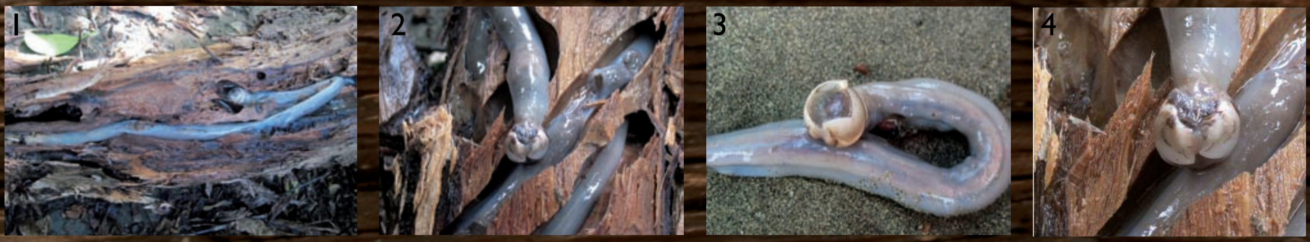


TERMITES of the sea

Known to mariners as 'termites of the sea,' shipworms belong to the genus Teredo. *It is actually a clam that tunnels through wood submerged in the sea.*

Although *Teredo* has an ecological value in degrading oceanic timber, the genus has also caused considerable damage to wooden boats ever since man first ventured out to sea. Shipworms have been a bane to ancient mariners until the advent of copper clad ships in the 18th century and modern toxic coatings.

These boring clams weaken the unprotected wooden hulls of ships to such an extent that they can break apart in the open sea without any warning. The Greeks and the Phoenicians certainly knew about them as early as 3,000 BC, lathering the hulls of their ships with wax and tar to keep them away. The Romans used combinations of lead, tar and pitch to protect their vessels.

Christopher Columbus unknowingly exposed his ships to the world's most *Teredo*-infested waters in his first voyage to the Caribbean Sea in 1492, where the proliferation of *Teredo* is probably due to the higher salinity of Caribbean waters. The ships that arrived later brought back *Teredo navalis* to Europe, where they can be found in the North Sea, having adapted to the colder temperatures. Unknown numbers of ships had been lost at sea as a result of *Teredo* infestation. These same worms caused the collapse of the wooden supports used for the dykes of Holland in 1731 causing flooding, 250 years after the first voyage of Columbus. Only the timely replacement of the outer surfaces of the dyke with stones prevented more catastrophes. Over the last few hundred years, all of the oceans have been colonized by *Teredo*.

The behaviour of the shipworm inspired the French engineer Marc Brunel (father of the renowned engineer Isambard Kingdom Brunel) to devise a method to tunnel under the Thames River in London, which he patented in 1818. This was the first of its kind ever built under a river bed. His technique called the 'tunneling shield' made use of his observations while working on a shipyard on how the valves with fine ridges were used by the *Teredo* to drill through the wood, while protecting itself from being crushed. The *Teredo* also secretes a calcium-rich framework that coated the inside surface of the tube, keeping it stable and preventing it from crushing.

Between 1919 and 1921, wharves, piers, jetties and piling started collapsing in San Francisco Bay, resulting in the modern-day equivalent of almost $20 billion worth of damage, all because of *Teredo*. The mouth of the Hudson River of New Jersey and New York was once considered a 'dead' waterway, devoid of fish life because of the overwhelming industrial pollution since the 1930s. So contaminated was the waterway, that captains would to sail their ships through New York harbour just to kill off shipworms and barnacles. In 1972, the US Federal Clean Water Act limited discharge into the rivers and proactively revitalized the waterways, and so by the 1990s the fish had returned. But so did the *Teredo*, with a vengeance. During this period also saw the voluntary ban by the lumber industry on the use of creosote and CCA (chromated copper arsenate) to prevent further leaching of the toxic chromium and arsenic to the environment. These wood preservatives prevented fungi from rotting the wood away and were also quite good at killing off the shipworms as well. The environmentally sound actions had unintended consequences—piers and piling that no longer used preservatives started collapsing, hollowed through by *Teredo*.

Considering the economic importance of preventing *Teredo* infestation, it is surprising how little is known about the life cycle of this clam. Some of the biological information comes from our ongoing observations at our marine test site in Panay Island, where the mangrove forests are home to *Teredo bartschi*.

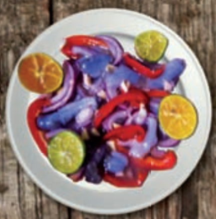
In general, the sex ratio in the wild is 1 *Teredo* male per 1,500 females. After fertilizing the eggs by the male *Teredo*, the developing embryos are protected inside the mother until they develop into larvae, which are competent enough to colonize other locations outside the home tunnel. Then, the little *Teredo*s settle in the same wood or nearby timber. They start burrowing through the wood as it grows, parallel to the grain, only turning to avoid knots or obstructions in the wood. By the time they young worm reaches adulthood, it is already at least a foot long and half inch thick. Unlike

FIGURES
1. & 2. Tunelling *Teredo* worms *in situ*.
3. *Teredo* removed from tunnel.
4. Close-up of shell and head.

6. Wood destroyed by Teredo burrowing.
Photographs courtesy of Coleen P. Sucgang, Poseidon Sciences.

EATING SHIPWORMS

So far, there is no known commercial value for *Teredo* other than in some Pacific Islands where they are a delicacy. The special Philippine dish is called tamilok, appreciated by natives of Palawan Island and Aklan Province of Panay Island, where extensive mangrove forests serve as home for the clams. It is prepared raw as a ceviche or kinilaw in the local language, with vinegar, chili peppers and onions. It is a delicacy that is certainly not for the timid



other typical clams, the shell covers only a tiny portion of the *Teredo* and used more like a drill bit to burrow a circular hole through the wood. The tube-like home is capped at the opening of the burrow with a secreted calcareous cover, with protruding siphons that allow the animal to breathe, feed on plankton and excrete wastes. It appears that the *Teredo* lives out its life within its tunnel home, continuing to extend the length of its burrow. The actual life span of the *Teredo* in the wild is not known.

The cellulose that makes up the wood is not sufficiently nutritious as food and the shipworm cannot normally digest it. It overcomes this limitation through a symbiotic relationship with bacteria, *Teredinibacter turnerae*. This bacterium lives in the gills of the *Teredo* and secretes enzymes, called cellulases and nitrogenases, which break down the cellulose and fix nitrogen to build amino acids. Cellulases are the same enzymes, derived from fungi, used to create stonewashed denim jeans by breaking down the cellulose on the outer surface of the cloth. Now, it is also a major ingredient in most laundry detergents to improve cleaning efficiency. The potential of *Teredo*-derived cellulases is in its future use in biofuels because it is likely to be more efficient than fungal cellulases in converting paper-mill cellulose waste into ethanol or methanol.

Although *Teredo* is present all over the world, developing biocontrol measures through new biocidal approaches takes much longer in temperate countries due to seasonal effects. For this reason a new test site has been established along the coast in the island of Panay in the Philippines, where Poseidon already has a station for subsea immersion. The *Teredo* site is located north of the island in the town of Batan in Aklan province .

The Poseidon *Teredo* Test Station is located within the mangrove forest, heavily populated with *Teredo*. Sizes of the clams vary depending on the size of the branch or tree trunk they are tunneling through. Seawater flushes the mangroves with 4 foot tides, exposing the trunks for a few hours each day, which allows easy access to the exposure site during low tides.

Initial observations on trunks brought to the laboratory for examination generated some interesting insights into the biology of the *Teredo* worm.

The calcareous wall of the tunnel remained soft when wet and easily damaged. However, when carefully removed, the 'tube' hardens, retaining the shape of the tunnel.

The color of the *Teredo* is milky white when the wood is opened to expose the clam. However in less than a minute after exposure to light and air, this colour changes to a blueish tinge. Ongoing investigations are focused on basic and applied research on *Teredo*. These include:

1. Determining the minimum period of marine exposure to observe settlement and tunneling.
2. Determining its preference for different wood types.
3. Understanding the seasonal and diurnal fluctuations that may affect *Teredo* settlement behavior
4. Determining optimal size of test stakes for wood protection studies
5. Developing convenient means of estimating *Teredo* size using correlation between tunnel depth and diameter of opening.

This is an exciting exploration which helps in the long term plans of developing nontoxic options to prevent Teredo damage to wood structures of economic value. Anyone interested in collaboration on basic Teredo biology or in applied research, please contact the author. www.poseidonsciences.com

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