Turk J Agric For
33 (2009) 569-576
© TÜBİTAK
doi:10.3906/tar-0902-28

Research Article

Variation in resistance to marine borers in commercial timbers from Turkey, as assessed by marine trial and laboratory screening

Hüseyin SİVRİKAYA[1,*], Simon M. CRAGG[2], Luisa M. S. BORGES[2]

[1]Department of Industrial Forest Engineering, Faculty of Forestry, Bartın University, 74100 Bartın - TURKEY

[2]University of Portsmouth, School of Biological Sciences, Institute of Marine Sciences, Ferry Road, Portsmouth PO4 9LY - UK

Received: 16.02.2009

Abstract: Commercial timbers from Turkey used in coastal construction and boat building were tested for their resistance to marine wood-boring invertebrates in a marine trial and in a laboratory screening test. The timbers tested were beech (*Fagus orientalis* Lipsky), oak (*Quercus petraea* (Mattuschka) Liebl.), chestnut (*Castanea sativa* Mill.), and Scots pine (*Pinus sylvestris* L.). The marine trial was conducted over a period of 5 months at Mersin on the southern Mediterranean coast of Turkey. Activity by teredinid (Mollusca, Bivalvia) borers during this period was very high, resulting in the maximum rating of 4 on the EN 275 scale for *P. sylvestris* sapwood and heartwood panels. *Q. petraea* panels averaged 2.8 and *C. sativa* panels were attacked the least with a mean rating of 2.3. There was little variation between the timbers tested in the size of the shells of the teredinids found, and so variation in the level of attack can be ascribed to fewer animals colonising *C. sativa* and *Q. petraea* than *P. sylvestris*. About one half of the teredinids identified were *Teredo navalis* (Linnaeus 1758), one quarter *Bankia carinata* (JE Gray 1827), and one quarter *Nototeredo norvagica* (Spengler 1792). No evidence of preference for a particular timber by any of these species was observed. Teeth on the ridges of the shells of teredinids from *C. sativa* were partially or wholly immersed in a dark brown substance that might reduce the boring efficiency of the shell. Some attacking by limnoriids (Isopoda, Crustacea) was also detected. Specimens of the amphipod crustacean *Chelura* sp. were observed on panels of *C. sativa*. In a laboratory screening trial in which the feeding rate of individual *Limnoria quadripunctata* (Holthuis 1949) was assessed by measuring faecal pellet production, feeding on heartwood of *C. sativa*, *F. orientalis*, and *Q. petraea* averaged less than half of that on the non-durable sapwood and heartwood of *P. sylvestris*. The correlation between wood density and feeding rate was weak.

Key words: Marine wood-borer, marine trial, laboratory screening, Mediterranean coast

Türkiye'de mevcut bazı ticari odunların deniz zararlılarına karşı dirençlerinin belirlenmesi

Özet: Türkiye'de kıyı inşaatlarında ve yat yapımında kullanılan odun türlerinin odun delici omurgasızlara karşı deniz denemesi ve laboratuar testleri yapılmıştır. Çalışmada kayın, meşe, kestane ve sarıçam odunları test edilmiştir. Deniz denemesi 5 ayın üzerinde Türkiye'nin güney kıyısında bulunan Mersin de gerçekleştirilmiştir. Bu süre boyunca teredinid'

* E-mail: h_sivrikaya@yahoo.com

lerin aktivitesi çok yüksek olmuştur ve sarıçam diri ve öz odun panelleri EN 275 standardında belirtilen puanlara göre maksimum olan 4 ile derecelendirilmiştir. Meşe panelleri ortalama 2.8 tahribat puanı ile kestane panelleri en az saldırıya maruz kaldığı için 2.3 ile sıralanmıştır. Test edilen odun örneklerinden toplanan teredinidlere ait kabukların büyüklükleri arasında az miktarda farklılık bulunmuştur. Organizmaların saldırı derecesindeki farklılık, çam örneğine nazaran kestane ve meşe panellerinde çok az sayıda canlının yerleştiğini ifade edebilir. Teşhis edilen teredinidlerin yaklaşık yarısı *Teredo navalis* (Linnaeus 1758), dörtte birlik kısmı *Bankia carinata* (JE Gray 1827) diğer dörtte birlik kısmı ise *Nototeredo norvagica* (Spengler 1792) olmuştur. Organizmaların belli bir odun türünü tercih ettiğine dair bir kanıt bulunamamıştır. Ayrıca, paneller üzerinde bazı limnorid saldırılarına da rastlanmıştır. Kabuklu organizmalardan Chelura sp. kestane panelleri üzerinde bulunmuştur. Laboratuar denemesinde *Limnoria quadripunctata* (Holthuis 1949) nın beslenme oranı dışkı üretimlerine göre değerlendirilmiştir. Kestane, kayın ve meşe öz odunları üzerindeki ortalama beslenme oranı sarıçam diri ve öz odununa göre yarıdan daha az bulunmuştur. Odun yoğunluğu ile beslenme oranı arasındaki ilişki zayıf bulunmuştur.

Anahtar sözcükler: Denizel odun delici, deniz testi, laboratuar incelemesi, Akdeniz kıyısı

Introduction

Wood is used in the marine environment for fixed structures, such as groynes, wharves, jetties, dolphins, and navigational posts. It is also important in many countries as a material for boat construction. The degree to which wood is used in the sea varies enormously from country to country. Recently introduced restraints due to environmental legislation have refocused attention on the natural durability of timbers in the sea. Most investigations of marine durability in the sea focus on tropical timbers (Borges et al. 2008), partly due to the superiority of the engineering properties and dimensions of these timbers, but also due to limited availability of locally grown alternatives in countries like the UK. Other countries with greater resources for mature trees are in a position to look to local timbers.

Turkey is an example of a country with abundant large-dimension hardwood resources. In this study the marine durability of 3 common Turkish timbers from the family Fagaceae were compared with *Pinus sylvestris* L. (Scots pine), which has been shown to be non-resistant to attack by marine borers (most notably in a collaborative IRG marine trial with comparable observations from sites ranging from Australia, Papua New Guinea, Europe, and the USA (Eaton et al. 1989). Scots pine is one of the main species for the forest industry in Turkey, which covers 5% of the total forest area. Oak is the most widespread species in Turkey, covering 30% of the total forest area. Turkish-origin oak wood has significant natural resistance against wood-degrading organisms because of its rich extractive content, but is difficult to treat with traditional methods. Chestnut is a vital species for yacht and boat construction in the Black Sea region; thus, its resistance to marine borers is of particular interest. Chestnut forests cover approximately 1.4% of the total forest area of Turkey. Like oak, this timber has a rich extractive content, which includes tannins. Beech covers 8% of the total forest area of Turkey and is commonly utilised by the furniture industry (OGM 2007).

These timbers have been assessed for resistance to white rot and brown rot fungi, and to termites (Kartal and Green 2003; Göktaş et al. 2007). There has been only limited testing of the marine durability of temperate timbers (Norman 1976), but extensive testing of tropical timbers has been undertaken (Borges et al. 2008). The present study aimed to investigate the marine durability of these Turkish timbers.

The density of the timbers tested was measured in consideration of the correlation between density and hardness, and of the role of hardness in determining borer feeding rates (Cragg et al. 2007). Basic information was collected about a site of particular promise for marine testing, in view of the high level of borer challenge. Conventional marine exposure trial results were compared with laboratory assay results.

Materials and methods

The timbers tested in this study were obtained from Bartın province on the northern Black Sea coast of Turkey. The timbers are listed in the Table. Oven dry density was calculated from 10 replicate blocks per wood type.

Marine exposure trial

For the marine exposure trial wood panels 25 × 75 × 200 mm, according to the EN 275 standard, were used. Both Scots pine sapwood and heartwood were exposed, whereas only oak and chestnut heartwood were used. Six replicate panels of each timber type were exposed. Two sides of the samples were drilled to make 1-cm diameter holes. Samples were fastened to each other with a rope via the holes to make the test system.

The test site used was in Mersin, on the southern Mediterranean coast of Turkey (36°33′N, 34°35′E). Samples were exposed between 14 February 2007 and 13 November 2007 at the harbour belonging to the Middle East Technical University, Institute of Marine Sciences. The harbour is an important area of marine biological diversity on the Mersin coast, as it is the only intact rocky habitat along the long sandy coast. The harbour also provides habitat for species of Red Sea origin, such as the mussel *Brachidontes variabilis* Krauss, 1848, bivalve *Saccostrea cucullata* Born, 1778, and gastropod *Nassarius arcularia plicatus* Röding, 1798, which probably passed through the Suez Canal as larvae. Another special feature of the harbour is the thin layer of freshwater at the surface, coming partly from the Lamas River and partly from ground water releases on the small beach within the harbour. Borges (2007) reports water temperatures between 15 and 31 °C, and salinity between 34 and 39 PSU.

Test panels were broken open to reveal the borers' tunnels and to rate the damage according to EN 275. All borer shells and pallets were extracted. Teredinid pallets were identified by their proportions, and the features of their calcareous and periostracal portions (Turner 1966). Air-dried shells were placed on adhesive conductive tabs and sputter coated with gold and palladium. They were examined in a JEOL 6060LV scanning electron microscope with an acceleration voltage of 15 kV, using the backscattered electron observation mode.

Laboratory assay

Sticks measuring 20 × 4.5 × 2.4 mm were prepared from each of the wood types in the marine trial plus *Fagus orientalis* Lipsky (Table). They were fine-sawn using a 75-mm diameter carbide-tipped circular saw. Sapwood was used for Scots pine and heartwood for all other species. Prior to experimentation, the sticks were leached in seawater for 1 week, with a change of water after 3 days.

Healthy individuals of the wood-boring isopod crustacean *Limnoria quadripunctata* (Holthuis 1949) were extracted from timber in wooden structures in the intertidal zone at Portsmouth, UK. Adult animals were transferred to 12-welled polystyrene cell culture dishes with a fine sable brush or fine forceps. The wells were 20 mm in diameter and contained 4 mL of seawater. A stick of wood and a single specimen of *L. Quadripunctata* was placed in each well. Twelve sticks of each wood species were tested. The containers were kept at 20 ± 1 °C under daylight fluorescent tubes with a light intensity on the culture shelf of 18.0 µmol s^{-1} m^{-2}.

Faecal pellets produced by the animals feeding on the sticks were counted every 3 days for 15 days. At each time interval a record was also made of animals that had moulted and those that had died. Moulting is a 2-part process, with the posterior part being shed first. The second phase of moulting—the shedding of the anterior exoskeleton—often took place after the shedding of the posterior exoskeleton. As moulting

Table. Details of the wood types investigated in the marine trial and in laboratory screening

Wood species	*Scientific name*	Family	Type	Oven dry density (kg m^{-3})	EN 275 rating
Beech	*Fagus orientalis* Lipsky	Fagaceae	heartwood	600.3 ± 8.4	not measured
Chestnut	*Castanea sativa* Mill.	Fagaceae	heartwood	528.3 ± 9.0	2.3
Oak	*Quercus petraea* (Mattuschka) Liebl.	Fagaceae	heartwood	746.0 ± 10.5	2.8
Scots pine	*Pinus sylvestris* L.	Pinaceae	heartwood	528.6 ± 15.8	4.0
Scots pine	*Pinus sylvestris* L.	Pinaceae	sapwood	430.2 ± 8.3	4.0

suppresses feeding (Delgery et al. 2006), data from the counting intervals in which moulting took place were excluded from both analysis and data display; so were counts from animals that were dead at the end of a counting interval. The feeding rate for individual animals was calculated only if counts from at least 3 counting intervals were available after these exclusions.

Statistics

Neither the number of faecal pellets nor shell size was distributed normally. Counts were converted by a square root transformation to a normal distribution. Shell sizes were log transformed before analysis. Transformed data were used in GLM ANOVA tests with Tukey's post hoc pairwise comparisons used to establish significant differences. Examination of residuals from these analyses indicated that the transformations gave data that fit the assumptions required for ANOVA.

Results

In the marine trial, distinct differences in borer susceptibility of the species tested were evident, despite the short testing period. Both sapwood and heartwood of *Pinus sylvestris* L. were totally riddled by teredinids (maximum EN 275 rating of 4). *Quercus petraea* (Mattuschka Liebl.) was attacked only moderately, with EN 275 ratings between 2 and 3 (mean: 2.8), while those for *Castanea sativa* Mill. ranged from 1 (slight) to 3 (mean: 2.3) (Table). *Fagus orientalis* Lipsky was not tested in the marine trial.

The frequency distribution of shell diameter in the marine trial panels was unimodal, showing no evidence of grouping by species or recruitment period. The distribution was slightly skewed and logarithmic transformation was used to correct the skew in statistical analysis. Mean shell size varied by less than 10% between wood types. Nonetheless, shells found in *Q. petraea* and in *P. sylvestris* heartwood were significantly smaller than those found in *C. sativa* and in *P. sylvestris* sapwood (Figure 1).

The pallets retrieved from the panels gave an estimate of the species mix within each panel. In all wood types examined, the teredinid *Teredo navalis* (Linnaeus 1758) was the dominant species, with over 50% of all pallets belonging to animals of this species. The remaining pallets belonged to *Bankia carinata* (JE Gray 1758) and *Nototeredo norvagica* (Spengler 1792), with *Nototeredo* being more numerous in both heartwood and sapwood of *P. sylvestris* (Figure 2).

The appearance of the shells of the teredinids taken from chestnut panels was distinctly different from those retrieved from Scots pine. The shells from chestnut had a dark brown coating on the denticulated ridges of the anterior slope of the shell, which is responsible for grinding fragments off the wood at the head of the tunnel. No such coating was evident on the shells from the pine samples. When examined in the scanning electron microscope, the teeth of the ridges were virtually clean in specimens from Scots pine (Figure 3a and 3b), but were obscured by the coating in specimens from chestnut (Figure 3c). Older teeth—teeth that were laid down when the animal was much smaller—were almost totally submerged in the coating substance (Figure 3d).

Some tunnels of limnoriid isopods were visible on 4 *P. sylvestris* sapwood panels, 2 *P. sylvestris* heartwood panels, 3 *Q. petraea* panels, and 4 *C. sativa* panels, but no animals were found in the tunnels. The wood-boring amphipod *Chelura terebrans* (Philippi 1839) was found, but only on 2 of the *C. sativa* panels.

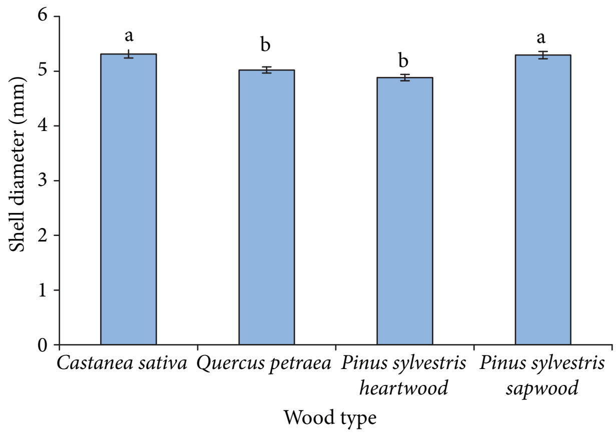

Figure 1. Diameter (mean ± SE) of the shells of teredinid wood borers in panels of a range of commercial Turkish wood types exposed at Mersin, southern Turkey. Wood types with significantly different shell diameters are indicated by different letters (GLM ANOVA with wood type as a fixed factor and diameter log transformed, Tukey's post hoc test)

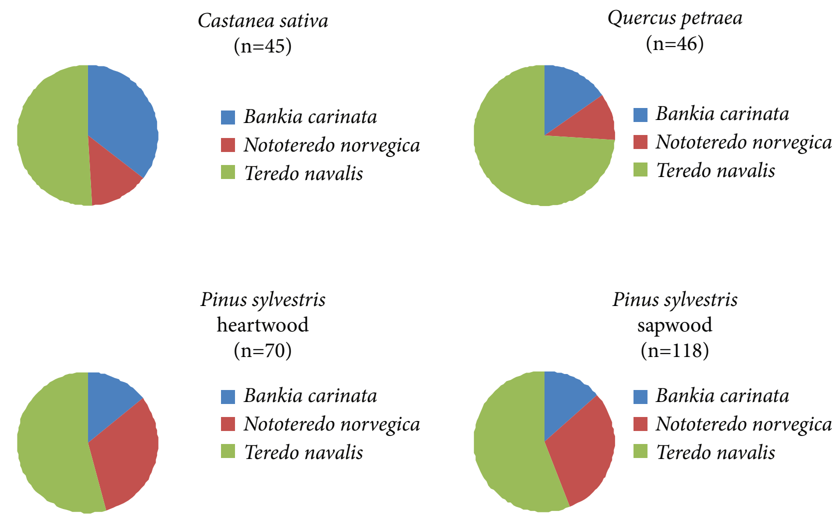

Figure 2. Proportion of species of teredinid wood borers in panels of a range of commercial Turkish wood types exposed at Mersin, southern Turkey

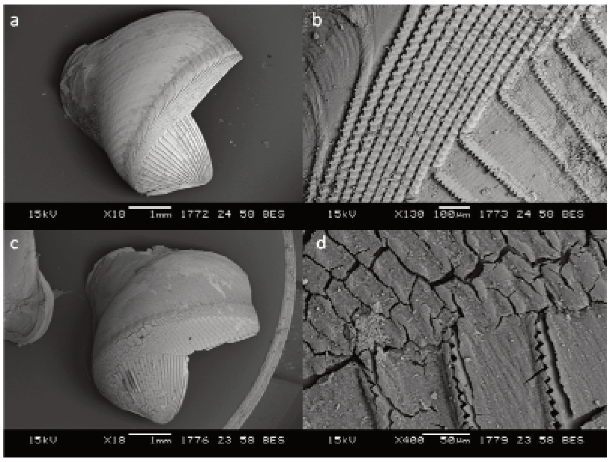

Figure 3. Air-dried shells of teredinids from the panels exposed at Mersin. a. Whole shell valve from Pinus heartwood. b. Detail of denticulated ridges of the anterior slope of the shell in Figure 3a. c. Whole shell valve from Castanea. d. Detail of Figure 3c showing older denticulated ridges obscured by the coating that was probably left by the Castanea heartwood

In the laboratory assay with *Limnoria quadripunctata* (Holthuis, 1949), feeding rates measured by faecal pellet production over a 15 day period were significantly lower on all members of the Fagaceae tested (*F. orientalis*, *Q. petraea*, and *C. sativa*) than on either the heartwood or sapwood of Scots pine. The differences between the species of Fagaceae were, however, not significant (GLM ANOVA with Tukey's test, Figure 4). Feeding rates on the Fagacaea were about half of those on *P. sylvestris*.

For the wood species tested, there was not a strong relationship between density and feeding rate, as measured by pellet production, although the trend was for less pellet production at higher densities

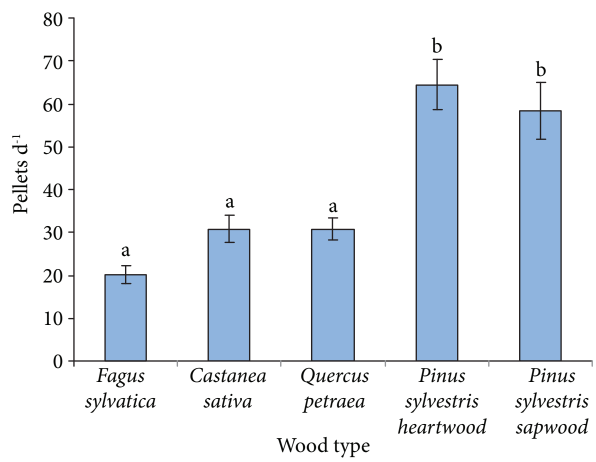

Figure 4. Effect of wood type on the feeding rate of *Limnoria quadripunctata*, as measured by faecal pellet production. Wood types with significantly different pellet production rates are indicated by different letters (GLM ANOVA with wood type as a fixed factor and pellets d^{-1} square root transformed, Tukey's post hoc test)

(Figure 5). It was notable that 2 wood types with similar densities, *Pinus sylvestris* and *Castanea sativa* heartwood, supported markedly different feeding rates; the feeding rate on *C. sativa* was less than half of that on *P. sylvestris*.

Discussion and conclusion

Factors affecting performance of the different wood types

In the marine trial clear differences in EN 275 ratings were evident between the timber types (Table), which could be ascribed either to differences in borer growth rates or in the number of borers. However, the differences between the various types of mean borer shell size were small (Figure 1), suggesting that the growth rate did not vary very much from type to type. Indeed, the small but significant differences between mean shell size could have been related to the timing of larval settlement, rather than differences in growth rates; slightly smaller shells might be the result of later settlement and thus a shorter growing period. In the marine trial the primary factor underlying differences in ratings, and thus resistance to borer attack, was larval recruitment. Variations in the level of larval recruitment to the adult borer population between wood types is evidenced by the smaller numbers observed on the better performing *C. sativa* and *Q. petraea* (respectively, 45 and 46 adult shells found on 6 panels of each timber) than on the poorly performing pine samples (70 on heartwood panels and 118 on sapwood, Figure 2).

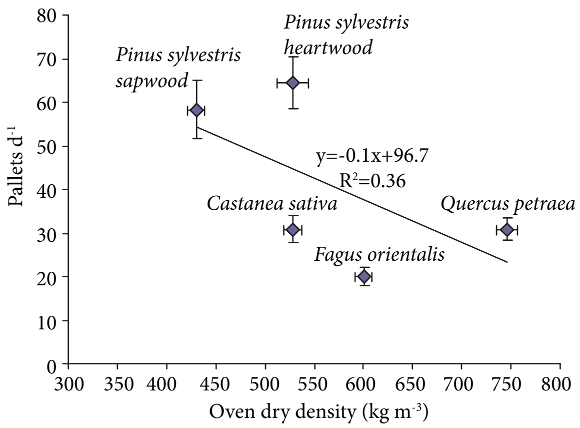

Figure 5. Relationship between density and pellet production rate in a range of commercial Turkish timbers. Error bars denote ± SE. Trend line calculated by regression analysis

Low recruitment would result in fewer adult tunnels, a feature used to determine ratings. Recruitment of juveniles to the adult population is affected by success of larvae in settling on the wood surface and by survival during early juvenile development. Settlement may be affected by repellent or toxic factors on the wood surface, while survival will be affected by speed of initial boring into the wood, which provides extra protection from predators and by a perhaps enhanced release of toxins from the wood during the boring process. Additionally, it appears that heartwood materials may affect the boring ability of teredinid shells. The shells taken from *C. sativa* had ridges of teeth that were almost totally obscured by a dark brown coating that might have been a polyphenolic substance derived from the extractives in the heartwood.

Differences in the feeding rate on different timbers in the laboratory assay with *L. quadripunctata* might have been due to differences in hardness, as reported in tropical hardwoods by Cragg et al. (2007), or might have been due to the presence of extractives with toxic or antifeedant effects (Borges et al. 2008). As the samples of *Pinus* heartwood and *Castanea* had similar densities, the marked difference in the feeding rate on these 2 timbers was likely due to extractives. *Castanea* from Turkey has polyphenolics in the heartwood (Balaban and Ucar 2003) that may interfere with the digestion processes of *Limnoria*. Furthermore, the similarities in the feeding rate on *Castanea* and *Quercus*, despite marked differences in their density, also indicate greater importance of extractives (acidic polyphenolics in both cases (Balaban and Ucar 2003)) in reducing the feeding rate. The significant but limited resistance of these 2 timbers and *Fagus orientalis* to marine crustacean and bivalve borers matched the resistance measured in tests using termites, white rot fungi, and brown rot fungi (Kartal and Green 2003; Aloui et al. 2004; Göktaş et al. 2007).

Field and laboratory testing methodology

The site at Mersin had the greatest range of borer species of the 15 sites (ranging from Reykjavik and Trondheim in the north to the Azores, the Algarve, and Mersin in the south) surveyed by Borges (2007).

The teredinids *B. carinata* (JE Gray 1827), *Lyrodus pedicellatus* (de quatreages 1849), *N. norvagica* (Spengler 1792), *Teredo bartschi* (Clapp, 1923), and *Teredo navalis* (Linnaeus 1758), and the isopod *Limnoria tripunctata* were found in pine panels exposed for 1 year at this site. In the present study, which had a shorter exposure period, no specimens of *L. pedicellatus* or *T. bartschi* were found, but another borer, the amphipod *Chelura* sp., was collected. *T. bartschi* and *B. carinata* are more commonly found further south, for example in the Red Sea or Indian Ocean (Haderlie 1983; Raveendran and Wagh 1991); their presence at Mersin may reflect the influence of larval supply via the Suez Canal.

The diversity of borers and high water temperature at the study site results in a rapid rate of biodegradation; thus, despite the short exposure period (7 months) meaningful differences between the durability of different timbers can be detected. To enable a better determination of the likely service life of the timbers, a longer exposure period, such as the 5 years advocated in the European standard for marine testing (BSEN 275 1992), would be needed, although the rate of degradation by teredinids at Mersin suggests that panels of even the most resistant timbers tested would not be likely to last for the full 5 years. However, such stringent testing assumes unprotected long-term service. In many end uses, other factors such as abrasion resistance may be as important in determining service life (Williams et al. 2004). The limited durability of *Castanea* may still be significant in a typical end use in Turkey—boat construction—for the wood will normally be protected by paint and will only be at risk when the paint layer is breached.

The correlation between performance in the marine trial (with the hazard being mainly teredinids) and in the laboratory assay (with only a limnoriid challenge) was quite close, suggesting that the rapid results available from the laboratory assay could be used to guide a marine testing programme. It could also be used to assess the variability in durability of timber of the same species from different sources, as has been demonstrated by Rosenbusch et al. (2006).

Acknowledgements

The laboratory work for this paper was conducted while HS was in receipt of funding from the Royal Society (UK) and the Scientific and Technological Research Council of Turkey (TÜBİTAK). Access to the test site of Middle East Technical University Institute of Marine Sciences enabled the marine test to be conducted. The support of METU is gratefully acknowledged. This study was presented at the 39th Annual Meeting of IRG held in İstanbul in 2008.

References

Aloui F, Ayadi N, Charrier F, Charrier B (2004) Durability of European oak (*Quercus petraea* and *Quercus robur*) against white rot fungi (*Coriolus versicolor*): relations with phenol extractives. Holz als Roh- und Werkstoff 62: 286-290.

Balaban M, Uçar G (2003) Estimation of volatile acids in wood and bark. Holz Als Roh-Und Werkstoff 61: 465-468.

Borges LMS (2007) Biogeography of Wood Boring Organisms in European Coastal Waters and Evaluation of New Approaches to Controlling Borer Attack. PhD Thesis, University of Portsmouth, p. 253.

Borges LMS, Cragg SM, Bergot J, Williams JR, Shayler B, Sawyer GS (2008) Laboratory screening of tropical hardwoods for natural resistance to the marine borer *Limnoria quadripunctata*: the role of leachable and non-leachable factors. Holzforschung 62: 99-111.

BSEN 275 (1992) Wood Preservatives. Determination of the Protective Effectiveness Against Marine Borers. pp. 24. London, British Standards Institution.

Cragg SM, Danjon C, Mansfield-Williams H (2007) Contribution of hardness to the natural resistance of a range of wood species to attack by the marine borer Limnoria. Holzforschung 61: 201-206.

Delgery CC, Cragg SM, Busch S, Morgan EA (2006) Effects of the epibiotic heterotrich ciliate *Mirofolliculina limnoriae* and of moulting on faecal pellet production by the wood-boring isopods, *Limnoria tripunctata* and *Limnoria quadripunctata*. Journal of Experimental Marine Biology and Ecology 334: 165-173.

Eaton R, Ampong F, Barnacle J, Beesley J, Bultman D, Cookson L, Cragg SM, Depalma J, Gambetta A, Henningsson B, Levi M, Levy C, Nilsson T, Orlandi E (1989) An international collaborative marine trial to investigate the effect of timber substrate on the efficacy of CCA and CCB wood preservatives. Material und Organismen 24: 51-79.

Göktaş O, Mammadov R, Duru ME, Özen E, Çolak AM (2007) Application of extracts from the poisonous plant, *Nerium oleander* L., as a wood preservative. African Journal of Biotechnology 6: 2000-2003.

Haderlie EC (1983) Wood boring marine animals from the Gulf of Elat. Israel Journal of Zoology 23: 57-59.

Kartal SN, Green F (2003) Decay and termite resistance of medium density fiberboard (MDF) made from different wood species. International Biodeterioration & Biodegradation 51: 29-35.

Norman E (1976) Natural resistance of different species of Swedish timbers to attack by marine wood-boring molluscs. Institutionen för Virkeslära Rapporter 98: 1-14.

OGM (2007) Türkiye'de Orman Ekosistemlerinin İzlenmesi L I ve L II Programları. T.C. Çevre ve Orman Bakanlığı, Orman Genel Müdürlüğü, Ankara.

Raveendran TV, Wagh AB (1991) Distribution and growth of wood-borers in Bombay offshore waters. Indian Journal of Marine Sciences 20: 143-146.

Rosenbusch K, Borges LMS, Cragg SM, Rapp A, Pitman AJ (2006) A laboratory assessment of the natural durability of the lesser-utilised species *Corynanthe pachyceras* Welw. and *Glyphaea brevis* (Sprengel) Monachino against the marine wood borer *Limnoria quadripunctata* Holthius. International Biodeterioration & Biodegradation 57: 71-74.

Turner RD (1966) A Survey and Illustrated Catalogue of the Teredinidae. Museum of Comparative Anatomy, Harvard, Massachusetts.

Williams JR, Sawyer GS, Cragg SM, Simm J (2004) A questionnaire survey to establish the perceptions of UK specifiers concerning the key material attributes of timber for use in marine and fresh water engineering. Journal of the Institute of Wood Science 17: 41-50.