Pacific Northwest Aquatic Invasive Species Profile

Great Naval Shipworm *Teredo navalis*

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Figure 1 (left) - An individual shipworm (Landau 2007), and (right) a colony of shipworms (Elder 2009)

Diagnostic Information

Common Names: Naval Shipworm, Atlantic Shipworm, Great Shipworm, Teredo

Phylum: Mollusca
Class: Bivalvia
Order: Myoida
Family: Teredinidae
Genus: *Teredo*
Species: *navalis*

Identification Guide

Christened 'the termite of the sea' by mariners, the shipworm is not a worm at all, but a bivalve mollusk with an elongated worm-like body (Figure 1) and a reduced, triangular shell located on the anterior portion of the body that can exceed 2cm long. The shells (Figures 2 & 3) are specialized for burrowing into the wood consumed by the shipworm. On the posterior end are 2 siphons used for respiration feeding and excretion/egestion (Figures 2 & 3). The siphons can be retracted and covered by two calcareous paddles called pallets (Figure 3). *T. navalis* burrows into wood creating 'honeycombing' (Figure 4) that degrades the structure of wood, compromising the watertight integrity of wooden vessels and leaving piers and docks unstable. The tubes are lined with calcareous porcelain to protect the mollusk from the contraction and expansion of the wood.

Overview

The shipworm or Teredo has been and remains to be "a constant source of anxiety to harbor

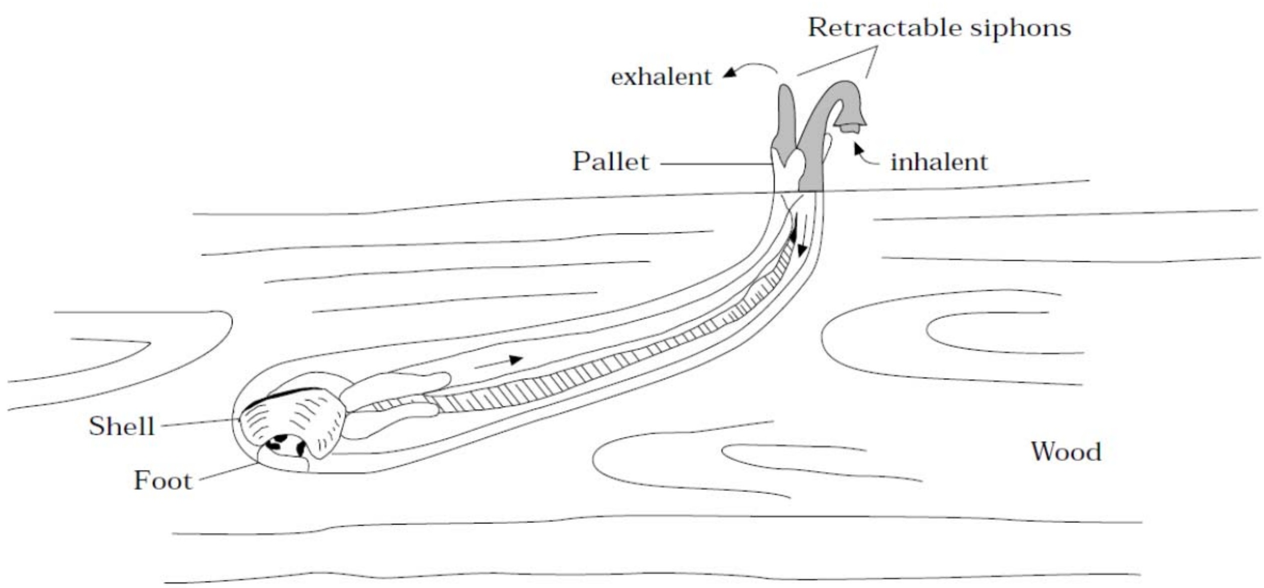

Figure 2 - Teredo navalis, cross-section (after Yonge, 1976: fig. 131)

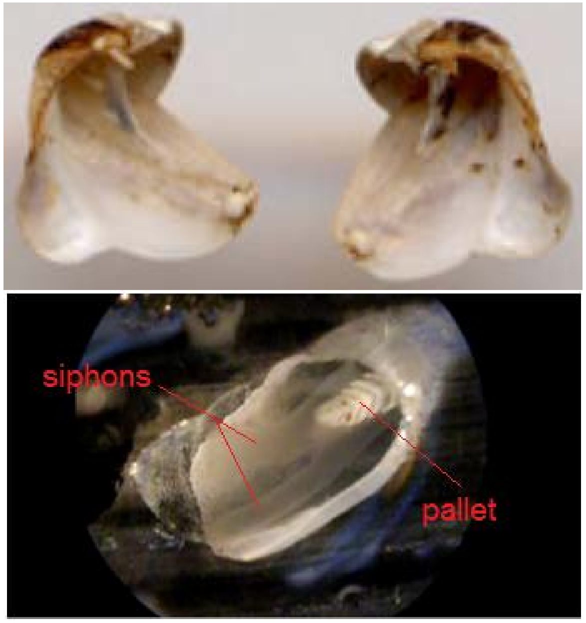

Figure 3 Shipworm shells (top), siphons and pallet (bottom)

Figure 4 Untreated Douglas fir from a

16 foot dolphin

Figure 5. Grounded and infested with shipworms, the wreckage of the

428-ton sailing ship Jhelum , constructed in 1849 in Liverpool, England.

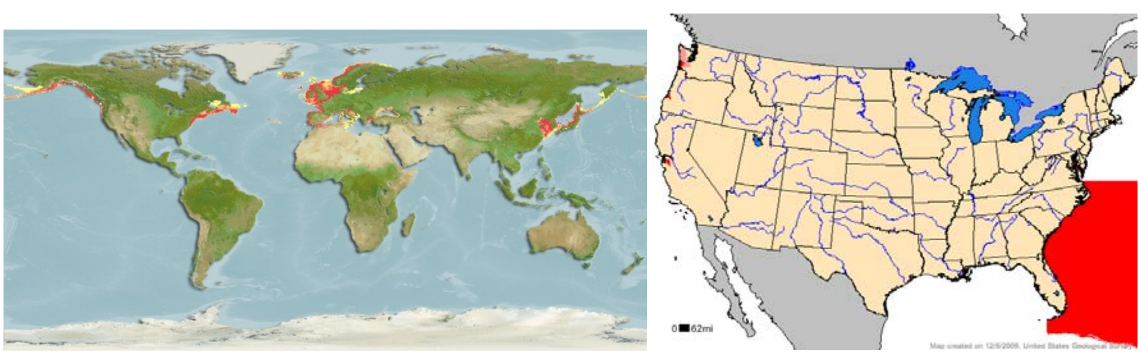

Figure 6 World distribution (left) and regions of introduction in U.S. (right) of *T. navalis*

engineers (Calma 1926), naval architects and mariners. While there are many types of shipworms, *T. navalis* is the most common (Calma 1926) and most often studied. *T. navalis* may be responsible for the outcome of many ancient naval battles in which ships would ram each other (Steinmayer Jr. and Turfa 1996). The rapid devastation caused by the shipworm is evident in the records of extensive damage after outbreaks, collapsed structures (Figure 7), and sunken or abandoned vessels including that described in the Manteño archeological expedition, 1996-1999, to explore the pre-Columbian trade route between what is now North-west South America and Western Mexico (Smith 1999). Researchers constructed a replica of one of the large balsa rafts thought to have been used at the time for the 5000 mile round trip journey, with the intention of sailing the route. By the 12th day of the expedition colonies of shipworms were discovered in exposed portions of the vessel where preventive treatments had failed. Damaged logs were replaced and retreated to seal the logs. After redeployment, shipworms again successfully infested the vessel; the balsa logs were losing buoyancy. On day 64 of the expedition the crew had to be rescued by a Costa Rican Coast Guard cutter and the vessel abandoned. While the research continued to determine how natives were able to travel such long distances and cope with the damage from shipworms, whether *T. navalis* was present is also in question. Was the mollusk already present in American waters or was it introduced by European explorers? More recently the fleet of codfish schooners would moor in the freshwater of Lake Union and Lake Washington for extended periods to kill the wood-boring organisms in the hull. While most of the wooden schooners were eventually destroyed, beached or burned to salvage the metal for scrap, the *Wawona* remained afloat until it was dismantled in 2009 due to a lack of political and financial support to convert her into a floating museum, and the *C.A. Thayer* is a floating museum in San Francisco's Fisherman's Wharf (Shields 2001).

Figure 7: After its introduction to San Francisco Bay in 1913, the shipworm resulted in an estimated $3.1 billion in damage to wooden structures between 1919 and 1921.

Origin and Distribution

History of Invasiveness

T. navalis originated in the Mediterranean, and has since spread throughout the world (figure 6), either by being transported within the hulls of wooden vessels or in floating wooden debris. There are many ancient references in "classical literature and epigraphic documents (naval equipment inventories), and analyses of …wrecked vessels" (Steinmayer Jr. and Turfa 1996) describing the destructive effects of the shipworm. These included a discussion of the replacement of an infested frame in a 4th century BC merchant vessel, and other literature by 'cool-sounding' ancient names such as Theophrastus who suggested that shipworm damage could not be repaired, Hippocrates and Aristotle who used the Greek term for teredo to describe conditions in bones and organisms, respectively (Steinmayer Jr. and Turfa 1996). While the year of its introduction to the North American continent is unknown, its discovery or introduction into some key ports have been established, and it is now found in all coastal waters of North America (Grave 1928). Some records show 2-3 yr long episodes of severe outbreaks (e.g., Holland in 1730, 1770, 1825 and 1858, and at San Francisco in 1917) where there had previously been no records of their presence (Calma 1926).

Extensive research has been conducted to study the shipworm on the eastern seaboard, including studying the range, vertical distribution and the spatial and temporal extent of damage of the species (Scheltema and Truitt 1956).

Native and Non-Native Distribution

Because *Teredo navalis* has been transported via ships and on drifting wreckage for centuries, its original range is unknown for certain, but it is considered a native species to the Atlantic Ocean, commonly found in the waters of the Faroe Islands, Norway and Iceland. It has now become established in the Baltic Sea throughout the Atlantic, including the coastal waters of Denmark, Germany, and Sweden. It has been occasionally found in Poland and Greenland, but has not established reproducing colonies in those countries (Didžiulis 2007). The species is considered an introduced species to both coasts of the Americas. *T. navalis* was first reported in Massachusetts Bay, infesting foreign wooden vessels, in 1839. A century later the species was abundant northward to Nova Scotia. The species was found in Chesapeake Bay as early as 1878, and was collected from North Carolina, Florida, Texas, the Bahamas and Puerto Rico in the 1950s.

Pacific Northwest Distribution

In the Pacific, *T. navalis* was introduced into San Francisco Bay in about 1913 and was first recorded as established in Willapa Bay, Washington in 1957, in other Washington coastal waters as of 1997, and in Coos Bay, Oregon coastal waters in 1988 and in 2000. In all events the primary pathway is “shipping hull fouling” (Elder 2009).

Life History and Ecology

Life History and Reproductive Strategies

Shipworms become sexually mature as early as 40-42 days. (B. H. Grave 1942). Being hermaphroditic, males convert to females and females convert to males during each breeding season (B. H. Grave 1942). As many as 1-5 million larvae can brood in the gills of an individual shipworm, which spawns 3-4 times per season, about once every four or five weeks (Grave 1928). The larvae remain in the gills for 2-3 weeks, until they have developed a velum and a straight-hinged shell, then they are released into the water column. The larvae can survive in a free swimming state for about 100 hours before it must settle on suitable wooden substrate. Averaging 0.25 mm in diameter, the larvae will penetrate wood and orient the burrow with the grain of the wood. As the mollusk grows, the chamber grows from the small pinhole entrapping the shipworm within its wooden prison, living 1- 3 years. The longest recorded naval shipworm from the Baltic Sea was 30 cm, and *T. navalis* may exceed 50 cm in the tropics. *T. navalis'* tubes can extend from 60cm to 1m in length and average up to 1cm in diameter (Masterson 2007).

Figure 8 - *T. navalis* veliger (Leppäkoski, Gollasch and Olenin 2002)

Feeding Habits

The naval shipworm lives almost exclusively on wood by scraping with its modified shells, and is also capable of filtering plankton from the water with the siphons (Masterson 2007). The veliger (Figure 8) begins consuming wood as soon as it settles. Boring increases between February and April, peaking during late summer and early fall, suggesting an increase in boring with an increase in temperature.

Environmental Optima and Tolerances

Teredo navalis are euryhaline, preferring a salinity range of 5-45 ppt (4-8 Practical Salinity Units (PSU)). Larval mortality occurs below 5ppt. *Teredo navalis* can survive up to six weeks of anoxia by discontinuing feeding and sealing itself inside its tube, surviving by metabolizing stored glycogen. *T. navalis* have been found in temperatures as low as 0.7^{o} C and can survive temperatures up to 30^{o} C. Growth ceases above 25^{o}C and reproductive temperature range is approximately 11-15^{o}C. *T. navalis* have a depth range of 0 – 150 meters.

Biotic Associations

The naval shipworm is primarily xylophagous, aided by "a symbiotic cellulolytic, nitrogen-fixing bacteria contained in specialized epithelial cells on the gills" that allows it to digest wood. In other words, a symbiotic bacterium allows the shipworm to utilize wood as a primary food source.

T. navalis' tolerance to decreased salinity allows it to thrive in brackish water and to survive periodic exposures to low salinities including freshwater. This is especially evident in the San Francisco outbreak of the early 20th century, where its tolerance to fresh water gave it an advantage over the native Pacific shipworm, *Bankia setacea*, (Cohen 1997) and its establishment in Oregon and Washington waters.

Invasion Process

Vectors and Pathways of Introduction

For centuries, the main vector of introduction has been wooden ships as well as in drifting wooden debris. One of the earliest possible introductions to the Americas may have occurred on Christopher Columbus' ships. Conflicting reports state that his crew was marooned in Jamaica in 1503 when his ships were eaten through by shipworms, but other sources claim his ships employed copper sheathing for protection.

Establishment and Spread

T. navalis is the most common, invasive and destructive species of shipworm found worldwide. Its history is marked with episodes of sporadic outbreaks lasting for 2-3 year followed by periods of endemicity.

Ecological and Economic Impacts

T. navalis is capable of quickly breaking down material that originated on land. This is especially important in tropical regions with mangroves where accumulating organic matter would normally take much longer to break down. This could potentially have a negative effect because it reduces the organic matter that would normally provide a nutrient source in the mangrove community. In The economic impact has been astronomical. The outbreak in San Francisco between 1919 and 1921 is estimated to have cost (in today's prices) as low as $500-900 million to as high as $20 billion. A 5-year outbreak in the 1990s along the coast of Mecklenburg-West Pomerania is estimated to have cost 10 million Euros.

The economic value of shipworms is limited to its use as a culinary delicacy in the Philippines called Tamilok (Figure 9). Shipworms are collected from mangroves and prepared raw with vinegar or lime juice, chili peppers and onions, similar to a Spanish dish called ceviche. It is described to taste similar to a wide variety of foods, including oysters and cheese (Cruz 2007).

The shipworm was also the inspiration for the first shield tunnel. Constructed under the Thames River beginning in 1825 (Wood 1995), Sir Marc Isambard Brunel devised a method of tunneling similar to that of the shipworm, sheathing the interior surface with bricks to protect it from potential collapse (Figure 9). Called shield-tunneling, simultaneously burrowing a tunnel while lining the tunnel during the digging process remains a common method for tunnel construction today (Wood 1995).

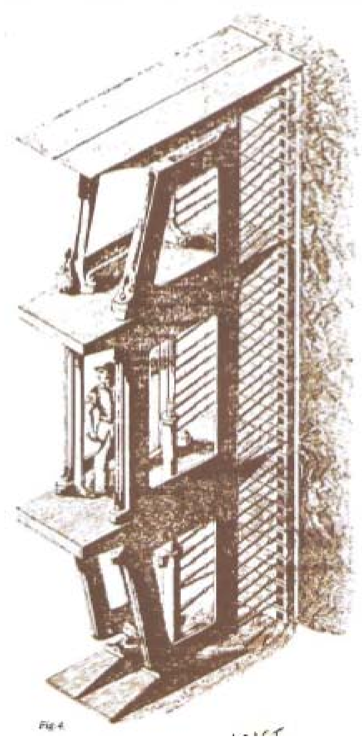

Figure 9 Above, Shipworms collected from mangroves used to prepare Tamilok. Left, the Thames Tunnel, constructed 1825-43, was where shield-tunneling was invented by Sir Marc Isambard Brunel.

Management Strategies and Control

The earliest recorded methods of managing or controlling the devastating effects of shipworm infestation was to attempt to dry out the mollusks by beaching the craft out of the water. A vessel left in the water would become waterlogged and slow; a disadvantage in a sea battle. A captain would have to take into consideration the length of stay in 'safe harbor', which would include determining if there would be time to beach the craft, allow it to dry out and to refit and repair the vessel before continuing a voyage (Harrison 2003).

In the days of wooden ships and iron men, depending on what preventive measures were employed, a ship may have a lifespan of as short as 3 years to as long as 20 years. In early times, pitch, wax, tar, and asphalt were all used to protect the wood from the effects of the mollusk (Woods Hole Oceanographic Institute 1952). Other attempts to protect the hulls of ships included the use of arsenic and sulfur mixed with oil in about 412 BC (Woods Hole Oceanographic Institute 1952); and the use of the Barbasco in the Americas (Smith 1999), a fruit which contains rotenone. One of the earliest coatings applied explicitly as a protection against fouling was patented in 1625, a composition of powdered iron, cement and a copper compound. Other patents followed during the 17th century, including one “composed of tar and resin in a varnish of beeswax, crude granulated lac dissolved in grain alcohol” (Woods Hole Oceanographic Institute 1952). Unfortunately, the shipworm has shown a resistance or tolerance to many of these methods. Lead sheathing was applied to the larger and slower merchant vessels, not feasible for warships that had to be smaller, faster and more maneuverable (Steinmayer Jr. and Turfa 1996). Later, copper sheathing was used to protect vessels, including man-of-wars, from the devastating effects of the shipworm, and became the standard for new construction in vessels of the British navy during the 18th century. But even this presented problems due to electrolysis which caused the rapid deterioration of iron in the vessels (Woods Hole Oceanographic Institute 1952). Recent research has involved the use of a fiberglass and polymer composite shield to protect wooden piers and marine structures (News - New material to fight shipworm attack 2002)

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