International Biodeterioration & Biodegradation 96 (2014) 97–104

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Biodegradation of wood exposed in the marine environment: Evaluation of the hazard posed by marine wood-borers in fifteen European sites

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ARTICLE INFO

Article history:
Received 22 May 2014
Received in revised form
2 October 2014
Accepted 2 October 2014
Available online

Keywords:
Biodegradation of wood
Marine wood-borers
Teredinids
Shipworm
Limnoriids
Gribble borer hazard
European coastal waters

ABSTRACT

The activity of marine wood-borers causes great destruction in maritime wooden structures. Therefore, the aim of this study was to evaluate the hazard posed by marine wood-borers in fifteen European sites, to assist authorities and researchers concerned with the protection of wood in the sea. In northern Europe, *Teredo navalis* is the species that poses the highest borer hazard while in the Atlantic coast of southern Europe *Lyrodus pedicellatus* is the most destructive species, with the exception of two sites in Portugal. In these sites, *Limnoria tripunctata* was more destructive than *L. pedicellatus*. In the Mediterranean both *T. navalis* and *L. pedicellatus* pose a very high borer hazard to wooden structures.

Salinity and temperature emerged as the environmental conditions that best explain the occurrence and abundance of wood boring species in the sites surveyed. Three of the species highlighted in this study are warm water species. Therefore their activity might increase in the future, due to global warming. Considering that wood is still a very valuable material for construction, its use for maritime construction should be favoured. Thus research to improve the durability of wooden materials in the marine environment is of paramount importance.

Introduction

In human history, wood has been the material used for maritime construction, possibly due to its wide availability and relative ease of fabrication and repair (Eaton and Hale, 1993; Cragg, 1996). For centuries, it has been the sole resource used in the construction of rafts, boats, ships and harbour structures (Cragg et al., 2001). In the past, the economy of seafaring nations depended upon their ability to maintain a sea-worthy fleet (Graham, 1973). Nowadays, wooden ships no longer play a major role in maritime commerce, but wood is still, a very important component of marine infrastructure in many countries (Love et al., 2000). However, wooden structures in the marine environment are vulnerable to attack by a group of xylotrophic organisms, collectively known as marine wood-borers, which are voracious consumers of wood (Betcher et al., 2012). This group includes Bivalvia (Teredinidae and Pholadidae), Isopoda (Limnoriidae and Sphaeromatidae), and Amphipoda (Cheluridae). In Europe most wood-boring bivalves belong to the Teredinidae, but species of the Pholadidae, such as *Xylophaga dorsalis* (Turton, 1819), also have been reported occurring in Europe (Santhakumaran and Sneli, 1978; Eaton et al., 1989). Wood-boring Crustacea occurring in Europe belong to the Limnoriidae and Cheluridae.

The fight against wood-boring ravage has been going on since early historic times (Turner and Johnson, 1971). From the literature and wrecks, it is known that the ancient Egyptians and Chinese, for instance, used protective coatings, such as resin, pitch or paint, and hull sheathing in their ships, in addition to regular beaching and drying (Steinmayer and Turfa, 1997). These methods probably provided a certain degree of protection to ships and boats. However, the advent of long exploration voyages that started in the 15th century, using large wooden ships, brought about new challenges. The destructive activity of wood borers was very problematic for sailors, but it was probably not felt as a vital problem for nations. This changed in 1730 in the Netherlands, when the country was under the threat of being flooded due to the huge destruction caused by wood borers in the wooden-faced dykes. The prospect of sudden calamity aroused a general interest in marine wood borers (Sellius, 1733; Vrolik, 1858). Since then, accounts of serious economic problems caused by the activity of wood borers have been

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http://dx.doi.org/10.1016/j.ibiod.2014.10.003
0964-8305/

documented in Europe (e.g. Schütz, 1961; Hoppe, 2002). Several methods have been developed with the aim of protecting wood exposed in the sea against marine borers. However, the control of marine wood borers remains an unresolved problem. In addition, the EU directive (European Commission, 2003) is now limiting the use of established and proven preservatives, such as creosote and copper-chrome-arsenic (CCA), in wood destined to be used in marine construction. Therefore, other approaches need to be explored to ensure an adequate service life for timber exposed in the sea. One approach has been to investigate the natural durability against marine wood borers of lesser utilised timbers species using laboratory tests (Rosenbusch et al., 2006; Borges et al., 2008) or field trials (Edmondson, 1955; Southwell and Bultman, 1971; Jones et al., 1972; Haderlie, 1983; Bultman et al., 1988; Eaton et al., 1989; Williams et al., 2004). Another approach, which has been developed in recent years, is the chemical modification of wood for use in the marine environment (Borges et al., 2005; Westin and Rapp, 2005; Lopes et al., 2014).

The destruction caused by wood-borers to wooden maritime structures has led to the choice of other materials, such as concrete and steel, for use in the marine environment. These materials are dominant in marine developments in countries such as the UK (Reynolds, 2004) and Portugal (Borges, pers. obsv.). Nevertheless, the properties of wood, such as resilience, favourable strength-to-weight ratio, relatively low energy costs of production and renewability, make it an attractive material to use for construction (Borges et al., 2003). Wood also suffers much less from the effect of the salt in the seawater than for instance steel or concrete (Williams et al., 2004), and a growing tree absorbs more carbon from the atmosphere than it emits and its processing also requires less energy than the production of concrete or steel (Burnett, 2006). In addition, the production of cement and steel alone accounts for over 10% of global annual greenhouse gas emissions (Burnett, 2006).Therefore, in line with the commitment of the European Union to reduce the emission of greenhouse gases, wooden materials, when the wood is obtained from sustainable sources, are more environmentally friendly and, therefore, should be favoured in marine construction. To this end, having knowledge on wood boring hazard in the area(s) is desirable to enable the choice of the most adequate wooden specie or for future development of tailor-made treatments. However information on borer hazard in European waters is very scarce, although some sites have been used to test the durability of a number of potentially durable wooden species and treated wood. Thus the wood borer hazard to untreated non-resistant wood, Scots pine, used as a comparator, is known (e.g. Jones et al., 1972; Eaton et al., 1989). However, according to EN 275 (1992) the sites chosen for these tests should have high borer hazard. Thus, the borer hazard from these sites is probably not representative of that in other sites in European coastal waters.

Therefore, the aims of the present study were to evaluate the borer hazard posed by teredinids and limnoriids to non-durable timber (*Pinus sylvestris* L.) using a standard methodology EN 275 (1992) to give information on the maximum severity of attack in the sites surveyed; to make it possible to compare with results from other studies (e.g. Eaton et al., 1989); to correlate the abundance of wood boring species in these sites with environmental factors. This information may assist researchers and authorities concerned with service life and protection of wood in the marine environment.

Materials and methods

Experimental set-up and laboratory assessment of test panels

To evaluate the severity of attack caused by wood borers in 15 sites in European waters (Fig. 1), collaborators (see acknowledgements) exposed six panels of *P. sylvestris* L. (Scots pine) at each site. The number of replicates follows the standard EN 275 (1992), which advises the use of at least five replicates. The main aim of EN 275 is to evaluate the relative effectiveness of a wood preservative applied by vacuum/pressure impregnation in the marine environment. In the present study the method was modified to suit the aims of the study (see above) and therefore only untreated Scots pine was used. The wood was uniform, straight-grained and free of knots, cracks, stains or other defects (EN 275, 1992). For detailed methodology, please refer to Borges et al. (2014b). Data on monthly surface temperature and salinity at each site were provided by the collaborators for the majority of test sites (Table 1).

After one year's exposure, the panels were removed and the severity of attack by marine borers was assessed. The fouling community was carefully scraped off. The surface of the panels was then inspected for signs of limnoriid attack. To identify the limnoriid species present, specimens were extracted from the wood and identified using the keys in Menzies (1957), Kühne (1971), Cookson (1990) and Castelló (2011). The severity of attack caused by teredinids was visually assessed using X-rays of the panels, and by splitting the panels to reveal the extent of interior damage and extract the specimens or, in certain cases, just the shells and the pallets. Teredinids were identified on the basis of the morphology of the pallets, using the keys in Turner (1971), the illustrations in Turner (1966) and later using molecular markers (Borges et al., 2012).

To quantify the severity of wood boring damage in the test panels caused by limnoriids and teredinids, the ranking system described in EN 275 (1992) was used. This system varies from 0 (no attack) to 4 (maximum attack, complete destruction of the wood). The abundance of teredinids and limnoriids was determined by counting the specimens found. In the case of teredinids the number of specimens was estimated also by counting the number of shells and pallets, when only these were found in the wood. In addition, the number of tunnels in X-rays of panels was counted whenever possible, but in some cases, due to heavy attack, it was not possible to differentiate individual tunnels.

Statistical analysis

Differences in species composition and abundance were compared using multivariate analysis in PRIMER V6 (Clarke and Gorley, 2006). The 'analysis of similarities' and species contribution ANOSIM was carried out to test the null hypothesis that there are no differences in the species composition between the sites tested. The data was square-root-transformed, prior to produce the Bray–Curtis similarity matrix (Clarke, 1993). The following hierarchical design was used (orthogonal, fixed, 15 levels). The similarity percentage (SIMPER) routine was then used to identify the relative species contribution to the differences observed between test sites (pairwise comparison) (Clarke and Gorley, 2006).

The Bio-Env analysis on BEST routine, in the PRIMER package V6, was used to test how variability and abundance of species could be explained by environmental differences (Clarke and Gorley, 2006). Several environmental factors have been identified as having influence on marine wood-borers. Thus, the factors with the highest influence on the survival and activity of marine wood-borers were tested, including temperature, salinity, dissolved oxygen and pH (Menzies, 1957; Turner, 1966; Nair and Saraswathy, 1971) (Table 1). The data on temperature salinity was obtained from the hybrid dataset compiled by Borges et al. (2014b). Data on dissolved oxygen and pH was extracted from Tyberghein et al. (2012). The analysis was based on the high rank correlation between the similarity matrix generated using the Bray–Curtis similarity coefficient on