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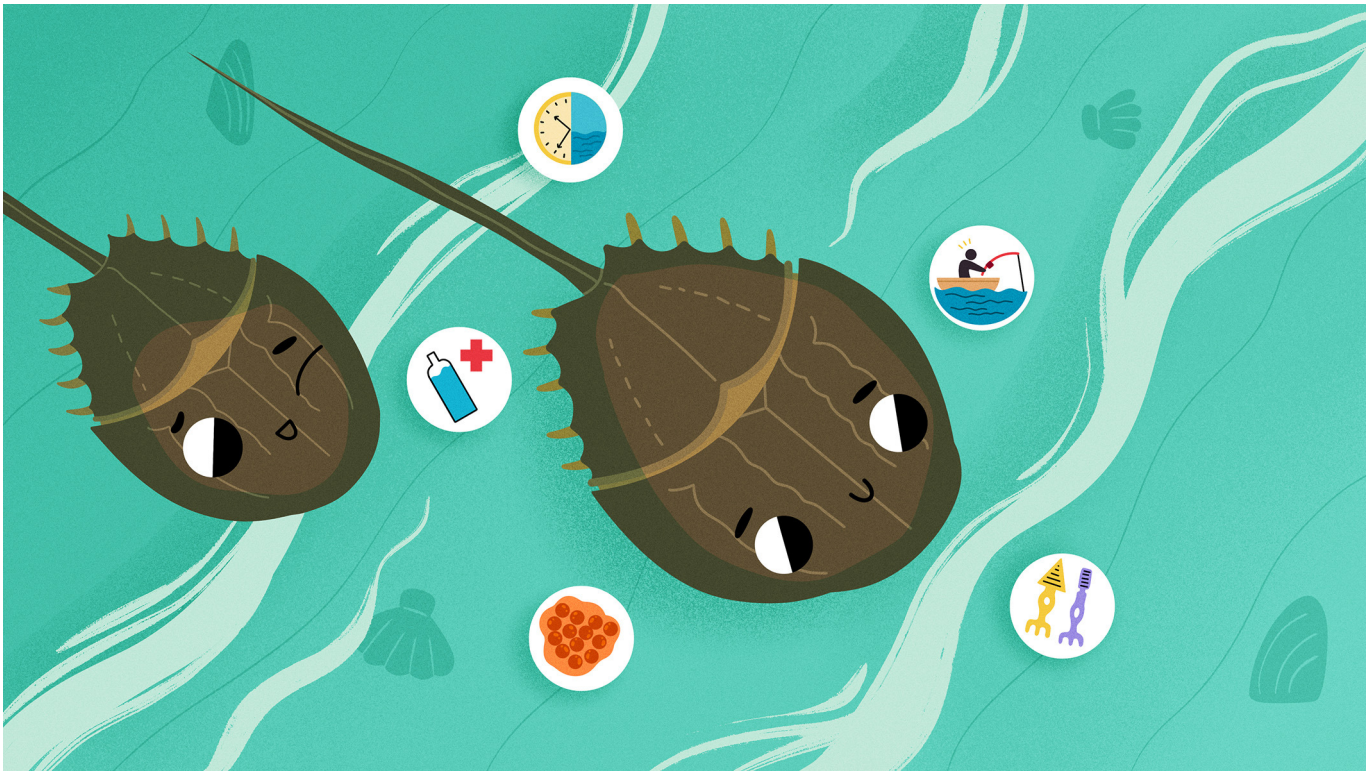
Published: 08 September 2026
doi: 10.3389/frym.2026.1695228



HORSESHOE CRABS: THE GOOD, THE BAD, AND THE AMAZING

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AGE: 12

What has: (1) ancestors that lived with the dinosaurs; (2) many eyes and blue blood; (3) helped save the lives of many humans and; (4) been the subject of discoveries leading to a Nobel Prize? If you answered, horseshoe crabs, you are correct! Horseshoe crabs have been wandering around our oceans and estuaries for more than 400 million years. We are lucky they have been around for so long, because currently their blood is used to make sure that the medicines and devices used in hospitals are free of contaminants. They are also one of the few marine species to mate along the shoreline, so it is easy to observe them and inspect all their interesting parts. There are so many interesting things about these unique creatures that it is hard to summarize them all, but I will try to do so in this article.

WHERE DO HORSESHOE CRABS LIVE?

ESTUARIES

Estuaries are aquatic environments where freshwater from rivers merges and mixes with saltwater from the ocean.

SPAWNING

The process of releasing eggs and sperm by aquatic animals (fish, crustaceans, corals, mollusks) into the water for external fertilization.

Fossil evidence indicates that horseshoe crabs existed as far back as 450 million years ago. This means they have been on Earth longer than most modern-day species. This tells us that they are very hardy and can withstand many physiological (internal) and ecological (the environment around them) challenges. For example, horseshoe crabs are found in coastal waters, bays, and **estuaries** from Maine to Mexico, so they can cope with a very wide range of water temperatures and salinities (salt levels). They can even survive out of water for several hours, which happens sometimes when they are stranded on beaches during their **spawning** season. While horseshoe crabs are probably easiest to find in the US mid-Atlantic States, like in Chesapeake Bay, Delaware, they can also be found all up and down the East Coast, and in the Gulf of Mexico. There are also related species (*Tachypleus tridentatus*) in Asia. If you want to see them, just go to the beach or shoreline during the high tides in May–June, and if you find one of their favorite mating sites you will see hundreds of them spawning.

HORSESHOE CRAB MATING BEHAVIOR

CIRCATIDAL

A biological rhythm that repeats about every 12.5 hours, matching the time between high tides.

In the spring, as the water is warming up, horseshoe crabs move from the deep waters where they spend the winter into shallower waters to spawn. If you find a beach where this takes place, you will see lots of horseshoe crabs near the water's edge at high tide. How do they know it is high tide? First, they have an internal **circatidal** clock [1], kind of like your circadian (about a day) clock, that informs them when it is about time for a high tide. Second, they can also sense changes in the depth of the water [2]. Horseshoe crabs migrate to their favorite beaches and mate during both daytime and nighttime high tides in the spring and early summer.

If you are lucky enough to find horseshoe crabs at one of their spawning areas, you will likely notice that many of them are in pairs. The small male is in the back, clasped onto the larger female in the front (Figure 1A). In fact, one way to tell a male from a female is that the male has special appendages that he uses for this purpose (Figure 2). Males grab onto the backs of females so they can be ready to provide sperm to fertilize the eggs when she lays them in the nest she digs (Figure 1B). Most of the single horseshoe crabs you see will be males looking for a female. There are almost always more males than females near the spawning beaches. Males find females using a combination of good eyesight (more on that later) and by smelling the **pheromones**, which are chemical attractants released by the females [3].

PHEROMONES

Chemicals released by an organism that can be smelled by others and change their behavior, often helping males and females find each other.

Female horseshoe crabs lay about 4,000 eggs in a shallow nest (Figure 3A) and, in areas such as Delaware Bay where these animals are particularly abundant, the eggs provide a vital source of nutrition for migrating birds [4]. The eggs hatch about 3 weeks after they are laid,

Figure 1

(A) A pair of horseshoe crabs, with the smaller male clasped onto the abdomen of the larger female. **(B)** A female partially buried in the nest she dug, with a male attached to her. There are also three "satellite males" surrounding the pair.

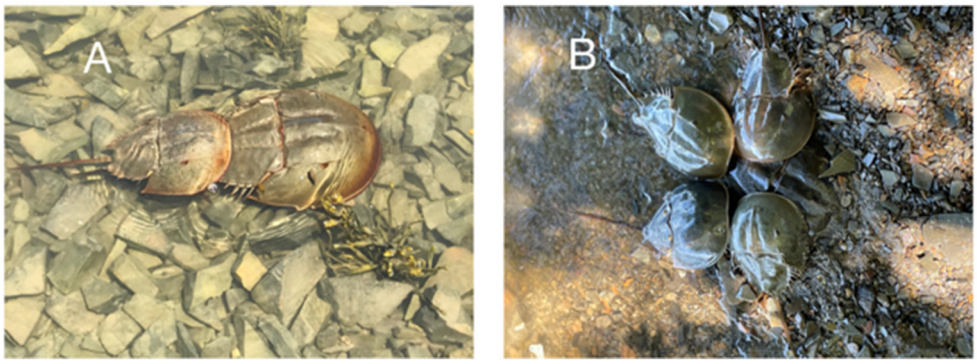

Figure 1

Figure 2

The ventral (belly) side of a horseshoe crab. **(A)** Clasping appendage used by males to grab onto the abdomen of females during spawning season. **(B)** The location of a horseshoe crab's ventral eyes. **(C)** The mouth, with some food in it. **(D)** Gill plates that move rhythmically to help the horseshoe crab "breathe", by passing oxygenated seawater over the book gills located under them.

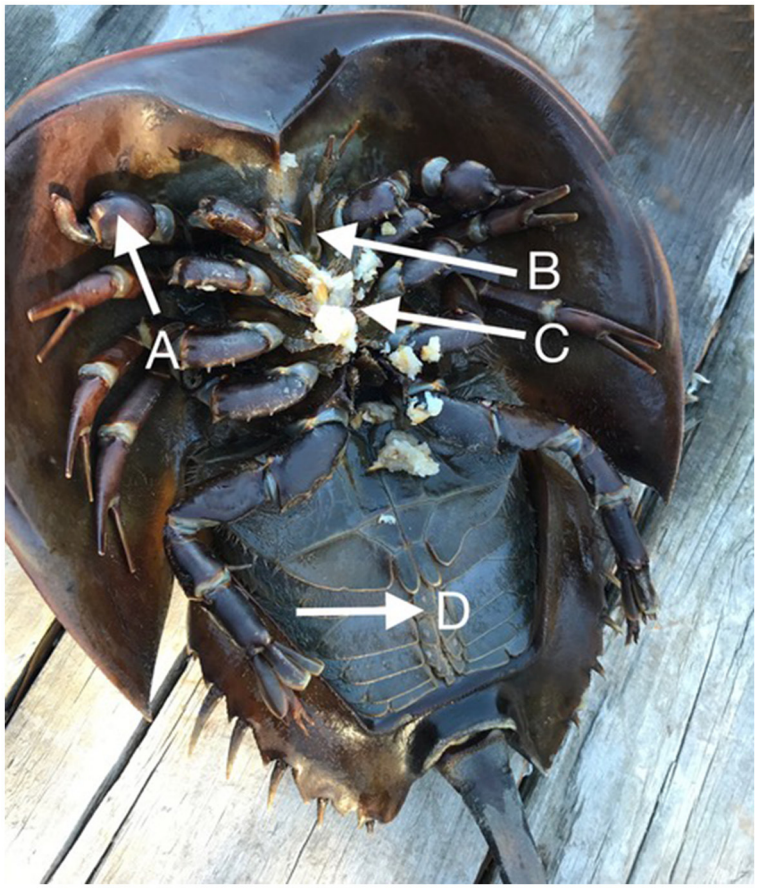

Figure 2

and the small larvae swim around in the water column for about 2–4 weeks (Figure 3B). After about a month the larvae settle to the bottom, where they will live the rest of their lives. They grow by molting, which involves shedding their old exoskeletons (shells). So, you might find empty horseshoe crab exoskeletons along the shoreline. They molt about 16 times, until they reach sexual maturity. Then it is estimated that they can live up to 10 years longer.

Figure 3

(A) Horseshoe crab eggs. **(B)** A newly hatched larva (Photo credit for **A**: David Smith).

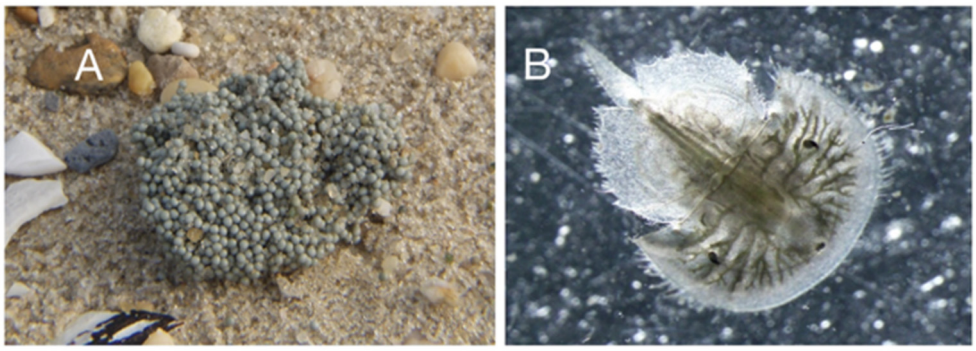

Figure 3

INTERESTING FACTS ABOUT HORSESHOE CRABS

Horseshoe crabs have two lateral (side) eyes, which are very obvious, and several simple **photoreceptors** located on the front of their shells, near their mouths (Figure 2), and on their tails. Photoreceptors, like the rods and cones in your eyes, can detect changes in light intensity and translate that information into nerve signals that they send to the brain. By studying the main lateral eye photoreceptors of horseshoe crabs, three scientists discovered some very fundamental information about how photoreceptors function and, in 1967, they were awarded the Nobel Prize for their work.

PHOTORECEPTORS

Photoreceptors are capable of detecting light and converting that signal into nerve impulses the brain can interpret. Different photoreceptors are designed to sense different wavelengths of light, ranging from ultraviolet to infrared.

You can see the photoreceptors near a horseshoe crab's mouth if you flip it over (Figure 2). You might also notice that its mouth is located in the middle of all its legs. In fact, horseshoe crabs chew their food using rhythmic leg movements. You can watch them feed by simply turning them over and placing something yummy, like the insides of a mussel or oyster, on their mouth. The Video 1 shows a horseshoe crab eating a food supplement we formulated for them. Horseshoe crabs typically obtain their food by digging through the soft sediments where they spend most of their time. When they are not searching for food, they usually bury in the mud to protect themselves from potential predators—even though there are currently few animals that eat horseshoe crabs. If you look at their last pair of legs, you can see that they are well-adapted for pushing their bodies into the soft sediment.

When you flip a horseshoe crab over, you will also notice its gills (Figure 2, Video 2), located on the bottom of the abdomen. These animals "breathe" by rhythmically flapping their gill plates, to which the gills are attached.

HORSESHOE CRAB BLOOD

When horseshoe crabs flap their gill plates to "breathe", blood circulates through the pages of the book gills, and seawater containing

HEMOCYANIN

A copper-containing blood pigment that carries oxygen in many invertebrates. Unlike human hemoglobin, which makes blood red, hemocyanin can make oxygen-rich blood look blue.

***LIMULUS* AMOEBOCYTE LYSATE (LAL):**

A substance that helps horseshoe crabs fight off infections, a bit like our white blood cells and immune system do for us.

oxygen flows over the outside of the gills and diffuses into the blood. (If you look closely at the gills, you can see why they care called "book gills".). The oxygen then binds to a respiratory pigment in the blood called **hemocyanin**. Unlike the respiratory pigment found inside our red blood cells, which is called hemoglobin, hemocyanin is a copper-containing molecule. So, when it binds oxygen, it turns blue—not red like our iron-containing hemoglobin.

Horseshoe crab blood also contains a substance that is important for fighting infections. This substance, called **Limulus amoebocyte lysate** (LAL), was discovered in 1956. LAL reacts very strongly when it encounters certain bacteria that can cause dangerous infections in humans. So, before you receive vaccines, medical devices, or any other material that is injected or placed into your body, it is first tested with LAL to make sure it is not contaminated with those dangerous bacteria.

As you can imagine, it takes lots of LAL to supply all the hospitals in the country and throughout the world! In fact, in a given year, more than 500,000 horseshoe crabs are bled so LAL can be extracted from their blood for biomedical uses. Unfortunately, after 30% of their blood is removed, 20%—30% of them die, and many of the survivors have low energy [5, 6]. As a result they are less active, and some of our work has shown that bled females spawn only half as many times as non-bled females [7]. This could impact their ability to reproduce and keep the horseshoe crab population stable.

Therefore, it is important to do what we can to improve the bleeding process and save some horseshoe crabs for the future. One possible solution that we have been investigating is feeding them before or after they are bled, to help them replenish their lost blood as quickly as possible. In fact, the video we linked earlier was taken while feeding them one of the food mixtures we have been developing. But an even better solution, which is already being used in some countries, involves using molecular biology laboratory techniques to check for contamination. Such techniques could make it unnecessary to bleed horseshoe crabs to obtain LAL.

BAIT

Because of their size, abundance, and the fact that they can be easily collected by hand while they are spawning, horseshoe crabs are also used for bait to catch channeled whelks. It is estimated that 1 million horseshoe crabs are captured for this purpose each year and all of them perish as a result. Our group is currently working to create a whelk bait that does not involve horseshoe crabs, but is just as inexpensive and effective [8]. If this effort is successful, it will also contribute to saving this amazing species.

CONSERVATION EFFORTS

Horseshoe crab populations appear to be declining in some areas and efforts are underway to aid in their recovery and avoid similar issues in other regions. While some of the reductions are due to harvesting for bait and biomedical purposes, climate change and shoreline development might also contribute in some areas. In response to this situation, several US states, including New York, Connecticut, and Rhode Island, have passed laws either eliminating or reducing the harvesting of horseshoe crabs. In a recent report by the Massachusetts Division of Marine Fisheries, it seems like the horseshoe population in that area is rebounding, which is a good sign. This is a good example of how monitoring the abundance of a species can help protect them by giving us warning signs that steps need to be taken to better manage their populations. In the case of horseshoe crabs, after 450 million years on Earth, we do not want to be the ones responsible for their demise!

ACKNOWLEDGMENTS

Most of the data that are included in this article was obtained with grants provided by Sea Grant (NOAA) and NIH (through the INBRE program). Dr. Chris Chabot (Plymouth State University) and Dr. Steven Jury (St. Joseph's College of Maine) played major roles in this research. It was also carried out with the support of many students at The University of New Hampshire, St. Joseph's College of Maine, and Plymouth State University.

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SUBMITTED: 29 August 2025; **ACCEPTED:** 10 July 2026; **REVISED:** 09 March 2026; **PUBLISHED ONLINE:** 08 September 2026.

EDITOR: John T. Van Stan, Cleveland State University, United States

SCIENCE MENTORS: Praveen Rao Juvvadi and Hong Li

CITATION: Watson WH III (2026) Horseshoe Crabs: The Good, the Bad, and the Amazing. Front. Young Minds 14:1695228. doi: 10.3389/frym.2026.1695228

CONFLICT OF INTEREST: The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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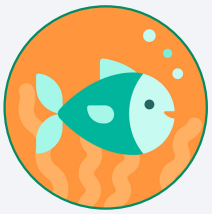
YOUNG REVIEWERS

ANAGHA, AGE: 11
I am Anagha. I love to read, draw and dance. My favorite subjects ELA, Math and Science. I would like to be a Teacher in the future.



ERIC, AGE: 11

My name is Eric, and I am 11 year old and go to Rossman School. I am most passionate about animals. They fascinate me a lot, and I hope to be a veterinarian when I grow up. Currently, I am in Archway Achievers 4H club, where we do presentations in front of judges about things I care about. I am also in a different club, where we do Vex Robotics and go to competitions. Lastly, I play golf. Right now, the Golf season has not started yet, so I am not playing right now. However, when it starts again, I will be going to practices and tournaments in the PGA Junior League. I also like to do Cross-Country and Swimming.

SAI, AGE: 14

Hi! My name is Sai, and I enjoy biology, space, and learning about how the world works. I like to run, and I like to challenge myself to discover new interests and hobbies. I am excited to be a young reviewer to learn more about science through reading and reviewing articles.

VIBHAV, AGE: 12

My name is Vibhav, and I am 12 years old and I enjoy many things such as soccer, reading, and building with LEGOs with my brother. I also enjoy playing outside with my friends or my brother; we usually play soccer, badminton, or other fun games together.

AUTHORS

WINSOR H. WATSON III

Dr. Watson was a professor at the University of New Hampshire for 41 years, before retiring in 2019. In collaboration with his colleagues and students, he has published more than 100 articles dealing with the physiology and behavior of marine species, ranging from nudibranchs to fish. His main focus has been on horseshoe crabs and American lobsters, and he has investigated these species both in the laboratory and the ocean. Photo: Brian Skerry. *win@unh.edu