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DETERIORATION OF MARINE TIMBER PILED STRUCTURES BY FUNGI, TERMITES AND CRUSTACEAN MARINE BORERS

by

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Wood differs from other materials used for marine structures such as steel and concrete in that the deterioration it suffers is predominantly caused by marine organisms. Because the distribution of marine organisms varies, wood placed in different marine sites may be subjected to different modes and intensity of attack. A decision on which available timber, or timber/preservative/barrier option to use, should be made only after considering the biological hazard at a particular site.

The following discussions show how to recognise the various organisms and their modes of attack on wood in the marine environment, so that an effective protective system may be employed. The bulk of this paper will be concerned with marine borers; however, other organisms that may also constitute a threat will be mentioned briefly.

BASIDIOMYCETE FUNGI

Although salt water often retards white-rot and brown-rot fungi (basidiomycetes) (Dale 1968), rain water can soak into wood above the high tide line, especially in joints, cracks and the top of piles. Wherever water can penetrate into wood and remain for extended periods of time, decay may become a problem. Therefore, at least moderately durable or adequately treated timbers should be used in this zone. Note that durability usually refers to a timber's comparative resistance to decay and termite attack, and does not necessarily indicate resistance to marine borers, unless specifically stated.

Pressure treated timbers are protected in the sapwood; however, the heartwood is usually not treated or poorly treated. Also, durable timbers often vary in durability across their section: the pith and sapwood are often less durable than the remainder of the section. These less decay-resistant portions of timber may become exposed to decay in bolt holes, pile cut-offs, and sawn timber. These surfaces require added protection for optimal service life.

The tops of piles should be covered, for example, by painting with tar-epoxy. As some condensation can occur under metal pile caps, pile tops should be flooded with preservative before these, and any other pile caps, are positioned. Scarfed joints and bolt holes should be treated with preservative while they are accessible during construction. Horizontal bore holes may be flooded with preservative using a bent funnel (Anon. 1980).

Relatively non-diffusible water-repellent preservatives applied by brushing or spraying (e.g. creosote, copper napthenate) may be useful in preventing decay-fungi from entering wood. As checks can develop in wood, this outer preservative barrier must be regularly re-formed by further preservative applications. For timber that already has decay, and for positions of high decay hazard (e.g. pile tops and joints), a penetrating preservative should be applied. These are often placed into drilled holes or saw cuts so that there is a reservoir of preservative. After preservative has been added, drilled holes should be plugged. Diffusing preservatives (for above high tide line) include fluor-chrome-arsenic-phenol (Highley and Scheffer 1975; Lee 1982), solid bifluorides (Highley and Scheffer 1975; Helsing and Graham 1980; Nijman 1983), fused (glass) boron preservative rods (Greaves *et al* 1982; Edlund *et al* 1983), and pastes and other preservatives such as Blue 7, Basilit BFB and Buckman pole preservative gel (Cookson *et al* 1981; Chin *et al*. 1982). Volatile fungicides may also be applied (Graham *et al* 1976; Helsing 1979; Ruddick 1983), although these may perform better in softwoods than in eucalypts where checking may occur resulting in a rapid loss of fumigant.

TERMITES

Termites may also attack marine structures above high tide. Termites are social insects that form concealed galleries in wood, their galleries become noticeable on outside wood (= shelter tubes) when they meet obstacles such as ant caps and some grades of concrete. Their gallery networks do not necessarily have to make contact with the soil. Winged alates (reproductives) leave nests to form new colonies. A colony of *Nasutitermes* sp. was found recently in a turpentine mooring pile situated about 1 kilometer from shore in Cairns Harbour (Barnacle, pers. comm., 1984). Subterranean termites require a source of moisture to survive.

At least moderately durable or treated timbers be used to lessen the possibility of attack by termites. Wood attacked by termites often remain unnoticed until there is structural damage, as they may honeycomb wood with their galleries while leaving a thin outer layer of wood intact. Information on the principles of the eradication of termites is available elsewhere (e.g. Anon. 1978). In buildings, soil-treatments are effective in preventing termite attack; however, such barriers cannot be applied to marine structures. Termite dusting may be the most useful method for eradicating termites in marine structures. This involves puffing a poisonous dust into occupied termite galleries. The dust settles on the bodies of termites which transport it to their nest and other termites when they groom each other. When termite infested wood or external shelter tube galleries are found, it is important not to disturb them so that the termites will not vacate the area before a dust can be applied by which means the entire nest may be destroyed.

The eradication of termites may prove difficult when a wooden pier has concrete platforms built over them, nests and major galleries may then become inaccessible for dusting. This situation has occurred at the Cairns wharf where *Mastotermes* is attacking timber in the structure, and also puncturing and short circuiting electrical cables (Barnacle, pers. comm. 1984).

MARINE MICRO-ORGANISMS

Below mudline, marine borers are unable to initiate attack on wood due to the clogging action of mud and sand and also due to the low oxygen levels present. This portion of a pile may remain sound for long periods after the remainder of the pile has been destroyed. In a 50 to 60 year old red gum pile removed from Brighton (Victoria), the only deterioration noted below mudline was extreme softening by micro-organisms of the sapwood located between mudline and 30 cm below mudline.

Marine fungi and bacteria can degrade wood in the sea to some extent. The surface softening they produce is often quickly removed by marine borers so that their importance in wood deterioration in the sea could be underestimated. The success of some wood preservatives in the sea against marine borers may be due partly to their inhibition of attack by marine micro-organisms so that wood is less easily attacked due to 'preconditioning' by certain marine borers.

MARINE BORERS

Marine borers are divided into two groups: Crustacea and Mollusca. I will deal with the crustacean borers. It is noteworthy at this stage that many of the more important Australian marine borers such as the crustaceans *Limnoria tripunctata* Menzies, *L. quadripunctata* Holthuis, *Sphaeroma terebrans* Bate, and the molluscans in the genera *Lyrodus*, *Teredo*, *Bankia* and *Martesia*, also often occur in certain other countries. Data from overseas sites which have similar marine borers, temperatures and salinities may often be useful in estimating likely problems at certain Australian sites.

Crustaceans are not insects, although both groups have their bodies divided into plate-like segments. The important crustacean marine borers are found in the families Limnoriidae (which also contains algal borers) and Sphaeromatidae (a large family containing mainly non-wood-boring species).

Limnoriidae (Gribbles)

There are about 20 species of wood-boring *Limnoria*, of which *L. tripunctata*, *L. quadripunctata* and *L. indica* Becker and Kampf have so far been recorded in Australia (Fig. 1). Many early Australian publications (e.g. Iredale *et al.* 1932; Watson *et al.* 1936) refer to *L. lignorum* (Rathke); however, this occurrence has yet to be confirmed for Australia. Prior to the comprehensive review on limnoriid taxonomy by Menzies (1957), few species were recognised and most limnoriids were called *L. lignorum*. It is now known that *L. lignorum* occurs mainly in cold waters such as in the arctic-boreal region (Kühne 1971).

Figure 1. Distribution of *Limnoria* sp. in Australia

Site	State	Date collected	Comments
(i) *L. quadripunctata*			
Hobart	Tas.	Dec. 81	*E. globulus* pile, *E. obliqua* CCA-treated pile
Williamstown	Vic.	Feb. 83	Boat keel
		April 83	*P. radiata* bait block
Lakes Entrance	"	May 83	Boat
Brighton	"	May 83	Red gum piles
Sandringham	"	April 83	*E. pilularis* crossbrace
Port Welshpool	"	Aug. 83	Stringybark-probably *E. obliqua* - pile
Point Cook	"	Sept. 83	Eucalypt pile
Queenscliff	"	Sept. 83	Huon pine from ferry *P. radiata* bait block
St. Kilda	"	Oct. 83	Eucalypt pile
Cape Woolami	"	Oct. 83	Eucalypt pile
Hastings	"	Nov. 83	Grey Gum pile
Port Arlington	"	Feb. 84	Red gum pile
Hanns Inlet	"	July 84	Eucalypt pile
Rhyll	"	July 84	*E. obliqua* pile
Inner Harbour Pt. Adelaide	S. Aust.	Dec. 83	*P. radiata* bait block
Sydney	N.S.W.	Dec. 82	
(ii) *L. tripunctata*			
Williamstown	Vic.	April 83	*P. radiata* bait block
Sandringham	"	April 83	*E. pilularis* cross brace
Hanns Inlet	"	July 84	Eucalypt pile
Arno Bay	S. Aust.	Dec. 83	*P. radiata* bait block
Tumby Bay	"	Dec. 83	*P. radiata* bait block
Albany	W. Aust.	Dec. 61	
Geraldton	"	Oct. 61	
Bunbury	"	May 61	
Sydney	N.S.W.	Dec. 82	
Port Stephens	"	Dec. 82	
Bowen	Qld.	May 84	
Cairns	"	May 84	
(iii) *L. indica*			
Sydney	N.S.W.	Dec. 82	
Port Douglas	Qld.	May 84	*S. glomulifera* pile

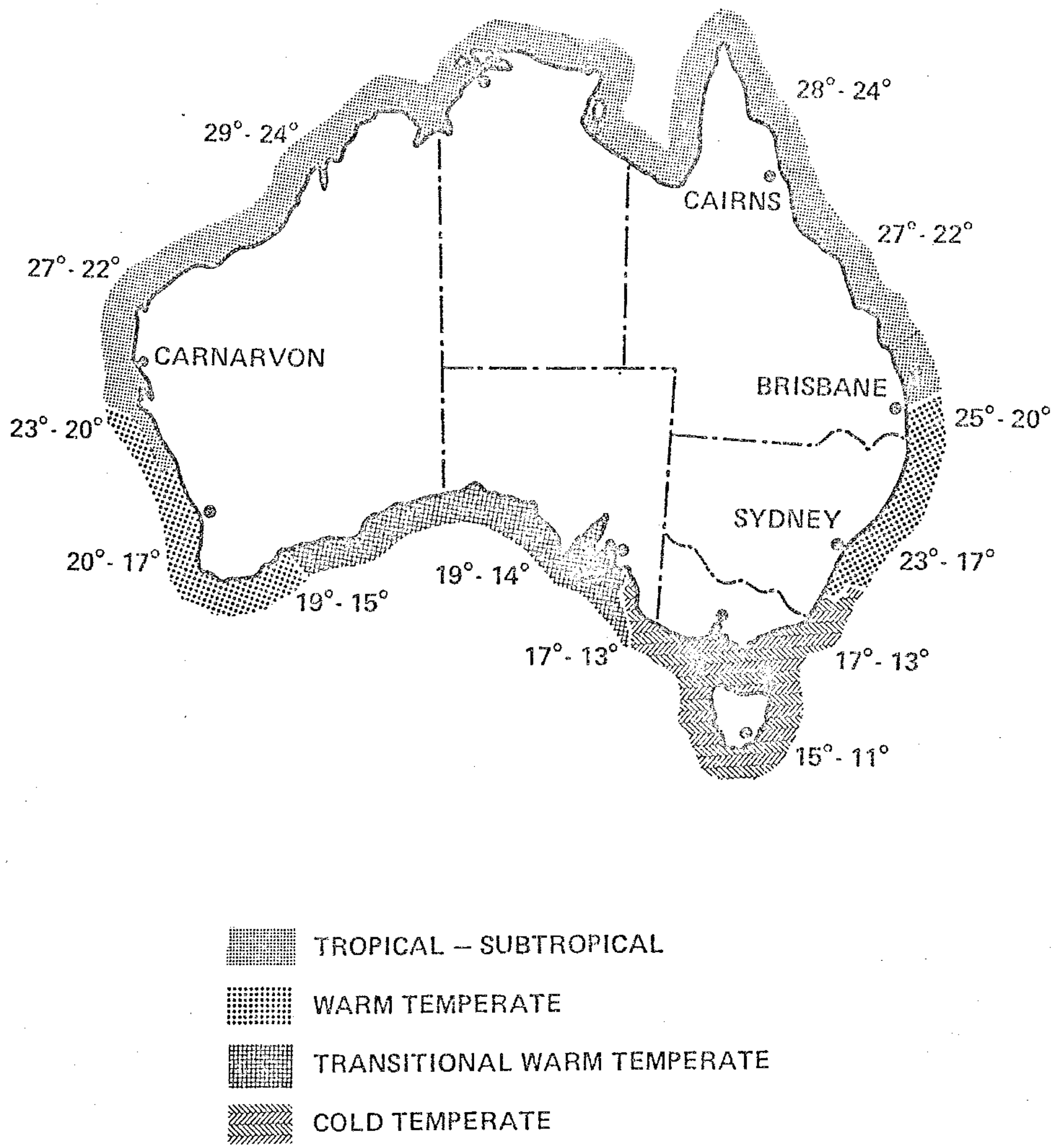

Figure 2. Principal Australian coastal water types. Shows mean surface water temperatures (°C) for summer (February) and winter (August). (After Knox 1963).

Limnoriids are about 2 to 5 mm long and white in appearance, although they may be darker in colour due to food in their gut or a film of micro-organisms and debris on their bodies. The edges of the mandibles of *Limnoria* (and *Sphaeroma*) have rasp and file ornamentations which enable them to 'chew' wood. Fan-like pleopods located under their abdomens are used for swimming and absorbing oxygen.

World wide, *L. tripunctata* has been the most extensively studied limnoriid species, mainly because it is largely responsible for the premature failure of creosote-treated softwoods (Hochman *et al* 1956) in certain temperate waters. The service life at Los Angeles of Douglas fir treated with creosote to 256 kg/m^3 is usually about 13 years (Wakeman and Whiteneck 1959), while at Puerto Rico some softwood piles treated to 416 kg/m^3 with creosote were replaced after five and a half years (Roche 1960). The premature failure of creosote-treated radiata pine blocks has also been observed in Sydney Harbour and Kwinana where *L. tripunctata* is active. However, some species of hardwoods treated with creosote may resist *L. tripunctata*, for example, creosote-treated sapwood of red stringybark (*Eucalyptus macrorhyncha* F. Muell. ex Benth.) has resisted this borer for nearly 25 years at Sydney Harbour.

Creosote tolerance by *L. tripunctata* may be due to its association with certain creosote degrading bacteria (Zachary and Colwell 1979; Parrish *et al.* 1983; Zachary *et al.* 1983).

In Australia, untreated and CCA-treated hardwoods are also used as piles. In these timbers *L. tripunctata* may not be any more important than *L. quadripunctata* or *L. indica* in their attack. For example, *L. quadripunctata* was the only limnoriid found in CCA-treated messmate (*E. obliqua* L. Herit.) piles in Hobart (attack up to 10 mm deep in patches after 12 years), as well as in association with *L. indica* and *L. tripunctata* in other CCA-treated timbers in Sydney (Barnacle *et al.* 1983). *L. indica* was also found in untreated turpentine at Port Douglas (near Cairns) and Goat Island (Sydney). *L. quadripunctata* has been removed from many old untreated red gum and stringybark piles in Victoria (Fig. 1).

Limnoria bores into wood for food, from which it mainly digests cellulose (Ray 1959; Kalnins 1976). *Limnoria* obtains some of its nitrogen, an essential element that is comparatively scarce in wood, by feeding on micro-organisms growing on their bodies or wood (Schafer and Lane 1957; Zachary *et al.* 1983). This may partly explain why *Limnoria* is often attracted to wood that has been submerged for a few weeks, as during this period the wood is probably attacked by marine fungi and bacteria (Meyers and Reynolds 1957; Jones and Irvine 1971). Micro-organisms are also considered likely to help *Limnoria* attack timber by slightly softening or 'conditioning' the wood's surface layers (Meyers and Reynolds 1957). This factor may be more important to the attack of hardwoods by *Limnoria* (Barnacle and Ampong 1975).

Attack by *Limnoria* may be found from above mid-tide to mudline. At sites where temperature varies with depth, *L. tripunctata* may occur in the warmer surface water layers with *L. quadripunctata* occurring further down the pile in the cooler water (Hall and Saunders 1967). In some sites, *Limnoria* attack may be greater in the tital zone than below low water.

Unlike teredinid attack, crustacean attack is usually obvious as it is the surface of the wood that is attacked; however, *Limnoria* may also eat out knots, and thus enter and destroy pith in durable timber or untreated heartwood in non-durable treated timber. Compared to its body-length, *Limnoria* makes long burrows (about 2.5 cm long), the diameter of which approximately corresponds with the diameter of its body (*Limnoria* can not turn about-face in its burrow). The burrow closely follows the surface of wood as *Limnoria* must regularly puncture its 'roof' with small holes to promote water movement for oxygen supply. Its activity is confined to about the outer 1 to 2 cm of wood, the contours of which gradually diminish in a continual process, as destroyed wood breaks away. This differs from the pattern of attack of teredinids which, after establishment, may attack an entire cross section of wood. Therefore they often destroy non-durable piles at a faster rate than *Limnoria*. *Limnoria* can survive short periods out of water (e.g. at low tide) by sealing the entrance to their burrows with their last abdominal segment (pleotelson).

Another crustacean often found in association with *Limnoria* is *Chelura*. *Chelura* feeds mainly on limnoriid frass, faeces and attacked wood (Becker 1971; Kühne 1982). *Chelura* assists *Limnoria* attack by preventing its burrows from becoming clogged with detritus.

In heavily attacked wood there may be 300 to 400 limnoriids/square inch (Iredale *et al.* 1932). *Limnoria* produces about 4 to 20 eggs per female which are hatched in an external brood pouch (The crustacean *Sphaeroma* has internal brood pouches) (Menzies 1954). The number of eggs produced by each female is much lower compared to those produced by molluscan borers; however, a build up of the crustacean population in a harbour may occur due to the presence of susceptible timber which act as breeding sites (Iredale *et al.* 1932, p. 47). This situation may also occur for teredinids (Neily *et al.* 1927, p 56 and 84). Therefore, the population of marine borers at a particular site will be lower if driftwood and destroyed piles are regularly removed.

Limnoria generally migrates over only short distances (unless it is in driftwood) (Watson *et al.* 1936, p. 48). It prefers to settle and bore into rough surfaces compared to smooth surfaces (Watson *et al.* 1936, p. 48; Eltringham 1971). Young limnoriids generally bore side-branching burrows from their parent's burrow. *Limnoria* often prefer to bore in concealed places such as in joints and crevices between structural members. For this reason, bracing should not be placed in the tidal zone or below low water (Anon. 1977).

The marine borer population is sometimes lower or even absent in heavily polluted waters, due partly to toxins or to an associated decrease in the dissolved oxygen content of the water (Mohr 1953; Jones *et al.* 1972). The influence of pollution was demonstrated in San Francisco where after the harbour had been 'cleaned up', an increase in borer activity followed (Neily *et al.* 1927, p. 57). Hedley (1901) attributed - rightly or wrongly - the 72 year survival of an ironbark pile in Circular Quay to pollution.

Limnoria is rarely found in brackish water. They are unable to survive for long periods below a salinity of 25‰ (Kühne 1982) and soon die below salinities of 15 to 20‰ (Becker 1971; Jones *et al* 1972).

Temperature also has a major influence on the distribution of *Limnoria*. Although no Australia-wide survey of limnoriid species has been conducted, the known distribution of limnoriid species in Australia is shown in Figure 1. The destruction caused by *Limnoria* appears to be less important compared to molluscan and sphaeromatid borers in the tropical-subtropical ocean regions of Australia (Figure 2) (e.g. Watson *et al.* 1936); however, it is a comparatively important borer in the temperate southern waters (Mackenzie 1927; Iredale *et al* 1932).

Although *L. tripunctata* is widespread in Australia (Figure 1), the most serious hazard from this borer occurs mainly in warm temperate waters (Figure 2). The temperatures found in this region correspond well to its optimal breeding temperature of 22^{o}C to 25^{o}C (Beckman and Menzies 1960) with the greatest population growth occurring at 23^{o}C to 24^{o}C (Kampf 1957). Breeding by *L. tripunctata* is retarded at temperatures above about 28^{o}C (Kampf 1957) and this fact was used to explain the meagre occurrence of *Limnoria* in India (Becker and Kampf 1959). It may also explain the seeming lack of importance of *L. tripunctata* or indeed most limnoriids in tropical- subtropical Australian waters (Figure 2). Low temperatures also decreases the activity of *L. tripunctata*. When the average annual water temperatures do not exceed 15^{o} to 16^{o}C, creosote-treated softwood piles may last greater than 25 years (Vind and Hochman 1961). These annual temperatures are found on the southern coast line of Australia (Figure 2), and may explain the satisfactory performance to date of creosote-treated radiata pine piles in South Australia (about 12-18 years; L. Pitcher pers. comm., 1984).

L. quadripunctata has been found in sites ranging from Hobart to Sydney; however, in southern Australia the hazard from this borer to suitably resistant or treated timbers appears to be relatively low. Although *L. quadripunctata* breeds at low temperatures (beginning at 12 ^{o}C, see Becker 1971), the cooler temperatures ensure that its boring rate is moderate compared to those of *Limnoria* sp. in, for example, Sydney Harbour.

It should be noted that small changes in salinity and temperature can greatly influence the hazard from various marine borers. For example, an estuary may become more saline due to lower rainfall, irrigation or dams that are built upstream, resulting in an advance of marine borers upstream (Neily *et al* 1927,

p. 26). At Port Hueneme there was a 20 fold increase in the population of *L. tripunctata* from 1956 to 1958 due to an increase in the annual mean temperature of only 3.3°F (1.8°C) (Hochman 1967). At Boyer Tasmania, effluent from a pulping mill increased nearby water temperatures in the Huon River and blue gum piling collapsed after 18 months due to a low salinity teredinid (*Nausitora* sp.)

Sphaeromatidae

This family contains two wood-borers that are important in Australia: *Sphaeroma terebrans* and *S. quoyana* Milne-Edwards. *S. triste* Heller is a wood-borer in Papua New Guinea (Cragg and Levy 1981) and may still be found in northern Australia although there are no records of its occurrence here. *S. walkeri* Stebbing is common in Australia, however there are doubts as to whether this crustacean regularly bores into wood (Iredale *et al* 1932; Pillai 1955). *Exosphaeroma alata* Baker has also been considered economically unimportant (Watson *et al.* 1936), even though it is not uncommon in wood in estuaries. It has been found in almost fresh water in rivers at Port Jackson and in the Brisbane River. In Victoria it was found boring into old softened eucalypt piles at Sale, which is about 90 km from the sea and about 19 km from Lake Wellington. The salinity at the time of collection was 0.5‰. The following discussion will be limited to *S. terebrans* and *S. quoyana*.

Sphaeromatids are much larger crustaceans than limnoriids, as *S. terebrans* reaches 8 mm in length (Baker 1926) and *S. quoyana* reaches 14 mm in length (Hale 1929). They are often called pill bugs as when an animal is disturbed it rolls itself into a ball in a similar fashion to garden slaters.

Sphaeroma attacks wood differently to *Limnoria*. Whereas *Limnoria* attacks wood for food, *Sphaeroma* uses wood primarily for shelter. *Sphaeroma* feeds mainly on plankton or micro-organisms on the surface of wood. Plankton is collected by grooming long hairs on their legs which have trapped organisms by filtration (so-called filter feeding) (Rotramel 1975). *Sphaeroma* can also bore into other substrates for shelter such as mud, sandstone, concrete (presumably inferior grades), living sponges, and styrene (Rotramel 1975). It has also been found attacking the caulking of boats, hence its description amongst boat owners as the putty borer.

Because *Sphaeroma* does not require wood for food, toxins impregnated into wood are much less effective in controlling them, except perhaps by decreasing microbial softening of wood so that boring is made more difficult, especially in hardwoods. Soft timbers are particularly favoured by *Sphaeroma* and, for example, CCA-treated softwoods (especially the end grain) and soft hardwoods (e.g. *Alstonia* sp.) are also readily attacked. Very hard eucalypts such as grey ironbark (*Eucalyptus paniculta* Sm.) and forest red gum (*E. tereticornis* Sm.) were usually least favoured by *S. terebrans* in Brisbane, although teredinids were much less influenced by hardness and could readily attack these timbers (Watson *et al.* 1936). Siliceous timbers such as turpentine

(*Syncarpia glomulifera* (Sm.) Niedenzu) are generally attacked by crustacean borers before they are attacked by molluscan borers (Fougerousse 1971).

The burrows of *Sphaeroma* are generally 1 to 2.5 cm long, and their attack is readily visible as it begins from the surface of the pile and proceeds radially. *Sphaeroma* occurs mainly in the tidal zone (Cragg and Levy 1981), although *S. terebrans* may also bore to some distance - for example 50 cm-below low tide (Iredale *et al.* 1932). This predominance in the tidal zone may be less obvious in estuaries. Piles attacked by *Sphaeroma* (and sometimes *Limnoria*) eventually develop an hour-glass appearance in the tidal zone.

If it is found that this borer is particularly responsible for the deterioration of a pile (e.g. turpentine piles), compared to other borers, the pile may be sufficiently protected by physical or chemical methods that are applied only in the tidal zone (e.g. Iredale *et al.* 1932).

S. quoyana has been recorded in temperate waters such as Tauranga Harbour, N.Z. (Mills 1978), Hobart, Victoria, Sydney, Port Stephens and Perth. It is very rarely found as far north as Brisbane (Watson *et al.* 1936). *S. quoyana* is an important borer at Sydney and Port Stephens; however, in the cooler southern coastal waters of Victoria and Tasmania it appears to be less destructive i.e. in a given wood species and in a given time. It has been found in its own burrows in softened wood, and in teredinid holes at Mt. Martha and Hanns Inlet, Victoria. It also caused some damage to CCA-treated *Pinus radiata* D. Don. in New Zealand (Mills 1978) in transitional warm temperate water (Knox 1963). *S. terebrans* has been found in Sydney Harbour (which may be about its most southerly occurrence) and is common and very active from about Port Stephens northwards.

Sphaeroma is particularly common in mangrove (mud) areas. It often bores into mangrove roots which appears to benefit the mangrove by promoting root branching (Simberloff *et al.* 1978). *Sphaeroma* can tolerate a wide range of salinities, with *S. terebrans* being more tolerant to low salinities than *S. quoyana* (Iredale *et al.* 1932). Estevez and Simon (1975) found that there may be greater boring by *S. terebrans* in conditions of changing salinities compared to stable salinities. In the Brisbane River, *S. terebrans* caused little damage to timber where the average salinity was less than 10‰ (96 km up river) (Watson *et al.* 1936).

To summarize, crustacean borer attack can be divided into various hazard zones on the Australian coastline. Temperature and salinity ranges are probably the most useful parameters for predicting or explaining the borer hazard at a particular site. Attack may also vary with depth with *Sphaeroma* being active mainly in the tidal zone and *Limnoria* often active from above mid-tide to mudline.

A knowledge of the types of borers present in a certain area aids greatly in determining which durable or chemically treated timbers may withstand attack, or if preservative and/or barrier systems are needed and where to position the barrier on the pile. A knowledge of the borer population at a particular site may already exist, or may be fairly easily obtained by collecting borers from attacked piles and bait blocks and sending them to me for their identification, together with details of their location and where possible, species and age of timber, depth in relation to low tide, temperature and salinity of the water.

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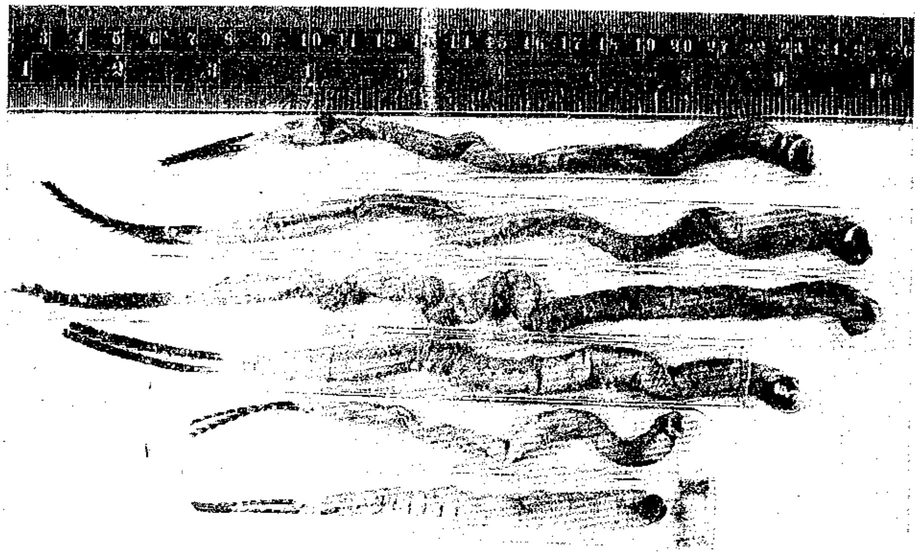
Bankia (Teredinid)

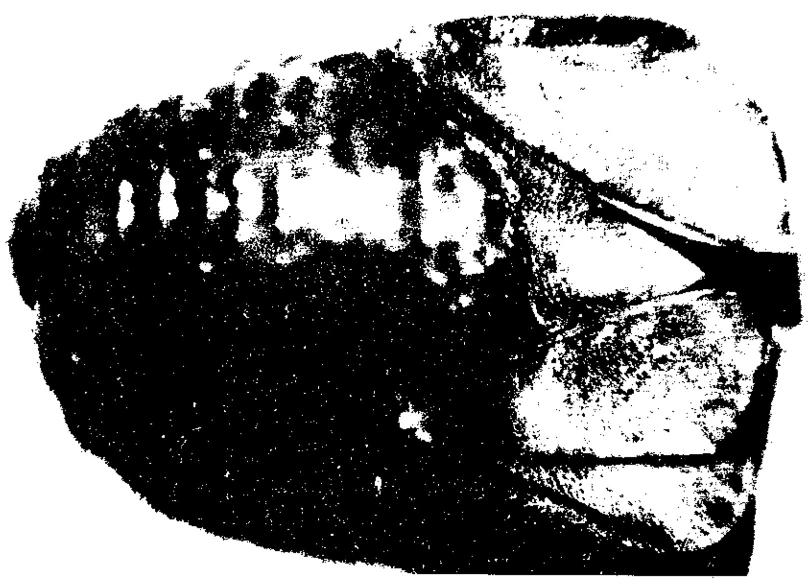


Chelura

(4 mm long)

Exosphaeroma alata - male

(12 mm long)



Limnoria tripunctata

(2 to 3 mm long)

Sphaeroma quoyana

(11 mm long)

Sphaeroma terebrans

posterior view (5 mm wide)