conservation, protection and restoration of the horseshoe crabs and red knots which depend upon Delaware Bay. It leads the largest community based horseshoe crab tagging program in the country, and has led, with its strategic partners, efforts to restore horseshoe crab spawning beaches along Delaware Bay.

Coastal Expeditions Foundation connects people with nature in meaningful ways along the South Carolina coast. Coastal Expeditions Foundation explores and protects the flora, fauna, and natural wonders of South Carolina.

Delaware Audubon is dedicated to developing better appreciation of our natural environment and promoting species and habitat conservation in the Delaware Bay and Coastal Zone. Delaware Audubon Society advocates for environmental issues and sponsors public programs and education.

Delaware Ornithological Society is an organization with a 60-year history of dedication to enjoying, protecting, and studying Delaware's bird life through community engagement, citizen science and conservation. Delaware Ornithological Society focuses conservation efforts on purchasing and protecting habitat for spawning horseshoe crabs whose eggs are a vital source of fuel for the migration of the endangered red knot.

Delaware Riverkeeper Network works across the Delaware River watershed on the issues, actions, regulations, legislation, policies, programs, and decisions that impact the health of waterways across the four-state watershed region of Pennsylvania, Delaware, New Jersey, and New York. Delaware River Network protects and restores the Delaware River Watershed for the benefit of all.

Forest Keeper is a coalition of scientists, attorneys, experts, and grassroots organizations protecting national forests and other public lands. Their public, legal, and political campaigns defend forests, protect watersheds, and sustain the long-term economic health of communities. Their network of Forest Keepers spans 18 states in the East, protecting 29 national forests that provide drinking water for 40 percent of Americans.

Healthy Gulf collaborates with and serves communities who love the Gulf of Mexico by providing the research, communications, and coalition-building tools needed to reverse the long pattern of overexploitation of the Gulf's natural resources. Healthy Gulf aims to restore the Gulf of Mexico's health, splendor, and thriving ecosystems—including the people, communities, and cultures that depend on the Gulf's resources.

The Humane Society of the United States fights the big fights to end suffering for all animals. Together with millions of supporters, the Humane Society of the United States takes on puppy mills, factory farms, the fur trade, trophy hunting, animal cosmetics testing and other cruel industries. Through their rescue, response and sanctuary work, as well as other hands-on animal care services, they help thousands of animals every year and fight all forms of animal cruelty to achieve the vision behind their name: a humane society.

The Human Society Legislative Fund works to pass animal protection laws at the state and federal levels, to educate the public about animal protection issues, and to support humane candidates for office. The Humane Society Legislative Fund works to ensure that animals have a voice throughout the halls of Congress and with the thousands of federal and state lawmakers in a position to pass legislation to address the suffering and abuse of animals.

League of Women Voters of New Jersey is a nonpartisan, grassroots organization working to protect and expand voting rights in New Jersey and ensure everyone is represented in our democracy. The League of Women Voters of New Jersey empowers voters and defends democracy through advocacy, education, and litigation, at the local, state, and national levels.

Mobile Baykeeper is a nonprofit working towards to defend and revive the waters of coastal Alabama. They seek real and measurable improvements in the health of coastal waters, including the recovery of oyster beds, seagrasses, and safe, swimmable waters.

New Jersey Audubon is committed to connecting all people with nature and stewarding the nature of today with all people of tomorrow. Founded in 1897, New Jersey is a statewide nonprofit and one of the oldest independent Audubon Societies. New Jersey Audubon maintains stewardship of 34 sanctuaries and conducts programs through seven staffed facilities. New Jersey Audubon also advances knowledge of New Jersey's flora and fauna, and their relationships to the habitat on which they depend, through field research.

One Hundred Miles is a coastal nonprofit working to protect and preserve Georgia's coast through advocacy, education, and citizen engagement. Led by a dedicated staff of twelve and a committed eleven-member Board of Directors, One Hundred Miles works to help residents and visitors better understand the critical issues facing our coast and take action to protect it. Their efforts focus on core issues of water and wetlands, land use, changing climate, and wildlife.

Revive & Restore is the leading wildlife conservation organization promoting the incorporation of biotechnologies into standard conservation practice. Their mission is to enhance biodiversity through the genetic rescue of endangered and extinct species. Biotechnology can be used to enhance genetic diversity, build disease resistance, and facilitate adaptation in species.

The Safina Center fuses scientific understanding, emotional connection, and a moral call to action to protect life on Earth. The Safina Center blends science, art, and literature—in the form of award-winning books, scientific research, photography, and film—to inspire the conservation of wild things and wild places.

Save Coastal Wildlife is a 501(c)(3) non-profit wildlife preservation organization educating the public about the biotic coastal environment along the Jersey Shore, providing educational resources that promote environmental stewardship, conducting citizen-science research, and advancing community based habitat restoration projects. The organization partners with other nonprofits, educational institutions, municipalities, government agencies, small businesses, ethical companies, and individuals.

Shark River Cleanup Coalition helps enhance the water quality of the Shark River Estuary and its freshwater tributaries and improves and protects habitats important to the conservation and abundance of wildlife, ensuring the ecological and economic stability of this important watershed. The coalition consists of community members from Neptune, Neptune City, Belmar, and Wall Township.

Southeastern Massachusetts Pine Barrens Alliance (SEMPBA) is an all–volunteer charitable organization. Their mission is to build a network of federal, state, tribal and municipal agencies, environmental organizations, businesses and individuals to further environmental understanding, conservation and sustainable living within the globally rare Massachusetts Coastal Pine Barrens.

Wild Cumberland is a registered 501(c)(3) nonprofit organization dedicated to protecting the wilderness, native species, and the ecology of Cumberland Island, Georgia. The complex history of Cumberland Island requires public oversight and stewardship; the organization’s purpose is to help educate the public and hold decision-makers accountable.

Thank you for considering this petition. Please contact Will Harlan at 828-230-6818 or email wharlan@biologicaldiversity.org if you have any questions or need any clarification on the information in this petition.

Respectfully submitted February 12, 2024.

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EXECUTIVE SUMMARY

Bromboid

Horseshoe crabs are one of Earth's most ancient creatures. Nearly twice as old as dinosaurs, they have endured five mass extinctions and survived for nearly a half-billion years.[1]

However, in the past three decades, horseshoe crab populations have crashed, and their habitat is rapidly disappearing across a significant portion of their range. Horseshoe crabs are being overharvested for both bait and blood, and their spawning beaches are threatened by development, dredging, erosion, pollution, and sea level rise.

Horseshoe crab harvests by commercial whelk and eel fisheries spiked in the 1990s, which resulted in a massive crash in horseshoe crab populations.

[1]Smith *et al.* 2017. 135.

Horseshoe crabs are also harvested by the biomedical industry for their blood; limulus Amebocyte Lysate (LAL), a clotting agent in horseshoe crab blood, is used to test drugs, patients, and intravenous devices for bacterial endotoxin.[2] Significant increases in horseshoe crab blood harvests have occurred in recent decades. Horseshoe crab blood harvests have doubled since 2017, and 2022 was the largest horseshoe crab blood harvest ever recorded, with numbers approaching 1 million horseshoe crabs.

As a result, horseshoe crab populations and spawning have steeply declined to historic lows. Since the 1990s, the Delaware Bay's horseshoe crab population has fallen by two-thirds, and horseshoe crabs have experienced similar declines across most of their range.[3]

Horseshoe crab spawning has also decreased sharply in the past 25 years. More than 1.2 million horseshoe crabs spawned in the Delaware Bay in 1990.[4] By 2002, horseshoe crab spawning numbers dropped to 333,500—a decrease of 72%. Since 2002, horseshoe crab spawning has remained historically low, even with quotas. In 2020, only 335,211 spawned.[5]

In addition, horseshoe crab egg densities on spawning beaches have declined steeply across a significant portion of their range. Since the 1980s, horseshoe crab egg densities on spawning beaches in the Delaware Bay have dropped from 40,000 per square meter to an average of 5,000 per square meter.[6] Horseshoe crab eggs located in the top 5 centimeters of sand have stagnated "an order of magnitude"[7] lower than densities recorded before crabs were overharvested. Horseshoe crab egg densities have decreased by more than 80% in the past four decades.[8]

In addition, dredging and harbor deepening have increased across the Atlantic and Gulf Coasts and resulted in substantial mortality events for horseshoe crabs and destruction of their habitat.

Sea level rise and extreme weather events fueled by climate change have resulted in the destruction of horseshoe crab's spawning habitat. Shoreline hardening and pollution have further degraded horseshoe crab habitat across most of its range. Habitat loss has reduced the available grounds for spawning horseshoe crabs and their eggs.

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[2]ASMFC 2019 Horseshoe Crab Stock Assessment. 35.
[3]Smith *et al.* 2017. 135.
[4]Delaware Bay Horseshoe Crab Spawning Survey 1990-2023.
[5]I*bid.*
[6]*Ibid.*
[7]*Ibid.*
[8]Hunt 2022. 3.

Despite the declines in horseshoe crab populations and habitat, the commission regulating horseshoe crab harvests, the Atlantic States Marine Fisheries Commission (ASMFC), is proposing significant increases to horseshoe crab harvest quotas for bait, including recommendations to increase total horseshoe crab bait harvest quotas in four Mid-Atlantic states and to resume the harvest of female horseshoe crabs for bait.

Horseshoe crab harvests for blood are also increasing, with little oversight, transparency, or regulation, which further depletes dangerously low horseshoe crab populations.

Especially concerning is the harvest of female horseshoe crabs by the biomedical industry. Because females are larger, they are more valuable to the biomedical industry. Female horseshoe crabs can, in most cases, be harvested at any time for blood harvest, including during spawning. Female and male horseshoe crabs can be harvested by the biomedical industry during mass spawning events each spring, which threatens the species' reproductive success, recruitment, and survival.

The population model informing horseshoe crab harvest quotas is fundamentally flawed, based on inaccurate assumptions, and overlook key scientific information. As a result, the model recommends female horseshoe crab harvests and increasing overall harvests at a time when horseshoe crab populations are dangerously low and not recovering.

The decline of horseshoe crabs has cascading effects across Atlantic coast communities and ecosystems. Endangered sea turtles, fish, and other imperiled species are suffering from the horseshoe crab's decline. Endangered shorebirds such as the red knot depend on the horseshoe crab's eggs to fuel their 19,000-mile migration.[9] Red knot populations have plunged concurrently with the crash in horseshoe crab populations, and in 2014, the U.S. Fish and Wildlife Service listed the red knot under the Endangered Species Act, citing commercial harvests as a " primary causal factor" in their decline.[10]

Habitat loss is also an existential threat to the horseshoe crab. Spawning beaches are being degraded and destroyed by development, pollution, impingement, and sea level rise. Mass horseshoe crab die-offs have been observed along Atlantic shores in the past three years. Horseshoe crab egg densities continue to decline on the beaches

[9]USFWS 2014.
[10]*Ibid*.

where they reproduce. In 2023, NOAA ranked the American horseshoe crab's Overall Vulnerability to Climate Change as Very High.

In Asia, horseshoe crabs are even more depleted, which increases pressure on the remaining American horseshoe crab population. The Asian tri-spine horseshoe crab — *Tachypleus tridentatus* — is a close relative of the American horseshoe crab and faces similar threats. It is nearly extinct due to habitat loss and overharvest. The IUCN has red-listed the tri-spine horseshoe crab as endangered. The American horseshoe crab is following a similar trajectory.

American horseshoe crab populations, spawning, and egg densities are depleted, and threats from habitat loss, overharvest, and climate change are increasing across their range.

In its nearly half-billion years on Earth, horseshoe crabs have survived asteroid impacts, toxic volcanic eruptions, Ice Ages, and five mass extinction events. In recent decades, however, their populations have plummeted and their habitat has been destroyed. Horseshoe crabs urgently need listing and critical habitat designated under the Endangered Species Act.

INTRODUCTION

Gregory Breese/USFWS

The horseshoe crab is one of the oldest living species on Earth, with fossils dating back as far as 450 million years ago. Horseshoe crabs have persisted through the ages and are often referred to as living fossils.[11]

American horseshoe crabs are a keystone species. Horseshoe crab eggs and larvae are a vital supply of nutrients for birds, fish, and reptiles. Each spring, American horseshoe crabs travel from deep Atlantic waters to the shore for their spawning season. Mating horseshoe crabs swarm Atlantic beaches under the full and new moons of May and June. Female horseshoe crabs lay 4,000 eggs at a time, and may lay over 100,000 over the course of several nights.[12]

[11]Smith *et al.* 2017. 135.
[12]USFWS 2004.

Migratory birds time their stopover in Delaware Bay to coincide with the mass spawn of eggs. Horseshoe crab eggs serve as a critical source of fuel for many migratory shorebirds, including the federally listed red knot (*Calidris canutus rufa*).
The endangered red knot migrates 19,000 miles annually from the southern tip of South America to the Arctic and back. As they fly north, most red knots stop on the U.S. Atlantic Coast just as horseshoe crabs emerge from the ocean to spawn on the beach. A superabundance of energy-rich horseshoe crab eggs nourishes red knots—and many other species—increasing their chance of survival. Red knots concentrate in regions such as Delaware Bay and South Carolina where horseshoe crabs are especially abundant. However, red knot populations have plummeted along with the horseshoe crabs'. The U.S. Fish & Wildlife Service listed red knots under the U.S. Endangered Species Act, citing the commercial harvest of horseshoe crabs as a "primary causal factor" in their decline.[13]

American horseshoe crab populations have declined by two-thirds in the past three decades in the Delaware Bay, primarily due to bait and blood harvests.[14] They have declined even further across the rest of their range. Horseshoe crab spawning on Atlantic beaches has declined even further. More than 1.2 million horseshoe crabs spawned in the mid-Atlantic in 1990. In 2020, only 335,211 spawned—a decrease of 72%.[15]

In addition, horseshoe crab egg densities on spawning beaches have declined by more than 80% since the 1980s.[16] Horseshoe crab egg densities on spawning beaches have dropped from 40,000 per square meter to an average of 5,000 per square meter.[17]

Horseshoe crabs are harvested by the biomedical industry. Horseshoe crab blood is uniquely sensitive to bacteria. When horseshoe crab blood comes into contact with a pathogen, it solidifies and forms a clot, preventing it from spreading through the crab's bloodstream. Because their blood reacts this way, the biomedical industry developed a method of extracting blood, separating the clotting agent, and using it to detect toxins in medical equipment. That clotting agent is limulus amebocyte lysate (LAL), and is valued at $15,000 a quart.[18] In 2022, nearly one million crabs were harvested for biomedical bleeding.[19] There are few restrictions on the biomedical harvest of horseshoe crabs and virtually no oversight. Biomedical harvests can occur at any time of year, including during spawning season, and they can include female horseshoe crabs.

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[13]FWS 2014.
[14]HCRC 2023.
[15]Delaware Bay Horseshoe Crab Survey 1990-2022.
[16]Hunt 2022. 3.
[17]*Ibid.*
[18]Madrigal 2014.
[19]ASMFC 2023.

Asian horseshoe crabs have become even more depleted than American horseshoe crabs, increasing demand for remaining American horseshoe crabs by international biomedical industries. The tri-spine horseshoe crab (*Tachypleus tridentatus)* is already listed as Endangered by the IUCN, and two other Asian species are expected to be red-listed as Endangered this year. With Asian horseshoe crabs spiraling toward extinction, harvest pressures for American horseshoe crabs are increasing. American horseshoe crab blood harvests have nearly doubled since 2017.[20]

Horseshoe crabs are also being overharvested for use as bait by commercial whelk and eel fisheries. Horseshoe crab harvests hovered around 100,000 until the mid-1990s, when an explosion in commercial horseshoe crab harvests occurred. Horseshoe crab harvests climbed to 2.5 million in 1998. Horseshoe crab populations along the Atlantic Coast were decimated and have never recovered.[21]

As a result of pressure from scientists and conservationists concerned about the future of the horseshoe crab, the Atlantic States Marine Fisheries Commission (ASMFC) created the Interstate Fishery Management Plan in 1998. Several attempts were made to regulate the harvest, including harvest quotas, yearly stock assessments, and a 2008 moratorium on harvest in New Jersey. In 2012, the ASMFC began using the Adaptive Resource Management (ARM) model to determine their harvest quotas.

Even with harvest quotas, horseshoe crab populations have shown no sign of recovery, and they remain at 1/3 of the population before the overharvest of the 1990s. Horseshoe crab egg densities on spawning beaches also remain at historic lows.[22]

Meanwhile, blood harvests of horseshoe crabs have doubled in the past six years. Nearly 1 million horseshoe crabs were harvested in 2022.[23] There are almost no limits or quotas on blood harvest: both females and males can be harvested for blood, and the harvests in most states can occur at any time of year—including during mass spawning events each spring. Because females are larger with more blood, they are targeted by the biomedical industry. Females are also targeted by the bait industry because their egg masses provide a stronger bait scent.[24]

Despite dangerously low horseshoe crab populations, spawning horseshoe crabs, and egg densities, the Atlantic States Marine Fisheries Commission revised its ARM model

[20]ASMFC 2023.
[21]Horseshoe Crab Recovery Coalition.
[22]Horseshoe Crab Recovery Coalition.
[23]ASMFC 2023.
[24]Fisher 2006.

in 2021 to recommend increased horseshoe crab harvests. The model also recommended harvests of female horseshoe crabs for bait—in addition to continued harvests of female horseshoe crabs for blood.

Habitat loss is also a dire threat to horseshoe crabs across a significant portion of their range. Sea level rise and extreme weather events fueled by climate change have resulted in the destruction of spawning beach habitat. In 2023, NOAA ranked the American horseshoe crab's Overall Vulnerability to Climate Change as Very High. Shoreline hardening through sea walls, jetties, and bulkheads, has further degraded horseshoe crab habitat.. Habitat loss has reduced the available grounds for spawning horseshoe crabs and their eggs. Dredging and harbor deepening have increased across the Atlantic and Gulf Coasts and resulted in substantial mortality events for horseshoe crabs and destruction of their habitat.

Horseshoe crabs are imminently threatened by habitat loss, overexploitation, inadequacy of existing regulatory mechanisms, and other natural and manmade factors, including climate change. These threats occur across a significant portion of their range and are likely to persist and worsen in the foreseeable future.

BIOLOGICAL INFORMATION

Taxonomy

The accepted phylogeny for the American horseshoe crab is as follows:

Kingdom	Phylum	Class	Order	Family	Genus	Species
Animalia	Arthropoda	Merostomata	Xiphosura	Limulidae	Limulus	polyphemus

American horseshoe crabs (*Limulus polyphemus*) belong to the Arthropoda phylum and the Chelicerata subphylum. The species shares a close evolutionary relationship with sea spiders, spiders, scorpions, ticks, and mites.[25]

The species is also known as the Atlantic horseshoe crab and is distinct from *Tachypleus tridentatus*, *Tachypleus gigas*, and *Carcinoscorpius rotundicauda*, which inhabit the coastal waters from India to Japan. The American horseshoe crab is the sole living representative of the genus *Limulus*.

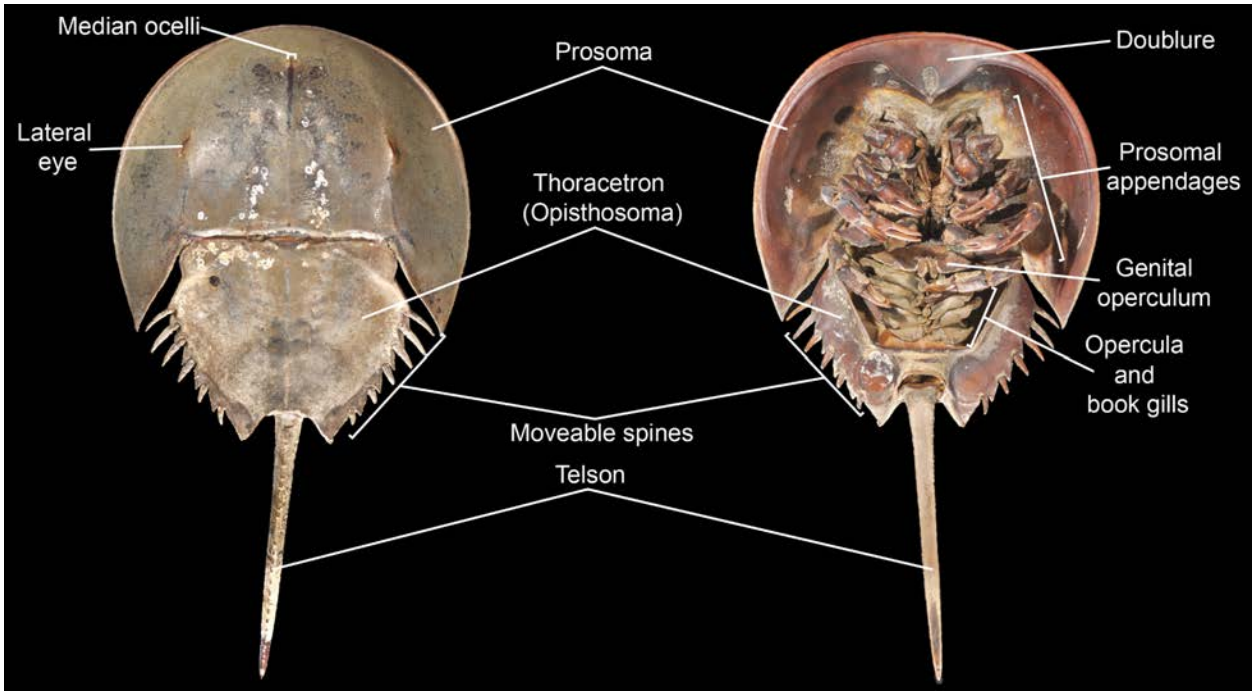
As a lineage, horseshoe crabs are at least 450 million years old.[26] American horseshoe crabs exhibit significant genetic and morphological diversity within the species.[27] A 2015 survey of thirteen DNA markers from samples of horseshoe crabs from thirty-five locations across the species' range found considerable allelic diversity, possibly indicating demographic independence and regional adaptation.[28] The IUCN recognizes six discrete American horseshoe crab metapopulations based on genetics, morphology, behavior, and geographic diversity: Gulf of Maine, Mid-Atlantic, Southeast, Florida Atlantic, Northeast Gulf of Mexico, and Yucatan units. [29]

Appearance

Horseshoe crabs generally exhibit a dull olive green or brown coloration when observed from above, while the underside tends to appear brown.[30] The horseshoe crab exhibits a primitive body structure consisting of three main parts: the prosoma (head),

[25]Barry, Abeels, & Krueger. 2020. 1.
[26]Smith *et al.* 2017. 135.
[27]Smith *et al.* 2017. 139-40.
[28]Smith *et al.* 2017. 140.
[29]Smith *et al.* 2017. 140.
[30]U.S. Fish & Wildlife Service.

opisthosoma (central area), and telson (tail). Its name is derived from the prosoma, which resembles the shape of a horse's shoe. The telson serves the purpose of helping the crab overturn itself in case waves on the beach flip it over.[31]



James Lamsdell

Figure 1. Horseshoe crab anatomy has not exhibited significant phenotypic change in 450 million years.

Atop their bodies, horseshoe crabs possess two compound eyes, resembling those found in many insects. These distinctive eyes house over 1,000 light receptors, enabling horseshoe crabs to perceive hundreds of duplicates of the same image. Eight more eyes are distributed along the sides of their bodies, which aid in gauging factors such as day length and the intensity of visual and ultraviolet light. The collective functionality of these ten eyes equips horseshoe crabs with the ability to see both during the day and at night.[32]

Horseshoe crabs display varied sizes along the Atlantic coast. The largest specimens, particularly along the Georgia coast, can have mature females reaching total lengths of 24 inches (60 cm), including the tail. Widths of females can reach up to 12 inches (30 cm) across the prosoma. Horseshoe crab weights also differ along the Atlantic coast, with the heaviest individuals located on the Georgia coast, where mature females can

[31]U.S. Fish & Wildlife Service.
[32]South Carolina Department of Natural Resources.

grow to approximately 11 pounds (4.8 kg). Typically, males are 25-30% smaller than their female counterparts.[33]

Plant Image Library

Behavior

Horseshoe crabs, often regarded as living fossils, are frequently encountered along the U.S. Atlantic coast. Their presence is particularly noticeable on beaches in late spring when they come ashore for spawning. Spawning aggregations involve thousands of individuals arriving during high tide events. Females are usually found with one male in amplexus, surrounded by several other “satellite” males.[34]

Despite their prehistoric appearance, marked by six sets of appendages and a long tail resembling a stinger, horseshoe crabs are entirely harmless and gentle creatures.[35] The

[33]U.S. Fish & Wildlife Service.
[34]*Ibid.*
[35]*Ibid.*

helmet-shaped carapace of horseshoe crabs serves as a protective covering, and their long tail is employed to correct their position when overturned in the surf. The expansive, domed shell plays a crucial role in safeguarding internal organs and facilitates the crab's ability to swim and burrow into the sand. Notably, the telson, or tail, lacks a stinger but is equipped with photoreceptors that enable the crab to sense light.[36]

The initial set of appendages closest to the horseshoe crab's mouth is called chelicerae and is primarily utilized for feeding. The remaining five pairs of appendages are legs, or pedipalps, all equipped with claws. In mature males, the first legs, resembling boxing gloves with a hook, help grasp the female during spawning. Horseshoe crabs employ their first four clawed legs to elevate themselves from the ground and then utilize their pusher legs to propel forward. When swift movement is necessary, horseshoe crabs can expel water from their book gills beneath the body, propelling themselves away rapidly.[37]

Diet

The diet of juvenile horseshoe crabs is diverse, encompassing particulate organic matter derived from both algal and animal sources. As horseshoe crabs mature, there is a noticeable shift in the composition of their diet towards larger prey.[38] Adult American horseshoe crabs depend on benthic organisms for their diets and generally eat several different species of bivalve mollusks, gastropods, polychaetes, amphipods, worms, insect larvae, and some plant matter.[39] They also consume decaying animal matter.

To obtain its food, the horseshoe crab digs in the sand, grasps its prey with its pincer-tipped legs, crushes its prey between its legs, and finally pushes the crushed organism into its mouth.[40] Horseshoe crabs are capable of crushing the tough shells of mollusks and other invertebrates. Similar to birds, they possess a gizzard containing small particles of gravel and sand, aiding in the grinding process of their food.[41]

[36]South Carolina Department of Natural Resources.
[37]*Ibid.*
[38]U.S. Fish & Wildlife Service.
[39]Banerjee & Mitra 2017. 51.
[40]*Ibid.*
[41]South Carolina Department of Natural Resources.

Life Cycle

Horseshoe crabs can have a lifespan of up to 25 years.[42] In warmer waters, they maintain year-round activity, but in cooler northern regions, horseshoe crabs burrow into the mud, becoming inactive during the winter.

Horseshoe crabs typically attain adulthood between nine to 12 years of age. Similar to other organisms with an exoskeleton, they undergo molting to facilitate growth. Males reach maturity after their sixteenth molt, during which they develop specialized front claws for mating. Females, usually at least 25% larger than males, reach maturity at their seventeenth molt.[43]

In spring, as estuarine water temperature approaches 20°C, adult horseshoe crabs move inshore to find suitable spawning grounds. Horseshoe crabs along the East Coast of the U.S. predominantly engage in spawning activities during May and June. This often occurs at night during a full moon, coinciding with a high tide that facilitates their movement onto the beach for egg-laying. Initially, males migrate to inshore waters, using their modified front legs to attach themselves to arriving females. The attached pair then moves onto the shore, where the female creates a small hole to deposit strands of dark green eggs. While the female lays her eggs, the attached male releases sperm to fertilize them. It is common for unattached males to also contribute to fertilizing external eggs.[44]

Horseshoe crabs typically choose nesting sites between the high and low tide marks on the beach, providing protection for the nests from the impact of harsh wave action. During one beach visit, females lay approximately 4,000 eggs in each of the five to seven nests they dig. Each female returns to the shore multiple times per spawning season and can lay as many as 80,000 to 100,000 eggs.[45]

The eggs, incubated by the sun-warmed sand, hatch within two to four weeks. Hatchlings emerge through the sand during high tide, allowing the waves to carry them out to sea. Despite resembling small adults, they lack a movable tail and functional compound eyes. After 21 days, they settle on the ocean floor, where they remain for the duration of their development. As juveniles, young horseshoe crabs inhabit shallow,

[42] *Ibid.*
[43] South Carolina Department of Natural Resources.
[44] *Ibid.*
[45] *Ibid.*

nearshore waters, primarily feeding within calm tidal flats. They undergo three to four molts each year, with molting occurring less frequently as they approach adulthood.[46]

With reduced molting, horseshoe crabs attract various marine invertebrates that attach to their exoskeletons. horseshoe crabs host a diverse array of creatures, including crustaceans, mollusks, bryozoans, and even a type of planarian on their shells.[47]

Gregory Breese/USFWS

Habitat

Adult horseshoe crabs are benthic creatures that inhabit shallow estuarine areas and offshore habitats near the continental shelf. Their range spans the Atlantic Coast from northern Maine to Florida, the Gulf Coast from Florida to Louisiana, and the Yucatan Peninsula. Horseshoe crabs have also been recorded in Nova Scotia, the Bahamas, Turks and Caicos, and Cuba. Their largest populations are found in Delaware Bay and coastal areas from Virginia to New Jersey.

[46] *Ibid.*
[47] *Ibid.*

Different populations are found in major estuaries along the Atlantic coast, distinguished by the size of adult crabs, the color of their carapace, and eye pigmentation.[48]Adults have been found in waters up to 200 meters, but most are found in water shallower than 20 meters. In cold weather, adults may remain in local embayments or migrate offshore to overwinter on the continental shelf.[49]

High-quality horseshoe crab habitat is characterized by continuous deep sand that offers adequate oxygen levels and minimizes exposure of developing eggs to hydrogen sulfide.[50] The majority of Atlantic and Gulf beaches rest on the shoreward edge of tidal marshes. As the beaches transgress into marsh, mud and peat outcrops appear in and around beaches.[51] American horseshoe crabs appear to avoid areas of mud and peat.[52]

Adult horseshoe crabs favor spawning in sandy beach areas within bays and coves protected from wave energy. Nests are typically situated between the low-tide terrace and the high-tide water line.[53] Spawning has been observed on offshore sandbars and oyster bars. Breeding on the Mississippi coastal islands primarily occurs on the protected north sides of the intertidal sand beach habitat. Sub-tidal nesting also takes place in sands with high oxygen levels, such as the sand flats proximal to beach habitat. Most nesting beaches are associated with nearby nursery habitats for juvenile horseshoe crabs.[54] The variation in geographic nest site selection can be attributed to differences in wave energy, beach morphology, and geochemistry.

Sediment grain size, in particular, can play a role in influencing the choice of spawning sites as environmental conditions such as moisture, temperature, and oxygen gradients can affect development. Females may avoid laying eggs in eroded beaches with hydrogen sulfide levels or where sediment-pore water is oxygen-poor, factors known to affect the development of horseshoe crabs. Egg development is influenced by interstitial environmental parameters such as temperature, moisture, oxygen, and salinity. The American horseshoe crab's embryonic development is significantly reduced by factors like low salinity, low oxygen, high hydrogen sulfide levels, or low temperatures — stressors that can interact synergistically.[55]

In Massachusetts, New Jersey, and Delaware, American horseshoe crabs prefer spawning beaches with coarse-grained and well-drained sand. Individuals spawning in Florida typically prefer fine-grained and poorly-drained substrates. In Long Island

[48]South Carolina Department of Natural Resources.
[49]Smith *et al.* 2017. 145.
[50]Smith, J et al. 2022. 92-94.
[51]*Ibid*.
[52]*Ibid*.
[53]*Ibid.*
[54]*Ibid.*
[55]*Ibid*. 149.

Sound, American horseshoe crabs will nest on beaches characterized by coarse-grained and well-drained to cobble-dominated substrates to fine-grained and poorly-drained muddy substrates.[56]

Two to four weeks after eggs are deposited, larval horseshoe crabs emerge from the nest, spending three weeks in a semi-planktonic stage before transitioning to a benthic existence. American horseshoe crabs settle near beaches where they were spawned and spend their initial two years in intertidal sand flat habitats.[57] Nearshore, shallow water, and intertidal flats adjacent and near breeding beaches are critical for the survival of juvenile horseshoe crabs in their first two years.[58] Following the spawning season, adults return to deeper estuary bays and continental shelf waters.

Wikimedia Commons/Dronepicr

[56]Smith *et al.* 2017. 146.
[57]South Carolina Department of Natural Resources.
[58]Smith *et al.* 2017. 149.

CURRENT AND HISTORICAL DISTRIBUTION

The American horseshoe crab inhabits the Atlantic coastline of North America from the Yucatan Peninsula in Mexico to Maine, but it is absent from the western and southern Gulf of Mexico.[59] Historically, American horseshoe crabs have been located as far north as Lahave Island, southwest of Halifax, Nova Scotia.[60] However, the northern extent of the breeding range is Frenchman Bay, near Mount Desert Island, Maine.[61] Horseshoe crabs are observed in bays, beaches, estuaries, and lagoons, along the Gulf of Maine, New England, Mid-Atlantic, South Atlantic, and Gulf coasts of the U.S.[62] American horseshoe crabs range from shallow coastal habitats such as lagoons and estuaries to depths of more than 660 feet (200 meters) up to 35 miles (60 kilometers) offshore.[63]

Horseshoe crabs exhibit significant genetic diversity, variety, and geographic differentiation.[64] A range of molecular genetic techniques applied across multiple studies has shown significant genetic variation consistent with patterns of previously identified morphological and behavioral variation.[65]

King *et al.* surveyed neutral genetic variation at 13 microsatellite DNA markers of 1,841 horseshoe crabs sampled at 35 spawning locations from northern Maine to the Yucatán Peninsula, México. This extensive intraspecific examination of the nuclear genome (nDNA) has revealed the presence of considerable allelic diversity and differentiation across the species' range.[66] Populations at both ends of the species' range are more differentiated from proximal populations than those in the middle.[67]

The IUCN recommended the following six demographically discrete lineages and metapopulations for the American horseshoe crab, which the IUCN suggested may be considered distinct management and recovery units for future management and planning:

- Gulf of Maine (USA) including embayments from Great Bay estuary in New Hampshire and north into Maine.

[59]Smith *et al.* 2017. 135.
[60]*Ibid.* 137.
[61]*Ibid.*
[62]*Ibid.*
[63]*Ibid.* 150.
[64]*Ibid*. 139.
[65]*Ibid.*
[66]*Ibid.*
[67]*Ibid.*

- Mid-Atlantic (USA) including all embayments south of New Hampshire to and including North Carolina.
- Southeast (USA) including embayments in South Carolina and Georgia, but note that the Georgia population extends into northern Florida.
- Florida Atlantic (USA) including embayments along the Atlantic coast of Florida south of the Georgia population.
- Northeast Gulf of México (USA) including embayments along the Gulf coast of Florida, Alabama, barrier islands of Mississippi, and easternmost barrier island of Louisiana .
- Yucatán Peninsula (México) including embayments on the western, northern, and eastern portions of the peninsula (the Mexican states of Campeche, Yucatán, and Quintana Roo) and Mexican portion of the Caribbean Sea.[68]

The IUCN concluded that these regional groupings of metapopulations may warrant management unit status based on the presence of statistically significant allele frequency heterogeneity, allocation of genetic diversity, and a high percentage of correct classification to region of origin.

The presence of demographically distinct and evolutionarily significant lineages delineated by zones of genetic discontinuity is also consistent with the findings of researchers assessing behavioral and morphological patterns.

[68]Smith *et al.* IUCN Red List Population Genetic Structure. 2022.

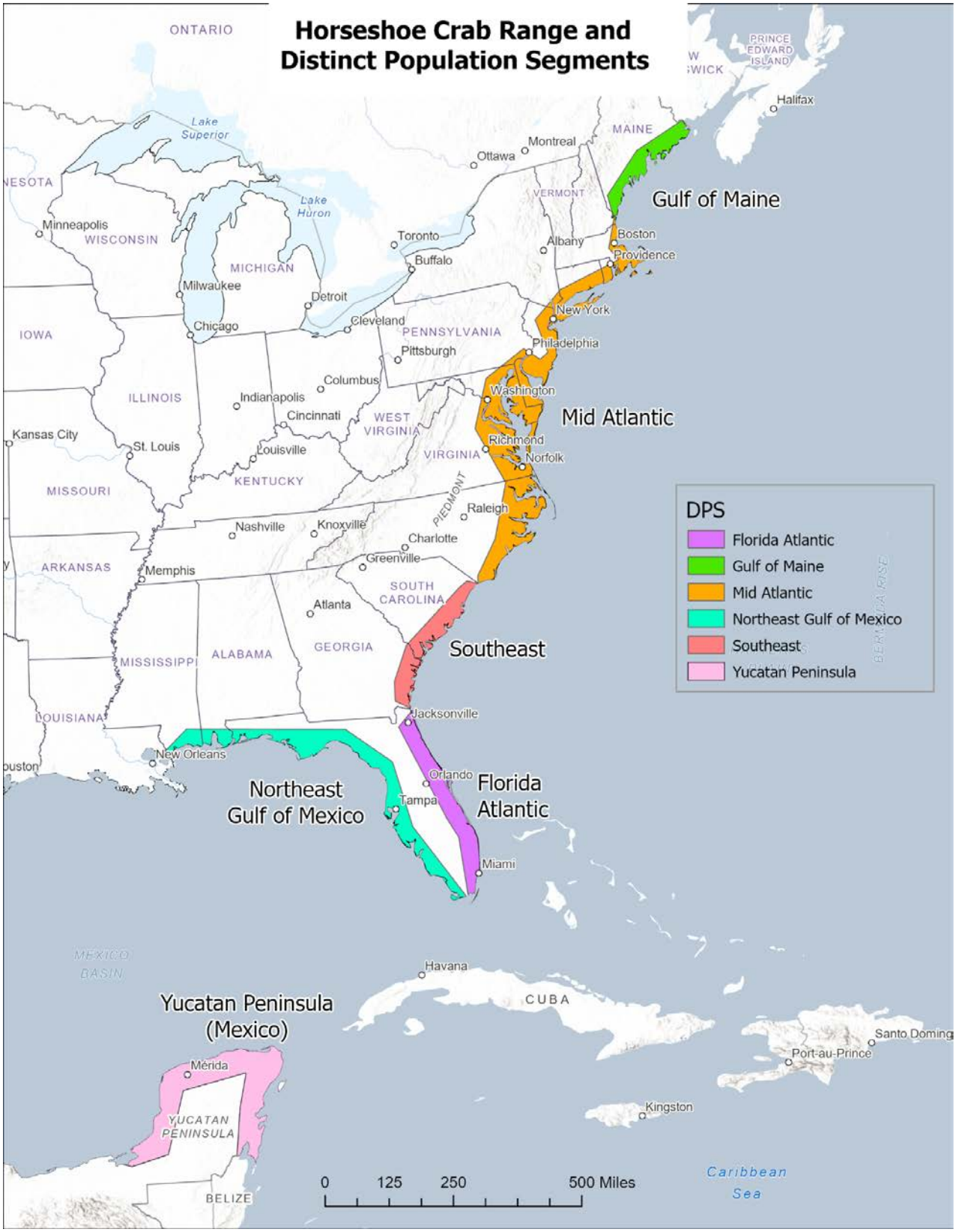


Figure 2. Range and distinct population segments of the American horseshoe crab.

POPULATION STATUS

Especially in the past three decades, horseshoe crab populations have crashed, and their habitat is rapidly disappearing. Horseshoe crabs are being overharvested for both bait and blood, and their spawning beaches are threatened by development, erosion, pollution, and sea level rise.

The IUCN states that "population reductions in *Limulus* have occurred over much of its range, but in particular within the Mid-Atlantic region."[69] The IUCN Red List categorizes the American horseshoe crab as vulnerable and facing a high risk of extinction in the wild.[70] The IUCN also describes the American horseshoe crab population as "decreasing."[71] Across the American horseshoe crab's six metapopulations, the IUCN notes declines across a significant portion of its range, including "significant declines in at least one dataset in all areas except the Southeast and Florida."[72]

Since 1994, the populations in the Yucatán Peninsula have been recognized as endangered under Mexican law. They have generally declined since the 1960s, although some areas are recovering, and remaining significant Yucatán populations are mostly within protected areas.[73]

Horseshoe crab harvests by commercial whelk and eel fisheries spiked in the 1990s, which resulted in a massive crash in horseshoe crab populations in the late 1990s. Annual harvests climbed from 100,000 in 1991 to 3 million in 1998. Female horseshoe crabs were especially targeted by commercial fisheries. Because of the dramatic reduction of crabs from the breeding population, horseshoe crab numbers plummeted across nearly all of its range.[74]

Since the 1990s, the Delaware Bay's horseshoe crab population has fallen by two-thirds, and horseshoe crabs have experienced similar declines across most of their range.[75]

Horseshoe crabs are also harvested for their blood, and significant increases in horseshoe crab blood harvests have occurred in recent decades. Horseshoe crab blood

[69]Smith et al. IUCN Red List 2017.
[70]Smith et al. IUCN Red List 2017.
[71]*Ibid*.
[72]*Ibid.*
[73]Zaldivar *et al.* 2009. 97.
[74]Delaware Bay Horseshoe Crab Survey 1990-2022.
[75]*Ibid.*

harvests have doubled since 2017, and 2022 was the largest horseshoe crab blood harvest ever recorded, with numbers approaching 1 million horseshoe crabs.

Bait harvest quotas have helped to slow the decline in horseshoe crab populations, but in the past 25 years, horseshoe crab populations have not come close to recovering. More than 1.2 million horseshoe crabs spawned in the mid-Atlantic in 1990. By 2002, horseshoe crab spawning numbers dropped to 333,500—a decrease of 72%. Since 2002, horseshoe crab spawning has remained historically low, even with quotas. In 2020, only 335,211 spawned, which is nearly the same number as 2002 and a fraction of their spawning populations from 25 years ago.[76]

Other areas have seen similar declines. On Long Island, N.Y., the Environmental Research and Coastal Monitoring Lab has observed declines in horseshoe crab populations on 75 of the 115 beaches monitored since 1991.[77]

Several horseshoe crab mass mortality events have occurred along the Atlantic coast in recent years. A 2021 horseshoe crab die-off in Ocean City, Maryland, resulted in thousands of horseshoe crabs clogging canals.[78] The die-off was specific to horseshoe crabs: no other aquatic species were associated or observed with the horseshoe crab die-off.[79] Mass horseshoe crab mortality events have been observed in Ocean City again in 2022 and 2023. Researchers suspect water pollution and loss of spawning habitat are contributing to the horseshoe crab die-offs.[80] Another horseshoe crab die off was reported at Brigantine Beach, Md. in 2022.[81]

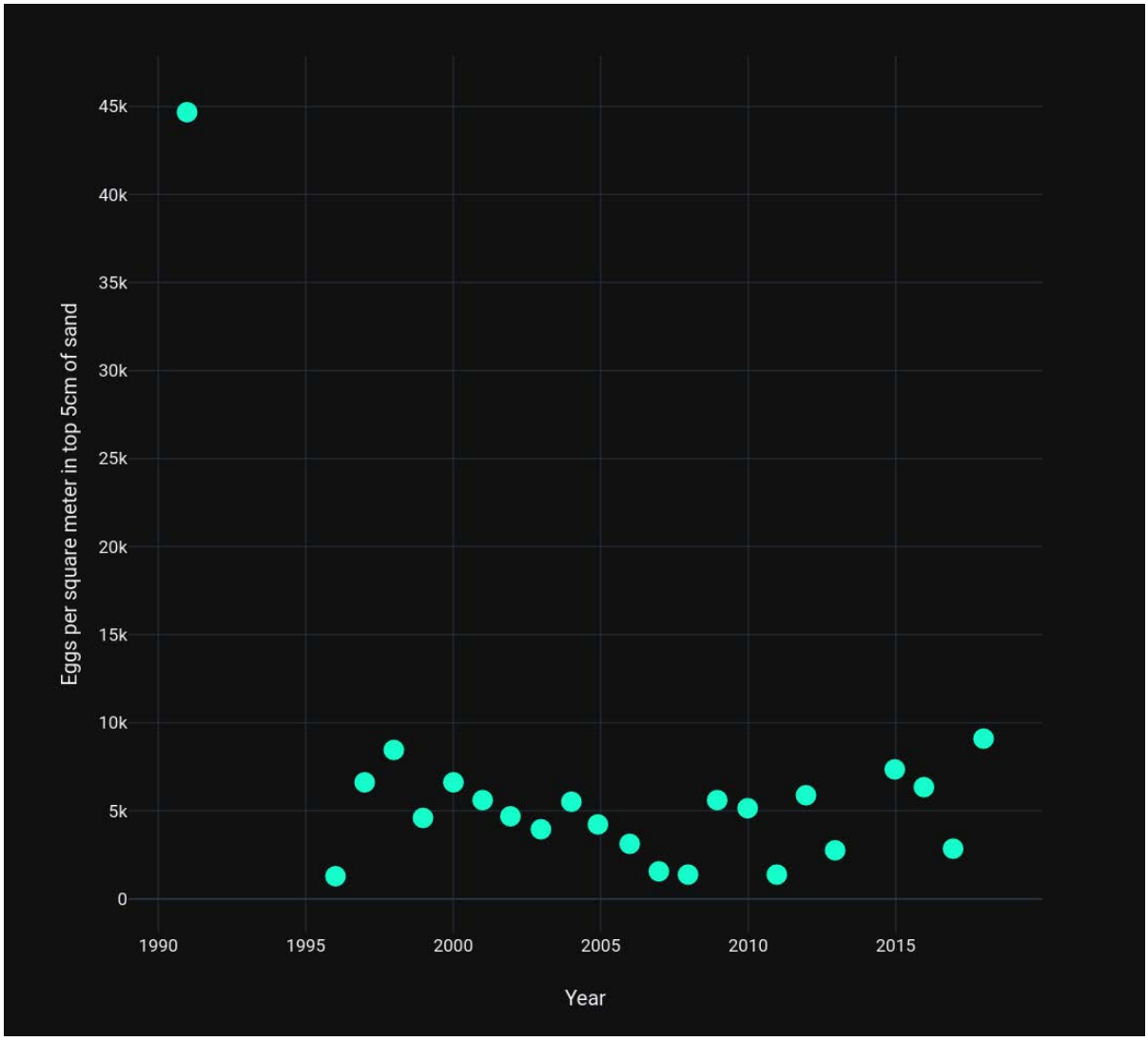
Similar horseshoe crab die-offs have been observed in Delaware, Massachusetts, and New Jersey in recent years. The most recent Massachusetts die-off occurred in 2023 when thousands of dead horseshoe crabs washed ashore near Cape Cod's Chatham Beach. According to the Massachusetts Division of Marine Fisheries, the mass mortality event was the result of crabs dying in the storage process during commercial bait harvests. After the crabs were harvested, they died somewhere in the storage process and were dumped at sea because they had decayed to the point where they were no longer marketable as bait crabs.[82]

In January 2024, volunteer monitors reported a significant number of dead horseshoe crabs along the Ocean City, N.J., shoreline. No other dead animals from other taxa

[76]Delaware Bay Horseshoe Crab Survey 1990-2022.
[77]Guzman 2020.
[78]Chesapeake Bay Magazine 2021.
[79]*Ibid.*
[80]Orens 2023.
[81]*Ibid.*
[82]Zuckoff 2023.

washed ashore with the dead horseshoe crabs. A horseshoe crab mortality event in the winter months was especially unusual since crabs typically do not come ashore.[83] Hypotheses for the cause of the mass mortality event include extreme weather, storms, pollution, or a biomedical bleeding harvest.[84]

Horseshoe crab egg density—the number of eggs per square meter—on spawning beaches is also a critical measure of horseshoe crab populations and health. Peer-reviewed studies indicate that horseshoe crab egg density has declined by an



Horseshoe Crab Recovery Coalition

Figure 3. Horseshoe crab egg densities in Delaware Bay indicate horseshoe crab declines since 1991.

[83]Faith Zerbe pers. comm. February 7, 2024.
[84]*Ibid.*

order of magnitude since the 1980s.[85] Egg densities were commonly at 50,000 eggs per square meter four decades ago. Today, egg densities are frequently less than 5,000 eggs per square meter.[86]

Unfortunately, the Atlantic States Marine Fisheries Commission has declined to include horseshoe crab egg density data in its adaptive resource management (ARM) model, which establishes annual quotas for horseshoe crab harvests. The current management of horseshoe crabs is not providing a sustainable fishery into the future — extremely low densities of spawning horseshoe crabs calls for changes in management to allow populations to recover.[87]

A 2021 analysis by Romuald Lipcius found that quotas are failing to protect and recover horseshoe crabs. The report found the following key trends and observations in horseshoe crab populations and demography:

Low abundances of newly mature females and spawning females: The female harvest prohibition would be expected to lead to a rebound in young mature females and an increase in the recruitment of immature males and females into the horseshoe crab population. However, in 2019 and 2020, the abundance of newly mature females reached an all-time low, and the recruitment of immature females and males remained extremely low and unchanged since before the prohibition. Additionally, female abundance in the spawning survey experienced a sharp drop in 2019. These indicators serve as warning signs that the horseshoe crab population has not fully recovered and may still be declining.[88]

Mature females are displaying smaller body sizes: Contrary to the expectation that the female harvest prohibition would result in an increase in female body size with constant recruitment, the data indicate otherwise. The mean size of mature female horseshoe crabs was the smallest from 2018-2020, and for newly mature females, it was the smallest in the last two years of the time series from 2002 to 2020. This trend persisted despite the prohibition on female harvest since 2012. These findings are inconsistent with the anticipated outcome and challenge the notion that female horseshoe crab populations have rebounded.[89]

[85]Smith *et al.* 2022. 8.
[86]Tim Dillingham. pers. comm. February 4, 2024.
[87]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[88]Lipcius Expert Report. 4.
[89]*Ibid.*

Decline in larger female horseshoe crabs and reduced egg production: The production of eggs is closely tied to the biomass of the spawning stock, mainly consisting of mature females. Changes in the size distribution of mature females can significantly impact overall egg production, especially with the loss of large females. Relying solely on the abundance of horseshoe crabs to estimate reproductive output overlooks critical biological factors like size structure and biomass, which play a key role in population egg production within the spawning stock.

The size distribution of mature females has shifted towards smaller individuals, and there has been a recent decline in the abundance of females larger than 300 mm prosomal width — those with the highest egg production potential. This decline, particularly notable from 2018 to 2020, suggests a decrease in the contribution of larger females to the spawning stock. With recent low recruitment, smaller mature females are not compensating for the loss of their larger counterparts. Consequently, overall reproductive (egg) output is likely not improving, making the recovery of both the horseshoe crab (HSC) and red knot (RK) populations more difficult.[90]

The sex ratio of males to females is not decreasing: The expectation when restricting horseshoe crab harvest to males is that the ratio of males to females would decrease. Despite this, male-to-female sex ratios have increased from 1999 to 2019. This discrepancy serves as another warning sign, suggesting that the current management strategy has not been effective and indicating a lack of comprehensive understanding of population dynamics.[91]

Mature female mortality is increasing: Mortality from discard and bait harvest for females has significantly increased in recent years, reaching levels comparable to those before prohibitions on female harvest. Assuming the effectiveness of the prohibition is presumptuous —the lack of effective control over the cumulative mortality from bait harvest and discard poses a significant obstacle to the recovery of horseshoe crab populations.[92]

Low egg densities in horseshoe crab spawning habitats: Recent data suggests that egg densities of horseshoe crabs in their spawning habitats and red knot feeding grounds are markedly lower compared to periods when both species were more abundant.

Habitat degradation: Horseshoe crab spawning habitats and feeding grounds for red knots have shrunk throughout the Mid-Atlantic region.

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[90] *Ibid.*
[91] Lipcius Expert Report. 5.
[92] *Ibid.*

Quantitative analysis in a 2017 study revealed significant declines throughout the horseshoe crab's range, except in South Carolina and Georgia, where populations were relatively stable. The steepest declines were observed in the New England area, gradually diminishing from the northern to southeastern areas, with declines also observed in the Florida Atlantic and Northeast Gulf regions.[93] Continuing these negative trends over 40 years would result in projected population reductions of 100% in the Gulf of Maine, 92% in New England, 11% in New York, 55% in Florida Atlantic, and 32% in the Northeast Gulf of Mexico.[94]

Gulf of Maine

American horseshoe crab populations in the Gulf of Maine region exhibit a limited and possibly fragmented geographic range. The absence of spawning in previously utilized locations suggests a historical decline in Extent of Occurrence (EOO).[95]

Between 2001 and 2004, surveys were carried out at five locations in the Gulf of Maine to establish baseline data on horseshoe crab spawning. A 2005 study indicated that the density of horseshoe crab spawning is low across Maine, and three historical spawning sites are no longer utilized by horseshoe crabs.[96]

New England

Numerous small populations in the Northeast are confined to bays and inlets, where limits set by the ASMFC and individual states may not be adequate.[97] The ASMFC's 'stock status determination' has concluded that the current harvest in regions like New York and New England is not sustainable. An example is Wellfleet Harbor, where overfishing for bait has led to a decline in horseshoe crab populations compared to nearby areas.[98] Similarly, in a relatively confined area near Mashnee Dike on the upper reaches of Buzzards Bay, Massachusetts, a small yet stable breeding population extensively studied by scientists from the Marine Biological Laboratory in Woods Hole was nearly eradicated through hand harvesting during spawning.[99] A similar scenario occurred at Stage Harbor. Two other surveyed bays in Massachusetts, Wellfleet Harbor and Cape Cod Bay, have also experienced significant declines linked to spawning

[93]Smith *et al.* 2017. 159.
[94]The IUCN Red List of Threatened Species 2016. 18.
[95]*Ibid.*
[96]Smith *et al.* 2017. 156.
[97]Smith *et al.* 2009.
[98]Novitsky 2015. 486.
[99]*Ibid.*

indices.[100] This kind of local population extermination is likely recurring in many other bays and inlets in the Northeast, even though state-wide harvest quotas initially set by the ASMFC are not fully reached, indicating that the demand for bait appears to be satisfied.[101]

Examining historical records reveals the former abundance of horseshoe crabs in Massachusetts. Well before the Atlantic States Marine Fisheries Commission acknowledged the significant decline in horseshoe crab populations along the eastern seaboard and before the initiation of the Massachusetts whelk fishery, which utilizes horseshoe crabs as bait, Massachusetts experienced a period of extensive horseshoe crab destruction. In the 1960s and 1970s, the Commonwealth implemented a misguided predator control program to protect soft shell clams for fishermen by offering subsidies to cities and towns that provided a bounty on horseshoe crabs.[102]

The Massachusetts Division of Marine Fisheries estimates that during this period, participating fishermen were responsible for killing over half a million horseshoe crabs annually. In Chatham alone, 50,000 horseshoe crabs were killed in 1960, and the Chatham shellfish constable recalls the removal of "tens of thousands of horseshoe crabs" from its waters. Duxbury, another participating town, recorded the removal of 14,000, 16,000, and 20,000 horseshoe crabs from its small beaches in the 1960s. A visit to the Duxbury dump during this period revealed "hundreds of crabs, many on their backs, waving their legs feebly in the sun." The recorded numbers in the bounty program are likely an underestimate.[103]

In 2010, Massachusetts implemented lunar closures with the intent to reduce the collection of horseshoe crabs for bait. Such closures were anticipated to have an impact by 2019-2020, given that horseshoe crabs take 9-11 years to reach sexual maturity. However, recent spawning surveys conducted in various Massachusetts locations do not indicate significant positive effects resulting from this management decision.[104] Lunar closures likely shifted the kill of horseshoe crabs from spawning areas to trawls in the ocean. The available data depict a population that has not recovered despite changes in management practices — including lunar closures and catch limits — implemented by the DMF over the past two decades.[105]

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[100] *Ibid.*

[101] ASMFC 2013; Novitsky 2015. 486-487.

[102] Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 7-8.

[103] Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 8.

[104] *Ibid.* 14.

[105] *Ibid.* 14.

After 20 years of regulation, horseshoe crab data in Massachusetts do not suggest recovery from decades of heavy exploitation. The most recent horseshoe crab stock assessment conducted by the Atlantic States Marine Fisheries Commission consistently underscores the importance of tracking horseshoe crabs not only by sex but also by maturity level, distinguishing between juvenile, newly mature, and mature female horseshoe crabs. Unfortunately, the Massachusetts trawl surveys do not and cannot provide this level of detailed information.[106]

The ASMFC has concluded that too few horseshoe crabs are captured to make meaningful distinctions based on maturity levels. Unfortunately, without such distinctions, the only means of evaluating trends in spawning females is through beach spawning surveys. However, there are several challenges associated with relying on these surveys. First, the surveys commenced after the horseshoe crab population had already been significantly depleted, making it impossible to establish a baseline for population levels. Second, the confidence intervals in most of the surveys are so narrow that detecting genuine trends in the overall population is virtually impossible. Finally, due to the limited number of crabs captured in these surveys, the ASMFC stock assessment analysis suggests that it's not feasible to identify trends in the overall population of female horseshoe crabs, let alone trends in mature females. There is no evidence to suggest that the horseshoe crab population is experiencing a rebound.[107] In South Carolina, horseshoe crabs continued to spawn on beaches until mature females were depleted, and shortly thereafter, the beaches became barren within a couple of years. There is a growing concern that a similar scenario could unfold in Massachusetts, and there are indications that this might already be happening in Cape Cod Bay.[108] Cape Cod's horseshoe crab population is in steep decline.[109]

Finally, the New England region consists of specific American horseshoe crab populations in various embayments, where tailored regulations to the specific characteristics of each population and habitat may be required to conserve the species. The variations in population characteristics can influence the recovery time of an overharvested population. It may take years to determine the most effective strategy for expediting population recovery within each specific embayment.[110]

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[106] *Ibid.* 14.
[107] Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 14-15.
[108] *Ibid.* 15.
[109] Brockmann, pers. comm, January 19th, 2024.
[110] Beekey & Mattei 2015. 437.

Mid-Atlantic: Connecticut and New York

Multiple studies have indicated a significant decline of the American horseshoe crab in Connecticut and New York. Sites along Long Island have “considerably reduced numbers” compared to past observations, and few individuals exist in areas previously home to large horseshoe crab populations. Of 68 beaches monitored in a 2015 study, there was an 8.2% increase in beaches exhibiting no breeding activity and horseshoe crabs have declined by 1% per year.[111] The Long Island Sound horseshoe crab population is being overharvested and continues to decline, a trend observed since the mid-1990s.[112]

As described by marine scientist Dr. Jo-Marie Kasinak, historically, surveyors would tag 11,000 horseshoe crabs in a single day, whereas today it would be fortuitous to tag 1,000 horseshoe crabs in one season. Tags are returned in high volumes by volunteers. Kasinak added that in the 2000s, researchers used to sit on the beach and let horseshoe crabs come to us — scooping individuals up as they crawled by to tag them and put them back down. This phenomenon is no longer observed, and only a few hundred horseshoe crabs are tagged per year.[113]

Dr. Jennifer Mattei, detailing 20 years of research on the population ecology of the American horseshoe crab population inhabiting Long Island Sound, concluded that "the population is in decline, and due to very low population numbers, the horseshoe crab is functionally extinct in Long Island Sound."[114]

Dr. Mattei also concluded that the no-harvest zones located in the sounds have “not resulted in an increase in the spawning horseshoe crab population. Instead, researchers have “documented the continued decline of this species."[115]

Dr. Mattei’s report added: "Even though only 12 permits exist to harvest horseshoe crabs and the reported catch is low, thousands of additional crabs are harvested every spawning season….Harvest of the breeding population is a major cause of population decline in the Sound. Other stressors include loss of habitat (both marsh and sandy areas), pollution, bycatch in ghost nets and abandoned lobster traps as well as entrapment in intake pipes of power plants.[116]

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[111]Tanacredi & Portilla 2015. 230.
[112]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[113]*Ibid.*
[114]Mattei, Jennifer. 2023.
[115]*Ibid.*
[116]Smith *et al.* 2017; Mattei, pers. obs.

The CT DEEP's Long Island Sound Trawl Survey conducts sampling in both Connecticut and New York waters during the spring (April, May, and June) and fall (September, November, October). Both the Connecticut and New York indices demonstrate a decline in horseshoe crab abundance in Long Island Sound since the early 2000s.[117] Despite an increase in American horseshoe crab populations during the 1990s, recent years indicate a downward trend attributed to various stressors, including habitat loss and illegal harvesting.[118]

On Long Island, N.Y., the Environmental Research and Coastal Monitoring Lab has observed declines in horseshoe crab populations on 75 of the 115 beaches monitored.[119]

A 2015 study found that the population of American horseshoe crabs in Long Island Sound (LIS) is aging, with a limited recruitment of newly molted adults and reproduction occurring well below the maximum rate. Observations indicate very low spawning densities, an increase in the number of single females on the beach, and less than 6% polyandrous mating behavior. These trends suggest that the current harvest quotas and management techniques are unsustainable. The study's authors recommended implementing a unified management plan for LIS with a shared harvest quota, increasing no-harvest zones on both sides of the Sound, and banning the harvest of spawning females. The authors also recommended the establishment of multiple Marine Protected Areas (MPAs) within LIS, where all types of commercial or recreational fishing would be prohibited.[120]

[117]Long Island Sound Study 2022.
[118]*Ibid.*
[119]Guzman 2020.
[120]Beekey & Mattei 2015. 433.

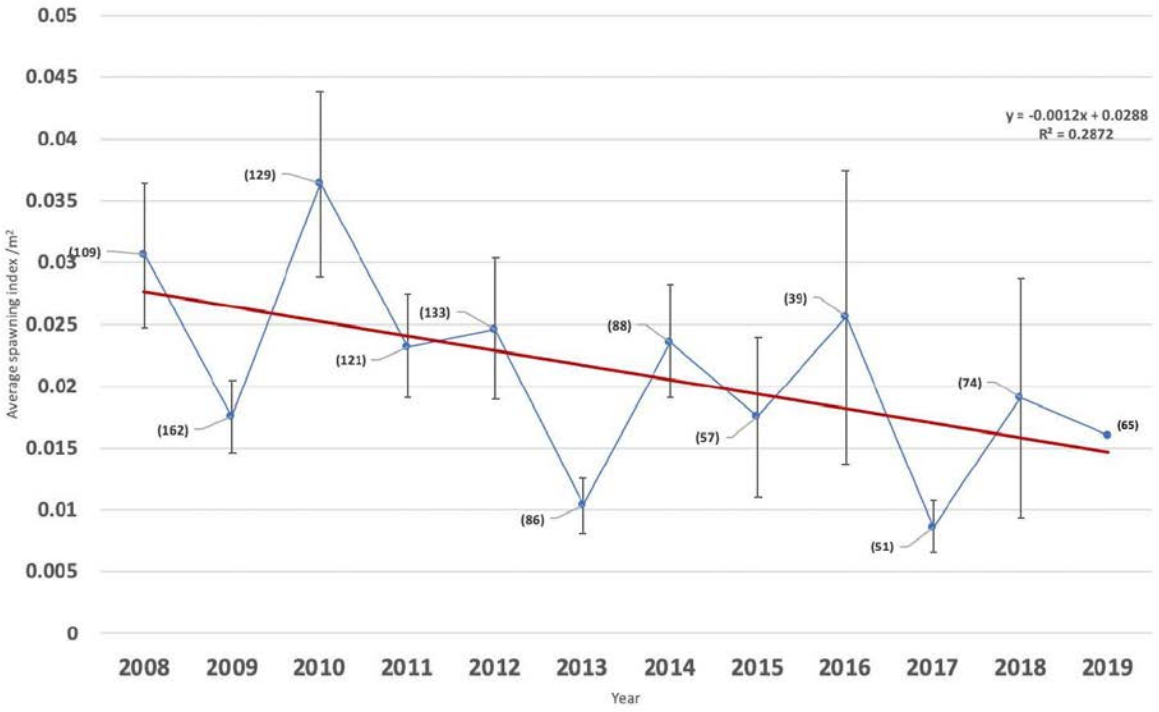

Figure 4. Spawning horseshoe crab populations in Connecticut from 2008-2018 have continued to decline even after quotas and no-harvest zones were established.[121]

Over the last 15 years, harvest quotas for this species have been established in Connecticut and New York, in accordance with the Atlantic States Marine Fisheries Commission (ASMFC) mandate to create a Fishery Management Plan for the American horseshoe crab. Despite the implementation of a self-reporting system in Connecticut, the harvest quotas are seldom met, yet populations in Long Island Sound are still experiencing a decline.[122]

Decreases in the Delaware Bay horseshoe crab harvest were offset by an increase in harvests in the New England and New York region, along with the State of Virginia, which experienced a significant rise in horseshoe crab landings after 2005. This shift in harvesting patterns has raised concerns about the sustainability of populations in the New England and New York regions. Several studies conducted in recent years have highlighted the vulnerability of horseshoe crab populations in New England to the risk of overharvesting.[123] Similarly, despite the implementation of no take zones in the region, these areas were designated for birding rather than their suitability as horseshoe crab habitat. Further, horseshoe crabs moving outside the bounds of protected areas are

[121]Mattei 2019; Kasinak 2023.
[122]Beekey & Mattei 2015. 434.
[123]Beekey & Mattei 2015. 437.

subject to harvest in other regions, nullifying the positive effects of protections in certain beach swathes.[124]

Over two years in this study, female recruitment to the spawning population was higher than male recruitment. Additionally, male portions of the population were aging more rapidly than female portions and were not replacing themselves. Previous studies have shown that older males are less likely to pair with females. Younger males may be more likely to pair and remain paired due to factors such as lower fouling, better physical condition, and less damage to claws used for clasping females. The percentage of unattached males in good condition was greater than the number of amplexed males, which is attributed to low spawning density. Results from this study indicate that horseshoe crabs along the Connecticut coastline are failing to maximize their reproductive efforts and have encountered difficulties in finding mates. The presence of relatively high numbers of single females and low levels of polygynandrous behavior further supports the evidence of a population in decline.[125]

Legal harvesting of horseshoe crabs is just one contributing factor to the population's decline in the LIS. Illegal, unregulated, and unreported harvesting have also contributed to the decline of the species. Thousands of horseshoe crabs are at risk of getting trapped in water intake pipes used by shoreline power plants and industrial complexes. Moreover, these crabs often become bycatch during bottom trawling operations, which can lead to indiscriminate pulling up of various organisms from the benthic area and the destruction of their habitat.[126] The endorsement of trawling for "stock assessment" purposes is in itself problematic, as this activity can directly or indirectly harm both sustainably managed species and those not currently covered by a management plan but are integral to the food web. Other factors contributing to the decline of horseshoe crab populations include the loss of eggs, young of the year, and subsequent juvenile life stages over 8–10 years of development. Mortality is also caused by predation and a range of destructive human activities such as habitat degradation, pollution, invasive species, and climate change.[127] Increased erosion on spawning beaches is of particular concern in Connecticut, where shorelines are highly developed. The state has lost 60% of its salt marsh and beachfront habitat, and heavy coastal development has further reduced viable horseshoe crab spawning habitat.[128] Impingement from power plant intakes represents another threat to the American horseshoe crab in Connecticut.[129] A researcher went scuba diving in the region, diving down to an intake catchment of a

[124]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[125]Beekey & Mattei 2015. 456.
[126]*Ibid.* 435.
[127]*Ibid.*
[128]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[129]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.

power plant, where they witnessed hundreds of horseshoe crabs stranded and stuck in a power plant intake. They were unable to escape and many were dead.[130]

Tagging data revealed that despite state and federal stock assessments classifying the western Long Island Sound horseshoe crab population as relatively stable, the population density is alarmingly low, leading to noticeable changes in population characteristics and signaling a significant decline in the population in the foreseeable future.[131]

Mid-Atlantic: Delaware Bay

The largest aggregation of spawning American horseshoe crabs in the world occurs in Delaware Bay and supports one of the largest concentrations of shorebirds in the western hemisphere where the birds feed on horseshoe crab eggs during migration.[132]

Significant declines of American horseshoe crabs have been observed in the Mid-Atlantic region, where Delaware Bay populations were historically far larger than those observed today.[133] Past overharvesting of the species for fertilizer and current bait and biomedical harvesting have been identified as primary factors contributing to these declines.[134]Declines of egg and shorebird abundance occurred shortly after horseshoe crab harvest reached its peak.[135]

In 2020, the Delaware Center for the Inland Bays conducted its thirteenth consecutive horseshoe crab survey, following protocols similar to those in the Delaware Bay. Five sandy beaches across Rehoboth and Indian River Bays were surveyed using quadrats on dates that coincide with the primary spawning surveys conducted in the Delaware Bay by Delaware's Department of Natural Resources and Environmental Control (DNREC). Surveys took place in conjunction with the new and full moon cycles and during the highest of the lunar high tides during these periods.[136]

A total of 16,198 crabs were counted, with a sex ratio of 5.67 males per female. The cumulative spawning density was 2.93 crabs per square meter, and the female spawning density was 0.44 crabs per square meter.[137]

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[130]*Ibid.*
[131]Beekey & Mattei 2015. 457.
[132]Smith *et al.* 2022. 1.
[133]Mark Botton, pers. comm. February 1, 2024.
[134]Smith *et al.* 2017. 156.
[135]Smith *et al.* 2022. 1.
[136]Garmoe, Z., A. T. McGowan, & D. H. Bartow. 2021. 8.
[137]Garmoe, Z., A. T. McGowan, & D. H. Bartow. 2021. 5.

Five beaches were surveyed, with results showing a decline in overall horseshoe crab observations compared to 2019. The 2020 survey indicated a decline in high-density spawning events, with 69.6% of surveys showing low-density and 14.4% with no crabs. The cumulative sex ratio was 5.7, a decrease from 2019.[138]

Virginia Tech has conducted its American horseshoe crab trawl survey in this region from 2002 to 2011 and from 2016 to 2022.[139] The Virginia Tech data has shown no statistically significant increase in the population of adult female horseshoe crabs essential for species restoration.[140]

The most recent survey conducted in 2022 found that the mean population estimate decreased for mature horseshoe crabs and newly mature male crabs, but increased for immature crabs and newly mature females compared to 2021 population estimates.[141] However, mean population estimates across all groups since 2002 are highly variable, with some categories showing significant decreases since a population peak in 2009.[142] For example, the mean population estimate for immature female crabs in 2009 was 39,032, compared to 9,930 in 2022.[143] Similarly, immature male crabs reached a peak of 29,864 in 2009, but have since decreased to 7,652 in 2022.[144]

Regulations in Delaware Bay, including a full bait moratorium in New Jersey in 2008 and a ban on taking female horseshoe crabs for bait in 2013, alongside substantial investments in beach renourishment in Virginia and New Jersey, have not been sufficient to rebuild the horseshoe crab population.

Horseshoe crab populations in the Delaware Bay have only stabilized at a depleted level and have not recovered in more than two decades.[145] Prospects for recovery are questionable due to sea level rise and the loss of spawning habitat.[146]

The declines and depletion of horseshoe crab populations in Delaware Bay led to the red knot being listed as threatened under the Endangered Species Act. As of 2021, the

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[138] *Ibid.* 12.
[139] Results of the 2022 Horseshoe Crab Trawl Survey.
[140] Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 12.
[141] ASMFC 2023.
[142] *Id.*
[143] *Id*.
[144] ASMFC 2022.
[145] Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 12.
[146] Mark Botton, pers. comm. February 1, 2024.

U.S. Fish and Wildlife Service still considers the red knot as "depleted." Horseshoe crab surface egg densities on New Jersey beaches, crucial for sustaining impacted shorebirds, remain at 5,000 eggs per square meter, far below historic levels—and below the 50,000 eggs per square meter needed to sustain horseshoe crabs and shorebirds.[147]

Past and current measurements of horseshoe crab eggs in the bay indicate that abundance in the 1980s was an order of magnitude greater than present-day estimates. An additional egg prevalence index, which characterizes the timing and magnitude of horseshoe crab egg output, revealed a similar pattern of higher prevalence in the 1980s (0.89) compared with the recent 2015–2021 interval (0.52).[148]

Southeast

The horseshoe crab bait fishery was banned by South Carolina's legislature in 1989. However, harvesting horseshoe crabs for blood has been permitted, and the ban on bait has effectively provided a monopoly on horseshoe crabs in South Carolina to Charles River Laboratories, a prominent multinational company and the largest U.S. manufacturer of Limulus Amebocyte Lysate (LAL). Since the 1990s, the horseshoe crab bleeding fishery has expanded steadily, resulting in a population in South Carolina that is no longer sustainable for the industry without causing severe impacts on the crab's viability.[149]

Three trawl surveys conducted in spring and fall track horseshoe crab populations in South Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) stock assessment discarded some surveys due to insufficient horseshoe crab catches. The remaining surveys consistently indicate declining trends in horseshoe crab numbers.[150]

The demand for horseshoe crabs from the biomedical industry has led to Charles River Laboratories unlawfully removing horseshoe crabs from Cape Romain National Wildlife Refuge without a permit. Over ten years, the beaches on Marsh Island and White Banks within the refuge were nearly devoid of spawning horseshoe crabs, with only males observed. This loss has adversely affected red knots' critical stopover, resulting in their disappearance from the refuge.[151]

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[147]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 12.
[148]Smith *et al.* 2022. 1.
[149]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 11.
[150]*Ibid.*
[151]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 11.

Southern Environmental Law Center and Defenders of Wildlife filed lawsuits against the U.S. Fish and Wildlife Service which ultimately halted horseshoe crab harvesting in Cape Romain National Wildlife Refuge in 2023. Additional litigation resulted in the prohibition of horseshoe crab harvests on 30 South Carolina beaches during red knot migration season and a prohibition on placing female horseshoe crabs in holding ponds for blood harvests.[152]

South Carolina's Turtle Island Wildlife Management Area, a vital feeding area for large flocks of red knots each spring near the Georgia border, has also experienced a rapid decline in horseshoe crab populations due to fishing activities. Local populations have been depleted and no spawning has been documented since an intensive harvest in 2019.[153]

Contrary to claims by lysate manufacturers asserting low mortality of bled horseshoe crabs, a joint study in South Carolina, conducted by the state and the bleeding company, revealed a 20% mortality rate for bled female horseshoe crabs.[154] More recent and widely accepted studies show mortality rates at 30%, which could be even higher when the damages incurred by harvest, transport, return, and post-bleeding health are included.[155]

In addition, biologists from the Georgia Department of Natural Resources have reported feral hogs feeding on horseshoe crabs and their eggs.[156] Feral hogs occur on every major barrier island along the Georgia coast.[157]

Florida Atlantic

Data indicate a potential decline in some populations of Florida horseshoe crabs. Several trawl surveys conducted in the last five years note significantly fewer horseshoe crabs compared to previous years. Spawning surveys at Seahorse Key suggest a recent decline. Catch Per Unit Effort (CPUE) in marine-life harvest data shows a decrease in recent years, with the exception of the Jacksonville trawl site. An additional concern exists in the fact that Florida horseshoe crabs are fragmented into genetically distinct populations with limited interchange, suggesting that local declines could lead to local extinctions.[158] The commercial harvest, habitat loss, pollution and water quality

[152]Southern Environmental Law Center August 25, 2023.
[153]Hunt 2022. 10.
[154]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 12.
[155]Leschen and Correia 2010. 135.
[156]Larry Niles. pers. comm. 2023.
[157]Georgia Chapter of the American Fisheries Society. 2022.
[158]H.J. Brockmann *et al.* 118.

issues, human population increases, disease outbreaks, the harvest of horseshoe crabs for marine life purposes, and the substantial number of horseshoe crabs killed at power plants[159] could all threaten the American horseshoe crab in Florida. Populations may be particularly threatened by red tides, which are common in southwest Florida.[160] Further, horseshoe crabs were also the most common invertebrate bycatch species in Florida shrimp trawls.

Declining horseshoe crab populations within Florida's Indian River Lagoon estuary have been a concern for many years. In the 1970s, a collection of sea turtles led to the capture of large numbers of horseshoe crabs in nets, but by the 1990s, only a few were caught. Additionally, researchers observed a shift in sea turtle species from predominantly loggerhead turtles, which heavily prey on horseshoe crabs, to mostly green sea turtles, which primarily consume plants, in the Indian River Lagoon from the 1970s to the 1990s. In 1999, an estimated 100,000 horseshoe crabs perished in the southern part of Mosquito Lagoon due to unknown causes, likely disease. A one-year study at two power plants on the Indian River documented significant horseshoe crab mortalities, with 39,097 trapped at the Florida Power and Light Cape Canaveral Plant and 53,121 at the Orlando Utilities Commission Indian River Plant. A prior study in 1975 estimated 69,662 horseshoe crabs trapped at the Canaveral Plant, and an annual mortality of 104,000 horseshoe crabs at the intakes of the Indian River plant. This level of mortality alone could contribute substantially to the decline in the Indian River population.[161]

Northeast Gulf of Mexico

Reports of severe, 30-year declines in horseshoe crab populations were recorded in Escambia Bay and Mobile Bay, Alabama.[162]

In the early 1980s, shrimp trawlers in the Northeast Gulf region began harvesting horseshoe crabs to address the growing demand for bait in the whelk fishery.[163] The practice intensified in 1999 when over 110,000 horseshoe crabs were harvested from the northwest coast of Florida. This surge was prompted by a bait shortage in Delaware Bay due to increased horseshoe crab regulations; an estimated 99,000 crabs were harvested in just 44 days.[164] Since 2000, the bait harvest along the west coast of Florida has significantly declined, with only 14,683 horseshoe crabs harvested for bait.[165]

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[159] *Ibid.* 119.
[160] *Ibid.* 118.
[161] *Ibid.* 119.
[162] Rudloe 1982. 299.
[163] Rudloe 1982. 297-300.
[164] Smith *et al.* 2017. 156.
[165] *Ibid*. 151.

Approximately 100,000 horseshoe crabs were harvested in St. Joe Bay around 1999. Populations have never recovered. Tractor trailer trucks were driven to St. Joe Bay to haul out horseshoe crabs. Since then, surveys have shown declines and populations in the bay remain at low levels.[166]

Red tides present another threat to the horseshoe crab in the northeast Gulf of Mexico. Red tides are frequent in the nearshore regions of the Gulf of Mexico, notably in southwest Florida and the Yucatán Peninsula, where horseshoe crabs are abundant. Florida's west coast experiences intermittent occurrences of red tides, impacting various species, including young horseshoe crabs.[167]

Yucatan Peninsula

Population sizes of horseshoe crabs in Mexico were reported to have significantly decreased from the 1960s to the early 1990s, particularly in the Laguna de Términos area.[168] A survey conducted on spawning events in a Mexican locality revealed relatively low abundances of reproductive individuals. In this survey, spawning pairs did not exceed the tens of pairs in a 100-meter transect during a peak high tide.[169] Reports from locals in other sites suggest that this pattern may be consistent throughout most of the species' distribution in Mexico.[170] Furthermore, spawning appears to be restricted to specific shoreline conditions within coastal lagoons, potentially limiting the availability of suitable spawning habitats.[171]

[166]Brockmann. pers comm. January 2024.
[167]Smith *et al.* 2017. 156.
[168]*Ibid.*
[169]*Ibid.*
[170]*Ibid.*
[171]*Ibid.*

Concurrent declines of horseshoe crabs and dependent species

Rufa red knots congregate on a horseshoe crab spawning beach. *Gregory Breese/USFWS*

Horseshoe crabs, once considered dominant in coastal ecosystems, play a crucial role in supporting a diverse web of life. Their decline poses significant threats to various species, including loggerhead sea turtles, American eels, weakfish, and many imperiled shorebirds. The concurrent decline of these species serves as an indication of the American horseshoe crab's decline and imperilment. The decline in body mass and population of red knots in Delaware Bay, for example, is correlated with an increase in the harvest of horseshoe crabs.[172] The concomitant decline of the American horseshoe crab and associated species serves as a critical warning and underscores the dire need to conserve the ecologically critical *L. polyphemus*.[173]

[172]Krisfalusi-Gannon *et al.* 2018. 7.
[173]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 5-7.

Rufa red knot

The *rufa* red knot (*Calidris canutus rufa*) is a federally threatened migratory bird protected under the Endangered Species Act. Rufa red knots rely on the horseshoe crab eggs along the Atlantic Coast to fuel their annual migration. Rufa red knots overwintering in Tierra del Fuego travel 19,000 miles roundtrip each year to and from their breeding grounds in the Canadian Arctic.[174]

During its 9,500-mile annual journey from the tip of South America to the Canadian Arctic, *rufa* red knots stop and feed along the Atlantic coast. While there, red knots must build up enough fat stores for the second leg of their journey in the form of nearly 400,000 horseshoe crab eggs per bird.[175] Easily digestible horseshoe crab eggs are a favored food source because they provide the highest energy accumulation rates in red knots worldwide.[176] Time is also a constraining factor. Red knots must double their body weight in 10-12 days to take advantage of the short Arctic breeding period. Because breeding season performance, recruitment, and population dynamics are correlated to body condition, the birds that fail to acquire such reserves are less likely to survive and reproduce.[177]

The *rufa* red knot has suffered due to the decline of horseshoe crabs in Delaware Bay, depleting their energy-rich egg supply for migration. The Atlantic States Marine Fisheries Commission notes that "[a] significant decrease in the number of horseshoe crabs could leave a large portion of migrating shorebirds without either the necessary food resources . . . or the necessary fat reserves" to complete their migration or reproduction.[178]

Surveys of horseshoe crab egg density reveal that the number of eggs per square meter of beach on Delaware Bay has declined by an order of magnitude since the 1980s. Horseshoe crab egg density is strongly correlated with red knot survival, and egg scarcity continues to constrain the birds' recovery.

Without enough horseshoe crab eggs to sustain their long migrations, red knot populations have declined by 75% since the 1980s.[179]

Recent studies also show that red knots are stopping in Delaware Bay for shorter periods. This could have far-reaching effects on breeding success and survival. Red knots departing from Delaware Bay in higher relative body condition migrate up to a

[174]USFWS 2014.
[175]Cramer, Deborah. 2018.
[176]Mizrahi, David S. & Kimberly A. Peters. 2009. 65, 70.
[177]Dey *et al.* 2020. 2.
[178]ASMFC FMP 1998. 13.
[179]HCRC 2023.

month later than individuals in lower condition, suggesting that the availability of horseshoe crab eggs leads to higher breeding success.[180]

Moreover, red knots leaving Delaware Bay with a lower relative body condition had a lower probability of being detected in autumn, suggesting greater mortality compared to individuals with higher relative body condition.[181]

The horseshoe crab eggs along the Atlantic Coast provide a critical source of nourishment. *Rufa* red knots must double their weight during their two weeks on Atlantic coast beaches consuming horseshoe crab eggs. Red knot populations have fallen by 75% in key areas since the 1980s, largely the result of overharvesting horseshoe crabs.[182]

Red knot field data shows that red knot populations are at population levels well below the thresholds that led them to being listed as threatened under the Endangered Species Act in 2014. *Rufa* red knot populations are nowhere close to the recovery threshold of 81,900 red knots established by ASMFC. The ASMFC acknowledges that a threshold of 81,900 red knots "represent(s) an established historical abundance that is considerably higher than recently estimated stopover sizes."[183] In the 1990s, more than 90,000 could be found along Delaware Bay. In 2021, the number was estimated at an all-time low of 6,800.[184] In 2022 and 2023, red knot numbers increased to 12,000 and 21,347 red knots, but populations remain far below established thresholds.

The U.S. Fish & Wildlife Service concluded that the commercial harvest of horseshoe crabs was a "primary causal factor" in the decline of red knots and the decision to list red knots under the Endangered Species Act in 2014.[185]

Other imperiled shorebirds

At least 14 species of migratory birds use horseshoe crab eggs to replenish their fat supply during their trip from South American wintering areas to Arctic breeding grounds. These species make some of the longest known migrations and rely on horseshoe crab eggs along the Atlantic Coast.

These bird species include the ruddy turnstone (*Arenaria interpres*), sanderling (*Calidris alba*), dunlin (*Calidris alpina*), and semipalmated sandpiper (*Calidris pusilla*). The

[180]Dujins *et al.* 2017. 1.
[181]*Ibid.*
[182]USFWS 2014.
[183]ASMFC ARM Revision 2022. 84.
[184]Niles, Larry. 2022. *"Delaware Bay Stopover Project Final Update."* June 2: https://www.arubewithaview.com/2022/06/15/2022-delaware-bay-stopover-project-final-update-5-june-22022/
[185]USFWS 2014.

semipalmated sandpiper is listed as near threatened by the IUCN Red List and has been declining at a rate of 5% per year. According to the IUCN, ruddy turnstone populations are also decreasing.

Nearly all of the shorebird species that depend on consuming horseshoe crab eggs are experiencing steep declines. Diminishing horseshoe crab populations have contributed to the decline of these shorebird species, with some facing an 80% decline in population since 1980.[186]

Similarly, long-distance migratory birds, like short-billed dowitchers, whimbrel, and Hudsonian godwit, now classified as Endangered by the IUCN standards, have suffered severe population declines — 90%, 86%, and 95%, respectively. These species' dependence on horseshoe crab eggs and associated food sources amplifies the urgency of restoring historic horseshoe crab abundances.[187]

Videos from the 1980s captured at the Monomoy National Wildlife Refuge showcase the presence of red knots, ruddy turnstones, Hudsonian godwits, and other shorebirds feeding on horseshoe crab eggs. Videos from present day show significant declines in both shorebirds and horseshoe crab eggs. The visual evidence underlines the historical importance of horseshoe crabs to these species.[188]

Loggerhead sea turtles

Federally listed loggerhead sea turtles (*Caretta caretta*) rely on horseshoe crabs. The NOAA Fisheries Sea Turtle Stranding and Salvage Network identified horseshoe crabs in 75% of loggerhead sea turtle gut contents.[189] The ASMFC notes that horseshoe crabs are an important part of the loggerhead sea turtles diet near the Chesapeake Bay.[190] Historically, horseshoe crabs once constituted more than 40% of the loggerhead sea turtle's diet.[191] However, the precipitous decline in horseshoe crab numbers have forced loggerheads to change their diets to more plentiful food sources.[192]

[186]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 5-7.
[187]*Ibid.*
[188]*Ibid.*
[189]ASMFC FMP 1998. 15.
[190]*Ibid*. 13.
[191]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 5.
[192]*Ibid*. 5-7.

Fish

Horseshoe crab eggs and larvae serve as essential food for various fish species, including white perch (*Morone americana*), killifish (*Fundulus spp.*), silver perch (*Bairdiella chrysoura*), weakfish (*Cynoscion regalis*), kingfish (*Menticirrhus saxatilis*), and silversides (*Menidia menidia*).[193]

Weakfish (*Cynoscion regalis)* is a saltwater fish native to the mid-Atlantic region of the East Coast of the United States that also feeds on horseshoe crab eggs. Weakfish populations have crashed concurrently with horseshoe crab populations (see Figure 5). Their populations plummeted at the same time that horseshoe crab overharvesting spiked. Like populations of horseshoe crabs, weakfish populations have remained historically low and not recovered.[194]

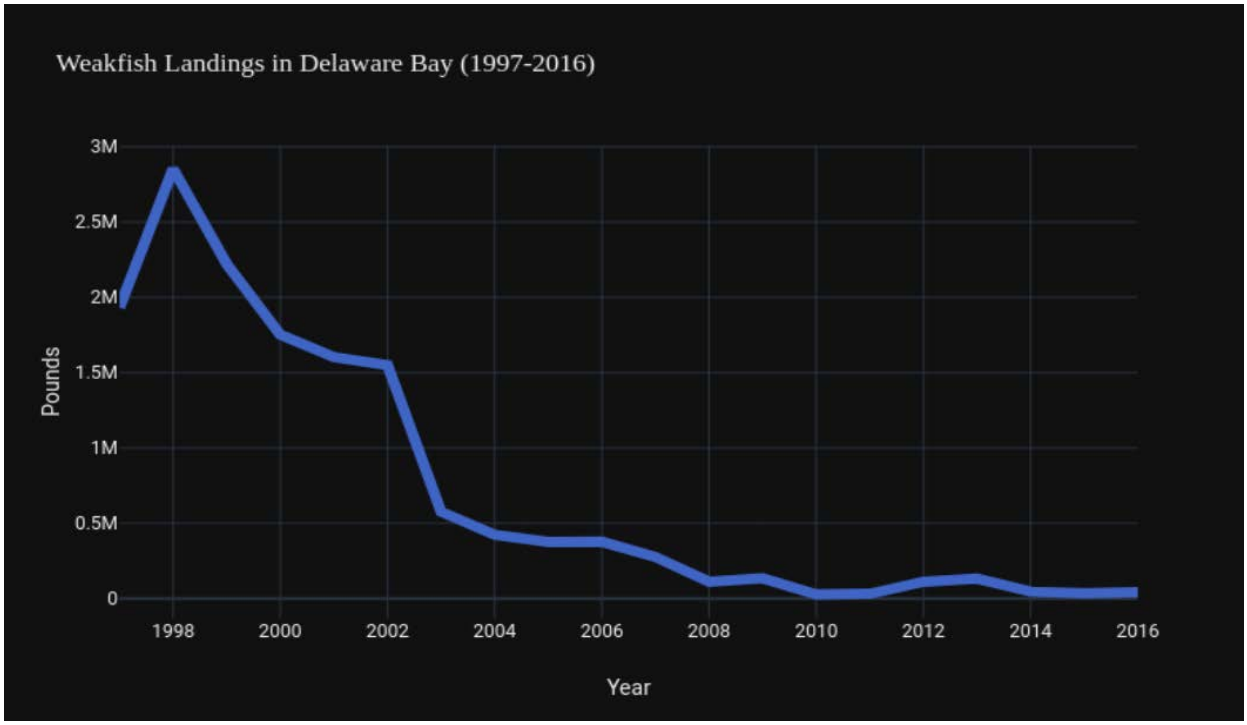

Figure 5. Weakfish populations in the Delaware Bay have crashed concurrently with horseshoe crab populations.

Sport fish, including striped bass (*Morone saxatilis*), summer flounder *(Paralichthys dentatus*), and winter flounder (Pleuronectes americanus), feed on horseshoe crab eggs and larvae.[195]

[193]Shuster *et al*. 1982. 133-154.
[194]Horseshoe Crab Recovery Coalition 2023.
[195]*Ibid.*

Leopard sharks (*Triakis semifasciatum*) have also been documented preying on adult horseshoe crabs.[196]

Other species

Diamondback terrapins (*Malaclemys terrapin*)—listed as vulnerable by the IUCN with decreasing populations, and state-listed across the Atlantic region—also feed on horseshoe crab eggs.[197]

The American eel (*Anguilla rostrata*), listed as endangered on the IUCN Red List, is experiencing historic lows in population levels. The decline is attributed to multiple factors, including alterations in the food web. Horseshoe crab eggs, a significant food source for eels, were abundant when both populations thrived.[198]

Most crab species, including blue crabs, feed on horseshoe crab eggs and larvae.[199] Abalones, periwinkles, sea snails, and other gastropods rely on horseshoe crabs, their eggs, or larvae as a food source. Shrimp also feed on horseshoe crab eggs and larvae. These organisms, in turn, are crucial for fish and shorebirds whose populations are in decline. The horseshoe crab population decline has cascading effects across marine and terrestrial life.[200]

[196]Shuster *et al*. 1982. 133-154.
[197]*Ibid.*
[198]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 5-7.
[199]Shuster *et al*. 1982. 133-154.
[200]*Ibid.*

THREATS

To be listed under the Endangered Species Act, a species must meet one of the factors enumerated in section 4(a):

(A) the present or threatened destruction, modification, or curtailment of its habitat or range;
(B) overutilization for commercial, recreational, scientific, or educational purposes;
(C) disease or predation;
(D) the inadequacy of existing regulatory mechanisms;
(E) Other natural or human-made factors.

The agency's review and determination must be based solely on the best scientific and commercial data available.

The American horseshoe crab clearly meets four of the factors for listing. The threats facing the American horseshoe crab include habitat loss and destruction, overutilization by bait and blood industries, inadequate regulatory mechanisms, and other natural or human-made factors such as impacts from climate change.

Present or threatened destruction, modification, or curtailment of habitat or range

Horseshoe crab coastal habitat throughout a significant portion of its Atlantic and Gulf coast range is being destroyed and degraded by development, dredging, shoreline hardening, erosion, pollution, recreational use, and climate-driven sea level rise and extreme weather.

Atlantic and Gulf coasts and waters provide critical habitat throughout the life cycle of the horseshoe crab. The majority of the horseshoe crab's life cycle is spent in the ocean, either along the continental shelf or in deep water bays as far as 35 miles from the coast and depths of 200 meters, though the average depth of adult habitation is less than 20 meters.[201] Studies from Mark Botton and colleagues suggest that horseshoe crabs may be particularly sensitive to and slow to recover from changes in habitat geomorphology.[202] Both the horseshoe crab's beach and marine habitats are being

[201]The IUCN Red List of Threatened Species 2016. 18.
[202] Botton *et al*. 2018.

rapidly destroyed and degraded. Horseshoe crab habitat—especially spawning habitat—has shrunk significantly throughout a significant portion of its range.[203]

According to the IUCN, horseshoe crab populations are significantly imperiled because of habitat loss from coastal reclamation and development. Shoreline alterations that are engineered to protect beaches from erosion and sea level rise due to climate change also affect their spawning habitats.[204]

The IUCN considers most horseshoe crab populations specifically identifies habitat loss to development, climate change, and sea level rise as principal factors that "prevent [the horseshoe crab] from being functional save for a few spatial units."[205]

In 2023, the IUCN added a green status process for analyzing the recovery potential of red-listed species. The horseshoe crab's green status was moderately depleted and given a zero chance of recovery in the next century: "Given the pressures of climate change, which affects spawning cues, and sea level rise, which reduces available spawning habitat, the species is expected in 100 years to lose…short-term gains, giving it a Recovery Potential of Zero."[206]

A 2023 analysis of the horseshoe crab's Green Status Assessment also found that current management and conservation of horseshoe crabs "is not expected to mitigate habitat loss at the scale required to restore range-wide ecological functionality, primarily because habitat loss is widespread and affected by climate change."[207] Habitat loss is a clear existential threat to the survival and recovery of the American horseshoe crab. The authors conclude: " The Green Status Assessment results, while indicating that there is potential for near-term recovery gains, reveal that long-term recovery is in doubt owing to expected loss of habitat."[208]

Habitat loss and degradation due to development

Habitat loss is occurring throughout a significant portion of the American horseshoe crab's range along the Atlantic and Gulf coasts. Coastlines are one of the major focal points of human activity in the United States, accounting for 10% of the nation's contiguous land mass and 40% of the population.[209] Some of the country's most populous coastal areas are also critical horseshoe crab habitat, and many human

[203]Lipcius Expert Report. 5-6.
[204] IUCN 2022.
[205] IUCN 2022.
[206] IUCN Green Status Assessment 2023.
[207] Smith et al. 2023. 1-2.
[208] Ibid.
[209]National Oceanic and Atmospheric Administration. 2013. *National Coastal Population Report: Population Trends from 1970 to 2020*. 4-5.

activities significantly threaten the species.[210] Urbanization that alters shorelines can eliminate spawning and nursery or foraging habitat by reducing the area of sandy beach.[211]

Shoreline hardening, for example, is commonplace for property owners along the coast who use barriers like walls or berms to shore up their beaches.[212] In the Mid-Atlantic and Northeast coast of the U.S., up to 50% of the shoreline has been reinforced with shoreline hardening.[213] These reinforcements "can eliminate or fragment intertidal beaches," critical habitat for spawning horseshoe crabs.[214]

Near the Delaware Bay, a crucial horseshoe crab spawning area,[215] a study conducted on the effects of infrastructure on the sandy beaches of the Eastern Shore demonstrated "that many of the bulkheads reduce horseshoe crab spawning habitat" by extending deep into the water and cutting portions of habitat away from its natural ebb and flow.[216]

A study conducted in the 1980s on the New Jersey side of the Delaware Bay found that only about 10% of that shoreline remained optimal spawning habitat for horseshoe crabs, and that figure has almost certainly declined further in the past four decades of more intense coastal development.[217]

Historically, horseshoe crabs could adapt to rising seas and changing shorelines by moving further inland with the water. However, today they are hemmed in by highways, development, and human infrastructure.[218]

Sand and sediment captured by coastal infrastructure can have deleterious effects on beaches far down the coastline, trapping material that would naturally flow along the coast and replenish beaches with vital "beach building material."[219]

Along the Atlantic coast, natural, energy-absorbing beach habitats such as sand dunes have been replaced by urban development. Despite robust beach restoration efforts, New Jersey has lost miles of shoreline to erosion.[220] Connecticut has experienced a 60% loss of marsh habitat and beach.[221] Beaches and shorelines across the Atlantic and Gulf Coasts have been degraded and destroyed.[222]

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[210]The IUCN Red List of Threatened Species 2016. 22.
[211] Hopkinson and Vallino 1995.
[212]Hartley and Weldon 2020. 17.
[213]*Ibid.*
[214]Jackson *et. al.* 2015. 1.
[215]The IUCN Red List of Threatened Species 2016. 4.
[216]Jackson *et. al.* 2015. 8.
[217]IUCN Horseshoe Crab Report. 22.
[218]Tim Dillingham, pers. comm. February 2, 2024.
[219]Kemper 2017.
[220]Mark Botton. Pers. comm. February 1, 2024.
[221] Jo-Marie Kasinak. Pers. comm. Feb 1, 2024.
[222]Marshall & Banks. 97.

Beach replenishments along the Atlantic and Gulf coasts often have different sand composition, dimensions, and grain size from those of natural beaches, which affects horseshoe crab egg abundance.[223] A 2020 study found that beach replenishments with sand grains finer than the natural beach had lower egg cluster abundances.[224] Fine-grained sand beaches are often characterized by greater compaction and lower dissolved oxygen, which may be contributing factors to the lower horseshoe crab egg abundances in these areas.[225] Beach nourishment and replenishment projects have become more frequent in the past 50-70 years and will likely continue to affect horseshoe crab spawning beaches for the foreseeable future.[226]

Development also increases the amount of impervious surfaces, which leads to increased runoff and changes to water chemistry. These changes affect sediment grain size and moisture, which can further affect horseshoe crab spawning behavior and egg development.[227]

The presence of beach structures can also reduce the accumulation of wrack on sandy shorelines.[228] Wrack consists of ocean vegetation, such as seaweed, which accumulates on beaches and provides critical nutrients for species like the American horseshoe crab. Wrack serves as food for small herbivores, amphibians, and insects which are then eaten by larger animals, thereby "transfer[ing] nutrients and energy into higher trophic levels and providing habitat.[229]

Horseshoe crabs are highly sensitive to and slow to recover from changes in habitat geomorphology. The increase in bare land and impervious surfaces, along with associated runoff and alterations to water chemistry driven by urbanization can impact sediment characteristics and moisture levels. These changes, in turn, influence horseshoe crab spawning behavior and egg development. Urban pollutants like heavy metals and contaminants that compromise water quality may impede the development and cause deformities in juvenile horseshoe crabs.[230]

Sand mining, the world's leading mine endeavor, can also wreak havoc on coastal ecosystems.[231] Horseshoe crab beaches and habitat in the eastern United States have had "entire beaches and dune systems… stripped bare," leaving large pits or flats that expose shoreline habitat to unmitigated storm surges and erosion.[232]

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[223]Smith J et al. 2020. 101-104.
[224] *Ibid.*
[225]*Ibid.*
[226] Qiu et al. 2020. 1-4.
[227]Paule-Mercado *et al.* 2017. 1-4.
[228]Jackson, *et. al., supra* note 20 at 5749.
[229]Marshall & Banks 2013. 95.
[230]Estes MG, Jr., Carmichael RH, Chen X, Carter SC. 2021. 2.
[231]Pearce 2019.
[232]*Ibid.*

Dams along the rivers of the Eastern United States have further decreased the sediment load that naturally flows to the Atlantic, causing erosion along tidal flats used by horseshoe crabs.[233] Once sandy beaches are left devoid of necessary fill, either because such material has been captured up the coast, stripped from the beach itself, or washed away by unimpeded storm surges. Egg-laying horseshoe crabs avoid degraded areas, which result in failed nests or developmental deficiencies among their clutches.[234]

Power plant development in coastal areas also results in habitat loss and horseshoe crab mortality. Power plant intakes can be particularly lethal to horseshoe crabs.[235] Two studies conducted along the Indian River in Florida found that tens of thousands of horseshoe crabs were killed after being sucked into the intake screens used by two power plants, a level of mortality that "can be a major threat to localized populations.[236]

Habitat loss and degradation due to dredging and deepening

Several East Coast ports have deepened their channels to accommodate larger ships that can pass through the Panama Canal since it was enlarged in 2016. Ports that have been deepened in the past decade include Boston, Mass., Charleston, S.C., Savannah, Ga., Jacksonville, Fla., and Port Everglades, Fla. In addition, New York and Baltimore deepened their channels to 50 feet. Congress has authorized Norfolk, Va., to deepen up to 55 feet, the deepest on the East Coast. The Port of Wilmington, N.C., is also planning to deepen its channels. All of these deepening projects have occurred or will occur in horseshoe crab habitat.[237]

Dredging occurs even more frequently in inlets, bays, and estuaries across the horseshoe crab's range, and rates of dredging have been increasing.[238]

Dredging and deepening projects have a direct impact on horseshoe crabs and their habitat. Horseshoe crabs often overwinter in the deep mud of bays and port areas. A 2010 study concluded that horseshoe crabs are routinely entrained in the course of dredging operations.[239] Horseshoe crabs occur frequently in inlets and navigation

[233]Miththapala, Sriyanie. 2013. *Tidal Flats*, 5 Coastal Ecosystem Series. 28. https://portals.iucn.org/library/sites/library/files/documents/CES-005.pdf.
[234]The IUCN Red List of Threatened Species 2016. 13-15.
[235]The IUCN Red List of Threatened Species 2016. 22.
[236]*Ibid.*
[237]Port of Philadelphia 2018.
[238]MarineLink 2023.
[239]Ray and Clarke 2010.

channels where dredging routinely takes place, and "substantial numbers of horseshoe crabs have been observed in hopper dredges."[240]

Loss of beach and tidal flat habitat

In the early stages of the horseshoe crab's life cycle—from egg to larvae to juvenile—undisturbed tidal flats are critical incubators and nurseries. Without these tidal flats, individual animals cannot mature. Similarly, tidal flats are essential to the late stages of horseshoe crab's life cycle—sexual maturity and reproduction—serving as the locus of reproduction and fertilization.

A 2019 study concluded that "tidal flats have declined by 16.02% since 1984," a loss of 0.55% of the total tidal flats every year.[241] The areas of tidal flat loss over the past three decades overlap with the entirety of the American horseshoe crab's range. Based on this data and the numerous stressors driving tidal flat loss, the researchers estimate maintenance and rehabilitation of tidal flats "has not occurred at a rate or scale required to offset ongoing losses," requiring "[w]idespread and substantial conservation actions."[242]

U.S. beaches rank the sixth most threatened globally by erosion, with approximately 2,451 miles of beaches threatened by erosion by 2050 and 3,436 miles by the end of the century.[243] Of the 20 U.S. counties with the worst coastal erosion, all 20 are counties where horseshoe crabs have spawned.[244]

Impingement

Horseshoe crabs can become stranded, overturned, or trapped in human-made structures or impingement hazards. Impingement can be a significant source of horseshoe crab mortality, especially near developed coastal infrastructure. For example, an impingement study conducted at two power plants along Florida's Indian River lagoon recorded more than 90,000 horseshoe crabs trapped on power plant intake screens over a 12-month period.[245] University of Florida professor Dr. Jane Brockmann described power plant mortality as a "very big concern" for the American horseshoe crab.[246] Adults can be trapped against intake screens by inflowing water, where animals are subject to physical stresses and/or suffocation sometimes resulting in death. Individuals small enough to pass through the intake screen's mesh, like larvae or eggs, are brought through the cooling water system along with water flow, whereby organisms are subject to potential mortality resulting from exposure to mechanical stresses,

[240] *Ibid.*
[241] Murray *et al*. 2019. 222-223.
[242] *Ibid*. 224.
[243] Vousdoukas *et al.* 2020. *Sandy Coastlines under Threat of Erosion*, 10 Nature Climate Change. 260, 263.
[244] *Ibid.*
[245] IUCN Red List 2022; Indian River Lagoon Study 1980.
[246] Jane Brockmann, pers. comm., January 19th, 2024.

elevated water temperatures, and/or biocide treatments.[247] Horseshoe crab mortality due to power plants has been observed throughout the species' range. Maryland's Calvert Cliffs Power Plant historically impinged a "substantial number" of American horseshoe crabs annually.[248] Horseshoe crab impingement was also observed at a power plant in Connecticut.[249]

After Hurricane Sandy, impingement hazards were widespread across Delaware Bay. Rubble, pilings, and concrete slabs significantly reduced horseshoe crab spawning habitat.[250] Between 2017-2021, more than 138,000 were impinged by rubble, riprap, rams, and houses, and other anthropogenic impingements in New Jersey alone.[251]

Pollution from oil spills

Since 2017, the Atlantic and Gulf Coasts of the United States have experienced an increase in oil shipped via tanker from the Gulf of Mexico.[252] While major spills are infrequent, hundreds of small oil spill incidents have occurred directly adjacent to or on the Eastern Seaboard over the past few decades.[253] In the past fifty years alone, nine oil spills have independently released over 10,000 gallons into Delaware Bay — the most recent of which spilled over a quarter million gallons.[254]

Delaware Bay is especially vulnerable to oil spills.[255] Delaware Bay is a major port for Philadelphia, but crude oil tankers cannot navigate up the Delaware River to reach the city. Instead, they unload their crude oil onto smaller vessels that can transport them to refineries near the Port of Philadelphia.[256] The unloading process—referred to as lightering—carries increased risk of oil spills in the Delaware Bay.[257]

Several studies have shown the significant negative effects of oil on horseshoe crabs. Horseshoe crabs are especially vulnerable to the effects of oil pollution when sand-bound eggs are developing.[258] Tests reveal that certain levels of oil in the water cause "higher rates of oxygen consumption" in larval-stage horseshoe crabs, indicating metabolic stress for the animals.[259] Further, a study using "Bunker C oil" found that at least twenty-five percent of the animals exposed did not survive, and "there was a significant lengthening of the intermolt period" between several life stages of horseshoe

[247]Dixon 2003. 1-2.
[248]2015 Maryland FMP Report. 3.
[249]Jo-Marie Kasinak, pers. comm. 2024.
[250]Wetlands Institute 2019.
[251]ReTURN the Favor 2023.
[252]U.S. Energy Information Admin. 2018.
[253]National Oceanic and Atmospheric Admin., *Incident Map*, https://incidentnews.noaa.gov/map.
[254]Botton & Itow 2009. 439, 441.
[255]Mark Botton, pers. comm. February 1, 2024.
[256]Port of Philadelphia. 2018.
[257]Mark Botton, pers. comm. February 1, 2024.
[258]Mark Botton, pers. comm. February 1, 2024.
[259]Botton & Itow 2009. 442.

crabs.[260] Another study noted a decrease in hatching success in horseshoe crab eggs when exposed to 50% water-soluble fraction of No. 2 fuel oil. Additionally, they observed metabolic stress among 2nd instar horseshoe crab larvae at lower concentrations, specifically in the range of 5–10% water-soluble fraction. Heavier residual oils can also have adverse effects on larval development and survival, with a documented minimum lethal dose of 2.25 mg/l in suspension.[261]

Pollution from other sources

Water quality in urban estuaries is frequently impacted by various forms of pollution, including municipal, industrial, and nonpoint source pollutants carried by stormwater runoff and groundwater discharges. Common pollutants encompass a range of biotic stressors such as heavy metals, pesticides, pharmaceuticals, plastics, and raw sewage. This pollution can alter nutrient cycling, leading to significant fluctuations in algal and bacterial populations and seasonal declines in dissolved oxygen levels, known as hypoxia. Urban pollutants such as heavy metals and other contaminants compromising water quality can impede the development of and cause deformities in juvenile horseshoe crabs.[262] These prevalent conditions in urban seas may have detrimental effects on the developmental success of horseshoe crab eggs, the growth and survival of juveniles, and the overall survival of adult horseshoe crabs.[263]

A study on *Tachypleus tridentatus,* one of four horseshoe crab species, found individuals were negatively impacted when exposed to PET (polyethylene terephthalate) microplastics. Toxic additives in PET can be lethal to horseshoe crabs.[264] Both high-density and low-density microplastics pose a threat to benthic organisms like the horseshoe crab.[265] Given the prevalence of microplastics in the ocean and horseshoe crab nursery grounds, PET pollution could pose a significant threat to the species — a 2015 study taking place in the Atlantic Ocean revealed both inputs and stocks of ocean plastics to be far higher than previously estimated. Within the top 200 meters of the Atlantic Ocean, the study identified 12 to 21 million tonnes of microplastics from three major plastic types, constituting roughly 5% of the ocean. This implies an overall concentration of about 200 million tonnes of these common plastics in the Atlantic.[266]

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[260] *Id.*
[261] Smith *et al.* 2017. 155.
[262] Estes MG, Jr., Carmichael RH, Chen X, Carter SC. 2021. 2.
[263] J.H. Mattei *et al.* 2015. 538.
[264] Fang *et al.* 2023. 5.
[265] *Ibid.*
[266] Pabortsava & Lampitt 2020. 1.

As a result of coastal pollution, American horseshoe crab eggs contain metal and metalloids — such as chromium, cadmium, lead, mercury, arsenic and selenium.[267] Such contaminants are indicators of toxic exposure in female crabs and may pose a threat to species consuming horseshoe crab eggs.[268] Previous laboratory experiments with Atlantic horseshoe crab larvae revealed mortality and developmental effects when exposed to heavy metals.[269] Different metals exhibited varying impacts on survival, molting, and regeneration, with Hg showing the greatest effects, followed by Cd, Cr, and copper. Additional studies also indicated that metals can inhibit limb regeneration. Studies focusing on the tri-spine horseshoe crab (*Tachypleus tridentatus*) revealed the highest metal concentrations in the animal's gills, where there were effects on antioxidant parameters, particularly during recovery periods. Laboratory experiments demonstrated developmental abnormalities in both the tri-spine horseshoe crab and the Atlantic horseshoe crab when exposed to metals. Researchers have also documented effects on growth and hemolymph quality in tri-spine horseshoe crabs exposed to metals. Coastal pollution is known to have contributed to the decline of the Japanese horseshoe crab[270] — the potential impacts of metal pollution on the American horseshoe crab could be significant and detrimental.

Delaware Bay waters are increasingly polluted by the chemical industry, factory farms, slaughterhouses, and suburban sprawl. Reports filed with the Environmental Protection Agency (EPA) indicate that Delaware has classified the highest percentage of its rivers and streams as impaired compared to any other state in the U.S. Specifically, 97 percent of the state's 1,104 miles of assessed waterways are listed as impaired for one or more uses. Furthermore, all 775 square miles of assessed estuaries in Delaware are reported to be impaired,[271] and 100% of estuaries are considered impaired for aquatic life.[272] Delaware's rivers and streams are plagued by a variety of pollutants — fecal bacteria, nitrogen, phosphorus, pesticides, PCBs, and dioxins. The state's water and sewage infrastructure has struggled to keep pace with the surge in residential and commercial real estate growth that occurred in the late 1990s and early 2000s.[273]

Further, urban estuaries, along with adjacent harbors and beaches, are subject to artificial light pollution — a 2010 survey of nightly light pollution in coastal areas revealed that Asia and North America ranked second and third, respectively, in terms of the largest areas affected by light pollution globally.[274] Established and potential impacts

[267]Burger 2023. 1.
[268]*Ibid.* 8.
[269]*Ibid.* 9.
[270]*Ibid.* 8.
[271]Kelderman *et al.* 2022. 37.
[272]*Ibid*. 38.
[273]*Ibid.*
[274]J.H. Mattei *et al.* 2015. 540.

of light pollution on estuarine biota include disruptions in reproductive cycles, diminished survival rates, and alterations in predator-prey interactions.[275] Changes in light exposure may influence the circadian or circatidal rhythms in horseshoe crabs.[276]

Harmful algal blooms

Red tides — harmful algal blooms resulting from unusually high concentrations of dinoflagellates — are a known occurrence in nearshore areas of the Gulf and Atlantic coasts. Red tides caused by *Karenia brevis* are common in southwest Florida and the Yucatán Peninsula, where horseshoe crabs are prevalent. Periodic red tides along Florida's west coast have been observed, impacting various species, including young horseshoe crabs.[277] The blooms stem from nutrient pollution from domestic, industrial and agricultural wastes, as well as climate change and water management decisions. In Florida, the U.S. Army Corps of Engineers routinely discharges algae-laden water from Lake Okeechobee into the Caloosahatchee and St. Lucie rivers and estuaries. The algae produce cyanotoxins, which threaten human health and wildlife.

In July 1999, an estimated 100,000 adult *Limulus polyphemus* died in the northern part of Florida's Indian River and the southern portion of Mosquito Lagoon due to a red tide event. In the Yucatán Peninsula, red tides are frequent, with notable events occurring in 2003, 2008, and 2011. These incidents were attributed to blooms of *Scripsiella trochoidea, Cylindrotheca clostridium,* and *Nitzchia longissima*. Severe impacts of harmful algal blooms on commercially important fish and benthic organisms have been reported on the northern coast of Yucatán, including octopus (*Octopus maya*) and sea cucumbers (*Isostichopus badionotus*); it is likely horseshoe crabs suffer the same negative effects.

Harmful algal blooms have been increasing in frequency and severity along the Atlantic and Gulf Coasts where horseshoe crabs occur. Favorable conditions for blooms include warm waters, changes in salinity, increases in atmospheric carbon dioxide concentrations, changes in rainfall patterns that intensify coastal upwelling, sea level rise, and high nutrient levels—all issues exacerbated by climate change.[278]

[275] *Ibid.*
[276] *Ibid.*
[277] Smith *et al.* 2017. 155.
[278] Totoiu and Lopez. 2022.

Overutilization

Horseshoe crabs are primarily harvested for bait and for blood. Both harvests have resulted in significant declines in horseshoe crab populations and health, and they both represent major threats to the species' long-term survival.

Gregory Breese/USFWS

Overutilization for blood

Harvests of horseshoe crabs for blood by the biomedical industry have doubled since 2017 and climbed to nearly 1 million horseshoe crabs annually in 2022.[279] There are no quotas on blood harvests except in Massachusetts, and no limitations on when and where they can be harvested. Both females and males can be harvested for blood, and the harvests can occur at any time of year—including during mass spawning events each spring. Because females are larger with more blood, they are targeted by the biomedical industry.

[279]ASMFC. November 2022 Annual Meeting: Horseshoe Crab Slideshow.

The blue blood of all horseshoe crab species is highly unique in its sensitivity to bacterial endotoxin.[280] Biomedical take of the American horseshoe crab began in the early 1900s when the crabs were used in research on the human eye, for surgical suture wound dressing, and bacterial endotoxin detection.[281]

Currently, the predominant use of the American horseshoe crab by the biomedical industry is to develop Limulus Amebocyte Lysate (LAL), a clotting agent in horseshoe crab blood used to test drugs, patients, and intravenous devices for bacterial endotoxins.[282] The LAL test was commercialized in the 1970s and remains the standard to test intravenous medical devices for bacterial contamination.[283]

Biomedical companies harvest horseshoe crabs by hand or by trawl.[284] First, harvested crabs are inspected to remove injured or nearly dead crabs, after which the remaining individuals are transported to a bleeding facility.[285] After a portion of their blood is extracted, horseshoe crabs are released alive, typically near the location of their capture.[286]

An estimated 244 males or 96 females are required to extract one quart of LAL, which sells for more than $15,000 commercially.[287]

Six companies along the Atlantic Coast have harvested and bled horseshoe crabs within the time period from 1999-2017: Associates of Cape Cod, Limuli Laboratories, Lonza, Wako Chemicals, Heptest Laboratories, and Charles River Laboratories.[288] In addition, Charles River Laboratories has expanded its operations and built new facilities near Chincoteague, Virginia, and Cape Cod, Massachusetts.

The number of horseshoe crabs taken by the biomedical industry has increased from 335,501 in 2004 to over 700,000 in 2021.[289] In 2022, the Atlantic States Marine Fisheries Commission reported that the total number of horseshoe crabs harvested for blood climbed to nearly 1 million.[290]

This massive growth in horseshoe crab harvests for blood has occurred despite the availability of proven effective synthetic alternatives to endotoxin detection, including

[280]Banerjee & Mitra 2017. 52.
[281]Shuster, C. N. Jr. 1950. 18-23.
[282]ASMFC 2019 Horseshoe Crab Stock Assessment. 35.
[283]*Ibid.*
[284]*Ibid.*
[285]*Ibid.*
[286]*Ibid.*
[287]HCRC 2023.
[288]ASMFC 2019 Horseshoe Crab Stock Assessment. 35.
[289]Eisner, Chiara. 2023.
[290]ASMFC. November 2022 Annual Meeting: Horseshoe Crab Slideshow.

recombinant Factor C (rFC).[291] Other synthetic alternatives that do not require the use of horseshoe crab blood include the Recombinant Cascade Reagent (rCR) and the Monocyte Activation Test (MAT). In 2023, the U.S. Pharmacopeia announced a draft chapter on endotoxin testing that provides techniques and guidelines for using these non-animal-derived reagents and would allow their use in the United States. The European Pharmacopoeia endorsed the use of rFC in 2019.

However, biomedical industries plan to continue bleeding horseshoe crabs even with synthetic alternatives, and Charles River Laboratories, the world's largest bleeder of horseshoe crabs, recently expanded, building a new facility in Massachusetts. Horseshoe crab harvests for blood have tripled since 2004.[292]

In 1998, the ASMFC's Interstate Fishery Management Plan for horseshoe crabs (FMP) set a bleeding mortality threshold of 57,500 horseshoe crabs.[293] However, with the exception of 2016, the 57,500 mortality threshold has been surpassed every year since 2007, and the management board has never taken action.[294]

The ASMFC uses a 15% post-bleeding mortality rate for horseshoe crabs harvested for blood.[295] However, there are several reasons to doubt the accuracy of a fifteen-percent mortality rate in capturing the true impact on the horseshoe crab population.

First, there are few long-term studies or studies that work with biomedical facilities to mimic their handling of the horseshoe crabs.[296] Records indicate that fishers paid by pharmaceutical companies handled the crabs in ways known to cause harm.[297]

Second, there are other negative effects on the population that the mortality rate does not consider. Sublethal effects of bleeding on American horseshoe crabs have been recorded, including diminished activity. At the population level, instances of reduced spawning have been noted in regions exclusively accessible for biomedical harvest.[298]

The mortality rate of horseshoe crabs, following the removal of up to 40% of their blood and subsequent handling and transport could range up to 30%. A mortality study

[291]Maloney, Phelan, & Simmons 2018. 1.
[292]ASMFC. November 2022 Annual Meeting: Horseshoe Crab Slideshow.
[293]ASMFC 2019 Horseshoe Crab Stock Assessment. 36.
[294]*Ibid.*
[295]ASMFC 2019 Horseshoe Crab Stock Assessment. 36.
[296]ASMFC 2019 Horseshoe Crab Stock Assessment. 36.
[297]Eisner, Chiara. 2023.
[298]Smith *et al.* 2017. 152.

conducted by the Massachusetts Division of Marine Fisheries, comparing unbled crabs to those bled by the Associates of Cape Cod, revealed a 30% mortality rate.[299] Mortality rates of bled horseshoe crabs is double those used in current management of the biomedical harvest.[300] As a result, biomedical harvest mortality data is artificially and inaccurately lower in the ARM model used to determine harvest quotas.

Horseshoe crabs depend on their blood pressure for movement, making the impacts of blood drainage all the more detrimental.[301]

Evidence is accumulating that mortality of bled horseshoe crabs is even higher than current estimates; that females may have an impaired ability to spawn following bleeding and release; and that bled crabs become disoriented and debilitated for various lengths of time following capture, handling, bleeding and release.[302]

Several studies in Massachusetts have explored the health and reproductive implications of horseshoe crabs after bleeding. Crabs have been observed disorientated post-bleeding and researchers have suggested potential impacts on reproductive capability. Effects on movement and activity, along with decreases in hemocyanin levels in bled crabs led researchers to conclude that sub-lethal effects from LAL extraction could reduce fitness and reproduction. Another study found that bled female horseshoe crabs approached mating beaches less frequently than controls, with the most significant impacts observed 1-2 weeks after bleeding.[303]

Another study detailed the detrimental effects of biomedical take beyond the direct impacts of bleeding. Blood loss may not emerge as the primary cause of death; instead, a combination of factors, including capture, handling, and transportation, may play a more significant role. The biomedical harvesting process typically involves dragging trawls along the shallow seabed to collect horseshoe crabs, which are then stacked on the boat's bed. Subsequently, crabs are transferred into plastic storage containers or bins, where they remain for extended periods. Throughout this procedure, crabs can experience crushing under the weight of other individuals, leading to broken telsons and cracked shells. Crabs are also at risk of accidental impalement by neighboring crabs' telsons. When assessing overall mortality, it is crucial to consider these aspects rather than relying solely on estimations.[304]

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[299]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 14.
[300]Leschen and Correia 2010. 135.
[301]Jane Brockmann pers. comm. January 19, 2023.
[302]Novitsky 2015. 483.
[303]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 14.
[304]Krisfalusi-Gannon *et al.* 2018. 4.

Crab containment ponds present yet another threat to the American horseshoe crab not accounted for in mortality assessments. American horseshoe crabs harvested in South Carolina are often placed in containment ponds, where shorebirds cannot access eggs and crabs are barred from spawning on beaches. Crabs are stored in ponds for weeks or months at a time before transport to bleeding facilities.[305] Ponds can hold 10,000-15,000 crabs, and individuals are not fed. Thousands of crabs “spawn in vain” — where billions of eggs could be lost annually — and experience unsanitary and crowded conditions.[306] 75% of crabs are held in such ponds before bleeding in South Carolina.[307]

Commercial bleeding facilities use holding ponds so that horseshoe crabs can be bled multiple times. A 2023 legal settlement prohibited female horseshoe crabs from being kept in holding ponds, but male horseshoe crabs can still be kept in holding ponds for multiple bleedings.[308] The 2023 legal settlement expires in five years, when it may or may not be extended.

Additionally, the proposed Best Management Practices (BMPs) for horseshoe crab blood harvests lack provisions to prevent crabs from being bled more than once in a single season, and the impact of multiple bleedings on crab mortality remains unknown.[309]

Additionally, due to the horseshoe crab's circulatory system design — which is open with no separate veins and capillaries connected to arteries for hemolymph circulation back to the cardiac sinus — once the cardiac sinus and 11 major arteries are emptied, blood flow slows to a drip or halts completely.[310] Using gravity flow instead of vacuum aspiration removes no more than 30% of an individual crab's total blood.[311] Although gravity flow has seemingly become an industry standard, the secrecy surrounding the biomedical industry and the lack of provisions in the BMPs make it unclear whether this method is universally employed.[312] Although equations quantifying the amount of blood that can be extracted from a single crab exist, relying on this information to establish a connection between the removed blood volume and mortality or other physiological impacts is deemed unreliable — the variability in the amount of blood taken from an individual crab remains highly unpredictable.[313]

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[305]Boyles *et al.* 2021. 2.
[306]Hunt 2022. 19.
[307]*Ibid.*
[308]SELC 2023.
[309]Novitsky 2015. 494.
[310]*Ibid.*
[311]*Ibid.*
[312]*Ibid.*
[313]*Ibid.*

A comprehensive evaluation of various parameters is necessary to gauge overall mortality accurately. This includes factors such as broken telsons, cracked shells, and unintentional impalement during the collection and storage process. Moreover, assessing the well-being of recently bled horseshoe crabs over an extended period beyond the standard 6-week assessment could offer more reliable insights into morbidity. Such a prolonged survey duration allows for a more thorough understanding of the potential impacts of the biomedical harvesting practices on horseshoe crab populations.[314] Current morbidity estimates do not take these long-term and critical factors into account.

The stress induced by extracting horseshoe crabs from the water during harvesting can be particularly detrimental to the species. Horseshoe crabs rely on a set of gills and hemocyanin for oxygen transport; the gills primarily serve to supply oxygen, not to eliminate carbon dioxide. As carbon dioxide is soluble in water, its removal is efficient when the crab is in an aquatic environment. However, when removed from water, crabs cannot effectively eliminate carbon dioxide, leading to an abnormal hemolymph pH.[315]

While these creatures can endure low-oxygen environments through physiological adaptations — such as a significant reduction in heart rate and increased oxygen affinity to hemocyanin — just 5 minutes out of water can result in severe hypoxia and metabolic acidosis.[316] Studies have demonstrated that after 24 hours of transportation without water, horseshoe crabs exhibit extreme respiratory acidosis.[317]

Studies have revealed the impact of hypoxic conditions on various marine organisms to be an average reduction of 74% in survival times when subjected to hypoxia. This phenomenon has been linked to diminished stamina in hermit crabs and alterations in fish migration patterns and distances. Extrapolating from these observed effects, it is conceivable that horseshoe crabs may experience similar consequences, with oxygen deprivation disrupting normal physiological functions, including spawning, even after their return to their natural habitat.[318]

Subjecting horseshoe crabs to elevated temperatures during capture or transportation also has detrimental effects on both blood quality and the overall health of horseshoe crabs. Crabs exposed to the highest temperature (23°C) experienced the most significant body weight loss, with some individuals perishing under the conditions.[319]

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[314]Krisfalusi-Gannon *et al.* 2018. 4.
[315]*Ibid.*
[316]Krisfalusi-Gannon *et al.* 2018. 4.
[317]*Ibid.*
[318]*Ibid.*
[319]*Ibid.*

The concentrations of hemocyanin and amebocytes exhibited an inverse relationship with temperature, as crabs in higher temperatures showed lower concentrations. Although amebocyte density decreased across all temperatures, the steepest decline occurred at the highest temperatures, with a 71.7% decrease in crabs held at 23°C, accompanied by noticeable morphological changes in the amebocytes.[320]

The bleeding process in horseshoe crabs can also lead to behavioral changes. Studies have documented alterations in horseshoe crab behavior persisting for up to two weeks post-harvesting, including slower walking, a 33–66% reduction in overall activity, and a diminished expression of tidal rhythms governing movement and spawning activity. Harvesting, especially during spawning when crabs are easily accessible on the beach, may decrease the spawning activity of females, with some exhibiting lethargic behavior and a failure to spawn upon habitat reintroduction.[321] Horseshoe crabs can feed, dig, and breed less after they are bled.[322]

Further, while coast-wide biomedical harvest data is reported to the Atlantic States Marine Fisheries Commission,[323] information on region-specific biomedical harvest is not publicly disclosed due to confidentiality agreements. This lack of transparency hinders the inclusion of mortality from biomedical activities in regional assessments and harvest management strategies. Despite biomedical harvest surpassing the *de minimis* threshold since 2007, which typically triggers regulatory attention, the ASMFC has not taken action on this exceeding threshold. Scientists have advocated for the open reporting of biomedical harvest and the revision of enforceable Limulus Amebocyte Lysate (LAL) industry best management practices (BMP) to promote the conservation of region-specific populations in embayments and beyond.[324] However, the Atlantic States Marine Fisheries Commission has refused to adopt enforceable Best Management Practices or provide more transparency.

The ASMFC has been monitoring horseshoe crab harvest mortality since 2004. Over the period from 2004 to 2012, there was a 78% surge in the number of crabs delivered to biomedical bleeding facilities, increasing from 343,126 to 611,827. Concurrently, total mortality witnessed a 75% rise. The percentage of horseshoe crabs that died before bleeding more than doubled from 2008 to 2012, potentially due to unfavorable harvest and transportation practices. Despite the ASMFC setting a maximum harvest mortality limit of 57,500, this threshold has consistently been exceeded by over 20,000 horseshoe crabs annually since 2007. Recent estimates indicate that the mortality of

[320] *Ibid.*
[321] *Ibid.* 5.
[322] Jane Brockmann pers. comm. January 19th, 2024.
[323] Smith *et al.* 2017. 152.
[324] Smith *et al.* 2017. 152.

horseshoe crabs harvested for the biomedical industry is approximately 137,000 - 273,000.[325]

The negative impacts of the biomedical harvest show in the numbers — extensively harvested areas have witnessed a decline in spawning horseshoe crabs. Spawning indices, as summarized by the Massachusetts Audubon Society from their annual surveys, indicated a decline in spawning females in Wellfleet Bay and Cape Cod Bay compared to other areas, such as Pleasant Bay, where regular surveys are conducted.[326] One particularly striking example not only showed a decline in spawning but the elimination of nearly an entire local population in the Mashnee Dike area of Buzzards Bay, MA. This specific population was essentially decimated in a relatively short period, with a 95% reduction in population between 1984 and 1999.[327]

Blood harvests by the biomedical industry include female crabs. Unlike the bait harvest, there are no restrictions or limits on the harvest of female horseshoe crabs for blood harvest. Female horseshoe crabs are larger and more desirable for biomedical harvesters because they provide more blood. The blood harvest of horseshoe crabs has a significant impact on female horseshoe crab populations, spawning, egg density, recruitment, and population declines of horseshoe crabs.

Charles River Laboratories, the largest producer of horseshoe crab blood in the United States, further influenced the obfuscation of horseshoe crab population data for the past five years.[328] A troubling arrangement existed between the South Carolina Department of Natural Resources (DNR) and pharmaceutical and animal breeding company Charles River Laboratories. Charles River paid South Carolina DNR nearly $1.5 million annually to lease an island,[329] and South Carolina DNR used the funds to pay salaries of at least 33 employees, including those of employees regulating Charles River's ventures. This financial arrangement raised significant concerns about conflicts of interest and South Carolina DNR's ability to regulate Charles River effectively. When it was made public in the media, this arrangement between Charles River Laboratories and South Carolina DNR ended in 2023.[330]

Increased demand for Limulus Amebocyte Lysate (LAL) in the coming decades could accelerate the horseshoe crab's decline. Vaccine demand is expected to expand in emerging markets, along with the excessive harvesting of Asian horseshoe crab populations. The drastic decline of Asian horseshoe crab species due to intense

[325]ASMFC 2023..
[326]Novitsky 2015. 494.
[327]*Ibid.*
[328]Bartelme and McCray 2022.
[329]*Ibid.*
[330]Bartelme and McCray 2023.

harvesting pressure and habitat destruction reveals the ease with which this ancient sea creature can be pushed to the brink of extinction. The decline of horseshoe crab species in Asia should serve as a warning to the vulnerability of the closely related American horseshoe crab.

Populations of *Tachypleus tridentatus*, a close relative of the American horseshoe crab, were “distributed extensively” until as late as the 1990s.[331] These once-robust populations, prevalent just three decades ago, are now observed to be “considerably reduced.”[332] Horseshoe crab populations are in decline across Asia due to unsustainable fishing, industrial pollution and coastal reclamation.[333]

The loss of tidal flats and sandy beaches have driven massive declines in *T. tridentatus* populations in Japan, where the species is considered critically endangered. The decline of horseshoe crab spawning grounds has led to the extinction of adult *T. tridentatus* in Kinmen Island, Taiwan. A substantial 90% decrease in the juvenile population of *T. tridentatus* in Hong Kong is likely to result in local extirpation. Gravid female-biased harvesting of *T. gigas* from Indonesia and Malaysia, exported to Thailand as a local delicacy, has significantly increased in the last decade, causing an imbalanced sex ratio in the wild. Ongoing population decline has led to a drop in the biomedical bleeding harvest of *T. tridentatus* for Tachypleus amebocyte lysate (TAL) production in mainland China from 600,000 pairs in the 1990s to the current 100,000 pairs. Recently, *T. tridentatus* has been classified as 'Endangered' on the IUCN list.[334]

Importantly, with Asian species in steep decline, *Tachypleus* species will no longer be able to feasibly support TAL production for the Asian pharmaceutical and medical device industries — meaning demand would shift onto the American horseshoe crab. The potential depletion of TAL sources is expected to redirect the global demand for amebocyte lysate toward the American horseshoe crab; Asian markets might have a need for horseshoe crab blood whereby the U.S. could end up exporting horseshoe crab blood.[335]

The near extinction of the Asian horseshoe crab species due to intense harvesting pressure and habitat destruction is a precursor to the decline of American horseshoe crab. Populations of the tri-spine horseshoe crab (*Tachypleus tridentatus)*, a close relative of the American horseshoe crab, were “distributed extensively” until as late as the 1990s.[336] These once-robust populations, prevalent just three decades ago, are now

[331] Y. Liao *et al.* 2019. 226.
[332] *Ibid*. 222.
[333] *Ibid.*
[334] John *et al.* 2020. 253.
[335] Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[336] Y. Liao *et al.* 2019. 226.

red-listed and designated endangered by the IUCN. Two other Asian species of horseshoe crab are also steeply declining and likely to be designated as endangered by the IUCN in 2024.[337]

Horseshoe crab populations are crashing across Asia due to unsustainable fishing, industrial pollution and coastal reclamation.[338] The loss of tidal flats and sandy beaches have driven massive declines in *T. tridentatus* populations in Japan, where the species is considered critically endangered. The decline of horseshoe crab spawning grounds has led to the extinction of adult *T. tridentatus* in Kinmen Island, Taiwan. A substantial 90% decrease in the juvenile population of *T. tridentatus* in Hong Kong is likely to result in local extirpation.

Ongoing population decline has led to a drop in the biomedical bleeding harvest of *T. tridentatus* for Tachypleus amebocyte lysate (TAL) production in mainland China from 600,000 pairs in the 1990s to the current 100,000 pairs. With Asian species in steep decline, *Tachypleus* species will no longer be able to feasibly support TAL production for the Asian pharmaceutical and medical device industries — likely shifting demand to the American horseshoe crab.

In addition, the increasing demands of the U.S. population, which is growing by 2.6 million people each year, and the rapidly growing medical device and vaccine industries, could lead to even more harvest of horseshoe crabs. The field of vaccine production, along with the global pharmaceutical and U.S. medical device markets, is experiencing rapid development, with annual growth rates trending towards 6–8% and 25%, respectively.[339]

Based on current rates of horseshoe crab mortality and related population trends, over the next two decades, demand for horseshoe crab is likely to reach even more unsustainable levels[340] — further endangering the long-term health and survival of the species.

Dual use of horseshoe crabs leads to increased mortality

Dual use of crabs has resulted in increased harvest and mortality in Massachusetts. Biomedical firms are permitted to participate in the dual use “rent-a-crab program” in Massachusetts where live horseshoe crabs are leased from bait dealers for bleeding and returned to bait dealers for sale as bait. The Massachusetts DMF supports the

[337] *Ibid.* 222.
[338] *Ibid.*
[339] Krisfalusi-Gannon *et al.* 2018. 10.
[340] *Ibid*. 5.

program to “maximize the utility of each horseshoe crab harvested.”[341] The theoretical premise of dual use is that every crab bled under the program would have been caught anyway for bait. In practice, dual use actually increases demand for horseshoe crabs, which increases harvests and mortality.

Dual use of horseshoe crabs creates several perverse incentives that lead to increased horseshoe crab harvests and mortality. First, dual use incentivizes biomedical companies to use bait-harvested crabs rather than biomedical-harvested crabs because it is cheaper and easier: bait-harvested crabs don’t have to be returned to the ocean. And because they are destined to be killed for bait, handling and treatment of horseshoe crabs during transport and bleeding is likely worse.

A second perverse incentive created by dual use of horseshoe crabs is that incentivizes a bigger bait harvest. If biomedical companies are willing to “rent” bait-harvested crabs, the bait harvest will increase to meet that demand. The result is more horseshoe crabs caught and killed under the 100% lethal bait program. Recent expansion of the biomedical industry in Massachusetts suggests the potential for further escalation of horseshoe crab harvests and mortality.[342]

Overutilization for bait

The bait harvest represents one of the greatest historic and ongoing threats to the American horseshoe crab. Historic harvests caused massive crashes in horseshoe crab populations; despite regulation, the species has not recovered from this devastation. The bait harvest continues today.

The harvest of horseshoe crabs extends well into the past. Historically, horseshoe crabs in Delaware Bay were harvested for fertilizer, with annual harvests ranging from 1 to 5 million dating back to the mid-1800s. In 1856, more than one million crabs were taken from a 1-mile stretch of New Jersey beach, and astoundingly, in just one year, more than four million crabs were taken from the Bay.[343] Masses of crabs were removed by horse-drawn wagon or scow and transported to plants where they were turned into ground meal.[344] By the late 1800s, there was evidence of declining populations. The harvest for fertilizer dwindled to negligible levels by the 1960s.[345]

The horseshoe crab harvest surged to high levels once again in the 1990s, mainly due to heightened demands for bait in the commercial eel and whelk fisheries — two

[341]The Commonwealth of Massachusetts Division of Marine Fisheries 2023.
[342]*Ibid*.
[343]Kreamer & Michels. 2015. 304.
[344]*Ibid*.. 306.
[345]Smith *et al.* 2017. 151.

fisheries species already in decline due to overharvesting. The American eel is red-listed by the IUCN as endangered, and whelk are also being harvested at unsustainable levels, using primarily horseshoe crabs for bait.[346] Horseshoe crabs —females in particular — are considered the best bait for potting eels and whelks.[347]

Between 1970 and 1990, the annual commercial whelk harvest fluctuated from less than 20,000 lb (9 metric tons) to above 2 million pounds (907 metric tons).[348] Reported harvests sharply increased during the late 1990s to over 6 million pounds (2722 metric tons) or 3 million animals in 1998.[349] [350] The significant increases in horseshoe crab harvests for bait resulted in a massive crash in horseshoe crab populations in the late 1990s. Declines of egg and shorebird abundance occurred shortly after horseshoe crab harvest reached its peak.[351]

Since the 1990s, the Delaware Bay's horseshoe crab population has fallen by two-thirds. Past overharvesting of the species for fertilizer and current bait and biomedical harvesting have been identified as primary factors contributing to these declines.[352] Horseshoe crabs have failed to recover from massive harvests in the 1990s, yet harvests for bait and blood continue today — greatly imperiling the species.

In recent years, reported bait harvests of horseshoe crabs have varied between 600,000 and 750,000 animals. While bait harvest quotas have helped to slow the decline in horseshoe crab populations, populations are nowhere near historic levels. In the past 25 years, horseshoe crab populations have shown no sign of recovery. More than 1.2 million horseshoe crabs spawned in the mid-Atlantic in 1990. By 2002, horseshoe crab spawning numbers dropped to 333,500—a decrease of 72%. Since 2002, horseshoe crab spawning has remained historically low, even with bait quotas in place. In 2020, only 335,211 horseshoe crabs spawned — nearly the same number observed in 2002 and a fraction of their spawning populations from 25 years ago.[353]

Other metrics reveal the severe impacts of the bait industry upon the American horseshoe crab and the total lack of recovery in its populations. Horseshoe crab egg density — the number of eggs per square meter — on spawning beaches is another critical measure of horseshoe crab populations and health. Peer-reviewed studies

[346]HCRC 2023.
[347]Kreamer & Michels. 2015. 309.
[348]Smith *et al.* 2017. 151.
[349]*Ibid*.
[350]*Ibid*.
[351] Smith *et al.* 2022. 1.
[352]Smith *et al.* 2017. 156.
[353]Delaware Bay Horseshoe Crab Survey 1990-2022.

indicate that horseshoe crab egg density has declined by an order of magnitude since the 1980s.[354]

According to a 2022 analysis, bait quotas are failing to protect and recover horseshoe crab populations. Despite 20 years of bait quotas, horseshoe crabs exhibit low abundances of newly mature females and spawning females, smaller mature female body sizes, declines in larger female horseshoe crabs, reduced egg production, no improvements in male-to-female sex ratios, lower egg densities in spawning habitats, and increases in female horseshoe crab mortality.[355] An examination of multiple data sources indicates that Delaware Bay's horseshoe crab populations are not in a healthy state, having failed to recover after a ban on female harvest in 2012.[356]

In 2019 and 2020, the abundance of newly mature females reached an all-time low, and the recruitment of immature females and males remained extremely low. Across nearly 20 years, the mean size of mature female horseshoe crabs was the smallest from 2018-2020.[357] This data indicates that horseshoe crab populations have not fully recovered and could be in decline.[358]

As the size distribution of mature females has shifted towards smaller individuals, there has also been a recent decline in the abundance of females larger than 300 mm prosomal width — those with the highest egg production potential. This decline, particularly notable from 2018 to 2020, suggests a decrease in the contribution of larger females to the spawning stock. With recent low recruitment, smaller mature females are not compensating for the loss of their larger counterparts. Consequently, overall reproductive output is likely not improving, making the recovery of both the horseshoe crab populations more difficult.[359]

Male-to-female sex ratios have also increased from 1999 to 2019, despite recent bans on female harvests for bait.[360] This issue is exacerbated by the fact that the biomedical industry is permitted to harvest female horseshoe crabs. Females are often targeted by the industry for their larger sizes and blood volumes.

Mortality from bait harvest for females has significantly increased in recent years, reaching levels comparable to those before prohibitions on female harvest.[361] While a

[354]Smith *et al.* 2022. 8.
[355]Lipcius 2021. 4-6.
[356]*Ibid.*
[357]*Ibid.*
[358]Lipcius Expert Report. 4.
[359]*Ibid*.
[360]*Ibid*. 5.
[361]*Ibid*.

female bait harvest prohibition exists, collective bait harvest and discard mortality continue to cause declines and hamper horseshoe crab recovery.[362]

In 2020, the Center for the Inland Bays survey in Delaware indicated a decline in high-density spawning events, with 69.6% of surveys showing low-density and 14.4% with no crabs. The cumulative sex ratio was 5.7, a decrease from 2019.[363]

Virginia Tech has conducted its American horseshoe crab trawl survey in this region from 2002 to 2011 and from 2016 to 2022.[364] The Virginia Tech data has shown no statistically significant increase in the population of adult female horseshoe crabs — essential for species restoration.[365]

Historic egg density provides another critical glimpse into the negative impacts of the bait harvest and the horseshoe crab's lack of recovery. Past and current measurements of horseshoe crab eggs in the Delaware Bay indicate that abundance in the 1980s was an order of magnitude greater than present-day estimates.[366]

Horseshoe crabs have experienced similar declines across most of their range over the same time period.[367] Quantitative analysis in a 2017 study revealed significant declines throughout the horseshoe crab's range, except in South Carolina and Georgia, where populations were found to be relatively stable. The steepest declines were observed in the New England area, gradually diminishing from the northern to southeastern areas, with declines also observed in the Florida Atlantic and Northeast Gulf regions.[368] Continuing these negative trends over 40 years would result in projected population reductions of 100% in the Gulf of Maine, 92% in New England, 11% in New York, 55% in Florida Atlantic, and 32% in the Northeast Gulf of Mexico.[369]

The CT DEEP's Long Island Sound Trawl Survey conducts sampling in both Connecticut and New York waters, and both the Connecticut and New York indices demonstrate a decline in horseshoe crab abundance in Long Island Sound since the early 2000s.[370] Despite an increase in American horseshoe crab populations during the 1990s, recent years indicate a downward trend.[371] On Long Island, N.Y., the

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[362]*Ibid*.
[363]Garmoe, Z., A. T. McGowan, & D. H. Bartow. 2021. 12.
[364]Results of the 2022 Horseshoe Crab Trawl Survey.
[365]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 12.
[366]Smith *et al.* 2022. 1.
[367]HCRC 2023.
[368]Smith *et al.* 2017. 159.
[369]The IUCN Red List of Threatened Species 2016. 18.
[370]Long Island Sound Study 2022.
[371]*Ibid*.

Environmental Research and Coastal Monitoring Lab has observed declines in horseshoe crab populations on 75 of the 115 beaches monitored.[372] Multiple studies compound this data, indicating a significant decrease of the American horseshoe crab in Connecticut and New York. Sites along Long Island have “considerably reduced numbers” compared to past observations. Researchers have observed an 8.2% increase in beaches exhibiting no breeding activity, and horseshoe crabs have declined by 1% per year.[373]

In the Northeast Gulf region, over 110,000 horseshoe crabs were harvested from the northwest coast of Florida, and the populations there still remain low and nowhere close to recovery.[374] Despite prohibitions, illegal horseshoe crab harvesting still occurs in Mexico. Local watermen engage in small-scale poaching by setting nets at the mouths of coastal lagoons during the tidal cycle and hand-picking horseshoe crabs. This activity is particularly prevalent in Chuburna, Progreso-Yucalpeten, Telchac, Chabihau, and Rio Lagartos, Yucatan, coinciding with the horseshoe crab spawning season.[375]

Illegally harvested horseshoe crabs are sold covertly and used as an alternative to commercial bait species in the artisanal octopus fishery of Campeche and Yucatan. The demand for horseshoe crabs has grown as the species is considered optimal for catching octopus using traditional drifting techniques in deep waters. Ship owners and seafood merchants buy horseshoe crabs from poachers and supply them to hired fishermen involved in commercial fisheries.[376]

Overharvest from bycatch

Horseshoe crabs are often harvested as bycatch in commercial fisheries primarily targeting other species.[377] Many horseshoe crabs are injured or killed during the capture process. Horseshoe crabs caught in bycatch are often discarded by commercial fisheries, including dredges, trawls and gillnets. The number of dead horseshoe crabs due to discarding can vary from about a fourth to half of the number of crabs harvested for bait.[378]

According to the 2019 benchmark stock assessment, discards and discard mortality have increased notably in the Delaware Bay region. Discards in the Delaware Bay

[372]Guzman 2020.
[373]Tanacredi & Portilla 2015. 230.
[374]Jane Brockmann pers. comm. January 19, 2024.
[375]Smith *et al.* 2017. 152.
[376]Smith *et al.* 2017. 151.
[377]*Ibid*. 153.
[378]ASMFC. 2023.

region have increased notably since 2013, according to the ASMFC.[379] Discard mortality impacts both males and females, as well as mature and immature crabs.[380]

In Tampa Bay, horseshoe crabs were notably the most abundant invertebrate bycatch species in shrimp trawls, with 2,867 individuals caught during two sampling seasons. A tagging study using dredges reported an 11% injury rate (4,459 out of 39,343) among horseshoe crabs. An assessment revealed that 6% of the total catch (2,542 out of 39,343) suffered injuries severe enough to cause mortality. These injury and mortality rates could occur in bycatch scenarios involving the use of dredges for whelk harvesting and bottom trawls for horseshoe crab harvest for Limulus Amebocyte Lysate (LAL) production.[381] There are no industry efforts to estimate horseshoe crab losses from bycatch. NOAA's Northeast Fisheries Observer Program has no programs or protocols for the monitoring of horseshoe crabs in bycatch. Agency experts estimate up to 50% of bycatch horseshoe crabs die in dredges and trawls.[382]

Harvest for aquarium trade and scientific collection

The American horseshoe crab is also harvested for the aquarium trade, especially in Florida, with a substantial aquarium trade harvest on the Gulf and Atlantic coasts.[383] On the Gulf Coast from 2008 to 2013, an average of 264 collecting trips occurred annually, resulting in an average of 22,597 animals collected per year (a mean of 85.5 animals per trip).[384] On Florida's Atlantic Coast from 2008 to 2013, an average of 109 trips collected about 4938 animals per year (a mean of 45.3 animals per trip). Florida horseshoe crab populations are already small and diminished, and the aquarium trade's impact could significantly affect Florida horseshoe crab populations.[385]

Approximately half of reported aquarium trade landings of horseshoe crabs are from the Florida Keys (49%),[386] where horseshoe crab numbers are low and suitable adult spawning habitat is limited. Extensive removal of first- or second-year juveniles due to aquarium trade landings could hinder the population's ability to sustain itself.[387]

[379] *Ibid.*
[380] *Ibid.*
[381] Smith *et al.* 2017. 153.
[382] HCRC 2023.
[383] Smith *et al.* 2017. 153.
[384] Smith *et al.* 2017. 153.
[385] *Ibid*.
[386] *Ibid*.
[387] *Ibid*.

Inadequacy of existing regulatory mechanisms

Federal regulations

Magnuson-Stevens Act

The Magnuson Stevens Act (MSA) provides for the management of marine fisheries in U.S. waters.[388] Originally enacted in 1976 to assert control of foreign fisheries that were operating within 200 nautical miles off the U.S. coast, the legislation has since been amended, in 1996 and 2007, to better address the twin problems of overfishing and overcapacity.[389] These ecological and economic problems arose in the domestic fishing industry as it grew to fill the vacuum left by departing foreign fishing fleets.[390]

Eight regional fishery management councils, composed of representatives of the fishing industry and state fishery officials, prepare fishery management plans for approval and implementation by NOAA Fisheries. The plans are amended frequently to adjust management policies and measures to changes in fish stock abundance and to meet the goals of the Magnuson-Stevens Act as they are revised by the Congress.

However, the Atlantic States Marine Fisheries Commission (ASMFC) is not a regional fishery management council. It was created separately by Congress in 1993, and it was never intended to manage horseshoe crabs. Congress never specifically granted the ASMFC exclusive authority for horseshoe crab management, but that is how it has been operating for more than two decades. ASMFC currently lacks oversight from any federal agency.

ASMFC and the states have a very poor track record in adequately protecting horseshoe crabs from extreme beach habitat loss, large and sustained pharmaceutical industry takes of the species, various forms of fishing on the species, and negative pollution impacts from mercury, oil pollution, raw sewage, and other sources.

However, horseshoe crabs are not adequately protected in either state or federal waters where they exist. The ASMFC merely coordinates state regulatory decisions and, thus, horseshoe crabs remain outside the protective mechanisms of the Magnuson-Stevens Fisheries Act, likely unlawfully.

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[388]U.S. Public Law 94-265.
[389]National Research Council. 2014. 15-28.
[390]*Ibid*.

Atlantic States Marine Fisheries Commission

Atlantic States Marine Fisheries Commission lacks regulatory oversight.

The Atlantic States Marine Fisheries Commission (ASMFC) lacks regulatory oversight. As a result, it has failed to recover nearly all of the fish stocks it is charged with protecting, including American horseshoe crabs.[391] Only one of 22 fish stocks—striped bass—is recovering, although years of inaction by ASMFC has led to the striped bass declines and a 2019 stock assessment that striped bass are overfished. Ten of the 22 species managed by the ASMFC are overfished or depleted.[392]

Meanwhile, other fisheries councils with enforceable oversight by NOAA have achieved significant recovery successes. For example, the Pacific Fishery Management Council has recovered nine of ten groundfish stocks that were declared overfished or depleted in 1999.[393]

Without legal oversight, ASMFC has been able to promulgate policies and quotas without using the best available science or independent peer review. Most recently, the ASMFC's revised ARM model for horseshoe crabs contains numerous errors, flaws, inaccuracies, and assumptions. This fatally flawed model is used to recommend horseshoe crab harvest quotas, and in the past two years, the model has recommended significant increases in horseshoe crab harvests, including the harvest of up to 175,000 female horseshoe crabs annually.[394]

The ASMFC's Interstate Fishery Management Plan and patchwork regulation fails to protect horseshoe crabs.

In 1998, ASMFC published the Fishery Management Plan (FMP), and its stated goal is to manage "horseshoe crab populations for continued use by: current and future generations of the fishing and non-fishing public, including the biomedical industry, scientific and educational researchers; migratory shorebirds; and other dependent fish and wildlife, including federally listed sea turtles."[395]

ASMFC has published eight addenda to the FMP:

[391]HCRC 2023.
[392]*Ibid*.
[393] HCRC 2023.
[394]ASMFC November 2022 Meeting.
[395]ASMFC Interstate Fishery Management Plan 1998. 2.

Addendum I establishes commercial bait harvest quotas in the Atlantic states;
Addendum II allows voluntary transfers of those quotas between states;
Addenda III and IV reduce quotas in the Delaware Bay region, implement a closed season for bait harvest of horseshoe crabs during spawning season, revise monitoring requirements, and strengthen protections in Maryland and Virginia;
Addenda V and VI extend Addendum IV's requirements;
Addendum VII established a new Adaptive Resource Management (ARM) framework which "directs that future regulations should take into account the populations of both red knots and horseshoe crabs" and sets a maximum allowable horseshoe crab harvest tied to red knot population recovery;
Addendum VIII introduces a new model and methodologies for determining horseshoe crab abundance.[396]

Each Atlantic state is responsible for implementing FMP requirements in its own jurisdiction. The FMP's patchwork of state-specific measures do not adequately protect horseshoe crabs and result in regulatory leakage.

For example, several states have imposed stricter horseshoe crab harvest quotas. Massachusetts, New York, and Rhode Island have each enacted state-level harvest restrictions allowing only 46-55% of the quota authorized by ASMFC.[397] Other states have imposed seasonal harvest restrictions, daily take limits, or even have instituted a complete moratorium on horseshoe crab harvest.[398]

However, data indicates that when one region strengthens its regulations, other regions experience corresponding increases in harvest rates.[399] ASMFC even facilitates this regulatory leakage.

For example, the state of New Jersey implemented a moratorium on horseshoe crab harvests in 2008. ASMFC has responded by re-allocating New Jersey's horseshoe crab harvest quota to other regional states, effectively undermining the state's moratorium.

Data also indicates that "[s]tricter horseshoe crab regulations around the Delaware Bay/New Jersey coastlines have led to increased harvesting in New England," and any population recovery observed in the Delaware Bay region has been "more than offset by shifting commercial activity to other geographic regions."[400]

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[396]ASMFC Addendum I-VIII, 2001, 2006, 2010, 2012, 2022.
[397]IUCN Red List, 25-27.
[398]*Ibid*.
[399]Krisfalusi-Gannon *et al.*, 2018. 47.
[400]*Ibid*.

The ASMFC's Fisheries Management Plan is not intended to protect horseshoe crabs. The FMP states that horseshoe crabs are a "resource…for continued use by" industry, listed species, and the public.[401] The FMP only considers whether there are sufficient numbers of horseshoe crabs for use by other entities.

As a result, the FMP has failed to regulate the biomedical harvest of horseshoe crabs. It explicitly exempts the biomedical industry from harvest quotas, and the FMP's only biomedical harvest threshold has never been enforced. The FMP states that "[i]f horseshoe crab mortality associated with . . . the biomedical industry exceeds 57,500 horseshoe crabs per year, [ASMFC] would reevaluate potential restrictions on horseshoe crab harvest by the biomedical industry."[402] Although this threshold has been exceeded every year since 2007 (except in 2016), the ASMFC has declined to reevaluate restrictions on the biomedical industry, even as biomedical harvests have nearly doubled in the past six years.[403] Horseshoe crab harvest by the biomedical industry climbed to more than 900,000 in 2022. Even using industry percentages of 15% mortality, at least 136,000 horseshoe crabs died—more than twice the FMP's stated threshold.[404]

Horseshoe crabs are threatened by fatal flaws in the ASMFC's adaptive resource management (ARM) model.

ASMFC's bait harvest quotas are also insufficient to protect horseshoe crabs. In 2022, ASMFC revised its ARM Framework to require a Catch Multiple Survey Analysis (CMSA) for estimating crab populations.[405] The CMSA collates the data of three trawl surveys to estimate horseshoe crab abundance and uses the results to set a "maximum allowable harvest value" for the crabs[406]. Of these surveys, only the Virginia Tech Horseshoe Crab Trawl Survey ("Virginia Tech Survey") was designed for the purpose of estimating horseshoe crab abundance in the Delaware Bay region, However, the CMSA weighs each survey equally, a skewed approach which has resulted in significant and arbitrary inflation in population estimates bolstered by the conclusions of less-reliable surveys.

In her minority opinion, ASMFC Horseshoe Crab Management Board Member Wendy Walsh specifically requested that the Virginia Tech survey be weighted more heavily than the other data sets, citing inflated population estimates, but her request was not

[401]ASMFC Addendum VII 2010. 1.
[402]Interstate Fishery Management Plan 1998. 27.
[403]2019 ASMFC Stock Assessment. 36.
[404]ASMFC November 2022 Meeting Slide Presentation.
[405]ASMFC Revision 2022.
[406]*Id.* 83, 102.

implemented.[407] These and other flawed and inaccurate methodologies have resulted in skewed ARM model recommendations to increase horseshoe crab harvests and to resume harvests of female horseshoe crabs.

The model's population estimates are unreliable and often contradictory, and they are sometimes accompanied by astronomical confidence intervals that hamper their usefulness for management decisions. For instance, one Delaware Bay horseshoe crab survey that is heavily relied upon by regulators presented a 95% confidence interval for mature female horseshoe crabs in 2021 ranging from 0 to nearly 36 million.[408]

The ARM model is so fundamentally flawed that artificial inflation of data was needed to make the model operate for 2023. The ARM model evaluates female horseshoe crab recruitment rate, and in 2023, the model determined that the recruitment of female horseshoe crabs was zero. This effectively meant that no juvenile female horseshoe crabs were advancing to adults.[409]

Rather than objectively consider this outcome, the ASMFC intervened to artificially inflate the female horseshoe crab recruitment rate from zero as a workaround for this model failure. Since the fatally flawed model literally could not run with zero as a female recruitment rate, the Horseshoe Crab Management Board arbitrarily decided to assume that 20% percent of females move from juvenile to mature.[410]

A detailed technical analysis by Dr. Kevin Shoemaker revealed several additional significant shortcomings in the adaptive resource management (ARM) model used to manage Delaware Bay-origin horseshoe crabs. The analysis indicated the ARM model's inability to accurately portray the effects of horseshoe crab harvesting on red knots and horseshoe crab populations. The inherent flaws within the core structure and functionality of the ARM model pose a substantial challenge, rendering its use in guiding management decisions ineffective in preventing the limitation of the red knot stopover population, impeding recovery, or ensuring compliance with the Endangered Species Act (ESA).

Dr. Romuald N. Lipcius completed an additional expert assessment of the ARM model, in which he concluded that the proposed harvest of female horseshoe crabs lacks justification based on the existing scientific evidence. The model, he concluded, is flawed primarily due to several risk-prone decisions and assumptions inherent in the Adaptive Resource Management framework and model, posing a substantial risk to

[407] *Id.* 101-102.
[408] Shoemaker 2022. (Wong 266.)
[409] ASMFC November 2022 Meeting.
[410] *Ibid.*

both the horseshoe crab population and the recovery of the Red Knot. “Risk prone” decisions entail implementing conservation or management actions based on overly optimistic assumptions about the status of a population and can disregard conflicting data that contradicts optimistic conclusions about population status.[411]

In the case of endangered or threatened species, it is crucial to adopt a *risk-averse* strategy, guided by the precautionary principle. This approach emphasizes caution, prioritizing measures that minimize risks and uncertainties. Such a strategy is essential for promoting population recovery, conservation, and sustainable resource management of endangered or threatened species.[412]

The ARM model overestimates and misrepresents horseshoe crab populations and health in Delaware Bay.

The ARM model gauges the abundance of horseshoe crabs by processing information from three trawl surveys.[413] However, the lack of significant correlation in the data from these surveys suggests that they predominantly reflect random fluctuations rather than meaningful biotic signals.[414]

In addition to the inherent limitations of trawl survey data, the model neglects to account for confounding factors such as water depth and temperature, which can influence survey outcomes. Adjustment for these factors and subsequent data reanalysis revealed no conclusive trend in horseshoe crab abundance, challenging the ARM model's assertion of a modest positive trajectory. This recent analysis complements analyses presented last year, elucidating how the model generates excessively optimistic projections for horseshoe crab populations.[415]

Contrary to the ARM model's assertion of horseshoe crab recovery, trawl surveys show no indication of an increasing trend in the population of female horseshoe crabs in Delaware Bay. Additionally, the three trawl surveys exhibit even lower correlation with each other than originally thought, meaning they are more likely to be reflecting random noise.

Even the Virginia Tech survey—considered “the preferred method to determine abundance in the region”by the ASMFC—has not demonstrated a consistent increase in horseshoe crab populations in the past two decades.

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[411]Lipcius Expert Report. 3.
[412]*Ibid*.
[413]ASMFC Revision 2022. 100-102.
[414]Earthjustice 2023. 4.
[415]*Ibid.*

Further, analysis of Virginia Tech's trawl survey data reveals concerning trends, such as decreasing body size of female horseshoe crabs, a decreasing ratio of females to males, and alarmingly low numbers of newly mature females.

Horseshoe crab populations are showing low recruitment and low abundances of newly mature females and spawning females.

The female harvest prohibition would be expected to lead to a rebound in young mature females and an increase in the recruitment of immature males and females into the horseshoe crab population. However, in 2019 and 2020, the abundance of newly mature females reached an all-time low, and the recruitment of immature females and males remained extremely low and unchanged since before the prohibition. Additionally, female abundance in the spawning survey experienced a sharp drop in 2019. These indicators serve as warning signs that the horseshoe crab population has not fully recovered and may still be declining.[416]

Mature females are displaying smaller body sizes.

Contrary to the expectation that the female harvest prohibition would result in an increase in female body size with constant recruitment, the data indicate otherwise. The mean size of mature female horseshoe crabs was the smallest from 2018-2020, and for newly mature females, it was the smallest in the last two years of the time series from 2002 to 2020. This trend persisted despite the prohibition on female harvest since 2012. These findings are inconsistent with the anticipated outcome and challenge the notion that female horseshoe crab populations have rebounded.[417]

Horseshoe crabs are experiencing a decline in larger females and reduced egg production.

The production of eggs is closely tied to the biomass of the spawning stock, mainly consisting of mature females. Changes in the size distribution of mature females can significantly impact overall egg production, especially with the loss of large females. Relying solely on the abundance of horseshoe crabs to estimate reproductive output overlooks critical biological factors like size structure and biomass, which play a key role in population egg production within the spawning stock.

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[416]Lipcius Expert Report. 4.
[417]*Ibid*.

The size distribution of mature females has shifted towards smaller individuals, and there has been a recent decline in the abundance of females larger than 300 mm prosomal width — those with the highest egg production potential. This decline, particularly notable from 2018 to 2020, suggests a decrease in the contribution of larger females to the spawning stock. With recent low recruitment, smaller mature females are not compensating for the loss of their larger counterparts. Consequently, overall reproductive (egg) output is likely not improving, making the recovery of both the horseshoe crab (HSC) and red knot (RK) populations more difficult.[418]

The male-to-female sex ratio is not decreasing.

The expectation when restricting horseshoe crab harvest to males is that the ratio of males to females would decrease. Despite this, male-to-female sex ratios have increased from 1999 to 2019. This discrepancy serves as another warning sign, suggesting that the current management strategy has not been effective and indicating a lack of comprehensive understanding of population dynamics.[419]

Mature female mortality is increasing.

Mortality from discard and bait harvest for females has significantly increased in recent years, reaching levels comparable to those before prohibitions on female harvest. Assuming the effectiveness of the prohibition is presumptuous —the lack of effective control over the cumulative mortality from bait harvest and discard poses a significant obstacle to the recovery of horseshoe crab populations.[420]

These data, trends, and observations are inconsistent with expectations for a recovering population, especially one with protected female harvest. These trends, along with previous analyses, strongly suggest that horseshoe crabs are not recovering in Delaware Bay. Harvesting horseshoe crabs at the levels recommended by a model that misrepresents their condition and trajectory will have high detrimental impacts for the species.[421]

[418] *Ibid*.
[419] *Ibid*. 5.
[420] Lipcius Expert Report. 5.
[421] Earthjustice 2023. 13-14.

The Catch Multiple Survey Analysis (CMSA) serves as a poor fit for training and independent data, rendering it inadequate to project future horseshoe crab abundance.

The CMSA model shows poor fit to both training and independent data, lessening its reliability for projecting future horseshoe crab abundance. While it explains the difference in mean horseshoe crab abundance before and after the "VT gap years,"[422] it poorly accounts for observed variations in primary data sources, particularly three trawl surveys in and around Delaware Bay. Although it fits well (R2 > 0.5) with recruitment data — which has only one data source — it performs poorly for adult and total abundance, which have three sources. The model's lack of fit to both training and validation data should warrant serious concern regarding its utility to informing the ARM — which impacts various models such as the red knot population model, horseshoe crab projection model, and annual harvest recommendations.[423]

The ARM model also assumes that data from the Delaware Estuary Survey and New Jersey Survey of horseshoe crabs in Delaware Bay are correlated with the Virginia Tech Survey. These data are utilized to fill in survey gaps in the Virginia Tech Survey. However, when all three surveys were conducted simultaneously, the data did not show correlation. In fact, data from the Delaware Estuary Survey and New Jersey Survey were relatively higher than that from the Virginia Tech Survey. Horseshoe crab abundance is thus overestimated during Virginia Tech Survey gap years.[424]

Trawl survey gap years led to unfounded assumptions, errors, and inaccuracies in estimates from the Catch Multiple Survey Analysis (CMSA).

Gap years in annual trawl surveys led to absurd assumptions and predictions. A significant data gap arose when the Virginia Tech (VT) trawl surveys — the sole source for estimating recruitment — were not conducted during the critical four-year VT trawl survey gap from 2013 to 2016. This gap poses a challenge to the veracity of the model. Modelers arbitrarily filled in data, and as a result, the CMSA artificially predicted increases in the horseshoe crab population during this period, with absurdly higher average recruitment rates.

To understand the impact of the nonsensical gap year estimates, first consider the years with empirically derived recruitment estimates. The average annual estimated

[422]Shoemaker 2022. 3.
[423]*Ibid*. 4.
[424]Lipcius Expert Report. 5.

recruitment for 2003-2012 was 1.2 million primiparous females. The average annual estimated recruitment for 2017-2019 was 1.9 million.[425]

Now consider the non-empirically derived gap year estimates. In 2013, the estimate was 9.6 million—roughly eight times larger than the average over the previous ten years, and four times larger than the maximum annual estimate from that period.[426]

In 2014, the estimate dropped to only two primiparous females across all of Delaware Bay, but the estimate is so uncertain that the upper limit of the confidence interval approaches infinity.[427]

All told, the average estimate for the four Virginia Tech gap years was 4.2 million primiparous females, which is nearly 2 million higher than the maximum ever estimated for any year with empirical observations.[428]

The CMSA is crucial to inform the ARM framework — especially in parameterizing horseshoe crab recruitment rates, a significant input for the horseshoe crab simulation model. These artificially and astronomically inflated rates were used to estimate mean horseshoe crab recruitment rates in the simulation models, which significantly overstated population resilience to harvest. Excluding data from the VT trawl survey gap years would likely reduce the expected resilience of the horseshoe crab population.[429]

The horseshoe crab population simulation model fails to correctly propagate uncertainty regarding mean recruitment rates.

The horseshoe crab population simulation model in the proposed ARM framework fails to adequately account for uncertainty in mean recruitment rates. Specifically, it treats uncertainty about annual recruitment rates as indicative of natural year-to-year fluctuations rather than a combination of parameter uncertainty and process variance. This oversight leads to simulation replicates closely resembling each other, as sources of uncertainty tend to regress to the mean. Correcting this issue, preliminary results suggest a highly uncertain future for horseshoe crab populations in Delaware Bay, especially under harvest pressures. Contrary to the original report, there is a significant probability (17.5%) of horseshoe crab populations falling below previously estimated levels — even without direct anthropogenic sources of mortality over the next 50 years. Harvest scenarios at current maximum rates pose a substantial risk of decline (33.45%)

[425]ASMFC Supplemental Report to the 2021 Revision. 2022.
[426]*Ibid.*
[427]*Ibid.*
[428]*Ibid.*
[429]Earthjustice 2023. 12-14.

and disruption to population age structure. An extreme harvest scenario predicts near-certain catastrophic population collapse over 50 years, in contrast to the original report suggesting stability even under such extreme conditions.[430]

ARM frameworks lack performance validation and null model benchmarks.

Null models are simplified representations of a system that lack proposed mechanisms explaining system dynamics. In statistics, a typical null model assumes all observed variation results from a single random error process. Comparing complex models — like those in the revised Adaptive Resource Management (ARM) — with null models helps determine if the complex models provide useful knowledge about a system. If a complex model performs poorly compared to a null model in terms of bias or precision, it may be improperly specified or "overfitted," fitting parameters to noise rather than true signal.[431]

The Catch Multiple Survey Analysis (CMSA) model in the ARM fails to outperform even the simplest null model. For the years before and after the Virginia Tech Survey gap—that is, for the vast majority of years evaluated—the coefficient of determination (R2) between the model and the Delaware Survey was negative, meaning that the model performed worse than a null model. The CMSA performs almost as poorly against data from the New Jersey Ocean Trawl Survey, with a weak positive correlation for the years prior to the Virginia Tech gap and a negative R2 for the years after. The CMSA's worst performance comes when measured against the Virginia Tech survey, with a negative R2 across the full time series for which data are available.[432]

For the red knot component, comparing the red knot simulation model against a null model without any effect of female horseshoe crab abundance would be informative. If either model fails to outperform a null model, it indicates that our understanding of harvest effects on horseshoe crab populations is insufficient for robust forecasting, suggesting a more precautionary approach may be necessary.[433]

Egg density data is the most useful metric for determining red knot survival, but egg density is excluded by the ARM model.

The direct and most meaningful factor influencing the survival of red knots is the availability of horseshoe crab eggs on the beach. The ARM model overlooks crucial data on egg density, or the number of horseshoe crab eggs per square meter of beach.

[430]Shoemaker 2022. 3.
[431]*Ibid*. 5.
[432]Shoemaker 2022. 19-22.
[433]*Ibid.*

Egg density is a direct indicator of whether horseshoe crabs numbers are meeting the nutritional requirements of red knots. Research demonstrates a strong correlation between egg density and red knot survival.[434] A peer-reviewed 2021 study indicates that horseshoe crab egg density has declined by an order of magnitude since the 1980s.[435] The study analyzed past and current measurements of horseshoe crab eggs in the Delaware Bay and found that "abundance in the 1980s was an order of magnitude greater than present-day estimates." An additional egg prevalence index, which characterizes the timing and magnitude of horseshoe crab egg output, revealed a similar pattern of higher prevalence in the 1980s (0.89) compared with the recent 2015–2021 interval of 0.52.[436]

However, the ARM model relies on the relationship between two factors with minimal connection: female horseshoe crab abundance data from trawl surveys and red knot abundance. The lack of a meaningful correlation between these datasets is likely due to challenges in collecting and assessing horseshoe crab abundance using trawl surveys. However, this absence of correlation does not imply an actual lack of significant connection between the two species. Unfortunately, the ARM model erroneously concludes that the population trajectories of red knots are weakly linked to horseshoe crab populations. It suggests that increasing the horseshoe crab harvest would have little impact on red knots, despite disregarding egg density data that strongly supports the opposite.[437]

The ARM model, by neglecting the interdependence of red knots and horseshoe crabs, predicts an increase in red knot abundance even if all horseshoe crabs were to suddenly disappear from Delaware Bay. In contrast, the correlation between egg density and red knot survival reveals a significant threat: should horseshoe crab egg density remain at the lowest observed level or vanish entirely, red knot populations would rapidly decline to near-zero levels.[438]

[434]Shoemaker 2022. 2.
[435]Smith *et al.* 2022. 1.
[436]*Ibid.*
[437]Shoemaker 2022. 2.
[438]Earthjustice 2023. 3.

Horseshoe crab eggs on a Delaware Bay Beach. *Gregory Breese/USFWS*

Exclusion of egg density data leads to faulty conclusions on horseshoe crab population recovery.

Horseshoe crab egg density data on spawning beaches is a more reliable source of horseshoe crab population and health than trawl surveys, but the Atlantic States Marine Fisheries Commission has not included egg density data in its population estimates, ARM Model, or quota determinations.

Assessing the effectiveness of horseshoe crab management has been severely hampered by poor methods used to quantify baseline population and demographic estimates before unregulated harvests. The 1998 population index is used as a reference point, representing the population when regulations were implemented.

To establish a more accurate understanding of pre-exploitation baselines, a study examined 1980s datasets on horseshoe crab egg abundance. Predating unregulated overharvest, this dataset offers crucial information on egg supply.[439]

Overharvesting led horseshoe crab egg densities to drop from 40,000 per square meter to an average of 5,000 per square meter— with scant signs of recovery in the last 25 years.[440] Horseshoe crab eggs located in the top 5 centimeters of sand have stagnated "an order of magnitude"[441] lower than densities recorded before crabs were overharvested. Horseshoe crab egg densities have shrunk by 80% in the past three decades with similar declines observed in South Carolina.[442]

The studies revealed a significant reduction in horseshoe crab egg availability in Delaware Bay compared to baseline conditions in the 1980s, preceding an uncontrolled harvest wave in the following decade. The time series data from the 1980s to the present shows a sharp decline in horseshoe crab egg abundance after an overharvesting wave.

This decline coincided with a rapid decrease in shorebird populations observed in aerial surveys in Delaware Bay, starting around the peak of horseshoe crab harvest in 1998. Five years later (2002–2003), red knot populations were at 30% of baseline counts and ruddy turnstone populations were at 40% of baseline counts.[443] Populations have since fluctuated dramatically, always at levels below the historical baseline.

Over half of North America's shorebird species are considered to be of high conservation concern due to persistent threats and population declines. Some hypotheses suggest that factors beyond the local conditions of Delaware Bay may explain shorebird decline, such as changing conditions in the Arctic or dispersal to other feeding sites. However, there is no evidence linking shorebird decline to Arctic conditions nor have shorebird populations been observed redistributing to other sites during periods of low food availability.[444] Shorebird declines are instead driven by decreasing horseshoe crab egg density drastically reduced from historic levels.

Simultaneous with the decline in shorebird populations in Delaware Bay, there has been a consistent trend of shorebird redistribution along the bay shoreline, moving away from Delaware and towards New Jersey. Aerial surveys conducted over the last decade show that the majority of the stopover population of red knots and ruddy turnstones now

[439]Smith *et al.* 2021. 2.
[440]*Ibid.*
[441]*Ibid.*
[442]Hunt 2022. 3.
[443]Smith *et al.* 2021. 8.
[444]Smith *et al.* 2022. 8-9.

occur on New Jersey beaches, whereas at baseline conditions, these species were evenly distributed between the shorelines of the two states.[445] Beach closures and restoration in New Jersey have likely been key drivers. [446]

Stock assessments of horseshoe crabs in Delaware Bay align with egg density data declines and populations languishing at low-levels even after the implementation of harvest management. The most recent assessment indicates that the Delaware Bay horseshoe crab population has not significantly changed from the level observed following its crash from peak of overharvest in 1998.[447]

With no indication of population recovery despite two decades of management, undergirded by missing or faulty baseline population information, the American horseshoe crab has failed to recover from extreme harvests in the late 1990s. Further, the reduction of horseshoe crab eggs in Delaware Bay means that a critical energy source for shorebirds and commercially and economically important fish species is lacking, placing the entire ecosystem at risk.[448] Egg density data clearly reveals the declines in horseshoe crab populations and its impacts to endangered shorebirds and beach ecosystems. Exclusion of egg density data in management decisions is hampering efforts to accurately assess horseshoe crab populations and their impacts on federally listed *rufa* red knots.

The ARM model may violate the Endangered Species Act.

ASMFC's ARM model could violate the ESA if it permits horseshoe crab harvest at levels that would result in the "take" of red knots, a federally protected species. The term "take" includes any action that harms the species, encompassing "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering." This prohibition extends to government authorizations that indirectly cause or solicit actions leading to the incidental take of ESA-listed species.[449]

The ARM model lacks the capacity to inform whether a specific horseshoe crab harvest level would lead to an unlawful take of red knots. Due to its inaccurate representation of horseshoe crab and red knot status and its failure to acknowledge the dependency of red knots on horseshoe crabs and egg density on spawning beaches, the model cannot

[445] *Ibid.* 9-10.
[446] *Ibid.* 10.
[447] *Ibid.* 10.
[448] Smith *et al.* 2022. 11.
[449] Earthjustice 2023. 5.

reflect ecological conditions. Consequently, the ASMFC cannot rely on the model to assess ecological impacts or ensure compliance with the law.

The U.S. Fish and Wildlife Service's assessment of the ARM framework does not offer meaningful insights into the likelihood of an ESA violation. By stating that the model's harvest recommendations would "pose negligible risk to red knot recovery and negligible risk of take," FWS merely echoed the model's outputs. As the model asserted that its recommended harvest quotas would be harmless, the agency concluded that the likelihood of take was minimal. This conclusion is contingent on the accuracy of a flawed model.[450]

Northeast Fisheries Observer Program

NOAA's Northeast Fisheries Observer Program has no protocols, guidelines, or monitoring of horseshoe crabs in bycatch. Horseshoe crabs are often harvested as bycatch in commercial fisheries primarily targeting other species, including Atlantic sea scallops, monkfish, skates, Atlantic mackerel, squid, butterfish, scup, black sea bass, bluefish, spiny dogfish, Atlantic herring, tilefish, Atlantic deep-sea red crab, summer flounder, and American lobster.[451] Many horseshoe crabs are injured or killed during the capture process. Agency experts estimate up to 50% of bycatch horseshoe crabs die in dredges and trawls.[452] In addition, current estimates of horseshoe crab bycatch may not have included discards from scallop and clams dredging, the main income for the Port of Cape May, N.J., the fourth largest in the US by income.[453]

There are no industry efforts to estimate horseshoe crab losses from bycatch, and the Northeast Fisheries Observer Program does not currently monitor or report bycatch of horseshoe crabs.

The Outer Continental Shelf Lands Act (OCSLA)

The Outer Continental Shelf Lands Act (OCSLA) defines the Outer Continental Shelf (OCS) as the submerged lands located beyond a state's coastal waters, typically extending three miles offshore, and falling under the jurisdiction of the United States. Within the framework of the OCSLA, the Secretary of the Interior holds the responsibility for overseeing the exploration and development of mineral resources of the OCS. The Act grants the Secretary the authority to issue leases to the most qualified and responsible bidders through a sealed competitive bidding process. Furthermore, the Secretary is empowered to create regulations as needed to ensure the effective

[450] *Ibid*. 5-6.
[451] Smith *et al.* 2017. 153.
[452] HCRC 2023.
[453] Larry Niles pers. comm. February 1, 2023.

execution of the Act's provisions. As amended, the Act establishes the guidelines for implementing a program focused on oil and gas exploration and development on the OCS.

The OCSLA requires that exploration and development is carried out in a manner providing for the “protection of the environment” and the “conservation of the natural resources of the outer Continental Shelf.” Despite these stipulations, oil and gas production continues to harm ecosystems along the Gulf of Mexico and Atlantic coastlines. Over 14,000 unplugged oil and gas wells exist in the Gulf of Mexico, structures that can leak oil into the marine environment and often remain undetected.[454] Despite legal obligations that mandate the decommissioning of offshore platforms and equipment on the seafloor, the actual implementation and enforcement of these requirements have been inconsistent. The OCSLA and its associated regulations govern oil and gas leasing in federal waters, and they specify that decommissioning should involve tasks such as permanently sealing wells, removing platforms, decommissioning pipelines, and clearing obstructions from the seafloor. These regulations also stipulate that within a year of lease termination, one must permanently seal wells and remove all platforms and facilities. However, the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) have not consistently upheld adherence to these decommissioning requirements.[455] There are more inactive and unplugged oil and gas wells than currently operational ones in the Gulf of Mexico.[456]

Additionally, the East Coast of the U.S. has seen an increase in oil shipped via tanker from the Gulf of Mexico, whereby hundreds of small oil spill incidents have occurred directly adjacent to or on the eastern seaboard over the past few decades. Nine oil spills over the past decade have released over 10,000 gallons into Delaware Bay. The most recent of these spills leaked over a quarter million gallons into the ocean.[457]

Furthermore, the regulations sometimes permit oil and gas operators to leave pipelines on the seafloor, a practice known as "decommissioning in place." This is allowed only in specific situations where structures will not obstruct navigation, fishing, or harm the environment. Nevertheless, in practice, BSEE often will enable operators to leave pipelines on the seafloor rather than removing them. The Government Accountability Office revealed that since the 1960s, BSEE has granted permission for the oil and gas industry to leave over 97 percent of pipeline mileage, almost 18,000 miles, on the seafloor in the Gulf of Mexico. Recent data also demonstrates that

[454]Loomis & Ramirez 2023.
[455]*Ibid.*
[456]*Ibid.*
[457]Botton & Tomio 2009. 431-535.

decommissioning-in-place has become the norm rather than the exception, with BSEE approving almost 96 percent of applications for this practice from 2015 to May 2020, resulting in hundreds of pipeline segments remaining on the ocean floor.[458]

Despite the potential adverse environmental impact of leaving oil and gas pipelines in the ocean, BSEE and BOEM officials have acknowledged that the ecological consequences of decommissioning-in-place practices have not been sufficiently studied.[459]

BOEM has also failed to require oil and gas operators to provide adequate upfront funding for decommissioning. These companies are supposed to offer financial assurances, such as bonds, to ensure that there are sufficient funds for decommissioning, even if a company goes bankrupt. However, a Government Accountability Office study found that less than eight percent of decommissioning costs in the Gulf were covered by financial assurances, potentially leaving the public responsible for billions of dollars in cleanup costs.[460]

The Outer Continental Shelf Lands Act not only fails to consider the conservation of imperiled species like the American horseshoe crab, but it actively threatens the long-term viability of the Gulf of Mexico's biodiversity. By authorizing oil and gas exploration and failing to enforce cleanup properly, the act furthers horseshoe crab habitat degradation.

National Wildlife Refuge System Act

The American horseshoe crab occurs within National Wildlife Refuges.The National Wildlife Refuge System Administration Act "administers a national network of lands and waters for the conservation, management, and restoration of fish, wildlife and plant resources and habitat," ensuring that the "biological integrity, diversity, and environmental health of refuges is maintained."[207]

The National Wildlife Refuge System Act has failed to protect the American horseshoe crab. South Carolina's Cape Romain National Wildlife Refuge was a site of high levels of harvest for many years. Legal action finally led to the closure of Cape Romain NWR to horseshoe crab harvesting. However, high levels of harvest also occur in nearby Tybee National Wildlife Refuge in Georgia.[461] The refuge is considered a critical site for red knots and other foraging shorebirds.

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[458]Loomis & Ramirez 2023.
[459]*Ibid.*
[460]*Ibid.*
[461]Hunt 2022. 12.

Some of the American horseshoe crab's most critical spawning sites lie within federal wildlife refuges. In the Delaware Bay, several national wildlife refuges are home to spawning horseshoe crabs, including Prime Hook National Wildlife Refuge, Bombay Hook National Wildlife Refuge, and Cape May National Wildlife Refuge.

Despite federal protections under the National Wildlife Refuge System Act, horseshoe crabs are still harvested from these critical habitats. The National Wildlife Refuge System Act is inadequate to protect the American horseshoe crab and its habitat.

Marine Reserves

Marine reserves are a promising solution to addressing the decline of horseshoe crabs and other marine species. The Carl N. Shuster, Jr. Horseshoe Crab Reserve was created near the mouth of Delaware Bay specifically to protect American horseshoe crabs and their habitat. The reserve begins three miles from the coast of Delaware and New Jersey and extends for 30 nautical miles into the Atlantic, covering an area of nearly 1,500 square miles of federal waters.[462] The reserve was designated in 2001 to honor the esteemed horseshoe crab biologist Carl Shuster, who devoted his life to horseshoe crab research and conservation. The reserve protects overwintering adult and sub-adult horseshoe crabs. Originally, the reserve prohibited any harvest of horseshoe crabs for bait or blood. However, the state of New Jersey now allows for biomedical harvests of horseshoe crabs within the reserve.

After more than two decades, the reserve has not been sufficient to recover horseshoe crab populations. Populations of horseshoe crabs remain historically low in the Delaware Bay and have not come close to recovering. Marine reserves can play an important role in horseshoe crab conservation, but the current number and size of reserves is inadequate to protect and recover horseshoe crabs.

State regulations

The patchwork of varying state regulations regarding horseshoe crabs is inadequate to address the declines and lack of recovery in horseshoe crab populations across its range. Even states that enact stricter regulations than the ASMFC fail to stem the overall or regional decline of horseshoe crabs. State-specific measures do not adequately protect horseshoe crabs and result in regulatory leakage.

Massachusetts, New York, and Rhode Island have each enacted state-level harvest restrictions allowing only 46-55% of the quota authorized by ASMFC.[463] Other states

[462]ASMFC Addendum III 2021.
[463]IUCN Red List, 25-27.

have imposed seasonal harvest restrictions, daily take limits, or even have instituted a complete moratorium on horseshoe crab harvest.[464] However, studies have shown that when one state or region strengthens its regulations, other states or regions experience corresponding increases in harvest rates.[465]

Data also indicates that "[s]tricter horseshoe crab regulations around the Delaware Bay/New Jersey coastlines have led to increased harvesting in New England," and any population recovery observed in the Delaware Bay region has been "more than offset by shifting commercial activity to other geographic regions."[466]

ASMFC exacerbates this regulatory leakage. The state of New Jersey has implemented a moratorium on horseshoe crab harvests since 2008. However, the ASMFC has responded by re-allocating New Jersey's horseshoe crab harvest quota to other regional states, effectively undermining the state's moratorium.

The following state regulations are currently in place for horseshoe crabs across its range as of February 2024. All have proven inadequate to prevent further declines in horseshoe crabs.

Maine & New Hampshire

The Maine Department of Marine Resources dictates that horseshoe crabs cannot be taken without a permit from the Commissioner, which are available at no cost upon request to the Department of Marine Resources. Individuals are prohibited from taking more than 25 horseshoe crabs per person per day, and possession of more than 25 horseshoe crabs per person is not allowed. It is unlawful to take, kill, or possess horseshoe crabs or their eggs in or from Maine waters between May 1 and October 30, inclusive.[467]

Horseshoe crab harvesting is permitted year-round in New Hampshire, but certain restrictions apply. Individuals are allowed to harvest a maximum of 10 horseshoe crabs per person per day. Harvesting must be conducted manually or with a dip net. To be legally harvested, horseshoe crabs must be at least 3 inches wide across the carapace. Harvesting is strictly prohibited within 500 feet of documented spawning beaches. Individuals engaging in horseshoe crab harvest are required to submit catch reports in compliance with regulations.[468]

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[464] *Ibid.*
[465] Krisfalusi-Gannon *et al.* 2018. 47.
[466] *Ibid.*
[467] Maine Department of Marine Resources. 2.
[468] N.H. Code Admin. R. Fis. 609.01

Maine and New Hampshire, are considered de minimis by the ASMFC Interstate Fisheries Management Fisheries Program Charter. De minimis is defined as a situation in which, under existing conditions of the stock and the scope of the fishery, conservation, and enforcement actions taken by an individual state would be expected to contribute insignificantly to a coastwide conservation program required by a Fishery Management Plan or amendment.[469] Maine and New Hampshire reported bait harvest totals to the ASMFC from 1998 to 2003 and 1998 to 2002, respectively, until they were granted de minimis status. This status can be sought if the average horseshoe crab bait landings for two consecutive years constitute less than one percent of the coastwide total. Once granted, ASMFC member states are no longer obligated to report their harvests as long as the conditions for maintaining their status persist.[470]

A lack of regional coordination between Maine and New Hampshire means that horseshoe crabs migrating across state lines can be harvested in certain areas, even where individual state regulations seem sustainable. New Hampshire, lacking a closed season, places year-round pressure on horseshoe crab populations. Furthermore, both New Hampshire and Maine base their quota regulations on biomass rather than female crabs, meaning that far fewer females than males exist. Focusing on biomass could mean the reproductive capacity of populations in Maine and New Hampshire is not adequately protected. Finally, limited data and monitoring in both states makes it difficult to assess the impact of harvest and set appropriate regulations. Existing regulations in Maine and New Hampshire are inadequate to protect the American horseshoe crab, as evidenced by declines throughout the region. Where regulations exist, a lack of regional coordination nullifies the potential benefits of protections existing in specific areas.

Massachusetts

It is prohibited for individuals to keep, own, or harvest more than six horseshoe crabs in a single day, unless granted permission.[471] Horseshoe crabs retained under this non-commercial possession limit are solely for personal or family use and may not be sold, traded, exchanged, or offered for sale, trade, or exchange.

The state's commercial bait fishery quota allows for the harvest of 140,000 horseshoe crabs.[472] The annual quota for biomedical processors is set at 200,000 horseshoe crabs. This quota is evenly distributed among all entities permitted as biomedical processors.[473] The count against the biomedical processor quota only applies to horseshoe crabs processed by biomedical processors and harvested from waters within

[469]Novitsky 2015. 487.
[470]ASMFC 2001; Novitsky 2015. 487.
[471]322 CMR 6.34(4) or 322 CMR 6.34(5).
[472]322 Mass. Reg. 6.34.
[473]322 CMR 7.01(3).

the Commonwealth's jurisdiction, exclusively by biomedical harvesters for biomedical purposes. Horseshoe crabs obtained from a bait dealer for processing or those imported into the Commonwealth from another jurisdiction are not included in the biomedical processor quota. The dual-use provision in Massachusetts' regulations has driven increased demand for horseshoe crabs and increased mortality of horseshoe crabs.[474]

Massachusetts still allows for the harvest of horseshoe crabs during spawning season, a period vital for the species' population stability and migrating shorebirds. Massachusetts is also one of the few states still permitting harvest of horseshoe crabs as bait for whelk, a species already considered overfished and depleted. Further, the bait and biomedical harvests represent a double whammy on horseshoe crab populations. Where biomedical regulations exist, the state's annual harvest quota still allows for a significant harvest (200,000 crabs), and concerns remain regarding handling practices and the impacts of post-bleeding mortality on populations. The state also relies on incomplete data to assess the impacts on populations and enact adequate regulations, and a lack of regional coordination means that horseshoe crabs protected in one area are subject to harvest in another. While there have been efforts to protect the horseshoe crab in Massachusetts, mounting mismanagement concerns remain. State laws in Massachusetts are inadequate to protect the American horseshoe crab.

Rhode Island

The recreational horseshoe crab season is open throughout the year, with a possession limit of five crabs per person per day. In the commercial bait fishery, the state's annual quota is determined by the ASMFC or DMF and allows for the harvest of sixty crabs per person per day from January 1 to April 30 and again from June 1 to December 31, while closed in May. The commercial biomedical fishery, with an annual quota determined in consultation with permitted biomedical facilities, has an open season from January 1 to December 31, an unlimited possession limit, and a harvest restriction during the 48 hours preceding and following the new and full moons in May.[475]

Rhode Island's year-round open season for bait harvest means the state's horseshoe crab populations are subject to continuous pressure. Further, the state's 60-crab daily limit is particularly high, especially during spawning months when females are most vulnerable. Smaller coastal areas with concentrated crab populations are more

[474]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023.
[475]250 R.I. Code R. § 250-RICR-90-00-5.10

vulnerable to overharvest. Finally, similar to other states, there is limited data on female crab abundance, meaning the true impacts of harvesting on crab populations is lacking.

Connecticut

The state of Connecticut banned the harvest of horseshoe crabs for bait in 2023. The law prohibits the Connecticut Department of Energy and Environmental Protection from issuing permits for commercial bait harvest. Connecticut DEP can only issue permits for scientific and educational purposes "if it is determined that doing so will not harm the overall horseshoe crab population." [476] Upon signing the law, Connecticut Governor Lamont stated, "Unfortunately, the number of horseshoe crabs in Long Island Sound and throughout the Atlantic Coast has been severely depleted in recent years, raising concerns that this ancient species that has been around longer than the dinosaurs could be driven into extinction from overharvesting." [477]

The Connecticut portion of Long Island Sound has experienced a tenfold decrease in spawning horseshoe crab populations.[478] New York's portion of the Long Island Sound still allows commercial horseshoe crab harvest, which means crabs protected in Connecticut are still subject to harvest in the same waters. Project Limulus has found that Connecticut's no-harvest zones have not resulted in an increase in the spawning horseshoe crab population. Instead, researchers have documented the continued decline of this species in Connecticut.[479] The Connecticut bait harvest ban is promising, but without similar bans in neighboring states, it will not be sufficient to stem the declines of horseshoe crabs across the region.

New York

When the commercial fishery is closed, horseshoe crab permit holders may continue to take the recreational limit of five crabs per day for personal use. These crabs are not included in commercial harvest reports.[480]

The total annual commercial bait harvest of horseshoe crabs may not exceed the amount annually allocated to New York State by the Atlantic States Marine Fisheries Commission. To protect the sustainability of horseshoe crab stocks, New York has voluntarily reduced the permitted annual harvest of horseshoe crabs in New York State to a total of 150,000 crabs. To prevent the annual harvest allocation from being

[476]Conn. Agencies Regs. § 26-159a-17
[477]Bruce 2023.
[478]Jo-Marie Kasinak pers. comm. January 26, 2024.
[479]Mattei 2019.
[480]N.Y. Comp. Codes R. & Regs. tit. 6 § 44.3

exceeded, DEC has developed a quota distribution plan for the commercial horseshoe crab fishery.[481]

Two horseshoe crab permit holders may now harvest from a single vessel; each can take a single harvest limit. No more than two harvest limits may be possessed on board a vessel or in a vehicle, provided there are at least two permit holders present. Each permit holder must submit their own separate VTR.[482]

Holders of biomedical harvester permits for horseshoe crabs in New York are required to submit precise and comprehensive monthly reports detailing their fishing activities for horseshoe crabs.[483] However, New York is the only state along the Atlantic coast that does not have a total moratorium on horseshoe crab harvest during critical breeding months. During the peak breeding season — particularly during high tide/full moon or new moon — masses of spawning adults congregate along the tidal coastal fringe, where horseshoe crabs are taken from the beach within a few hours. Horseshoe crabs authorized by NYS DEC for harvesting for "bleeding" purposes are transported to Massachusetts, where a single company extracts blood from up to 135,000 animals. Unfortunately, instead of releasing the horseshoe crabs back into New York State waters as mandated by the NYS DEC permit, these crabs are released into local waters in Cape Cod. Subsequently, many of these animals are "reharvested" for use as bait and sold back to NYS fishermen, with an average cost of US $5 per crab, to the great economic benefit of all involved parties.[484]

Compared to other states, New York still allows a significantly higher annual quota for commercial harvest, at 150,000 crabs. Further, a year-round open season for recreational harvest places pressures on local populations, particularly during non-spawning seasons. The transport of horseshoe crabs from New York to Massachusetts further pressures horseshoe crab populations while proving to be extremely lucrative to industry. New York state regulations are inadequate to protect the American horseshoe crab, as evidenced by significant declines throughout the state and continued, high-volume harvest.

Maryland

Maryland horseshoe crab harvesting regulations detail that allowable landings for the commercial fishery are determined and subject to potential modifications through public notices. Any overages in the fishery during a given year are subtracted from the total

[481] *Id.*
[482] *Id.*
[483] *Id.*
[484] Tanacredi & Portilla 2015. 231.

allotment for the subsequent year. Harvesting seasons are established and can be adjusted through public notices. Time restrictions prohibit horseshoe crab catch or landing on Saturdays or Sundays. Catch limits vary, where individuals without a valid Maryland horseshoe crab landing permit are limited to 25 crabs per day. The state has a prohibition on catching or possessing female horseshoe crabs. Permit holders have specific catch limits, which may be modified through public notices. The issuance of horseshoe crab landing permits is capped at ten, based on reported catch and landing records in 1996. The transfer of landing permits is subject to department approval, with no more than two horseshoe crab quotas harvested from one vessel per trip.[485]

Additionally, specific provisions govern individuals authorized for scientific research, allowing exemptions and outlining acceptable practices. The Secretary holds the authority to modify catch limits, quotas, and seasons through public notices to align with the Atlantic States Marine Fisheries Commission Interstate Fishery Management Plan for Horseshoe Crab.[486]

Maryland allows for male harvest year-round (excepting Saturdays and Sundays), placing continuous pressure on horseshoe crab populations. The state has a high catch limit for individual permitted harvesters, of particular concern for smaller bay populations or for spawning populations. Allowing for significant harvest, particularly during peak spawning periods, endangers Maryland's horseshoe crabs. The state's regulations are not adequate to protect declining American horseshoe crab populations.

New Jersey

While bait harvest is banned in the state, biomedical companies are still permitted to harvest horseshoe crabs from New Jersey, including female horseshoe crabs. And ASMFC has shifted New Jersey's allotted quota to other states, effectively diminishing the impact of New Jersey's bait harvest ban. Despite the ban on bait harvests, horseshoe crab spawning populations and egg densities in New Jersey have failed to recover. Regulations are inadequate to protect the American horseshoe crab in New Jersey.

Delaware

The possession limit for horseshoe crabs in Delaware is generally set at 3,000 unless otherwise authorized. Exceptions include individuals with a validated receipt from a person holding a valid commercial collecting or dredge permit. Commercial eel fishing license holders are exempt from the possession prohibition if they submit required reports and may collect horseshoe crabs by hand for personal, non-commercial use as

[485]Md. Code Regs. 08.02.10.01

[486]*Id.*

bait for eel pots. The possession limit is strictly enforced; it is illegal to commingle horseshoe crabs between different permit holders or possess more than 3,000 horseshoe crabs, except in a stationary cold storage or freezer facility. The state enforces a daily collection limit of 3,000 horseshoe crabs during a 24-hour period.

The annual harvest limits for horseshoe crabs in the State are determined based on the sex-specific allocations set by the Atlantic States Marine Fisheries Commission's Horseshoe Crab Management Board. When the Department observes that 95% of a sex-specific quota has been reached, it will establish a date and time to close that component of the horseshoe crab fishery for the remainder of the calendar year. Any overages in the annual quota will be deducted from the following year's horseshoe crab quota allocation.[487]

Delaware allows for male harvest year-round, as well as a high daily catch limit for individuals and high quotas for the bait industry. Home to the largest populations of spawning horseshoe crabs, significant harvests still permitted by the state continue to endanger populations. Delaware state regulations are inadequate to protect the American horseshoe crab.

Virginia

In Virginia, individuals can hand harvest up to five horseshoe crabs per day for noncommercial purposes without a license. However, for commercial activities, a horseshoe crab permit is mandatory, and possession beyond the noncommercial limit is presumed to be for commercial reasons. Different permits are required for specific harvesting methods.[488]

Allowing a year-round harvest of male horseshoe crabs, a high daily catch limit (200 crabs), and continued harvest of horseshoe crabs for biomedical and bait purposes entails continued, significant pressures on American horseshoe crab populations in the state. Virginia state regulations are inadequate to protect the American horseshoe crab.

North Carolina

In 2023, the state specified a daily harvest limit of 50 horseshoe crabs per fishing operation per day. The annual commercial quota for horseshoe crabs in North Carolina is determined by the Atlantic States Marine Fisheries Commission. The Fisheries Director has the authority, through proclamation, to enforce various restrictions on horseshoe crab harvesting. These restrictions aim to ensure compliance with the

[487]Del. Admin. Code § 3200-3210 - Horseshoe Crab Reporting Requirements
State Regulations.
[488]4 Va. Admin. Code § 20-900-25.

Atlantic States Marine Fisheries Commission Interstate Fishery Management Plan for horseshoe crabs and to implement specific state management measures as needed.[489]

A year round open season on male harvest, high daily catch limits, and limited restrictions on biomedical harvest leave American horseshoe crabs vulnerable in the state of North Carolina. State regulations in North Carolina are inadequate to protect the species.

South Carolina

The annual commercial quota for horseshoe crabs in South Carolina is determined by the Atlantic States Marine Fisheries Commission. The taking or possession of horseshoe crabs in South Carolina is prohibited without a permit issued by the department. However, possessing a cast-off or molted shell (exoskeleton) of a horseshoe crab does not require a permit.[490] The department may grant permits with specified conditions, such as fishing areas, size requirements, net dimensions, by-catch regulations, fishing times, catch reporting, and holding facilities.[491] Horseshoe crabs used for blood collection must be held in approved facilities, minimizing harm, and returned to state waters after bleeding.[492] Incidental capture during legal fishing operations is permissible if crabs are promptly returned unharmed.[493] Horseshoe crabs collected in South Carolina cannot be taken out of the state.[494]

As the biomedical industry is lightly regulated by ASMFC, harvesters are unencumbered by time, place, or quota restrictions.[495] A recent court order prohibits the harvest of horseshoe crabs from Cape Romain National Wildlife Refuge and 30 other beaches across the state, but that agreement expires in 2028.

A year-round harvest of male horseshoe crabs, a high daily catch limit, and continued harvest of horseshoe crabs for biomedical and bait purposes entails continued and significant pressures on American horseshoe crab populations in the state. South Carolina state regulations are inadequate to protect the American horseshoe crab.

Georgia

Georgia prohibits the harvesting of horseshoe crabs for bait, except during specific periods. To harvest horseshoe crabs, individuals need a valid commercial fishing

[489]15A N.C. Admin. Code 3L.020
[490]Section 50-5-1330 A.
[491]Section 50-5-1330 B.
[492]Section 50-5-1330 C.
[493]Section 50-5-1330 D.
[494]Section 50-5-1330 F.
[495]Hunt 2022. 3.

license, with limits set at twenty-five crabs per person or seventy-five per boat. An exception is granted for medical purposes with a valid permit from the Georgia Department of Natural Resources. Georgia does not restrict the interstate import of horseshoe crabs, given the importer possesses a legitimate bill of lading confirming the crabs were not unlawfully taken from the state under these regulations.

Georgia manages its horseshoe crab population independently from the ASMFC. The state sets its own quotas and regulations for harvesting. The Georgia Department of Natural Resources (GADNR) is responsible for overseeing horseshoe crab conservation and implementing harvest regulations. As of January 2024, there are no closed seasons or size limits for harvesting horseshoe crabs in Georgia.[496]

A year round open season for recreational harvest and continued commercial bait harvest places significant pressure on horseshoe crab populations in Georgia. State regulations are inadequate to protect the American horseshoe crab in Georgia.

Florida

Florida's horseshoe crab management falls under the umbrella of the ASMFC's Interstate Fishery Management Plan. Florida’s state regulations specify that individuals without a valid saltwater products license cannot harvest, possess, or sell horseshoe crabs. The general harvest limit is set at 25 horseshoe crabs per day, with no more than 25 in possession on or around the waters. Individuals with a saltwater products license and a marine life endorsement can harvest up to 100 horseshoe crabs per day and possess up to 100 in or around waters. Those with a saltwater products license and a permit for commercial eel harvesting are also allowed up to 100 horseshoe crabs per day and can possess up to 100 in or around saltwaters. Individuals collecting horseshoe crabs for biomedical purposes under a valid permit are exempt from bag and possession limits.[497]

An open season for male harvest and high catch limits for permitted harvesters leave the American horseshoe crab vulnerable in the state of Florida. State regulations are inadequate to protect the American horseshoe crab.

Alabama, Mississippi, Louisiana, and Texas

Alabama, Mississippi, Louisiana, and Texas currently have no regulations in place specifically for horseshoe crab harvesting. State regulations are therefore inadequate to protect the American horseshoe crab.

[496]Ga. Comp. R. & Regs. R. 391-2-4-.15
[497]Fla. Admin. Code Ann. R. 68B-46.002

International Regulations

Mexico

Since 1994, horseshoe crab populations in the Yucatán Peninsula have been recognized as endangered under Mexican law. They have generally declined since the 1960s, although some areas are recovering. Remaining significant Yucatán populations are mostly within protected areas.[498] While the species is listed as "in danger of extinction" in Mexico, no comprehensive enforcement of the horseshoe crab's endangered status or other national regulations exist for the conservation of horseshoe crabs. Regulations in Mexico are inadequate to protect the American horseshoe crab.

[498]Zaldivar *et al.* 2009. 97.

Other natural or manmade factors affecting the continued existence of the species

Wikimedia Commons/Asturnut

Climate change

The primary threat posed by climate change to the American horseshoe crab is the potential loss of spawning habitat resulting from rising sea levels and storm events. Ocean warming and rising ocean surface levels have been "unprecedented over decades to millennia."[499] NOAA has listed the horseshoe crab's vulnerability to climate change as "very high" due in part to its susceptibility to sea level rise (see Figure 6).[500]. Even where fishing pressures are relieved, potential population rebounds will be offset due to sea level rise and the corresponding loss of habitat.[501]

[499]IPCC 2014. 2.
[500]NOAA 2023.
[501]Mark Botton, pers. comm. February 1, 2024.

Sea level rise is already contributing to the accelerated disappearance of crucial horseshoe crab spawning habitats, and it heightens the risk of horseshoe crab spawning areas being confined between the advancing sea and existing infrastructure and housing developments. Over the past century, sea levels have risen by 20–40 cm due to both sea level rise and the sinking of land.[502]

Delaware Bay is especially vulnerable. The tectonic plate for Delaware Bay is sinking, making sea level rise impacts even more severe. Sea levels in the Delaware Bay have risen more than 0.5 meters in the past century, and the state of Delaware anticipates sea level rises between 0.5 - 1.5 meters in the coming decades.[503] Historically, coastal wetlands were able to handle these events. As the sea levels rose, wetlands were able to migrate inland and adapt to the change in inundation level. However, due to development, roads and infrastructure, wetlands are now unable to migrate inland and thus are gradually eroding away and sinking beneath the rising sea. This leaves horseshoe crab spawning beaches especially vulnerable to climate change and sea level rise.[504]

Wind and wave activity, factors influenced by climate change, can also affect spawning success. Events like Hurricane Sandy have led to the destruction of optimal horseshoe crab habitats. Coastal infrastructure designed to mitigate sea level rise and storms can impede beach migration and exacerbate erosion, further reducing suitable spawning grounds. Sea level rise and hardening shorelines in tandem represent a significant threat to the American horseshoe crab. Horseshoe crabs have previously experienced sea level rise, but they never have had to contend with buildings and development blocking their access to critical spawning grounds.[505]

Climate change also causes more extreme weather events and increased horseshoe crab mortality. More frequent and intense storm events, especially during spawning activity, causes crabs to be flipped by the intensified energy of storm waves and become stranded.[506]

Attempts to restore horseshoe crab spawning habitat have proved challenging. In New Jersey, conservation groups have worked to replenish and restore several high value beaches for the horseshoe crab. However, storm surges, rising sea levels, and ensuing erosion have often changed these restored beaches drastically within a few years. During storm events of the May and June high tides, horseshoe crabs have become

[502]Smith *et al.* 2017. 155.
[503]DNREC 2023.
[504]*Ibid.*
[505]Jane Brockmann pers. comm. January 19, 2024.
[506]Larry Niles. pers. comm. January 25, 2024.

stranded in back bay marsh areas or impinged in human infrastructure. Without rescue, the crabs are unable to become free from the grasses and desiccate in the sun.[507]

In addition, climate change is affecting the cues required for the American horseshoe crab to carry out its adult life cycle. Horseshoe crabs rely on environmental indicators like water level, temperature, and tidal patterns for crucial life stages.[508]Changing temperatures is influencing horseshoe crabs daily and tidal rhythms and also affecting their breeding synchronization and foraging behavior.[509] Water level changes, especially cycles of inundation, remain the dominant cue for horseshoe crabs. With projected increases in sea level, changing cues could mislead spawning horseshoe crabs.

Horseshoe crabs also rely heavily upon salinity and temperature cues to locate suitable beaches for laying their eggs;[510] as salinity patterns amplify[511] and average surface temperatures increase[512] in the ocean, these cues could be significantly disrupted. Increasing water temperatures and changing storm frequencies and severity could influence the timing and success of spawning activity in some regions. Changed spawning activity would have uncertain consequences to horseshoe crab population viability and could initiate broader ecosystem effects by creating mismatches in predator-prey dynamics.[513] Given the reliance of horseshoe crabs on such cues for activities such as breeding and foraging, climate change could significantly impact the species' life cycle, with rippling ecosystem impacts.

Further, variations in temperature have significant potential to impact various aspects of the mate attraction and selection process. Temperature plays a role in influencing chemical signals throughout the entire communication process, ranging from the production and dissemination of pheromones to the detection of signals and subsequent behavioral responses. Global warming may pose a threat to long-range chemical communication. At extreme temperatures, signals and preferences may become mismatched, resulting in breakdowns in sexual communication. Temperature also plays a role in determining the reliability of quality signals and the ability of individuals to differentiate between potential mates, potentially leading to sexual isolation. Temperature can also influence the success of mating interactions by affecting copulation and fertilization outcomes.[514]

[507]Faith Zerbe pers. comm. February 1, 2024.
[508]Chabot *et al.* 2011. 53-57.
[509] Larry Niles. pers. Comm. January 25, 2024.
[510]Cheng *et al.* 2015.
[511]Cheng *et al.* 2020.
[512]NOAA 2021.
[513]Smith 2017. 156.
[514]Leith *et al.* 2021. 109.

NOAA assessed the American horseshoe crab's vulnerability to climate change as "very high" (83%). Three factors contributed to this assessment: ocean surface temperature (3.9), ocean acidification (4.0) and sea level rise (3.6). As a slow-growing and long-lived species with spawning requirements specific to certain lunar cycles and beaches, the horseshoe crab was rated as high in biological sensitivity due to population growth rate (3.4) and complexity in reproduction (3.1).[515]

According to NOAA's assessment, climate change is negatively affecting horseshoe crab spawning habitat and egg and larval survival and reducing productivity.[516]

The assessment also underscores the potential negative impacts of climate change upon larval survival and spawning habitat. The horseshoe crab's growth and larval development are temperature-dependent, where at 30 degrees Celsius maximum growth and development takes place. Multiple factors influence embryo development rate, and temperature and salinity changes could significantly impact larval survival, and at length, recruitment and population productivity. Sea level rise and beach erosion present another threat with predicted loss of spawning habitat in Delaware Bay, one of the species' most critical habitat strongholds and spawning sites.[517]

Furthermore, temperature and salinity significantly impact the larval growth of the American horseshoe crab. Climate-related changes to these abiotic factors, therefore, could severely affect the species' development. Horseshoe crab larvae exhibit sensitivity to temperature changes.[518] Warmer temperatures caused by climate change may affect the survival and development rates of the larvae. If temperatures rise beyond the species' optimal range, it could impact the overall success of horseshoe crab larvae development.[519]

Changes in precipitation patterns resulting from climate change could also influence salinity levels in estuarine habitats where horseshoe crabs breed — increases in rainfall, for example, might reduce salinity levels, affecting larval development. Estuarine salinity, influenced by freshwater discharge, is a known determinate for horseshoe crab habitat suitability at 8–10 parts per thousand and below. Freshwater discharge and changes in salinity could affect horseshoe crab occurrence.[520] Importantly, horseshoe crab larvae have limited metabolic compensation for the effects of temperature and salinity — extreme or rapidly changing climate conditions could

[515]NOAA 2016. 147.
[516]*Ibid.*
[517]*Ibid.*
[518]Laughlin 1983. 99.
[519]*Ibid*. 93-94.
[520]Estes MG Jr, Carmichael RH, Chen X, Carter SC 2021. 2.

Horseshoe Crab – *Limulus polyphemus*

Overall Vulnerability Rank = Very High

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 92% of scores ≥ 2

	Limulus polyphemus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Stock Status	2.0	2.8	
	Other Stressors	2.4	2.2	
	Population Growth Rate	3.4	2.6	
	Spawning Cycle	2.8	3.0	
	Complexity in Reproduction	3.1	2.8	
	Early Life History Requirements	2.0	3.0	
	Sensitivity to Ocean Acidification	2.1	2.6	
	Prey Specialization	2.2	2.4	
	Habitat Specialization	2.3	2.8	
	Sensitivity to Temperature	2.1	3.0	
	Adult Mobility	2.6	2.8	
	Dispersal & Early Life History	2.9	3.0	
	Sensitivity Score	High		
Exposure variables	Sea Surface Temperature	3.9	3.0	
	Variability in Sea Surface Temperature	1.0	3.0	
	Salinity	2.4	3.0	
	Variability Salinity	1.2	3.0	
	Air Temperature	3.1	3.0	
	Variability Air Temperature	1.0	3.0	
	Precipitation	1.3	3.0	
	Variability in Precipitation	1.4	3.0	
	Ocean Acidification	4.0	2.0	
	Variability in Ocean Acidification	1.0	2.2	
	Currents	2.0	1.0	
	Sea Level Rise	3.6	1.5	
	Exposure Score	Very High		
	Overall Vulnerability Rank	Very High		

Low
Moderate
High
Very High

Figure 6. NOAA's analysis of the American horseshoe crab's climate vulnerability determined that the species' overall vulnerability rank is Very High.

challenge the larvae's ability to adapt metabolically, making them more vulnerable to environmental stressors.

Today's ocean is about 30% more acidic than during industrial times; by 2100, the ocean's pH could decrease to 7.8,[521] making the ocean 150 percent more acidic and affecting half of all marine life.[522] pH can have distinct impacts on certain aspects of early horseshoe crab development, including carapace length and width and a reduced developmental advancement.[523] In one study, no horseshoe crab juveniles survived in systems with pH 6.0, 6.5, nor 7.0.[524] Increasing ocean acidification has the potential to impact horseshoe crabs globally.[525] Any change in the chemistry of seawater due to climate change could adversely affect reproduction in marine invertebrates, including the horseshoe crab.[526]

Life history strategies

The American horseshoe crab is slow to mature, taking 9 to 11 years to attain sexual maturity, and easily harvested with little financial investment[527] — making the species particularly susceptible to overharvest and exploitation.[528] Furthermore, changes in abundance are difficult to detect due to the long timescale of such shifts.[529] As the American horseshoe crab takes a long time to replenish from population impacts and juveniles have an extremely low success rate, the species' life history represents a "significant threat" to its long term viability.[530] Once a population is depleted, the timeline for recovery is at least one or more generations.[531]

Horseshoe crabs also have very low survival rates, where only 3 out of 100,000 survive the first year and only 1 out of 100,000 survive to adulthood.[532] The high natural mortality of juvenile horseshoe crabs, along with the species' slow sexual maturation of approximately 10-12 years, spells "high risk and a low scope for recovery of impacted populations." For all species of horseshoe crab, the addition of human-driven mortality, targeted at adult individuals, renders horseshoe crabs highly vulnerable to extirpation.[533]

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[521]IAEA 2022.
[522]IPCC Sixth Assessment Report.
[523]Tanacredi & Portilla 2015. 285.
[524]*Ibid*. 284.
[525]*Ibid.* 286.
[526]Subramoniam 2018. 10.
[527]ASMFC 1998. 1.
[528]*Ibid*. iii.
[529]*Ibid*. 18.
[530]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[531]Mark Botton, pers. comm. February 1, 2024.
[532]Gauvry 2015. 2; Jo-Marie Kasinak, pers. Comm. 2023.
[533]Botton *et al.* 2021. 3.

Shifting baselines

The challenge of horseshoe crab conservation and management is significantly impacted by shifting baselines. In conservation biology, the concept of "shifting baseline syndrome" refers to the bias in our perception of a baseline or pre-impacted condition, influenced by the absence of reliable long-term data on the abundance and distribution of a species.[534] Even in the United States, where mid-Atlantic horseshoe crab populations have been studied intensively for four decades, there is limited data on the much larger populations in the 1800s.[535] While today's horseshoe crab populations are sometimes considered "stable," in reality, these populations have shown no sign of recovery. They remain at 1/3 of the population before the overharvest of the 1990s; egg densities on spawning beaches also remain at historic lows.

According to Dr. Mark Botton, co-chair of the IUCN Species Survival Commission Horseshoe Crab Specialist Group, shifting baselines place us in a "tenuous position"[536] when exploring the ecological importance of a species with significantly reduced abundance such as the American horseshoe crab. We are at risk of "misinterpreting the current situation as the norm, when in fact horseshoe crabs may have already been reduced to a small fraction of their historic abundances."[537] Delaware Bay population peaks occurring during the nineteenth century could be far greater than any living scientist has witnessed.[538] Historical populations of horseshoe crabs are likely magnitudes greater than today. In failing to consider the historical context of significantly larger populations, we risk underestimating the true magnitude of this species' decline and therefore setting potentially inadequate management targets.

The lack of sufficient baseline data is even more apparent for Asian horseshoe crab populations. Detailed ecological studies, particularly in countries like Malaysia, Indonesia, Philippines, Vietnam, Thailand, Myanmar, Cambodia, India, and Bangladesh, are generally lacking, with sporadic and limited data on population density and abundance. Field surveys, however, provide empirical evidence that all three Asian species were once abundant but have disappeared in many locations due to various natural and anthropogenic influences described above.[539]

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[534] *Ibid*. 5.
[535] *Ibid*.
[536] Botton 2009. 46.
[537] *Ibid*.
[538] *Ibid*. 47.
[539] Botton *et al.* 2021. 5.

Genetic factors

Sex-biased dispersal observed among the American horseshoe crab means that if a population were to be extirpated, gene flow alone would not suffice to repopulate an area due to limited female migration and larval dispersal,[540] placing populations at risk of disappearance. Isolated subpopulations of the American horseshoe crab in the Southeast and Northeastern regions breed locally with very little to no overlap with other subpopulations. There is very little gene flow or transfer between these populations, and several subpopulations are highly vulnerable. A major climatic event preventing horseshoe crabs from feeding, such as a hurricane, would leave isolated subpopulations vulnerable to extinction.[541]

Female horseshoe crabs display reduced vagility, or movement ability, and males display heightened vagility, with the peak occurring in the region between the Chesapeake and Delaware Bays. The notable male migration between these two bays surpasses female gene flow. This sex-biased dispersal suggests that in the event of population extirpation, relying solely on gene flow may not be adequate for repopulating an area due to constrained larval dispersal potential and limited female migration between embayments.[542]

Sex ratios and impacts on migration and abundance

Both biomedical and bait fisheries show a preference for females when available because of their larger sizes.[543] As a result, female horseshoe crabs are even more rare. The disproportionate impacts of overharvest on females could be exacerbated by increased blood and bait harvests. Declines in female populations represent a significant threat to the American horseshoe crab. A decrease in the actual number of female animals in conjunction could have additive negative population impacts, especially in a species that takes a relatively long time to reach reproductive maturity.[544]

Conversely, while the preferential harvest of females represents the greatest threat to American horseshoe crab populations, in some areas, sex ratios are skewed towards a male bias. If fewer males are arriving to pair with females and less nursery habitat exists, populations are susceptible to “declining dramatically” and “very quickly.”[545] Many instances of unfertilized nests have been observed on spawning beaches.[546]

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[540]Smith *et al.* 2017. 142.
[541]Jane Brockmann pers. comm. January 19, 2024.
[542]Smith *et al.* 2017. 142.
[543]Species Listing Proposal Form: Listing Endangered, Threatened, and Special Concern Species in Massachusetts. 2023. 8-9.
[544]Tuxbury 2023. 1.
[545]Jo-Marie Kasinak, pers. comm. Jan 26, 2024.
[546]*Ibid*.

Before the sex ratio of spawning female to male horseshoe crabs became disproportionately high, even the Atlantic States Marine Fisheries Commission (ASMFC) acknowledged that shifts away from the normal 1:1 sex ratio, particularly towards fewer females, indicated overfishing of females.[547]

In Massachusetts, areas where horseshoe crab take was absent maintained a female-to-male sex ratio of nearly 1:1. However, in areas where a horseshoe crab fishery operated, the ratio became highly skewed towards males. Without Endangered Species Act protections, overharvesting will further skew sex ratios and cause even steeper declines in horseshoe crab populations.

In Raritan Bay and Sandy Hook Bay in New Jersey, where horseshoe crabs have been monitored for more than 10 years, the ratio of female horseshoe crabs to males is highly skewed. Total female horseshoe crabs in 2023 were tallied at 680 — making up approximately 20 percent of the population.[548] This percentage is similar to the previous year. Adult male crabs tallies in 2023 were 2,297 — representing approximately 80 percent of the population. Around 60 percent of these males were single.[549] This extensive difference between sexes has been attributed to the harvest of crabs for bait and the biomedical industry in nearby New York state waters.[550]

The removal of females from breeding grounds violates a “common rule” in wildlife management.[551] In the commercial cod and lobster industries, females are not removed, especially from their breeding sites. The same rule applies to horseshoe crabs. Ideally, breeding animals — the healthiest and most mature portion of a population — should not be taken at all.[552]

Niche divergence in American horseshoe crabs

The conservation needs of *Limulus polyphemus* vary significantly among its six genetically-defined metapopulations. The inadequacies of a uniform conservation approach could represent a potential threat to overall populations of the American horseshoe crab. Unique environmental conditions, such as sea surface temperature, tidal regime, chlorophyll a concentrations, and seafloor depth influence the distribution and conservation requirements of different metapopulations. The distribution of one metapopulation of *L. polyphemus* cannot be substituted by another — a one-size-fits-all

[547]ASMFC 1998. 4.
[548]Save Coastal Wildlife 2023; Jenna Reynolds pers. comm. January 22nd, 2024.
[549]*Ibid.*
[550]*Ibid.*
[551]Jane Brockmann pers. comm. January 19th, 2024.
[552]*Ibid*.

approach to conservation assessments, such as the ARM framework, will not suffice to preserve the American horseshoe crab.[553]

An expanding body of evidence highlights that effective conservation strategies for horseshoe crabs should take into account local habitat characteristics and assess individual population's vulnerability to habitat fragmentation and local human-induced disturbances. Locally tailored conservation strategies that address within-region variations in habitat type and anthropogenic pressures will be critical to preserving the American horseshoe crab.[554] Failure to address these specific needs in tailored conservation efforts may lead to the fragmentation and decline of subpopulations, posing a broader risk to the species as a whole.

Global horseshoe crab decline

The drastic decline of Asian horseshoe crab species due to intense harvesting pressure and habitat destruction reveals the ease with which this ancient sea creature can be pushed to the brink of extinction. The decline of horseshoe crab species in Asia should serve as a warning to the vulnerability of the closely related American horseshoe crab.

Populations of *Tachypleus tridentatus*, a close relative of the American horseshoe crab, were “distributed extensively” until as late as the 1990s.[555] These once-robust populations, prevalent just three decades ago, are now observed to be “considerably reduced.”[556] Horseshoe crab populations are in decline across Asia due to unsustainable fishing, industrial pollution and coastal reclamation.[557]

The loss of tidal flats and sandy beaches have driven massive declines in *T. tridentatus* populations in Japan, where the species is considered critically endangered. The decline of horseshoe crab spawning grounds has led to the extinction of adult *T. tridentatus* in Kinmen Island, Taiwan. A substantial 90% decrease in the juvenile population of *T. tridentatus* in Hong Kong is likely to result in local extirpation. Gravid female-biased harvesting of *T. gigas* from Indonesia and Malaysia, exported to Thailand as a local delicacy, has significantly increased in the last decade, causing an imbalanced sex ratio in the wild. Ongoing population decline has led to a drop in the biomedical bleeding harvest of *T. tridentatus* for Tachypleus amebocyte lysate (TAL) production in mainland China from 600,000 pairs in the 1990s to the current 100,000 pairs. Recently, *T. tridentatus* has been classified as 'Endangered' on the IUCN list.[558]

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[553]Zhu, Yuan & Fan 2019. 4.
[554]Estes MG, Jr., Carmichael RH, Chen X, Carter SC. 2021. 18.
[555] Y. Liao *et al.* 2017. 226.
[556]*Ibid*.. 222.
[557]*Ibid*.
[558]John *et al.* 2020. 253.

Importantly, with Asian species in steep decline, *Tachypleus* species will no longer be able to feasibly support TAL production for the Asian pharmaceutical and medical device industries — meaning demand would shift onto the American horseshoe crab.

REQUEST FOR CRITICAL HABITAT DESIGNATION

Gregory Breese/USFWS

NOAA Fisheries should designate critical habitat for the American horseshoe crab concurrently with its listing. Critical habitat as defined by Section 3 of the ESA is: (i) the specific areas within the geographical area occupied by a species, at the time it is listed in accordance with the provisions of section 1533 of this title, on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) the specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of section 1533 of this title, upon a determination by the Secretary that such areas are essential for the conservation of the species (16 U.S.C. § 1532(5)).

Congress recognized that the protection of habitat is essential to the recovery and/or survival of listed species, stating that: “classifying a species as endangered or threatened is only the first step in ensuring its survival. Of equal or more importance is the determination of the habitat necessary for that species’ continued existence... If the protection of endangered and threatened species depends in large measure on the preservation of the species’ habitat, then the ultimate effectiveness of the Endangered

Species Act will depend on the designation of critical habitat." In addition, species with designated critical habitat are more than twice as likely to recover.[559]

The American horseshoe crab urgently needs critical habitat protection to be issued concurrently with its endangered species designation. American horseshoe crab critical habitat consists of coastal areas, bays, beaches, estuaries, continental shelf waters, and open marine habitat which are essential to the species' long-term genetic health and survival. Critical habitat will protect the American horseshoe crab from further harm and population decline and ensure its full recovery.

The American horseshoe crab is threatened with extinction across a significant portion of its range. According to the IUCN Species Survival Commission's Horseshoe crab Specialist Group, habitat loss due to sea level rise and climate change threatens the American horseshoe crab across the entirety of its range.[560] Overharvesting also threatens the species across a significant portion of its range, including its last population stronghold in Delaware Bay.

Critical habitat is essential to protect, restore, and expand spawning beaches, and it must also safeguard bays, inlets, and continental shelf habitat where horseshoe crabs overwinter.

Other species of conservation concern also depend on the habitat where the American horseshoe crab resides, including the semipalmated plover, ruddy turnstone, and diamondback terrapin. All of these species are experiencing significant declines and could soon be candidates for federal listing. Providing critical habitat for the American horseshoe crab would help provide protections for other rare and imperiled aquatic species who are similarly reliant upon specific threatened coastal and estuarine ecosystems.

Critical habitat is urgently needed to ensure the long-term health and survival of the American horseshoe crab.

[559]Taylor *et al.* 2005.
[560]IUCN Green Status Assessment 2023.

CONCLUSION

Gregory Breese/USFWS

Horseshoe crab populations, spawning, and egg densities are depleted, and threats from overharvest, climate change, and habitat loss are increasing across most of their range.

In the past three decades, horseshoe crab populations and spawning have crashed and not recovered. Since the 1990s, the Delaware Bay's horseshoe crab population has fallen by at least two-thirds, and horseshoe crabs have experienced similar declines across most of their range.[561]

Horseshoe crab spawning has also decreased by 72% in the past three decades. More than 1.2 million horseshoe crabs spawned in the Delaware Bay in 1990. In 2020, only 335,211 spawned.[562]

[561]Smith *et al.* 2017. 135.
[562]Delaware Bay Horseshoe Crab Survey 1990-2022.

In addition, horseshoe crab egg densities on spawning beaches have declined steeply—from 40,000 per square meter in the 1980s to an average of 5,000 per square meter in 2019.[563] Horseshoe crab eggs located in the top 5 centimeters of sand have stagnated "an order of magnitude"[564] lower than densities recorded before crabs were overharvested. Horseshoe crab egg densities have decreased by more than 80% in the past four decades.[565]

Endangered sea turtles, fish, and shorebirds are suffering from the horseshoe crab's decline. Red knot populations have crashed along with horseshoe crab populations, and the U.S. Fish and Wildlife Service identified commercial harvests of horseshoe crabs as "a primary causal factor" in the red knot's decline and subsequent listing under the Endangered Species Act in 2014.[566]

American horseshoe crab populations have crashed primarily due to habitat loss and overharvesting by commercial fisheries and biomedical industries. In 2022, nearly one million crabs were harvested for biomedical bleeding, including female crabs. Biomedical harvests also can occur at any time of year, including during spawning season. Horseshoe crab blood harvests have nearly doubled since 2017.

Horseshoe crabs are also being overharvested for use as bait by commercial whelk and eel fisheries. Horseshoe crab harvests in the mid-Atlantic climbed from 100,000 in 1991 to their peak of 2.5 million in 1998. As a result, horseshoe crab populations along the Atlantic Coast were decimated and have never recovered. Horseshoe crab populations have shown no sign of recovery, and they remain at 1/3 of the population before the overharvest of the 1990s. Horseshoe crab egg densities on spawning beaches also remain at historic lows.

Despite low horseshoe crab populations and egg densities, the Atlantic States Marine Fisheries Commission revised its ARM model in 2021 to recommend increased horseshoe crab harvests and harvests of female horseshoe crabs.

Habitat loss is occurring across the horseshoe crab's entire range. Beaches along the Atlantic and Gulf Coasts have been affected by development, shoreline hardening, pollution, extreme weather, and sea level rise, limiting the amount of available grounds for spawning horseshoe crabs. In 2023, NOAA ranked the American horseshoe crab's Overall Vulnerability to Climate Change as Very High. Sea level rise and extreme

[563] *Ibid.*
[564] *Ibid.*
[565] Hunt 2022. 3.
[566] USFWS 2014.

weather events fueled by climate change have resulted in the destruction of spawning beach habitat. Shoreline hardening through sea walls, jetties, and bulkheads, has further degraded horseshoe crab habitat. Habitat loss has reduced the available grounds for spawning horseshoe crabs and their eggs. Dredging and harbor deepening have increased across the Atlantic and Gulf Coasts and resulted in substantial mortality events for horseshoe crabs and destruction of their habitat.

Asian horseshoe crabs are even more depleted than American horseshoe crabs, increasing pressure on remaining U.S. horseshoe crab populations. The tri-spine horseshoe crab (*Tachypleus tridentatus)* is listed as Endangered by the IUCN, and two other Asian species are expected to be red-listed as Endangered this year. The American horseshoe crab faces similar threats and is following a similar trajectory.[567]

Across a significant portion of their range, horseshoe crabs are threatened by habitat loss, overexploitation, inadequacy of existing regulatory mechanisms, and other natural and manmade factors, including climate change. These threats are likely to persist and worsen in the foreseeable future. This ancient lineage of life has endured for nearly a half-billion years, but its future now depends on us. American horseshoe crabs urgently need listing and critical habitat under the Endangered Species Act.

[567]Jane Brockmann, pers. comm., January 19th 2024.

WORKS CITED

Arctos. “Limulus polyphemus.” arctos.database.museum/name/Limulus/polyphemus.

Arnold, Carrie. 2020. National Geographic. “Horseshoe crab blood is key to making a COVID-19 vaccine—but the ecosystem may suffer.” nationalgeographic.com/animals/article/covid-vaccine-needs-horseshoe-crab-blood

Atlantic States Marine Fisheries Commission. 1998. Fishery Management Report No. 32 of the Atlantic States Marine Fisheries Commission Interstate Fishery Management Plan for Horseshoe Crab.

Atlantic States Marine Fisheries Commission. 2000. Addendum I to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2001. Addendum II to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2004. Addendum III to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2006. Addendum IV to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2008. Addendum V to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2010. Addendum VI to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2012. Addendum VII to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2019. Horseshoe Crab Benchmark Stock Assessment Peer Review Report. https://asmfc.org/uploads/file/63d2ed62HSCAssessment_PeerReviewReport_May2019.pdf

Atlantic States Marine Fisheries Commission. 2022. Addendum VIII to the Fishery Management Plan for Horseshoe Crab. asmfc.org

Atlantic States Marine Fisheries Commission. 2022. *Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation*, ii, v. 83, 100-102.

Atlantic States Marine Fisheries Commission. 2022. November 2022 Annual Meeting Slideshow. Review of the Interstate Fishery Management Plan: Horseshoe Crab (Limulus polyphemus), 2021 Fishing Year, in ASMFC, Meeting Materials for October 2022 meeting of the ASMFC Horseshoe Crab Management Board.

Atlantic States Marine Fisheries Commission. 2023. Review of the Interstate Fishery Management Plan: Horseshoe Crab (Limulus polyphemus), 2022 Fishing Year, in ASMFC, Meeting Materials for October 2023 meeting of the ASMFC Horseshoe Crab Management Board, 9 tbl. 2 (297 of PDF) (Oct. 2023), https://asmfc.org/files/2023AnnualMeeting/HSCManagementBoard_October2023_1.pdf.

Atlantic States Marine Fisheries Commission Slide Presentation. 2023. November 2023 Annual Meeting Slideshow. Review of the Interstate Fishery Management Plan: Horseshoe Crab (Limulus polyphemus), 2022 Fishing Year, in ASMFC, Meeting Materials for October 2023 meeting of the ASMFC Horseshoe Crab Management Board, 9 tbl. 2 (297 of PDF) (Oct. 2023), https://asmfc.org/files/2023AnnualMeeting/HSCManagementBoard_October2023_1.pdf.

Banerjee K, Mitra A. 2017. Horseshoe crab: A biogem of the estuarine ecosystem. MOJ Biol Med. 1(2):50–54. DOI: 10.15406/mojbm.2017.01.00012

Barry, Savannah, Holly Abeels, and Shelly Krueger. 2020. The American horseshoe crab (Limulus polyphemus), SG190 (School of Forest Resources and Conservation University of Florida) https://edis.ifas.ufl.edu/publication/SG190.

Bartelme, T and McCray, Shamira. 2022. Monkeys and blood: SC Agency rakes in millions from pharma company it regulates. Post and Courier: March 4th: https://www.postandcourier.com/news/special_reports/sc-agency-rakes-in-millions-from-pharma-company-it-regulates/article_60a80662-82e1-11ec-94d8-2791d3f53dcd.html

Bartelme, T and McCray, Shamira. 2023. Alpha Genesis takes over management of Morgan Island. Post and Courier: March 20, 2023.

https://www.postandcourier.com/news/alpha-genesis-takes-over-management-of-south-carolinas-monkey-island/article_fb08a7d2-ce5a-11ed-bd91-8b72f090aac4.html

Becker A, Whitfield AK, Cowley PD et al. 2013. Potential effects of artificial light associated with anthropogenic infrastructure on the abundance and foraging behaviour of estuary associated fishes. J Appl Ecol 50:43–50

Beekey MA, Mattei JH. 2015. The mismanagement of Limulus polyphemus in Long Island Sound: what are the characteristics of a population in decline. In: Carmichael RH, Botton M, Shin PKS, Cheung SG (eds) Changing global perspectives on horseshoe crab biology, conservation and management. Springer, New York, pp 537–555

Botton, M.L., R.E. Loveland and T.R. Jacobsen. 1994. Site selection by migratory shorebirds in Delaware Bay and its relationship to beach characteristics and abundance of horseshoe crab (Limulus polyphemus) eggs.

Botton ML, Mattei J, Robinson GS et al. 2009. Horseshoe crabs in New Haven Harbor: an initial study of reproductive biology and beach quality. In: Tanacredi JT, Botton ML, Smith DR (eds) Biology and conservation of horseshoe crabs. Springer, New York, p 613

Botton, Mark. 2009. The Ecological Importance of Horseshoe Crabs in Estuarine and Coastal Communities: A Review and Speculative Summary. 10.1007/978-0-387-89959-6_3.

Botton M. L., & Itow, T., 2009. The Effects of Water Quality on Horseshoe Crab Embryos and Larvae, in Biology and Conservation of horseshoe crabs, 439, 441.

Botton M. L., Colón C. P., Rowden J., Elbin S., Kriensky D., McKown K., & Madden R. 2018. Effects of a beach nourishment project in Jamaica Bay, New York, on horseshoe crab (Limulus polyphemus) spawning activity and egg deposition. *Estuaries and Coasts*, 41(4), 974–987.

Botton, Mark & John, Akbar & Carmichael, Ruth & Faridah, M. & Bhadury, Punyasloke & Zaldívar-Rae, Jaime & Shin, Paul & Tanacredi, John & Cheung, Siu Gin. 2021. Horseshoe Crabs: “Living Fossils” Imperiled in the Anthropocene. 10.1016/B978-0-12-821139-7.00103-3.

Boyles, RH *et al.* 2021. Notice of Intent to Sue to Remedy Violations of the Endangered Species Act. Southern Environmental Law Center.

https://www.southernenvironment.org/wp-content/uploads/2021/11/Horseshoe-Crab-NOI.pdf

Brockmann HJ, Black T, King TL 2015. Florida horseshoe crabs: populations, genetics and the marine-life harvest. In: Carmichael RH, Botton ML, Shin PKS, Cheung SG (eds) Changing global perspectives on horseshoe crab biology, conservation and management. Springer, New York, pp 97–127.

Bruce, Sharon. 2023. New law aims to increase horseshoe crab populations. Audubon. https://ct.audubon.org/news/new-law-aims-increase-horseshoe-crab-populations

Burger, J. 2023. Metal Levels in Delaware Bay Horseshoe Crab Eggs from the Surface Reflect Metals in Egg Clutches Laid beneath the Sand. Toxics, 11, 614. https://doi.org/10.3390/toxics11070614

Carmichael, Ruth, Mark L. Botton, Paul K.S. Shin, and Siu Gin Cheung. 2015. Changing Global Perspectives in Horseshoe Crab Biology. Conservation, and Management. Springer Cham: 15-39, 41-63. 65-96. https://doi.org/10.1007/978-3-319-19542-1.

Chabot, Christopher C., Jeffrey F. Yelle , Conor B. O'Donnell & Winsor H. Watson III. 2011. The effects of water pressure, temperature, and current cycles on circatidal rhythms expressed by the American horseshoe crab, Limulus polyphemus , Marine and Freshwater Behaviour and Physiology, 44:1, 43-60, DOI: 10.1080/10236244.2010.541992

Chabot CC, Watson WH III. 2010. Circatidal rhythms of locomotion in the American horseshoe crab Limulus polyphemus : underlying mechanisms and cues that influence them. Curr Zool 56:499–517

Cheng, Helen, Chabot CC, Watson WH III. 2015. The Life History Cycle of Limulus polyphemus in the Great Bay Estuary, New Hampshire U.S.A. Changing Global Perspectives in Horseshoe Crab Biology. Conservation, and Management. Springer Cham: 237-253. https://doi.org/10.1007/978-3-319-19542-1.

Cheng L., K. E. Trenberth, N. Gruber, J. P. Abraham, J. Fasullo, G. Li, M. E. Mann, X. Zhao, Jiang Zhu. 2020: Improved estimates of changes in upper ocean salinity and the hydrological cycle. Journal of Climate. In press, doi: external pagehttps://doi.org/10.1175/JCLI-D-20-0366.1call_made.

Chesapeake Bay Magazine. 2021. What's causing the horseshoe crab die-off in Ocean City?
chesapeakebaymagazine.com/whats-causing-horseshoe-crab-die-off-in-ocean-city/

Cramer, Deborah. 2018. Inside the Biomedical Revolution to Save horseshoe crabs and the Shorebirds that Need Them. National Audubon Society.
https://www.audubon.org/magazine/summer-2018/inside-biomedical-revolution-save-horseshoe-crabs

Delaware Bay Horseshoe Crab Survey. 1990-2022.
www.delawarebayhscsurvey.org/surveyreports

Delaware Department of Natural Resources and the Environment. 2023. Sea level rise and Delaware's wetlands.
https://dnrec.delaware.gov/watershed-stewardship/wetlands/and-sea-level-rise/

Dey, Amanda D., Niles, Lawrence J., Smith, Joseph A.M., Sitters, Humphrey P, Morrison, R.I. Guy. 2020. Update to the Status of the Red Knot (Calidris canutus rufa) in the Western Hemisphere.
https://dep.nj.gov/njfw/wp-content/uploads/njfw/redknotupdate-Final-3-3-20.pdf

Dixon, Douglas, J. Veil, and J. Wisniewski. 2003. Defining and Assessing Adverse Environmental impact from Power Plant Impingement and Entrainment of Aquatic Organisms. CRC Press: 165-184. https://doi.org/10.1201/b16996.

Dujins, Syoerd, Lawrence J. Niles, Amanda Dey, Yves Aubry, Christian Friis, Stephanie Koch, Alexandra M. Anderson, and Paul A. Smith. 2017. Body Condition Explains Migratory Performance of a Long-Distance Migrant. Proceedings of the Royal Society B. Biological Sciences. 284. https://doi.org/10.1098/rspb.2017.1374

Earthjustice, 2023. Comments on Draft Addendum VIII to the Horseshoe Crab Fishery Management Plan. September 25, 2023.

Eisner, Chiara. 2023. Coastal biomedical Laboratories are bleeding more horseshoe crabs with little accountability. June 30th: NPR:
https://www.npr.org/2023/06/10/1180761446/coastal-biomedical-Laboratories-are-bleeding-more-horseshoe-crabs-with-little-accountability

Environmental Integrity Project: The Clean Water Act at 50: Promises Half Kept at the Half Century Mark. 2022.

https://environmentalintegrity.org/wp-content/uploads/2022/03/CWA@50-report-EMBARGOED-3.17.22.pdf

EPRI. 2003. Evaluating the Effects of Power Plant Operations on Aquatic Communities: Summary of Impingement Survival Studies. Palo Alto, CA. 1007821.

Estes MG Jr, Carmichael RH, Chen X, Carter SC. 2021. Environmental factors and occurrence of horseshoe crabs in the northcentral Gulf of Mexico. PLoS ONE 16(1): e0243478. https://doi.org/10.1371/journal.pone.0243478

Fang, J. K. H., Tse, T. W., Maboloc, E. A., Leung, R. K. L., Leung, M. M. L., Wong, M. W. T., Chui, A. P. Y., Wang, Y., Hu, M., Kwan, K. Y., & Cheung, S. G. 2023. Adverse impacts of high-density microplastics on juvenile growth and behaviour of the endangered tri-spine horseshoe crab Tachypleus tridentatus. Marine Pollution Bulletin, 187, 114535. https://doi.org/10.1016/j.marpolbul.2022.114535

Fisher, Robert and D.E. Fisher. 2006. The use of bait bags to reduce the need of horseshoe crab as bait in the Virginia whelk fishery. Virginia Institute of Marine Science. 3-11.

Galtsoff PS. 1949. The mystery of the red tide. Sci Mon 68:108–117

Garmoe, Z., A. T. McGowan, and D. H. Bartow. 2021. Inland Bays Volunteer horseshoe crab Spawning Survey Annual Report 2020. Delaware Center for the Inland Bays. Rehoboth Beach, DE. 23pp.

Gauvry, Glenn. 2015. Current Horseshoe Crab Harvesting Practices Cannot Support Global Demand for TAL/LAL: The Pharmaceutical and Medical Device Industries' Role in the Sustainability of Horseshoe Crabs. 10.1007/978-3-319-19542-1_27.

Georgia Chapter of the American Fisheries Society. 2022. Feral hogs: an aquatic nuisance weakens the resiliency of coastal marshes. https://gaafs.org/2022/09/06/feral-hogs-an-aquatic-nuisance-species-weakens-the-resiliency-of-coastal-marshes/

Gerhart SD. 2007. A review of the biology and management of horseshoe crabs, with emphasis on Florida populations. Fish and Wildlife Research Institute, technical report 12, St. Petersburg

Gittman, R.K., et. al. 2015. Engineering Away our Natural Defenses: An Analysis of Shoreline Hardening in the US, 13 Frontiers in Ecology and the Environment 301-307, 301.

Guzman, Joseph. 2020. Horseshoe crabs are crucial to creating vaccines, but they are facing extinction. The Hill. November 10. thehill.com/changing-america/sustainability/environment/525413-horseshoe-crabs-are-crucial-to-creating-vaccines/

Haro, Alex, Richkus, W., Whalen, K., Hoar, A. et. al. 2000. Population decline of the American eel: Implications for research and management. Fisheries. 25: 7-16.

Harramis, G.M., W.A. Link, P.C. Osenton, D.B. Carter, R.G. Weber, N.A. Clark, M.A. Teece and D.S. Mizrahi. 2007. Stable isotope and pen feeding trial studies confirm the value of horseshoe crab Limulus polyphemus eggs to spring migrant shorebirds in Delaware Bay. Journal of Avian Biology. 38: 367376. doi: 10.1111/j.2007.0908-8857.03898.x.

Hartley, M.J. and A.J. Weldon, eds. 2020. Saltmarsh Sparrow Conservation Plan. Atlantic Coast Joint Venture, 17, acjv.org/documents/SALS_plan_final.pdf.

Hopkinson and Vallino. The relationships among man's activities in watershed and estuaries; A model of runoff effects on patterns of estuarine community metabolism, Estuaries. 1995;18:598–621.

Horseshoe Crab Recovery Coalition. 2023. hscrarecovery.org.

Hunt, Christian. 2022. A call for intervention: the decline of South Carolina's Horseshoe Crab Population. Defenders of Wildlife. https://defenders.org/sites/default/files/2022-03/A%20Call%20for%20Intervention%20-%20The%20Decline%20of%20South%20Carolina%27s%20Horseshoe%20Crab%20Population%20%282022%29.pdf

Intergovernmental Panel on Climate Change, Climate Change. 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC. 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K.

Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

(IUCN) International Union for the Conservation of Nature Red List. 2021. Rufa red knot (Calidris canutus rufa). Loggerhead sea turtle (Caretta caretta). Diamondback terrapin (Malaclemys terrapin). horseshoe crab (Limulus polyphemus). American eel (Anguilla rostrata).iIucn.org.

(IUCN) International Union for the Conservation of Nature Red List. 2023. American horseshoe crab (Limulus polyphemus). Green Status Assessment Information. .iucnredlist.org/species/11987/80159830

Jackson, N.J., et. al. 2015. Influence of Configuration of Bulkheads on Use of Estuarine Beaches by horseshoe crabs and Foraging Shorebirds, 74 Env't Earth Sci. 5749, 5749

John, A., Shin, P. K. S., Botton, M. L., Gauvry, G., Cheung, S. G., & Laurie, K. (2021). Conservation of Asian horseshoe crabs on spotlight. *Biodiversity and conservation*, *30*(1), 253–256. https://doi.org/10.1007/s10531-020-02078-3

Karpanty, S.M., J.D. Fraser, J. Berkson, L.J. Niles, A. Dey and E.P. Smith. 2006. horseshoe crab eggs determine Red Knot distribution in Delaware Bay. Journal of Wildlife Management. 70: 1704-1710.

Kelderman, K. *et al.* 2022. The Clean Water Act at 50: Promises Half Kept at the Half-Century Mark. Environmental Integrity Project: March 17th: https://environmentalintegrity.org/wp-content/uploads/2022/03/CWA-report-3.23.22-FINAL.pdf

Kemper, K. 2017. Swallowed by the Sea. Where Coastal Infrastructure and Jobs meet Climate Change, World Bank Blogs: Nov. 9: https://blogs.worldbank.org/voices/swallowed-sea-where-coastal-infrastructure-and-jobs-meet-climate-change#:~:text=Coastal%20infrastructure%20%E2%80%93%20especially%20ports%2C%20but,withdraw%20'beach%20building%20material'.

Kreamer, G, Michels, S. 2015. History of Horseshoe Crab Harvest on Delaware Bay. Changing Global Perspectives in Horseshoe Crab Biology. Conservation, and Management. Springer Cham: 299-313. https://doi.org/10.1007/978-3-319-19542-1.

Krisfalusi-Gannon, J., Ali, W., Dellinger, K., Robertson, L., Brady, T. E., Goddard, M. K. M., Tinker-Kulberg, R., Kepley, C. L., & Dellinger, A. L. 2018. The Role of horseshoe crabs in the Biomedical Industry and Recent Trends Impacting Species Sustainability. Frontiers in Marine Science, 5. https://www.frontiersin.org/articles/10.3389/fmars.2018.00185

Lamsdell JC. 2020. The phylogeny and systematics of Xiphosura. PeerJ 8:e10431 http://doi.org/10.7717/peerj.10431

Laughlin, R. 1983. The Effects of Temperature and Salinity on Larval Growth of the horseshoe crab Limulus polyphemus. Biological Bulletin, 164(1), 93–103. https://doi.org/10.2307/1541193

Leith, N. T., Macchiano, A., Moore, M. P., & Fowler-Finn, K. D. 2021. Temperature impacts all behavioral interactions during insect and arachnid reproduction. Current Opinion in Insect Science, 45, 106-114. https://doi.org/10.1016/j.cois.2021.03.005

Leschen, A.S. and S.J. Correia. 2010. Mortality in Female horseshoe crabs (Limulus Polyphemus) From Biomedical Bleeding and Handling: Implications for Fisheries Management, 43 Marine & Freshwater Behaviour and Physiology. 135-147.

Liao, Y., Hsieh, H., Xu, S., Zhong, Q., Lei, J., Liang, M., . . . Kwan, B. (2019). Wisdom of Crowds reveals decline of Asian horseshoe crabs in Beibu Gulf, China. Oryx, 53(2), 222-229. doi:10.1017/S003060531700117X

Liou, Joanne. 2022. *What is ocean acidification?* International Atomic Energy Agency: June 8th: https://www.iaea.org/newscenter/news/what-is-ocean-acidification

Lipcius, Romuald. 2022. Expert Report on Draft Addendum VIII to the Horseshoe Crab Fishery Management Plan for Public Comment. Atlantic States Marine Fisheries Commission. September 29, 2022.

Long Island Sound Study, 2022. https://longislandsoundstudy.net/

Loomis, Rebecca and Ramirez, Rebecca. 2023. Study Shows 14,000 Unplugged Oil and Gas Wells in Gulf of Mexico. Natural Resources Defense Council: May 23: https://www.nrdc.org/bio/rebecca-loomis/study-shows-14000-unplugged-oil-and-gas-wells-gulf-mexico

Lyons, J. and Haig, S. 1995. Fat content and stopover ecology of spring migrant semipalmated sandpipers in South Carolina. The Condor: Ornithological Applications. 97: 2. 427-437.

Madrigal, Alexis. 2014. The Blood Harvest. The Atlantic. https://www.theatlantic.com/technology/archive/2014/02/the-blood-harvest/284078/

Maine Department of Marine Resources. 2023. Chapter 31: Horseshoe Crabs. https://www.maine.gov/dmr/sites/maine.gov.dmr/files/docs/31.pdf

Maloney, T., Phelan, R., & Simmons, N. 2018. Saving the horseshoe crab: A synthetic alternative to horseshoe crab blood for endotoxin detection. PLoS biology, 16(10), e2006607. https://doi.org/10.1371/journal.pbio.2006607

Manion, M.M., R.A. West, and R.E. Unsworth. 2000. Economic assessment of the Atlantic coast horseshoe crab fishery. Division of Economics, United States Fish and Wildlife Service, Arlington, Virginia.

Marshall, F. E. & Banks, K. 2013. Shoreline Habitat: Beaches, MARES-Marine and Estuarine Goal Setting for South Florida. https://www.aoml.noaa.gov/ocd/ocdweb/docs/MARES/MARES_SEFC_ICEM_20131001_Appendix_Beaches.pdf

Massachusetts Division of Marine Fisheries. 2022. Whelks and Whelk Management. mass.gov/service-details/whelks-and-whelk-management.

Maryland FMP Report. 2015. Section 12. Horseshoe Crab (Limulus polyphemus) https://dnr.maryland.gov/fisheries/Documents/Section_12_Horseshoe_Crab.pdf

Mattei, Jennifer. 2023. Executive Summary of 20 years of research on the population ecology of the American horseshoe crab population inhabiting Long Island Sound. Comments submitted to Connecticut General Assembly via Jo-Marie Kasinak. https://www.cga.ct.gov/2023/envdata/TMY/2023HB-06484-R000130-Kasinak,%20Jo-Marie-Supports-TMY.PDF

McGowan, Conor, Smith, D., Sweka, J., Martin, J., Nichols, J., Wong, R., Lyons, J., Niles, L. Kalasz, K., Brust, J. et al. 2011. Multispecies modeling for adaptive management of horseshoe crabs and red knots in the Delaware Bay. Natural Resource Modeling. February: 117-156.

Miththapala, S., Tidal Flats, 5 Coastal Ecosystem Series at 28. 2013. https://portals.iucn.org/library/sites/library/files/documents/CES-005.pdf.

Mizrahi, D.S. and K.A. Peters. 2009. Relationships Between Sandpipers and Horseshoe Crab in Delaware Bay: A Synthesis, 65, 70.

Murray, N. J., Phinn, S. R., DeWitt, M., Ferrari, R., Johnston, R., Lyons, M. B., Clinton, N., Thau, D., & Fuller, R. A. 2019. The global distribution and trajectory of tidal flats. Nature, 565(7738), 222–225. https://doi.org/10.1038/s41586-018-0805-8

National Oceanic and Atmospheric Administration. 2013. National Coastal Population Report: Population Trends from 1970 to 2020, 4-5.

National Oceanic and Atmospheric Administration. 2021. Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. https://www.ncei.noaa.gov/products/extended-reconstructed-sst

National Oceanic and Atmospheric Administration. 2022. Incident Map, https://incidentnews.noaa.gov/map.

National Oceanic and Atmospheric Administration. 2023. *Horseshoe Crab* – Limulus Polyphemus, https://www.stnmfs.noaa.gov/Assets/ecosystems/climate/images/species-results/pdfs/Horseshoe_Crab.pdf

NOAA Sea Grant Programs. seagrant.noaa.gov. Accessed November 13, 2023.

National Parks Service, Oceans, Coasts & Seashores, https://www.nps.gov/subjects/oceans/sea-level.htm.

National Research Council. 2014. *Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States*. Washington, D.C.: National Academy Press. 15–28.

NatureServe. 2022. Rufa red knot (Calidris canutus rufa). Loggerhead sea turtle (Caretta caretta). Diamondback terrapin (Malaclemys terrapin). horseshoe crab (Limulus polyphemus). American eel (Anguilla rostrata). Natureserve.org.

Niles, Larry. 2022. *“Delaware Bay Stopover Project Final Update.”* June 2: https://www.arubewithaview.com/2022/06/15/2022-delaware-bay-stopover-project-final-update-5-june-22022/

NOAA Office for Coastal Management, Economics and Demographics, https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html

Novitsky, Thomas J. 2015. “Biomedical Implications for Managing the Limulus polyphemus Harvest Along the Northeast Coast of the United States.” Changing Global Perspectives in Horseshoe Crab Biology. Conservation, and Management. Springer Cham: 483-500. https://doi.org/10.1007/978-3-319-19542-1.

Orens, Kyle. 2023. Mass Mortality Rate of Horseshoe Crabs in an Ocean City Canal. July 21, 2023. WBOC. https://www.wboc.com/news/trying-to-solve-the-mystery-of-a-high-mortality-rate-for-horseshoe-crabs-in-an/article_e67f2a64-273f-11ee-a2a3-0b1e49dedf6b.html

Pabortsava, K., Lampitt, R.S. 2020. High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. *Nat Commun* 11, 4073. https://doi.org/10.1038/s41467-020-17932-9

Paule-Mercado M. A., Lee B. Y., Memon S. A., Umer S. R., Salim I., & Lee C. H. (2017). Influence of land development on stormwater runoff from a mixed land use and land cover catchment. Science of the Total Environment, 599, 2142–2155. 10.1016/j.scitotenv.2017.05.081. https://www.sciencedirect.com/science/article/abs/pii/S0048969717311816

Pearce, F., The Hidden Environmental Toll of Mining the World’s Sand, Yale Environment 360. 2019. https://e360.yale.edu/features/the-hidden-environmental-toll-of-mining-the-worlds-sand

Pilkey, O.H., Duke Univ. Nicholas Sch. of the Environment. 2022. https://nicholas.duke.edu/news/vanishing-sands-how-sand-mining-stripping-away-earths-beaches

Port of Philadelphia. 2018. Delaware River deepening: 30 years and 16 million cubic feet of sand, muck, and rock later. https://www.philaport.com/delaware-river-deepening-30-years-and-16-million-cubic-later

Qiu, Yun, S. Gopalakrishnan, H.A. Klaiber, and X. Li. 2020. Dredging the sand commons: the economic and geophyisca;l drivers of beach renourishment. C>imate Change: June 6, 2020. https://par.nsf.gov/servlets/purl/10186102

Ray, Gary and D. Clarke. 2010. Issues related to the entrainment of horseshoe crabs (Limulus polyphemus) by hopper dredges. https://www.westerndredging.org/phocadownload/ConferencePresentations/2010_SanJuanPR/Session2A-EnvironmentalAspectsOfDredging/3%20-%20Ray%20-%20Issues%20Related%20to%20Entrainment%20of%20Horseshoe%20Crabs%20by%20Hopper%20Dredges.pdf

Return the Favor. 2023. 2023 Final Report: Impingement. https://returnthefavornj.org/wp-content/uploads/2023/12/2023_RTFreport.pdf

Rudloe, A.E. 1982. Man's influence as an environmental threat to Limulus. In: Bonaventura J, Bonventura C, Tesh S (eds) Physiology and biology of horseshoe crabs: studies on normal and environmentally stressed animals. Alan R. Liss, New York, pp 297–300.

Save Coastal Wildlife. 2023. Horseshoe Crab Monitoring Data: Sex Ratios. https://www.savecoastalwildlife.org/horseshoe-crab-monitoring

Seney, Erin and John A. Musick. 2007. Historical Diet Analysis of Loggerhead Sea Turtles (Caretta caretta) in Virginia. American Society of Ichthyologists and Herpetologists (ASIH). Copeia: 2, 478-489.

Shuster, C. N. 1950. Observations on the natural history of the American horseshoe crab, Limulus polyphemus. Woods Hole Oceanographic Institution Contribution 564: 18-23.

Shuster, C.N. 1982. A pictorial review of the natural history and ecology of the horseshoe crab Limulus polyphemus, with reference to other Limulidae. Prog. Clin. Biol. Res. 81: 1-52.

Shuster, C.N. R. Barlow, and J. Brockman. 1982. The American Horseshoe Crab. Harvard University Press. 133-154.

Smith, D. R., Millard, M. J., and Carmichael, R. H. 2009. "Comparative status and assessment of Limulus polyphemus with emphasis on the New England and Delaware Bay populations," in Biology and Conservation of Horseshoe Crabs, eds J. T. Tanacredi, M. L. Botton, and D. R. Smith (New York, NY: Springer Science), 361–386.

Smith, D.R., Beekey, M.A., Brockmann, H.J., King, T.L., Millard, M.J. & Zaldívar-Rae, J.A. 2016. Limulus polyphemus. The IUCN Red List of Threatened Species 2016:

e.T11987A80159830.
https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T11987A80159830.en.

Smith, David, Brockmann, J., Beekey, M., King, T., Millard, M., Zaldivar-Rae, J. 2017. Conservation status of the American horseshoe crab (Limulus polyphemus): A regional assessment. Reviews in Fish Biology and Fisheries. 27:1: 135-175.

Smith, J. A., Dey, A., Williams, K., Diehl, T., Feigin, S., and Niles, L.J. 2022. Horseshoe crab egg availability for shorebirds in Delaware Bay: Dramatic reduction after unregulated horseshoe crab harvest and limited recovery after 20 years of management. Aquatic Conservation: Marine and Freshwater Ecosystems, 32(12), 1913-1925. https://doi.org/10.1002/aqc.3887

Smith, David, J. Brockmann, R. Carmichael, E. Hallerman, W. Watson, and J. Zaldivar-Rae. Assessment of recovery potential of the American horseshoe crab: An application of the Green Status Assessment Process.

South Carolina Department of Natural Resources. “Horseshoe Crabs.” https://www.dnr.sc.gov/marine/pub/seascience/horseshoecrab.html

Southern Environmental Law Center. 2023. A historic victory for horseshoe crabs in South Carolina. September 23: southernenvironment.org/news/a-historic-victory-for-horseshoe-crabs-in-south-carolina/.

Species Listing Proposal Form. 2023. “Listing Endangered, Threatened, and Special Concern Species in Massachusetts.”

Subramoniam, T. 2018. Mode of Reproduction: Invertebrate Animals. In M. K. Skinner (Ed.), Encyclopedia of Reproduction. vol. 6, pp. 32–40. Academic Press: Elsevier. http://dx.doi.org/10.1016/B978-0-12-809633-8.20533-5

Tanacredi, J. T., Botton, M. L., & Smith, D. (Eds.). 2009. Biology and Conservation of horseshoe crabs. Springer US. https://doi.org/10.1007/978-0-387-89959-6

Tanacredi, J. T., Portilla, S., 2015. Habitat Inventory Trend Analysis of Limulus polyphemus Populations on Long Island, U.S.A.: From the Tip of Brooklyn to the Tip of Montauk, 2003–2014. In: Carmichael RH, Botton ML, Shin PKS, Cheung SG (eds) Changing global perspectives on horseshoe crab biology, conservation and management. Springer, New York, pp 229–236.

Tanacredi, J. T., Portilla, S., 2015. Preliminary Investigation of Effects of Seawater pH on Early Development of Limulus polyphemus. In: Carmichael RH, Botton ML, Shin PKS, Cheung SG (eds) Changing global perspectives on horseshoe crab biology, conservation and management. Springer, New York, pp 281–287.

Taylor, Martin, Kieran Suckling, and Jeffrey Rachlinksi. 2005. The Effectiveness of the Endangered Species Act: A Quantitative Analysis. Bioscience: Vol 5, #: 360-367.

The Commonwealth of Massachusetts Division of Marine Fisheries. 2023. Proposal to Adjust Commercial Horseshoe Crab Limits for 2023. https://www.mass.gov/doc/2023-dmf-horseshoe-crab-memo/download

Totoiu, Jason and J. Lopez. 2022. Holding States Accountable for Harmful Algal Blooms: Florida's Water Crisis in Focus. University of Florida. https://ufjlpp.org/wp-content/uploads/2023/04/1_Totoiu.pdf

Tuxbury, Kathryn. 2023. Review of the Proposal to List Horseshoe crabs as a species of Special Concern in Massachusetts.

U.S. Energy Information Admin., East Coast Refineries Receiving More Domestic Crude Oil from Gulf Coast by Tanker and Barge. 2018. https://www.eia.gov/todayinenergy/detail.php?id=37073.

U.S. Fish and Wildlife Service. "The Horseshoe Crab (Limulus polyphemus): A Living Fossil. 2004. https://www.fws.gov/sites/default/files/documents/Horseshoecrab.pdf

U.S. Fish and Wildlife Service. "Atlantic horseshoe crab." https://www.fws.gov/species/atlantic-horseshoe-crab-limulus-polyphemus

U.S. Fish and Wildlife Service. 2014. Rufa red knot (Calidris canutus rufa). FWS Focus. https://www.fws.gov/species/red-knot-calidris-canutus-rufa.

U.S. Fish and Wildlife Service. 2014. Service protects red knot as threatened under the Endangered Species Act. Final Rule: FWS-R5-ES-2013-0097, regulations.gov. https://www.fws.gov/press-release/2014-12/service-protects-red-knot-threatened-under-endangered-species-act-0

Valentino, S. 2020. New Study Forecasts Dramatic Beach Erosion Along U.S. Coastline, The Washington Spectator: May 2: https://washingtonspectator.org/beach-erosion-valentino/

Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L. et al. 2020. Sandy coastlines under threat of erosion. Nat. Clim. Chang. 10, 260–263. https://doi.org/10.1038/s41558-020-0697-0

Wallace G.E. 1999. Potential effects of a horseshoe crab fishery on migratory shorebirds in the state of Florida. Technical report, Bureau of Wildlife Diversity Conservation, Florida fish and Wildlife Conservation Commission, Panama City, Florida.

Wetlands Institute. 2019. Restoring Shorebird Foraging and Horseshoe Crabs Spawning Habitat to Delaware Bay Beaches. Wetlandsinstitute.org. Visited November 12, 2023.

Wolf, Shaye, B. Hartl, C. Carroll, M. Neel, and N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience: https://academic.oup.com/bioscience/article/65/2/200/243883

Zaldívar-Rae, J.; Sapién-Silva, R.E.; Rosales-Raya, M.; Brockmann, H. J. 2009. "American horseshoe crabs, *Limulus polyphemus*, in México: open possibilities". In Tanacredi, J.T.; Botton, M.L.; Smith, D.R. (eds.). *Biology and Conservation of horseshoe crabs*. Springer. pp. 97–113. ISBN 9780387899589.

Zhu, G., Yuan, X., & Fan, J. 2020. Insight into intraspecific niche divergence and conservatism in American horseshoe crabs (Limulus polyphemus). *Global Ecology and Conservation*, *22*, e00896. https://doi.org/10.1016/j.gecco.2019.e00896

Zuckoff, Eve. 2023. Thousands of dead horseshoe crabs wash up on Chatham Beach. NPR - CAI affiliate. June 14, 2023. https://www.capeandislands.org/local-news/2023-06-14/thousands-of-dead-horseshoe-crabs-wash-up-on-chatham-beach