Assessment of Wood Pile Deterioration due to Marine Organisms

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Abstract: In this paper a description of the major groups of marine organisms causing significant wood pile damage is presented. These organisms are divided into two groups: (1) fungi and (2) marine borers. The basic physical and biological characteristics of these organisms are presented, as well as the type of damage that they cause in marine wood piles. The objective of the study presented in this paper is to characterize deterioration of wood piles due to marine organisms and to assess damage in the wood pile zones of a typical waterfront installation. Marine borer activity in Maine coastal waters is assessed through a survey directed to harbor masters; the results of the survey are correlated with historic data. In order to illustrate the type and extent of wood pile deterioration, two case studies in Maine harbors are presented.

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Introduction

The problem of deterioration of wood piles due to marine organisms dates back to the historic use of wood in piers and other waterfront facilities. Even though wood pile deterioration has been mitigated to some extent with the use of preservative treatments, it still remains a concern. Some of the chemicals used for wood preservation have been linked to human health concerns and, therefore, their use has been restricted. For these reasons, waterfront owners are looking for alternative solutions for wood pile protection.

There are two major groups of organisms that deteriorate wood in waterfront structures. Wood degrading fungi generally attack above the water-line region where adequate oxygen allows them to survive and decay the wood. Marine borers attack a variety of wood substrates but are only found in marine environments. Some marine borer species are not of concern from the standpoint of marine piers and waterfront facilities, but aggressive attack by these organisms will occur particularly in temperate marine waters. These two groups of organisms attack the wood in different zones of a waterfront pile. Fungi are typically found above the waterline, while marine borers primarily attack wood that is submerged or in the tidal zone.

Wood-boring organisms found in saltwater that cause damage to wood piles can be classified as: (1) molluskan borers (shipworms and pholads); and (2) crustacean borers including multiple species commonly known as gribbles (Goodell 2000). Both shipworms and gribbles attack the wood piles for shelter and, at least in the case of shipworms, wood can also be digested through the aid of microbial symbionts (Goodell 2000) to supplement filter feeding nutrition.

Studies conducted in Maine over a period of 23 years (1936–1959) using wood test boards revealed problems associated with shipworms during certain years and at specific geographic locations (Wallour 1959). *Limnoria* spp. were present in Maine waters every year during the period studied and caused significant damage.

Understanding the cause and characterizing the extent of wood pile deterioration is the first step in designing a repair method for damaged piles, as well as in devising a protection strategy to prevent further attack from marine organisms. For example, a system for structural restoration of wood piles with fiber reinforced polymer (FRP) composite shells was designed based on this approach (Lopez-Anido et al. 2004b). This system provides shear transfer capability between the wood pile and the encasing FRP composite shells, which strengthens the damaged pile portion (Lopez-Anido et al. 2003, 2004a). The repair system can also reduce the rate of future deterioration by introducing a barrier that protects the wood pile from marine borer attack.

The objective of the study described in this paper is to characterize the deterioration of wood piles due to wood deterioration organisms and to assess damage in the microenvironment zones of a typical waterfront installation. An early study of marine borer activity in Maine waters is reviewed. The results of a recent survey of wood pile deterioration in Maine harbors are discussed. Two case studies in Maine harbors that illustrate typical gribble and shipworm damage are presented.

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Review of Wood Pile Deteriorating Organisms

Fungi

Wood decay fungi are found growing either as parasites on living trees or as saprophytes on the dead remains of the trees (U.S. Army et al. 1978). Fungi can reproduce by means of microscopic spores, which can be single or multicellular, and in many cases wood degrading fungi can be spread through dissemination of mycelial fragments. Brown rot decay is the most common type of decay occurring in coniferous wood species and in early stages of attack the wood will have lost a limited amount of weight and can appear visually to be sound, yet have lost as much as 70% of modulus of elasticity and modulus of rupture (Wilcox 1978). In advanced decay stages physical and chemical changes have occurred which can be noted in features such as: (1) Change of color—advanced decay of wood by fungi is almost always accompanied by a change in color of the attacked wood (Cartwright and Findlay 1958; Kelly 1999; Goodell et al. 2003); (2) softening—the area where decay fungi have attacked appears to be soft in texture in advanced decay stages (Cartwright and Findlay 1958; Kelly 1999; Goodell et al. 2003); (3) change in density—as the wood is decayed it loses mass. Wood in advanced stages of fungal decay will be extremely light when the wood is dry; (4) change in odor—wood attacked by fungi will often have a mushroom like smell, or other uncharacteristic odor, but the presence of this smell does not necessarily mean that decay is present; and, (5) in brown rot the wood will develop checking, or a cracked appearance, perpendicular with the grain. Once these advanced decay features are present, the wood is normally beyond the stage where remediation can be applied to control the decay and removal and replacement of the wooden member is required.

Most wood decay fungi cannot survive submerged in water because the high moisture content excludes the levels of oxygen required for their growth. Yet they do require moist wood, above 30% moisture content, to be active and degrade the wood. It has been found that some fungal species can grow in the above-water portion of wood piles submerged in saltwater. The portion of the wood pile that is in the atmospheric zone is less affected by saltwater, but still is wetted by freshwater precipitation. This creates favorable conditions for the growth of conventional fungi (brown or white rot) that can cause considerable damage (U.S. Army et al. 1978).

Molluskan Borers: Shipworms

One of the families of shipworms is the family of Teredinidae, which includes *Teredo* spp. and *Bankia* spp. This type of marine borer has a modified shell (valves) that does not fit around the body of the animals as occurs in clams (Abood et al. 1995; Goodell 2000). *Teredo* spp. is a wormlike borer with a gray body that produces a shell-like material to line its burrow (Chellis 1961; U.S. Army 1990). Modified small shells at the anterior end form a pair of abrasive plates that are used to burrow into the wood, producing wood particles that are ingested. External evidence of attack is hard to find because small siphons are the only portions extending to the wood surface. Initially *Teredo* spp. larvae begin excavation with a 0.5–3 mm diameter hole. The borer can extend its tunnel along the grain (Goodell 2000). The length of this type of marine borer varies ranging from 150 mm to 1.8 m length and diameters up to 25 mm (Chellis 1961). The length of the tunnels depends on the extent of the attack. When the attack is extensive, the tunnels become crowded and their length and diameter may be limited. The white shell-like material lining the tunnels can be found mixed with shavings if the wood is bored with a drill during inspection (Highley 1999). Cellulosic portions of the wood are digested with the help of bacterial symbionts. Borer activity will turn the wood into a honeycomb-like matrix, which will lead to a severe reduction in strength even though the outer portion of the pile appears sound (Goodell 2000). A picture of *Teredo navalis* is shown in Fig. 1, where the arrows point to the valves that have been modified for boring through wood (Gillis, personal communication, 2002). *Bankia* spp. is very similar to *Teredo* spp., but is usually larger (Chellis 1961). *Bankia* spp. is shown in Fig. 2. Typical shipworm damaged wood pile sections extracted from Belfast Harbor, Me., are shown in Fig. 3.

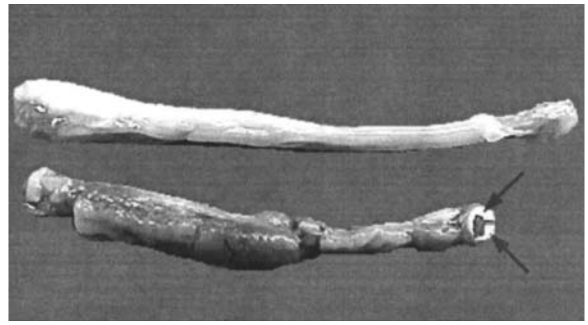

Fig. 1. *Teredo navalis* (courtesy of Gillis, personal communication, 2002)

Molluskan Borers: Pholads

Borers, such as *Martesia* spp. and *Xylophaga* spp., belong to the Pholadidae (pholads) family. They are similar to shipworms in the sense that they are also mollusks. The adult body of pholads, unlike shipworms, remains loosely surrounded by shells as it grows in its burrow (Highley 1999). Pholad shells do not fit tightly but they have ridges which function as rasps for burrowing. Pholads also have up to four external plates in addition to the two primary plates covering their soft body parts. When pholads die, remnants of the primary plates can remain in the burrow. Although pholads are particularly aggressive in tropical waters, deepwater species can operate in cold waters causing extensive damage to wood. The length of pholad tunnels is relatively short

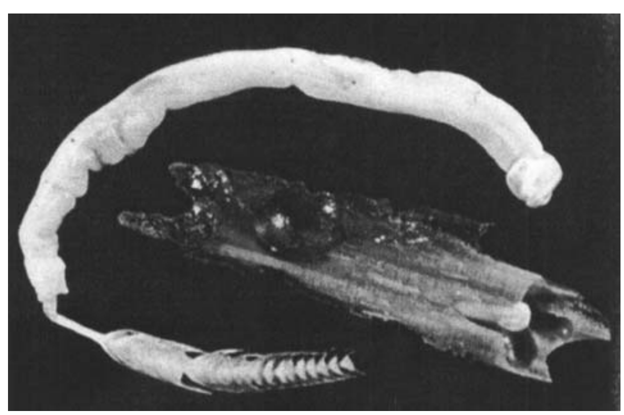

Fig. 2. *Bankia* spp. (courtesy of Wilson, personal communication, 2001)

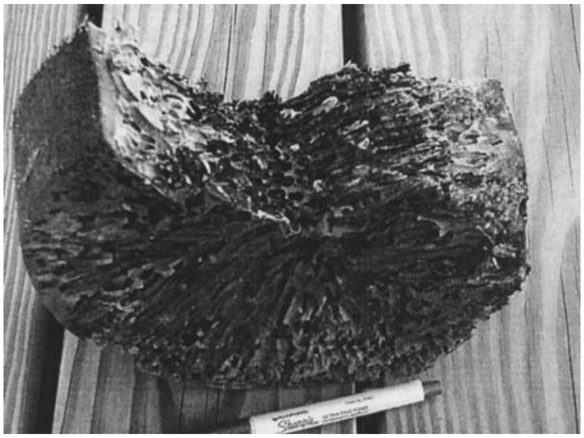

Fig. 3. Typical shipworm damage, Belfast, Me.

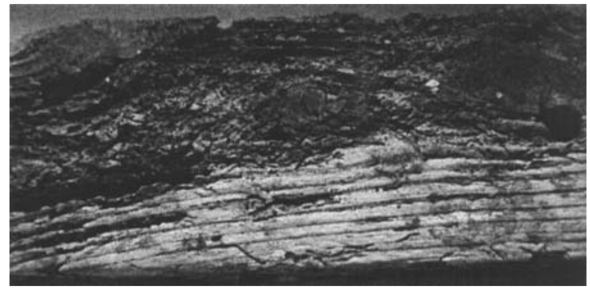

Fig. 4. *Limnoria* spp. damaged wood

(up to 60–70 mm) and their diameters are up to 25 mm. The tunnel opening can often be smaller than the diameter of the borer (Chellis 1961; Goodell 2000).

Crustacean Borers: Gribbles

Limnoria lignorum is one species of *Limnoria* spp., which are also known by the common names "gribbles" and "sea lice." Gribbles resemble the wood louse and have a length between 3 and 6 mm. Their width ranges from one third to one half of their length. They are often slipper shaped with horny boring mandibles, two sets of antennae and seven major sets of legs. Their legs are equipped with sharp hooked claws to grip the wood. Gribbles can roll themselves into a ball, swim, crawl, and jump (Chellis 1961). Gribbles can swim throughout their lives and they can leave or be dislocated from wood being attacked and return to tunnel at another location. They commonly attack in coastal regions making shallow burrows in the surface of the wood (Johnson 2002) as shown in Fig. 4. When large numbers of gribbles attack, only a thin layer of wood is left between the burrows. The action of the waves and tidal currents wash away these thin layers exposing new surfaces for the gribbles to attack. This causes extensive thinning of the wood section. In wood piling, the damage caused by gribbles is typically greater in the tidal zone (Chellis 1961).

Damage Zones in Wood Piles

Wood piles that support piers or other marine structures are driven into the mud and extend above the waterline to the deck or structure they support. The vertical variation of exposure conditions of the wood pile has previously been delineated into different microenvironment zones by the U.S. Army Corps of Engineers and allied organizations (U.S. Army Corps of Engineers et al. 2001). The microenvironment variation affects the type and the extent of damage produced by marine organisms. Wood pile damage at the mudline observed in Portland Harbor, Me., is shown in Fig. 5(a). A typical damage profile in the different zones of a wood

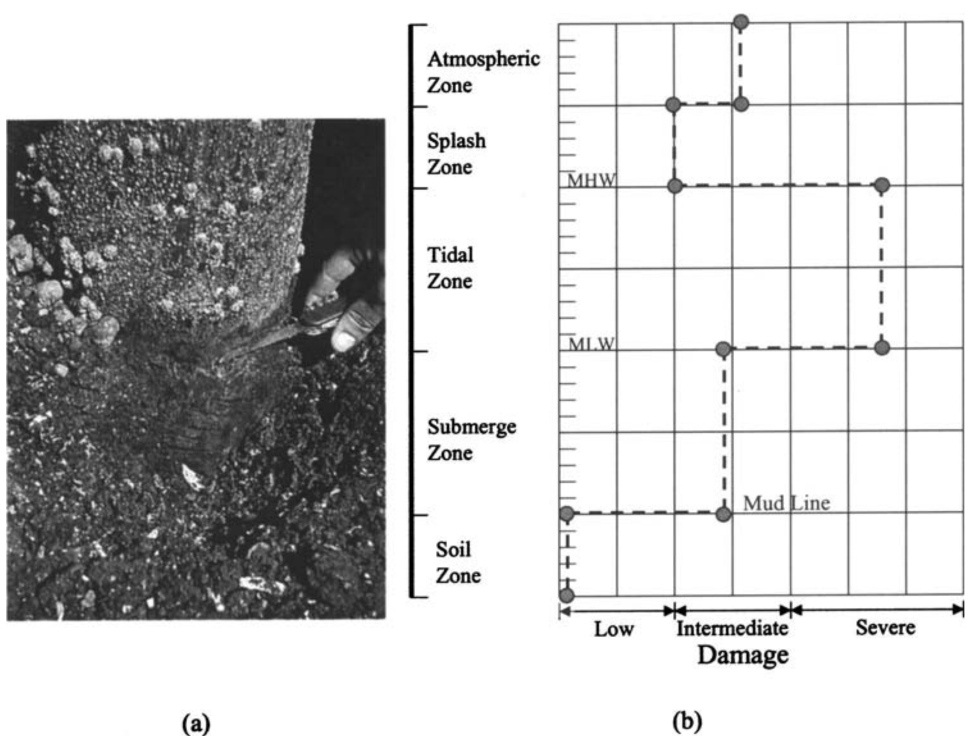

Fig. 5. (a) Wood pile at mudline in Portland Harbor, Me.; (b) typical damage profile of wood pile

pile is illustrated in Fig. 5(b). Similar to the case of corroded steel piles in marine structures (Coburn 2000), the exposure of marine wood piles can be separated into five different zones: Atmospheric, splash, tidal, continuously submerged, and soil. Wood pile damage due to marine organisms in each zone is assessed.

Atmospheric Zone

The atmospheric zone is the top portion of the wood pile, which is above the splash zone. This zone is accessible for maintenance and repair. In this zone, the presence of moisture and oxygen creates a favorable environment for the growth of fungi. Fungal spores are present in the environment and when the conditions in this zone are favorable, fungi will grow and start decaying the wood. Wood piles are often vulnerable to fungal attack in their center portion because preservative treatment does not penetrate all the way into the wood section. Marine borers such as gribbles and shipworms will not attack the wood in the atmospheric zone, since they cannot survive in this environment.

Splash Zone

The mean high water level at the bottom and the atmospheric zone at the top delimit the splash zone. The wood pile surface is exposed to continuous water spray. This zone is accessible for maintenance and repair at low tide with some limitations. Although this zone is subjected to continued salt-water spray, it is possible for fungi to survive and damage the wood because there is adequate oxygen and the salinity is not very high. Fungal activity can be lower in this zone if the conditions are less favorable for their growth.

Tidal Zone

The tidal zone is delimited by the mean low water level and the mean high water level. This zone is exposed to cycles of water immersion. This zone is accessible for maintenance and repair at low tide with difficulty. The tidal zone is often heavily attacked by gribbles when these organisms are present. In this zone, marine borers such as shipworms and gribbles can both attack the wood and cause significant damage. The conditions in this zone seem to be the most favorable for the marine borers to flourish. The presence of salt water and oxygen is a necessity for the survival of marine borers. If the mud line is above mean low water level then attack by gribbles is often severe at the mud line. In some cases, one type of marine borer will predominate and another will not be present. Year to year variability in the type and severity of attack can be related to the type of marine borer. For example, gribble attack may be more prevalent in some years and shipworm attack in other years.

Continuously Submerged Zone

The continuously submerged zone extends between the mud line and the mean low water level. This zone is permanently under water. If the mud line is above the mean low water level, then this zone does not exist. This zone is only accessible for maintenance and repair with cofferdams or specialized underwater techniques. Marine borers such as shipworms and gribbles can attack the wood since saltwater and oxygen are available at this zone.

Soil Zone

The soil zone is the zone below the mud line. In general, this zone does not require maintenance. In this zone oxygen is extremely limited, which prevents the survival of marine borers. For this reason, wood piles below the mud line are generally in good condition. In Fig. 5(a) it can be observed that above the mud line, some reduction in cross sectional area occurred because of the action of gribbles, but below the mud line there is no visible reduction.

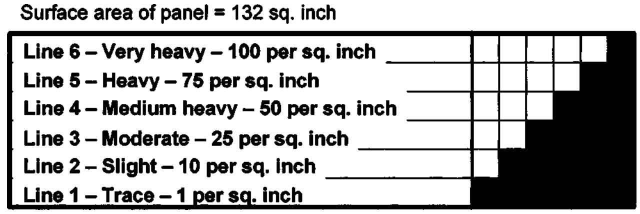

Fig. 6. Key to determine extent of attack to wood test boards by *Teredo* spp. (adapted from Wallour 1959)

Marine Borers in Maine Waters

Between 1936 and 1959, W. F. Clapp Laboratories, Inc. of Duxbury, Mass., monitored the marine borer activity at different locations around the United States and the world by conducting wood test panel studies. An assessment of *Teredo* spp. and *Limnoria* spp. activity on Maine harbors was reported (Wallour 1959). The report revealed the presence of *Teredo* spp. at specific geographical locations along the coast of Maine. In order to identify the extent of the damage caused by either *Teredo* spp. or *Limnoria* spp., keys were developed for each case. The key for *Teredo* spp. activity is shown in Fig. 6 and the key for *Limnoria* spp. activity is shown in Fig. 7. Although, in general the presence of *Teredo* spp. was not accompanied by severe wood panel destruction, in certain years severe damage to the wood test panels was observed. Sporadic medium–heavy and heavy damage as defined by Wallour (1959) was reported in places such as Searsport, Rockland, Thomaston, Scarborough, and Portland. Typical wood test panel results for *Teredo* spp. attack in Searsport, Me., are shown in Fig. 8(a) (Wallour 1959). On the other hand, *Limnoria* spp. was found to be widespread in Maine waters with significant activity in places such as Southwest Harbor, Rockland, Searsport, Wiscasset, and Portland. Portland was especially affected by *Limnoria* spp. damage with the amount of attack ranging from heavy to very heavy in most cases. Typical results of *Limnoria* spp. attack on wood test panels in Portland, Me., are shown in Fig. 8(b) (Wallour 1959).

A survey conducted by the University of Maine between November and December of 2000 on shipworm damage in wood piles is summarized in Table 1. Responses from 13 harbormasters along the coast of Maine were correlated with the responses from Boston harbor. The questions addressed in Table 1 are: (1) Tradi-

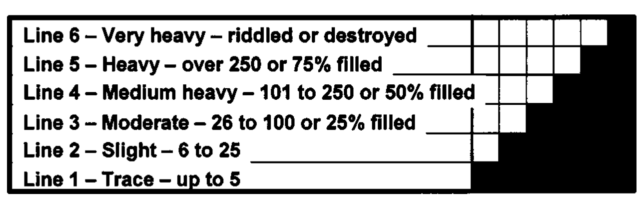

Fig. 7. Key to determine extent of attack to wood test boards by *Limnoria* spp. (adapted from Wallour 1959)

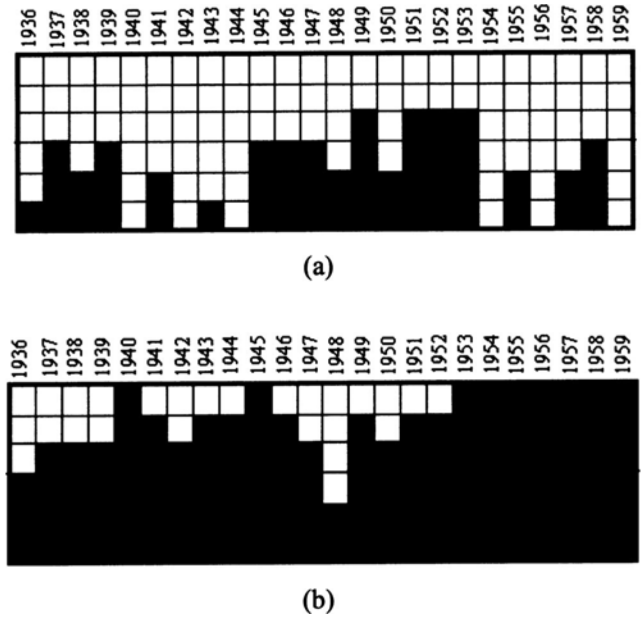

Fig. 8. Typical wood test board results adapted from Wallour (1959): (a) *Teredo* spp., Searsport, Me.; and (b) *Limnoria* spp., Portland, Me.

tional extent of marine borer damage; (2) recent changes in the amount of marine borer attack; and (3) type of marine borer organism. The survey results revealed problems with shipworm damage in wood piles at the same geographic locations in Maine coastal waters reported 41 years earlier (Wallour 1959).

First Case Study: Wood Pile Deterioration in Portland Harbor, Me.

The condition of structural wood piles in Portland Harbor piers was visually assessed in May 2000. The objective of the inspection was to determine the type and extent of damage in structural wood piles. Wood pile damage in two piers was inspected during low tide: Portland Pier and Custom House Wharf, as shown in Lopez-Anido et al. (2004b).

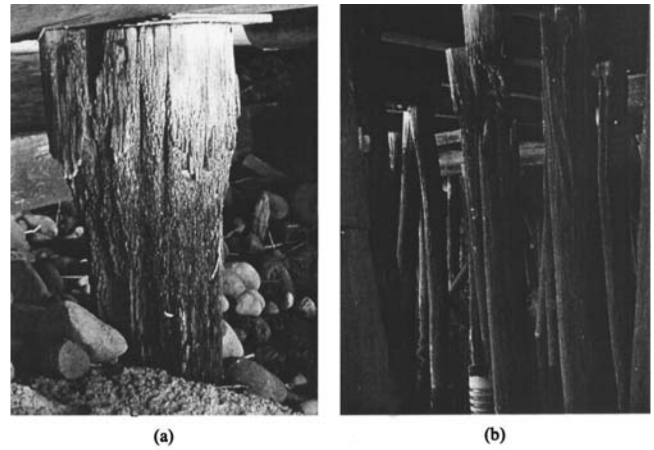

Fig. 9. (a) Typical *Limnoria* spp. damage, Portland, Me.; (b) damaged piles, Portland, Me.

The Portland Pier has a timber retaining wall with solid fill, wood piles, and a wood deck supporting a parking lot [Maine Department of Transportation (DOT) 1986]. The Custom House Wharf is an earth-filled pier structure with wooden-timber and a steel crib bulkhead, wood piles, and an asphalt paved wood deck. There are several marine-related businesses operating on the pier (Maine DOT 1986).

Damage was observed at the Portland pier in several wood piles, as shown in Figs. 9(a and b). In some cases, a loss of cross section (necking in the intertidal zone) up to 70% was observed. It was observed that several old damaged piles were left in place, and new wood piles were driven nearby. In other cases the old damaged piles were cut off, and a new pile portion was spliced on top.

The observations made at the Custom House Wharf were similar to the ones made at Portland Pier. Several piles had reduced cross-sections in the tidal zone between low and high tide. Other piles had extensive visible damage at the butt (reduction in cross section), as well. One wood pile was measured at two locations: The diameter at the butt was 254 mm, and the diameter at the mud line level (1.83 m below the butt) was only 165 mm. This loss of cross section represents about a 50% reduction in the cross

Table 1. Survey Responses on Traditional and Recent Marine Borer Attacks in Maine

City or town harbor (from south to north)	Traditional extent of marine borers damage	Change in relative amount of attack in recent years	Type of marine borer
Boston (out-of-state correlation)	Moderate	No	*Limnoria tripunctana*
York, Me.	Nonexisting	No	Unknown
Wells Harbor, Me.	Nonexisting	No	Unknown
Kennebunk, Me.	Unknown	No	Gribbles
Portland, Me.	Moderate	No	*Teredo*
Falmouth, Me.	Nonexisting	No	Unknown
Georgetown, Me.	Nonexisting	No	Unknown
Wiscasset, Me.	Moderate	No	Gribbles
Saint George, Me.	Moderate	No	*Teredo* and Gribbles
Rockland, Me.	Nonexisting	No	Unknown
Belfast, Me.	Nonexisting	Yes	*Teredo*
Searsport, Me.	Moderate	Yes	Unknown
Castine, Me.	Nonexisting	No	Unknown
Mount Desert, Me.	Nonexisting to moderate	No	Unknown

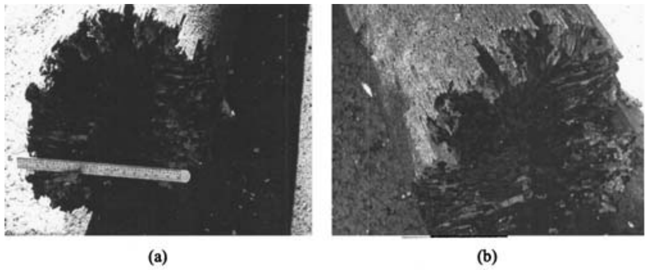

Fig. 10. Wood piles with shipworm damage extracted from Belfast Harbor, Me.

sectional area. To assess the condition of a wood pile below the mud line, a hole of approximately 130 mm in depth was excavated in the surrounding soil. Visual inspection indicated that the wood pile had no reduction in cross section or any apparent damage below the mud line. This observation confirms previous findings on the condition of extracted wood piles from the Portland Harbor. In general, the wood pile damage observed in Portland Harbor was attributed to *Limnoria* spp. This finding is in agreement with an earlier report (Wallour 1959). No internal coring or inspection was performed to determine if shipworm damage had also occurred; however, visual inspection of the areas of reduced cross section revealed no shipworm boring.

Second Case Study: Wood Pile Deterioration in Belfast Harbor Municipal Pier, Me.

Structural wood piles that had been damaged by marine borers were inspected in September 2000 by a team of scientists and engineers from the University of Maine. The wood piles inspected at Belfast Harbor were untreated white oak and had been in service for approximately 1–1 1/2 years.

Wood fender piles with diameters up to 380 mm that were extracted from the harbor revealed severe damage from shipworms. Typical shipworm damage to the wood piles extracted from the harbor is shown in Figs. 10(a and b). Although casual visual inspection of the wood pile exterior showed no evidence of deterioration, the interior of the piles was severely deteriorated. The density of the channels made by the borers indicated a very large infestation of shipworms. The individual borers channeled into the pile interior riddling the intertidal portion of the piles completely. The borers did not turn to orient along the grain nor did they reach their mature length because of the heavy attack which limited the space and time for the shipworms to extend to their full potential. The severity of this attack was surprising but perhaps not unique. In colder waters such as those typically found on the coast of Maine, marine borer attack is normally much slower in more temperate waters. No evidence of extensive marine borer attack in several years prior to the year 2000 had been reported by marinas in the Belfast area. Yet the borers were able to completely riddle the dense wood oak in as little as one year in 2000. The following year, again evidence of severe marine borer infestation was lacking in the Belfast harbor. It is unknown why the sporadic type of attack occurs, but similar patterns of attack have been noted previously in Maine and other eastern seaboard marine waters (Wallour 1959). It is also unknown, given the relatively low level of activity of marine boring in the years preceding and following an aggressive attack year, how the organism can build up its larval population so quickly in the bay, or why the large population would either die off or be unsuccessful in colonization in succeeding years.

The short time span and the extent of the marine borer damage illustrate the importance of protecting wood piles or providing the means to repair such structures. It is worth noting that the solution adopted to replace the deteriorated wood piles in Belfast Harbor was to import from Venezuela a naturally-durable tropical wood called Greenheart (Griffin 2003). However, the exploitation of tropical woods is not a sustainable solution for marine pier protection and results in the "exportation" of environmental concerns in the U.S. to other countries for solution.

Conclusions

Based on the survey of information presented in this paper, the following conclusions are drawn:

1. There is a serious problem with marine pile deterioration specifically in the state of Maine and generally along the coastal waters of the United States. This problem is not new, and it is sometimes sporadic, as the results from wood board tests conducted as far back as the 1940s show. The sporadic nature of some marine borer activity does not mean that this problem can be ignored since the rapid, aggressive attack requires protection of piles for the worst case conditions. Both shipworms and gribbles were found to cause significant wood pile damage in Maine waters.
2. The presence of shipworms at specific geographic locations in Maine coastal waters and their aggressiveness contradicts the general preconception that shipworms are not active in cold waters.
3. Field observations indicate that marine borer organisms need to be characterized to understand the potential and nature of wood pile attack. Furthermore, classification of damage zones in wood piles serves not only to assess damage but also to develop a protection strategy.

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