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INVESTIGATIONS ON WOOD DESTROYING MARINE BORERS IN THE TURKISH COASTAL WATERS

Hüseyin Sivrikaya
hsivrikaya@bartin.edu.tr
Bartın University, Department of Industrial Forest Engineering, Bartın, Turkey

Abstract

Wood is used in the marine environment for several purposes such as groynes, wharves, jetties, dolphins, and navigational posts. It is also important material in the boat construction in many countries due to the wide availability, ease of fabrication, repair and maintenance, strength and elasticity properties. In the marine environment, wood is susceptible to attack and deterioration by marine wood-borers. Temperature and salinity of the seawater influence the distribution of wood-boring organisms. Most studies on wood durability in the marine environment involved in using of tropical timbers as well as wood preservatives or modified wood in different test sites in the world. Although Turkey is surrounded on three sides by the sea, less attention has been given to the marine borers and protection of wood in the marine conditions. The existence of *Teredo navalis* (shipworm) in the deep waters of Marmara was reported by early investigations. *T. navalis* was also found to be dominant species in the Western part of the Black Sea, heavily destroyed the Scots pine samples in one year. Investigations revealed that CCA and creosote shoved resistance to marine borers while the performance of copper azole was promising in the Black Sea. From the tropical wood species, wenge, douka, azobe and paduk showed great resistance to marine borers in the Turkish coastlines. Test sites in Trabzon, Ereğli and İskenderun exhibited the highest boring activity in comparison to the other test locations. *Bankia carinata*, *Nototeredo norvagica*, *Teredo navalis*, *Lyrodus pedicellatus* and *Limnoria tripunctata* were found in the wood samples in the Southern coasts of the Turkey. *Teredothyra dominicensis* was identified as an invasive species in the coast of Kaş in Antalya. DNA barcoding study proved that there was no difference in the barcodes of *N. norvagica* collected from the Atlantic and the Mediterranean Sea.

Keywords: Marine wood-borers, Teredinids, Limnoriids, Turkish coastal waters

1. Introduction

Wood material has been used for centuries to meet the needs of human beings. Because, wood has unique characteristics compared to alternative materials such as renewability, the aesthetic appearance, its performance from past to today, the design and flexibility in use and manufacturing, easy repair and maintenance, high strength and elasticity under load.

Due to the wide availability and easy of fabrication and repair, wood has been the main resource used in the construction of rafts, boats, ships and maritime structures (Borges 2014a; Cragg et al., 2001). Liphschitz and Pulak (2007) investigated the identification of wood species used in ancient shipbuilding in the Eastern Mediterranean. Lebanese cedar, Calabrian pine, Corsica pine and Turkey oak were the main wood species used in wooden shipbuilding in their report.

In the marine environment, wooden materials are susceptible to attack by wood borers. Although microorganisms decay the surface of wood in the sea water, marine borers molluscs and crustaceans are the cause of the wood destruction. The superficial decay of microorganisms accelerates the settlement of marine borers on the wood surface (Eaton 1985). The boring organisms include Bivalvia (Teredinidae and Pholadidae), Isopoda (Limnoriidae and Sphaeromatidae), and Amphipoda (Cheluridae).

Wood is generally impregnated with preservatives or tropical species is used against marine borers, another alternative is the using of physical barriers. Impregnation of wood with creosote or chromated copper arsenate provided resistance to marine borers and this application was found economically viable. However, such these traditional preservatives have been limited by European Commission (2003) in

marine structures due to the environmental concerns. Naturally durable timbers from tropics are widely used in marine structures, but a few species particularly have a high demand because of their reputation in this field. For example, tropical species such as turpentine and greenheart shows resistance against teredinids are not immune to attack by limnoriids (Borges et al., 2008).

Wood-boring organisms cause economic damage to the structures such as wharves, piers, groynes, lock gates, house stilts and other facilities used in the marine (Cragg et al., 1999). The damage to submerged coastal structures was estimated to be $1 billion annually in the USA, and crustacean borers was mainly shown as responsible for this cost (Boyle 1988). Estimated economic loss was reported to be ranged from 300 to 3000 million Rs. annually due to the wood borers in India (Karande and Chongdar 2001). The cost of damage by limnoriids has been estimated to be of the order of billions of Euros worldwide (Borges et al., 2014b).

Marine borers are also a major threat to the cultural heritage under water. For example, shipworm, *Teredo navalis* can cause great destruction to wooden archaeological remains in the marine environment. (Eriksen et al., 2016).

The activity of marine wood-borers is still of great concern in Europe. Several factors including climatic change, physiological and ecological mechanisms probably have an effect on the increasing of the wood-borer attack. For this purpose, an exploratory workshop on "Marine wood borers: new frontiers for European waters" was held in Venice in 2013. The main output of this workshop was to establish a research network that coordinates scientists with a global perspective, to create new research areas on wood-boring organisms and to cooperation in the future (Tagliapietra et al., 2013).

The aim of this paper is to introduce marine wood-borers, take attention to the destructive effect of these organisms in wooden structures, and present investigations performed in the Turkish waters.

2. Marine Wood-Borers

There are four kinds of wood-boring organisms living in the sea, two of which are crustaceans and the other two are molluscs. The destruction of wood in the sea is mainly carried out by wood-boring molluscs and crustaceans and their diagnostic methods are given by Turner (1971a) and Kühne (1971).

2.1. Molluscs

The molluscs comprise the species belonging to teredinids and pholads. Although the teredinids are widespread throughout the world, the distribution of pholads is limited and live in temperate and salty tropical waters (Eaton 1985).

Teredinids or shipworms are bivalve molluscs and Lyrodus, Bankia, Teredo and Nausitora are known the members of Teredinids. Teredinids can attack wood from mud-line to mid-tide, but the most severe attack is near the mud-line. The shell in these organisms is small and covers the front of the animal act as a rasp in the boring of wood. Teredinids release microscopic larvae in the sea water, become active between 1 and 30 days depending on the development stage and can grow up to two meters in length (Cookson 1986). Most of the teredinids are grown feeding in the wood and at the same time filter feed. Cellulolytic nitrogen-fixing bacteria were also isolated from teredinids (Waterbury et al., 1983). Distribution of the larvae can take place by the way of currents or ballast water in the ship. Even, the adults of *T. navalis* can be spread by driftwood (MacIntosh et al., 2012).

If the larvae settle on a substrate like untreated wood, begin to bore for entry holes. These holes on the wood are hardly visible since the larvae are too small. Therefore, the surface of the wood may appear sound but the interior is riddled. After settlement, a larva develops in to adult form, wormlike in the burrow where the calcareous substance secreted by the borer is deposited. Shipworms contain a pair of siphons and a pair of calcified pallets at the posterior of the body. The function of the siphons is the intake of seawater and the expulsion of the waste while the pallets close off the burrow to protect the borer from the predators. The structure of the pallet is of great importance due to the identification of the species (Johnson 1986).

Another group of molluscs is the pholad, destroying wood in the sea and *Martesia striata* L., is the most well-known species, which causes significant damage in the wood. *M. striata* live in tropical and subtropical waters with high salinity, and is fed by filtering the water like Sphaeroma species. They do not feed with wood, only burrow wood and produce pear-shaped tunnels (Turner and Johnson 1971). Pholads are not as destructive as teredinids for some reasons such as less widely distributed, have no ability to close off burrows by their pallets and do not burrow deeply (Johnson 1986).

Researches on marine trials stated that the increase in temperature in the sea water led to an increase in the numbers and activities of marine wood-borers. In addition, another factor that affects the distribution of marine wood-borers is the salinity in the sea water (Turner 1971b).

2.2. Crustaceans

The most important species of wood-boring crustaceans are Limnoria, Sphaeroma and Chelura. While Limnoria species spread throughout the world from cold water to warm water, Sphaeroma live in mild salty water. The diagnosis of these organisms is made on the basis of their external morphological characteristics (Eaton 1985).

Limnoria are from small crustaceans, 1-4 mm in length, and borrow the wood for feeding. They are from the group of invertebrates and degrade the cellulose in wood without the aid of any microorganisms since they produce own cellulase enzyme. They form small ventilation holes in the longitudinal direction in borrows, close the wood surface. Limnoria can attack wood anywhere from mud-line to mid-tide, rarely seen in the areas where the salinity is below 25 parts per thousand. Important species of Limnoria are *L.tripunctata*, *L.quadripunctata* Holthuis and *L. indica* Becker and Kampf. *L.tripunctata* Menzies is a widely studied species of limnoriid in the world (Barnacle et al., 1983).

Sphaeroma species are from crustaceans, larger than Limnoria, and can grow up to 8-14 mm in length. Among these species, three important wood-boring are *S.terebrans* Bate, *S.quoyanum* Milne Edwards and *S. Treste* Heller. Sphaeroma species can tunnel in the wood, sandstone, weak concrete and polystyrene materials. The cavities are small and in the same direction with the surface. Sphaeroma species produce an appearance like hourglass in the destruction of the wooden poles, can destroy wood in the waters where the salinities ranging from 10 to 35 parts per thousand (Cookson 1986).

Sphaeroma species are fed by filtering the seawater. They burrow wood, but do not feed with wood. However, the data obtained from the laboratory feeding experiment showed that *S. terebrans* had the ability to use the wood as food source. *S. terebrans* is widespread in tropical and subtropical estuarine waters and may burrows in cypress, cedar, palm, and pine (Benson et al., 1999).

Three species of chelurids *Chelura terebrans*, *Chelura insulae* and *Chelura brevicauda* were introduced by Kühne (1971). From these species, *C. terebrans* shows worldwide distribution in temperate and subtropical regions. Chelura attack is usually associated with limnoria in the maritime timbers in which chelura generally occupies the outer region whereas limnoria is found interior of the wood. The chelurids have less tolerance than limnoriids with regard to environmental change such as low salinity or low-oxygen conditions. Thus, the chelurids are the least important of the crustacean borers (Eaton and Hale 1993).

3. Test Method and Evaluation in The Marine Trials

For the marine exposure, Scots pine (*Pinus sylvestris*) is used as a reference sample. Wood samples are prepared to 25 × 75× 200 mm in size according to the EN 275 standard (1992). Wood is drilled on the center to a connection hole of 25 mm diameter. At least 5 replicates samples are used for each protection system and test site, and also 5 for control. Full-cell process is required for the samples to be impregnated.

The test specimens should be deployed within 6 meters below the waterline into a medium height. The samples should be inspected every year for a five-year testing period. Assessment of the samples is carried out based on the X-ray inspection and visual evaluation. In the X-ray inspection, each sample is rated according to damage by marine borer attack from 0 to 4. In this system, zero (0) indicates no attack, 1 little damage, 2 moderate damage, 3 severe destruction and 4 means complete destruction.

4. Marine Trials in The Turkish Waters

First investigation was held in the Marmara Sea where *T. navalis* was identified in Turkey (Demir 1954). Berkel reported that maritime structures around Istanbul was destroyed by teredinids in a short period. Sekendiz (1981), examined the *T.navalis* damage in the Black Sea and drew attention to the presence in the Turkish waters.

In the earlier times, a considerable study was conducted by Pınar (1997), covering the test sites in the Black Sea, Marmara, Aegean and the Mediterranean Sea in 1968. Test sites were selected in Amasra, Istanbul, Çanakkale, İzmir and Mersin where the test material exposed to marine borers for 12 months. Observations on the untreated black pine panels revealed that *Noroteredo norvagica*, *Limnoria tripunctata* and *Chelura terebrans* were the identified species. The activities of these organisms were found to be very

high in all test stations except İzmir. The activity of *T. navalis* in Amasra and *L. tripunctata* in Mersin were found to be more active.

Effectiveness of the creosote and CCB (Copper, chrome, Boron) wood preservatives against marine borers by using Scots pine, fir, beech and oak wood species was studied by Bobat (1994). Control and impregnated samples were left at the test stations located in İzmit (Derince) and Mersin (Erdemli) and in Trabzon port for 14 months. At the end of the marine trial, it was determined that the samples in the Marmara Sea were not destroyed. Control samples excluding oak wood in the Mediterranean and the Black Sea were totally destroyed by marine wood-borers, while oak control specimens were found more durable than the others. A few molluscs were seen in the Scots pine and oak samples impregnated with CCB in the Mediterranean and the Black Sea, and the best results was obtained by the creosote treated samples. In the control samples exposed to the Mediterranean Sea, marine wood-borers *Lyrodus pedicellatus*, *Teredo utriculus* and *Bankia carinata* were recorded, while in the Black Sea only *T. navalis* was encountered in the control samples.

Scots pine sapwood and heartwood, oak and chestnut samples impregnated with CCA were tested in the Black Sea (Amasra) for twelve months. A heavy attack of *T. navalis* occurred in the Scots pine control panels. However, CCA treated Scots pine samples showed great resistance to marine borers, while treated samples of oak and chestnut were moderately attacked. In addition, dynamic MOE measurement indicated good correlation between untreated wood and treated wood in the assessment of borers attack (Sivrikaya et al., 2012).

Copper azole wood preservative, free of chromium and arsenic, was performed against marine borers in Amasra for 7 and 14 months intervals. *T. navalis* has been the only species, as it was in the earlier study, identified on wood panels. No damage was observed on the impregnated Scots pine and fir samples except for a few specimens at the end of 7 and 14 months exposure period. All control panels were attacked heavily, while moderate attack was seen on the black pine impregnated panels (Sivrikaya et al., 2016).

Industrial wood species used in wood yacht, boat and harbour constructions have been tested against wood-boring organisms in the Mediterranean Sea. In this context, Scots pine, oak and chestnut species were exposed to marine conditions over five months in Erdemli. During the study, the activity of teredinids was found to be very high and the most damage was observed in Scots pine sapwood and heartwood panels and followed by oak and chestnut respectively (Figure 1). Approximately half of the identified teredinids were *T. navalis*, one-fourth were *B. carinata* and the other one-fourth were *N. norvagica*. From crustaceans, chelura sp., economically less important than other species, found only in the chestnut panels (Sivrikaya et al., 2009).

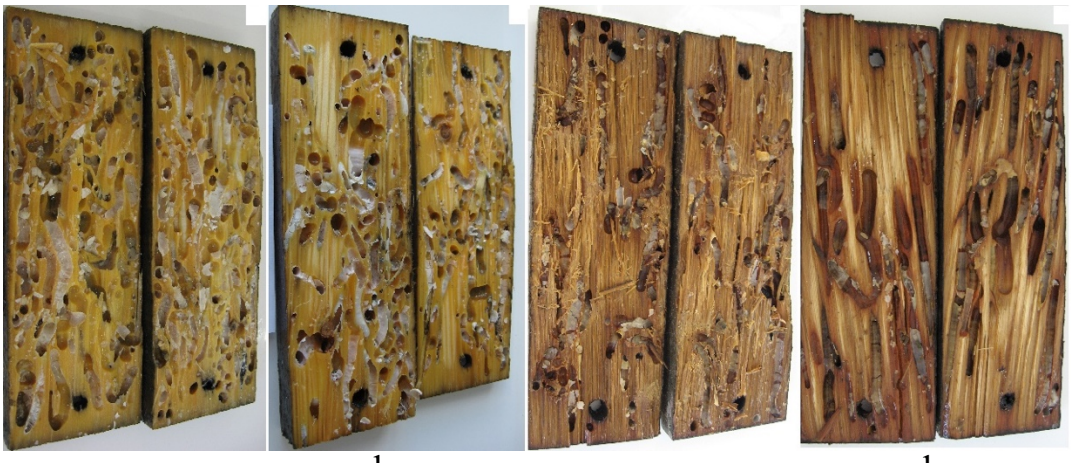

Figure 1. Scots pine sapwood (a), Scots pine heartwood (b), Oak heartwood (c), Chestnut heartwood (d)

A comprehensive study was carried out by Şen et al. (2009) in the Turkish waters covering the Black Sea, Mediterranean, Aegean and Marmara Sea, determining the performance of 18 wood species from Europe and 15 from tropical woods against marine borers for 14 months. From the European species hornbeam, elm, Austrian pine, Scots pine (*Pinus sylvestris*), ash (*Fraxinus excelsior*), beech (*Fagus orientalis*) alder (*Alnus glutinosa*) and fir (*Abies nordmanniana*) were severely attacked by marine borers while olive wood samples were slightly damaged. Tropical species such as wenge (*Millettia laurentii*), douka (*Tieghemella heckelii*), azobe (*Lophira alata*) and paduk (*Pterocarpus soyauxii*) showed high resistance to boring organisms. From the commercial ports, Trabzon, Ereğli and İskenderun showed the highest boring

attack. However, slight attack was shown in the marinas of Bandırma, Alaçatı and Finike. In overall experiments, 5 wood-boring organism species and 26 fouling species were identified. When compared to test stations, *T. navalis* and *L. pedicellatus* were exist in all test sites, whereas *N. norvagica* was only found only in Trabzon and İskenderun ports and *B. carinata* only in İskenderun port. From the crustaceans, *L. tripunctata* was only identified in the test sites in Finike and İskenderun (Şen et al., 2010).

To draw attention to the destruction of wooden shipwreck under water, the replica of the historical Uluburun (III) shipwreck was built, made of *Pinus brutia* including sapwood and heartwood, and deliberately sunk in the Kaş in the Eastern Mediterranean Sea in 2006. Neither wood preservatives nor surface protection was applied in the building of the replica. The degradation of the shipwreck was monitored by several dives throughout four years. The survey revealed that the hull planks and other wooden parts and frames were heavily destructed by shipworms at the end of the October 2009. The complete destruction took place in August 2010. The only remaining parts of the wreck were the mast, frame and keel, found scattered along the seabed. The obtained shipworms from the wreck concluded that the ship was infested by *N. norvagica* and *Teredothyra dominicensis*. *T. dominicensis* was the dominant species representing 92% of the shipworms collected, has previously never been reported in the Mediterranean Sea before. This wood borer was previously reported in the Caribbean Sea and The Gulf of Mexico (Shipway et al., 2010).

Identification of wood-boring teredinids according to their morphological characteristics is quite difficult. Because, the shell morphology of teredinids shows high intra-species variability, so their diagnosis is made according to the palette morphology.

To obtain precise result, Borges et al. (2012) conducted a research in which morphological evidence and mitochondrial and DNA sequences were combined to obtain a taxonomic solution in some species of teredinids. Specimens were collected in France from three areas, from Erdemli in Turkey, and the other specimens were obtained from a shipwreck site in Kaş, Turkey. According to obtained results, DNA barcodes of Atlantic and Mediterranean populations of *L. pedicellatus* diverged by 20% indicated the cryptic species. The low intra-species divergence in barcodes of *N. norvagica* specimens suggests that the Atlantic and Mediterranean forms are the same species. *T. dominicensis* was detected for the first time in the Mediterranean, and it was reported that this was the same species found in the Caribbean Sea. It was also mentioned that *B. carinata* from the Mediterranean and Caribbean may indicate cryptic species.

In addition, first occurrences of the warm-water shipworm *Teredo bartschi*, collected from Mersin, Turkey, and Olhão, Portugal was examined. It was estimated that this species found in Mersin came by rafting from the Red Sea along the Suez Canal. This was the first time that the existence of this species in the Mediterranean and the North East Atlantic was reported by Borges et al. (2014c).

Recently, biogeographic distribution of marine wood-borers in Europe has been conducted by the scientists from Eurolag and European network. Scots pine panels were exposed simultaneously in lagoons, estuaries and harbours. Experiments were carried out in 21 sites spread over 13 Countries, covering from the South Mediterranean to the Baltic and from the Black Sea to the Atlantic Ocean. Zonguldak port in Western part of the Black Sea was one of the test sites where wood borer *T. navalis* only identified. This result has confirmed again the domination of this species in the Black Sea (Guarneri et al., 2018).

5. Conclusion

Turkey is surrounded by the sea on three sides and wood is used for boat and yacht building and for various purposes such as construction of piers and docks. Marine borers either molluscs or crustaceans are the main biological hazards for wood in the marine environment. In addition, invasive species, originating from the other parts of the world increase the biodiversity and also threat to the facilities or materials, even cultural heritage made of wood under the sea water.

Therefore, more attention should be paid to the presence of marine wood-borers and distribution of them in the Turkish waters. On the other hand, researches are needed to develop novel protection methods, environmentally friendly, against marine wood-borers.

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