THE ROLE OF CRUSTACEA IN THE DESTRUCTION OF SUBMERGED TIMBER

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ABSTRACT

During the last fifty years considerable attention has been paid to the study of the marine animals, which directly or indirectly bring about the deterioration of submerged timber. They belong to two groups, molluscs and crustaceans. A lot of work has been done on the molluscan wood-borers but even now information on the crustacean wood-borers is scanty. The present paper gives a classified list of the crustaceans which are known to bore into timber and a resume of the published information on their biology.

INTRODUCTION

DURING the last fifty years marine animals which directly or indirectly cause deterioration of submerged timber attracted the attention of biologists and harbour engineers. These animals mainly belong to two groups, Mollusca and Crustacea. The molluscs have been fairly extensively studied, but no comparable work has been done on the crustaceans.

The crustacean wood-borers belong to three families, Cheluridae, Limnoriidae and Sphaeromidae; the first belongs to the order Amphipoda and the other two to Isopoda. From the waters around the Indian mainland *Chelura* has not so far been recorded. Six species of *Limnoria* have been recorded but none of them is abundant enough to cause any appreciable damage. Four species of *Sphaeroma* have so far been recorded. Of these three are very abundant. Underwater wooden structures, especially those standing in estuarine waters, are heavily attacked by *Sphaeroma*.

Limnoria, particularly *L. lignorum*, has a world-wide distribution and hence attracted the attention of biologists very early. Consequently the biology of *Limnoria* is fairly well known. On the other hand, *Sphaeroma* has a rather restricted distribution and causes serious damage only in estuarine waters. Hence the biology of *Sphaeroma* is little known. In the present report I have summarised the available information on marine crustacean borers with the hope that it may prove of some value to those engaged in the study of these animals, especially in India.

TAXONOMY

Order	..	**AMPHIPODA**
Sub-Order	..	GAMMAROIDEA
Family	..	CHELURIDAE
Genus	..	***Chelura*** Philippi

Chelura terebrans Philippi (Barnard, J. L., 1950, p. 90, pls. 32–33; 1959, p. 4, figs. 1, 4, F–G).

Genus ***Tropichelura*** J. L. Barnard

Tropichelura insulae (Calman) (Barnard, J. L., 1959, p. 6, figs. 2, 4, C–E).

Genus ***Nippochelura*** J. L. Barnard

Nippochelura brevicauda (Shiino) (Shiino, 1957, p. 186, figs. 13–15, *Chelura*; Barnard, J. L., 1959, p. 6, figs. 3, 4, A–B).

Order	..	**ISOPODA.**
Sub-Order	..	FLABELLIFERA.
Family	..	LIMNORIIDAE.
Genus	..	***Limnoria*** Leach.
Sub-genus	..	*Limnoria* Menzies.

Limnoria lignorum (Rathke) (Shiino, 1950, p. 334, figs. 1–3; Menzies, 1957, p. 123, fig. 9).

Limnoria pfefferi Stebbing (Stebbing, 1905, p. 714, pl. 53 *a*; Menzies, 1957, p. 135, fig. 15).

Limnoria japonica Richardson (Richardson, 1909, p. 95, fig. 21; Menzies, 1957, p. 165, figs. 27–28).

Limnoria septima K. H. Barnard (Barnard, K. H., 1936, p. 174, figs. 11–12; Menzies, 1957, p. 168, fig. 29).

Limnoria quadripunctata Holthuis (Holthuis, 1949, p. 167, fig. 2; Menzies, 1957, p. 127, figs. 10–14).

Limnoria tripunctata Menzies (Menzies, 1951, p. 86, pl. 36; 1957, p. 137, fig. 16).

Limnoria platycauda Menzies (Menzies, 1957, p. 139, fig. 17).

Limnoria saseboensis Menzies (Menzies, 1957, p. 141, fig. 18).

Limnoria simulata Menzies (Menzies, 1957, p. 144, fig. 19).

Limnoria multipunctata Menzies (Menzies, 1957, p. 170, figs. 30–31).

Limnoria unicornis Menzies (Menzies, 1957, p. 173, fig. 32).

Limnoria faveolata Menzies (Menzies, 1957, p. 175, fig. 33).

Limnoria sublittorale Menzies (Menzies, 1957, p. 175, fig. 34).

Limnoria insulae Menzies (Menzies, 1957, p. 178, fig. 35).

Limnoria indica Becker and Kampf (Becker and Kampf, 1958, pl. 1, figs. 2–3; Pillai, 1961, p. 23, pl. 2, figs. 4–5, t.-figs. 11–12).

Limnoria carinata Menzies and Becker (Menzies and Becker, 1957, p. 88, figs. 1–3).

Limnoria bombayensis Pillai (Pillai, 1961, p. 29, pl. 2, fig. 6, t.-fig. 16).

Limnoria magadanensis Jesakova (Jesakova, 1961, p. 180, figs. 1, 2, 5; Kussakin, 1963, p. 287, figs. 1 C, 4).

Limnoria borealis Kussakin (Kussakin, 1963, p. 287, figs. 1, *d–f*, 5, 6).

Sub-genus *Phycolimnoria* Menzies

Limnoria segnis (Chilton) (Chilton, 1883, p. 76, pl. 2, fig. 1; Menzies, 1957, p. 182, fig. 37).

Limnoria antarctica (Pfeffer) (Pfeffer, 1887, p. 96, pl. 2, figs. 12–13, pl. 5, figs. 2–22; Menzies, 1957, p. 180, fig. 36).

Limnoria algarum Menzies (Menzies, 1957, p. 146, figs. 20–21).

Limnoria segnoides Menzies (Menzies, 1957, p. 184, fig. 38).

Limnoria nonsegnis Menzies (Menzies, 1957, p. 186, fig. 39).

Limnoria rugosissima Menzies (Menzies, 1957, p. 189, fig. 40).

Limnoria stephenseni Menzies (Menzies, 1957, p. 189, figs. 41–42).

Limnoria bituberculata Pillai (Pillai, 1957, p. 151, figs. 1–2; 1961, p. 31, pl. 2, fig. 7, t.-figs. 17–18).

Limnoria sinovae Kussakin (Kussakin, 1963, p. 281, figs. 1*a*, 2).

Genus ***Paralimnoria*** Menzies

Paralimnoria andrewsi (Calman) [Calman, 1910, p. 184, pl. 5, figs. 7–14 (*Limnoria*); Menzies, 1957, p. 148, figs. 22–24].

Family SPHAEROMIDAE

Genus ***Sphaeroma*** Bosc

Sphaeroma terebrans Spence Bate (Spence Bate, 1866, p. 28, pl. 2, fig. 5; Stebbing, 1904, p. 16, pl. 4; Pillai, 1961, p. 2, pl. 1, fig. 1, t.-figs. 2–3).

Sphaeroma walkeri Stebbing (Stebbing, 1905 *a*, p. 31, pl. 7; Pillai, 1961, p. 8, pl. 1, figs. 2–3, t.-figs. 4–5).

Sphaeroma annandalei Stebbing (Stebbing, 1911, p. 181, pl. 10; Pillai, 1961, p. 13, pl. 1, fig. 4, t.-figs. 6–7).

Sphaeroma triste Heller (Heller, 1868, p. 142, pl. 12; Barnard, K. H., 1936, p. 177, fig. 13 *a*; Pillai, 1961, p. 17, pl. 2, figs. 2–3, t.-fig. 9).

Sphaeroma sieboldii Dollfus (Dollfus, 1889, p. 93, pl. 5, fig. 3; Shiino, 1957, p. 161, figs. 1–3, 12).

Sphaeroma retrolaevis Richardson (Richardson, 1904, p. 47, fig. 23; Shiino, 1957, p. 167, fig. 4–6, 12).

Sphaeroma quoyana Milne Edwards (Paradice, 1926, p. 319; Chilton, 1911, p. 134; Nierstrasz, 1917, p. 106).

Sphaeroma pentodon Richardson (Richardson, 1905, p. 286).

Sphaeroma peruvianum Richardson (Richardson, 1910, p. 83).

Sphaeroma laeviusculum Heller (Heller, 1868, pl. 138).

Sphaeroma exosphaeroma Boone (Boone, 1918, p. 599; Nierstrasz, 1930, p. 8).

Sphaeroma obesum Dana (Dana, 1853, p. 779; Kossmann, 1880, p. 112; Thompson and Chilton, 1887, p. 155).

Sphaeroma granti Walker and Scott (Walker and Scott, 1903, p. 218).

Sphaeroma serratum Fabricius (Stebbing, 1910, p. 220; Torelli, 1930, p. 303).

Sphaeroma bigranulatum Budde-Lund (Budde-Lund, 1908, p. 304).

Sphaeroma tuberculato-crinitum Hildendorf (Hildendorf, 1878, p. 846).

Sphaeroma propinquum Nicolet (Gerstaecker and Ortmann, 1901, p. 264).

Sphaeroma laevigatum Philippi (Gerstaecker and Ortmann, 1901, p. 264).

Sphaeroma gayi Nicolet (Gerstaecker and Ortmann, 1901, p. 264).

Note: The above list may probably include species of doubtful validity. It is also not sure that all are wood-borers.

Distribution

Chelurids have a comparatively restricted geographical distribution. *C. terebrans* is the most widely distributed and has been recorded from several localities in the Western and Northern Atlantic, Mediterranean, Black Sea, South-Eastern Atlantic and South-Western and Eastern Pacific. J. L. Barnard (1959) has given a list of the actual localities. *T. insulae* has been recorded from the Hawaiian, Caroline and Mariana islands in the Pacific, Costa Rica, Trinidad and Puerto Rico in the Caribbean Sea and Christmas island in the Indian Ocean. *N. brevicauda* has so far been recorded only from Misaki, Japan.

Because of the large number of species involved and the absence of precise information, it is rather difficult to summarise the data on the geographical distribution of *Limnoria*. Menzies (1957) observed that no species of *Limnoria* has been found living in truly arctic water though *L. lignorum* is found to occupy the fringe of the Arctic. Only *L. lignorum* among the known species has a truly boreal distribution. Likewise only one species, *L. quadripunctata*, is known as a typical temperate water species. *L. tripunctata* has a distribution extending from the temperate to the tropical waters. A vast majority of the known species inhabit tropical waters and, therefore, limnoriids can be considered as an essentially warm water group of animals.

The distribution of *Sphaeroma* is still less understood. Members of the family Sphaeromidae attain maximum development in tropical waters and are poorly rapresented elsewhere. Among the species recorded from the Indian waters only three have a wide distribution. *S. annandalei* has been recorded from South Africa and India, *S. walkeri* from South Africa, Suez Canal, Egypt, India, Ceylon and New South Wales. *S. terebrans*, the most destructive of all the species, has a truly circumtropical distribution and is known from the Mediterranean, North Africa, South Africa, Congo, Mosambique, Zanzibar, India, Ceylon, Queensland, Florida and Brazil. The distributional pattern appears to indicate that uniformly high temperature is essential for their maximum development.

Factors Influencing the Distribution of the Crustacean Borers

Among the factors which directly or indirectly affect the distribution of the crustacean borers the most important are salinity, temperature and the availability of food.

Salinity

Limnoria and *Chelura* are truly marine animals and have so far been known to inhabit only the open sea or harbours directly connected with the sea. It has been reported (Menzies, 1957) that they cannot survive a day in freshwater. So also areas having uniformly low salinity below 10‰ or those having widely fluctuating salinity (0·00— to 35·00‰) are unfavourable for the establishment and growth of *Limnoria*. Menzies (1957) concluded that field data on the salinity tolerance of *Limnoria* is conflicting and in several cases erroneous and that the animal appears to be moderately euryhaline.

Sphaeroma is extremely euryhaline. All the sphaeromids are inhabitants of littoral waters and slow acclimatisation to gradual variation in salinity inherent in the littoral, appears to have helped them to invade and colonise estuaries and brackish water localities. At least one species, *S. terebrans*, can tolerate even absolutely freshwater for polonged periods. According to McNeil (1932) this species is a most adaptable one and has been recorded from freshwater in the Brisbane river. The distribution of the Indian species is very significant in this context. *S. triste* has so far been collected only from the open sea. *S. walkeri* is predominently marine but stray individuals wander into the bar mouth of the lakes. *S. annandalei* is present in the sea but is more abundant in typically estuarine localities. On the other hand, *S. terebrans* has become an exclusively brackish or freshwater form. In the backwaters of Kerala (West coast of India) it is extremely abundant but during my several collection trips I have not seen it in any typically marine localities. What we find here is the progressive evolution of a group of typically marine animals into brackish and freshwater forms (Pillai, 1961, p. 35).

Temperature

According to J. L. Barnard (1959) the winter isotherm of 22 °C. in both hemispheres provides an effective isolation between *C. terebrans* and *T. insulae*. The former is restricted to waters colder than 22° and the latter to waters warmer than 22°. Chelurids have not been recorded from the immediate vicinity of India but *T. insulae* can be expected to inhabit these waters.

In the case of *Limnoria* much more field data is necessary for arriving at any definite conclusion about the effect of temperature on their distribution. Menzies (1957, p. 156) observed that temperature above or below an optimal range might adversely affect a species by killing the adults, causing a cessation of the breeding activity or slowing the rate of egg production. But the information so far gathered from laboratory experiments and field observations has shown that the critical range of temperature, both optimal and minimal, varies for different species. Depending on temperature Menzies broadly grouped *Limnoria* populations into five categories, arctic, boreal, temperate, temperate-tropical and tropical. It may, however, be remarked that there is considerable overlapping in the known distribution of many species. This is quite natural since the borders of two zoogeographical realms can always be inhabited by the representatives of both the realms.

As stated above the wood-boring species of *Sphaeroma* are more or less confined to the tropical waters where uniformly high temperature prevails. In the backwaters of Kerala shallow bodies of water get isolated during low tide. In such temporary pools the temperature sometimes goes up to nearly 40 or 50° C. Yet *Sphaeroma* living there is apparently unaffected. Specimens of *S. terebrans* can be easily transported over long distances in a piece of wet cloth. The widely fluctuating temperature of the estuarine waters has conditioned at least the wood-boring species of *Sphaeroma* to such an extent that they are at present extremely eurythermic.

Food

Because all the records of *C. terebrans* have been from wood it has always been considered a true wood-borer. But experimental evidence showing that *Chelura* subsists on wood was lacking till recently. From detailed experiments conducted in the laboratory, J. L. Barnard (1955) produced evidence to show that *C. terebrans* is a true wood-borer. However, whether it eats and digests wood is not yet definitely known. J. L. Barnard (1955, p. 94) observed that chelurids might be browsing on microscopic organisms which grow on the wood and that the ingestion of woody matter is a consequence of the scraping off of this other food material. In this connection it may be observed that *Melita zeylanica*, an amphipod, was observed to scrape the surface of submerged timber in the Kerala backwaters (John, 1955). This browsing action results in the formation of shallow furrows on the surface of the wood.

Younge (1927) found that cellulase is absent in the digestive tract of *Limnoria* and he also failed to find the presence of wood digesting protozoa. He, therefore, concluded that *Limnoria* feeds on the microscopic fauna and flora within the burrow. Ray and Julian (1952) disputed this contention on the basis of experiments and observed that the cells of the intestinal diverticula of *Limnoria* produce cellulase.

Based on the feeding habits Menzies (1957) divided limnorias into two groups, *Phycolimnoria* (algal borers) and *Limnoria* (wood-borers). Menzies (1957, p. 153) succeeded in keeping both in the laboratory on a diet of particulate cellulose which shows that the diet requirements of both are the same. Yet in nature wood-borers have never been found to bore into algae or algal borers into wood. According to Chilton (1914) the scarcity or nonavailability of timber necessitated the development of the weed-boring habit. This has resulted in certain changes in the feeding and masticating apparatus with the result that the two groups of animals are unable to change their feeding habits. Wood-boring species have a rasp and file-like series of grooves on the incisor process of the mandibles while this is lacking in sea-weed borers. Wood is rather scarce in the sea except in harbours. But sea weeds of some kind are available practically everywhere in the littoral region. This practice of boring into sea-weeds obviously helped *Limnoria* to enjoy a very wide distribution.

Sphaeroma apparently does not eat wood. At any rate there is no conclusive evidence that they digest wood. Working on *S. terebrans* John (personal communication) demonstrated the presence of cellulose digesting enzymes in the alimentary tract. It appears that *Sphaeroma* subsists on plant or animal matter which grow or settle on the surface of the wood.

Majority of the known species of *Sphaeroma* are free living. The few that are true wood-borers have a restricted distribution and are predominantly brackish-water inhabitants. Food appears to have exerted considerable influence in this distribution. As already stated wood is rather scarce in the open sea. Unlike *Limnoria, Sphaeroma* cannot bore into algae because of their comparatively large size. Hence they were forced to go in search of wood. Wood is always present in sufficient quantities in the estuaries. It is, therefore, likely that *Sphaeroma* braved the hazards of the estuaries in their search for wood. It is significant that they bore even into the stem of trees growing in water. Whether they subsist on wood or bore only for the sake of protection, wood of some sort is absolutely essential for the existence of the truly wood-boring members. This appears to explain why *Limnoria* is not found in the estuaries while *Sphaeroma* thrives there, in spite of the fact that both are essentially inhabitants of the littoral waters of the sea.

Reproduction

All the known wood-boring crustaceans belong to Peracarida, in which the development of the young takes place in a brood pouch and the young leave the brood pouch of the female in an advanced stage of development when they are quite capable of taking care of themselves. This obviously is one of the reasons for the crustacean borers becoming a very successful group of animals.

Chelurids have undergone very little morphological change consequent on taking up a wood-boring habit. As in free-living amphipods pairing probably takes place outside the burrows while the adults migrate from one wood to another. The eggs are very few (according to Shiino, 1958, only 3 in *N. brevicauda*), and are shed into a brood pouch formed of four pairs of small oostegites.

Limnoriids generally live in pairs but the members of a pair are not always of different sexes. How pairing takes place is hence not clearly known. Probably the sexes make contact by entering the burrow through the external openings or through the openings on the side walls. The eggs number 10–15 but the number varies from region to region. As in *Chelura* the eggs are incubated in a brood pouch formed of four pairs of overlapping oostegites. The brood pouch projects on the ventral side of the peraeon.

Sphaeroma generally lives singly though there are reports that more than one specimen are occasionally found in the same burrow. Even if this is true it must be very rare since generally each burrow is only just sufficient to accommodate one individual. Therefore, pairing must obviously take place outside the burrow. Unlike *Limnoria, Sphaeroma* has no true brood pouch formed by the usual oostegites. The eggs are, therefore, incubated in an internal brood pouch which occupies a large part of the available space within. The eggs number up to fifty. Breeding is apparently continuous at least in the Kerala waters. According to McNeil (1932) breeding is continuous in all the crustacean borers in the Australian waters.

The newly hatched young in all the three groups are very much similar to the adult except in colour and in the absence of the seventh pair of legs. Within a short period after emerging from the brood pouch the young are capable of burrowing into wood.

Burrowing

J. L. Barnard has given a detailed account of the burrowing activity of *C. terebrans*. In the laboratory he found evidence of attack after two weeks, consisting of a surface furrowing in the soft layers of the wood. The furrowing always started on the darker side. The concave surface of the furrows was smooth. The furrows made by chelurids are the result of collective rather than individual effort.

In nature chelurids attack only wood previously attacked by *Limnoria*. They settle in the uncovered and abandoned limnoriid tunnels and the large furrows created by the combined activity of several limnorias. Chelurids do not bore distinct furrows but by some sort of browsing action creates hemicylindrical furrows which are unroofed. Attack of fresh timber is always started by the adults and in nature adults are always found in the outer tiers and the young ones deeper. Available data show that though *Chelura* is able to make its own furrows, in nature it fails to survive on smooth fresh wood. Invariably it settles on wood previously attacked by limnoriids. It is concluded that as its burrowing capacity is rather low it is subject to attack by predators. Hence chelurids prefer a previously constructed protective niche. The attack of *Chelura*, therefore, supplements that of *Limnoria*. Nevertheless McNeil (1932) observed that in favourable localities *Chelura* soon becomes more abundant than *Limnoria* particularly on soft wood.

Unlike chelurids limnoriids are efficient burrowers. Here also attack of fresh timber is started by the adults. In the early stages of attack they produce burrows which run parallel to the surface one to two millimetres below it. The entrance is oval or rounded and at first penetrates the wood obliquely. The burrow is circular in cross-section and so narrow that the animal within cannot turn back. Hence the animals within always face the blind end of the burrow. Occasionally more than one individual may enter through the same entrance, in which case there will be a number of interconnected burrows, each branch excavated by a separate individual. An unbranched burrow may sometimes lodge more than one individual (Shiino, 1950).

The burrows communicate with the exterior by a series of holes at short intervals in addition to the original hole. This facilitates proper aeration of the burrows. Necessity for a large supply of oxygen appears to be the reason why the burrows are always located parallel to the surface. When there is heavy infestation the nature of the burrows shows change. The latecomers are forced to burrow deep to reach a supply of wood and hence the initial part of their burrows is vertical. *Limnoria* produces innumerable holes on the surface of the wood giving it a sponge-like texture and a lace-like appearance. Up to 300–400 individuals can be taken from one cubic inch of wood (McNeil, 1932).

The newly liberated young always remain at the end of the burrow. Though a few may leave the burrow, most of them begin tunnelling from the original burrow itself. Therefore, an attack once begun is continued by successive generations.

In the case of *Sphaeroma* both the adults and the young attack fresh timber. Given the chance the softer parts are attacked first but the texture of the wood is not of much consequence. Even the wood of cocoanut and palmyra palms, whose vascular bundles are perhaps the hardest, are cut across. In all field and laboratory observations I have found that *Sphaeroma* has a tendency to attack the vertical surfaces first. The burrows are generally straight, a centimetre deep and perfectly circular in cross-section, the end of the burrow is hemispherical. In each burrow the animal just fits in and the head is turned to the blind end and the tip of the telson is just visible from outside. When the attack is heavy, as is the case in estuarine waters, the burrows are so close to each other that only a thin film of wood separates the adjacent burrows. The timber then presents a typical honeycomb appearance.

Economic Consequence of the Activity of the Crustacean Borers

More than the purely scientific interest, it is the economic consequence of the activity of these boring animals that focussed the attention on them. It is rather difficult to assess the destructive potential of any one of these groups separately since the crustaceans combine their effort with that of the molluscs. The sea also plays a very dominent role in the destruction of timber. Precise data is lacking since the sudden and dramatic collapse of marine structures alone gets publicity (Menzies, 1957, p. 107).

Though it has been reported that *Limnoria* attacks wood from the mud line right up to the high watermark, the attack is heaviest in the intertidal level. The attack of *Sphaeroma* is concentrated at this level. The same is true of the molluscs, particularly *Martesia*. When the attack is heavy the holes of *Limnoria* become vertical and very close to each other making the wood spongy. *Sphaeroma* bores mainly for shelter and in all cases of heavy attack the adjacent holes are saparated by only a thin film of wood. This renders the wood fragile. Natural agencies like the waves will easily make the wood crumble exposing the animals. The animals would then burrow deeper, *Limnoria* for eating fresh wood and *Sphaerama* for further shelter. The action of water and that of the animals regularly alternate with the result that the pilings get considerably thinned at the intertidal level and evantually breaks.

The loss due to the attack of the borers is rather heavy. According to Menzies (1957) the loss in the United States alone comes to about 50 million dollars a year.

A lot of money and effort have been spent in devising methods to protect marine pilings from the attack of marine borers. The usual practices areto pressure creosote or impregnate the wood with poisonous compounds under pressure. These have to some extent succeeded in protecting the piles from the attack of molluscs which begin the attack as larvae. The preservatives are nearly always highly toxic to these delicate larvae. But in the case of the crustaceans the attack is always started by the adults which are comparatively resistant. Even if a treated wood resists the attack for some time sooner or later slow leaching of the preservatives will make the wood susceptible to attack. Pressure creosoting has succeeded to some extent in reducing the attack of limnoriids since they eat wood. But *Sphaeroma* bores into wood only for protection and they are extremely euryhaline and eurythermic. Therefore, *Sphaeroma* is likely to pose a more serious problem wherever they are present in large numbers, like the backwaters of Kerala.

References

Barnard, J. L. 1950. The occurrence of *Chelura terebrans* Philippi in Los Angeles and San Francisco harbours. *Bull. S. Calif. Acad. Sci.*, **49**: 90–97.

——— 1955. The wood-boring habits of *Chelura terebrans* Philippi in Los Angeles harbour. *Essays in the Natural History in Honour of Capt. Allan Hancock*, 87–92.

——— 1959. Generic partition of the amphipod family Cheluridae, marine wood-borers. *Pac. Nat.*, **1**: 3–10.

Barnard, K. H. 1936. Isopods collected by the investigator. *Rec. Ind. Mus.*, **38**: 147–191.

Bate, C. Spence 1866. Carcinological gleanings. No. 3. *Ann. Mag. nat. Hist.*, **17** (3): 28.

Becker, G. and Kampf, W. D. 1958. Funde der holzzerstorenden Isopoden-Gattung Limnoria au der Festlandkuste Indiens und Neubeschreibung von Limnoria indica. *Zeitscher. angew Zool.*, **45**: 1–9.

Boone, P. L. 1918. Description of ten new isopods. *Proc. U.S. Nat. Mus.*, **54**: 591–604.

Budde-Lund, G. 1908. Isopoda von Madagaskar und Ostafrika. *Wissensch. Ergebn. Voelzkowi. Reise Ostafrika'* **2**: 263–308.

Calman, W. T. 1910. On two new species of wood-boring crustacea from Christmas Island, *Ann. Mag. nat. Hist.*, **8** (5): 181–186.

CHILTON, CH. 1883. Further additions to our knowledge of the New Zealand crustacea. *Trans. N.Z. Inst.*, **15**: 69–86.

——— 1911. Miscellaneous notes on some New Zealand crustacea. *Ibid.*, **44**: 128–135.

——— 1914. Distribution of *Limnoria lignorum* (Rathke) and *Limnoria anatarctica* Pfeffer. *Ann. Mag. nat. Hist.*, **76**(8): 448.

DANA, J. D. 1853. *Crustacea in United States Exploring Expedition*, 1838–42. **13**: 696–805.

DOLLFUS, A. 1889. Sur quelques Isopodes du Musee de Leyde. *Notes Leyden Mus.*, **11**: 91–94.

EDWARDS, H. MILNE 1840. *Histoire naturelle des Crustaces*, **3**: 115–284.

GERSTAECKER, A. AND A. E. ORTMANN 1901. *Die klassen und Ordnungen der Arthropo den in Bronns K ldssen—5, Crustacea*, Leipzig.

HELLER, C. 1868. *Reise der Novara Crustacea*, **2**: 1–280.

HILGENDORF, F. 1879. Die von Herrn W. Peters in Mocambique gesannelten Crustaceen Monatsber. *Akad. wiss., Berlin*, 782–851.

HOLTHUIS, L. B. 1949. The Isopoda and Tanaidacea of the Netherlands, including the description of a new species of Limnoria. *Zool. Meded. Rijk. Natur. Hist. Leiden*, **30**: 163–190.

JESAKOVA, S. E. 1961. A new species of the wood-boring *Limnoria*. *Trudui Inst. Okeanol. Acad. Sci., U.S.S.R., Moscow*, **49**: 180–186 (in Russian).

KOSSMANN, R. 1880. *Zoologische Ergenesse einer Reise in der Kustengebiete des Rothen Meeres*, Lief 1, Leipzig.

KUSSAKIN, O. G. 1963. Some data on the systematics of the family Limnoriidae (Isopoda) from northern and far-eastern seas of the U.S.S.R., *Crustaceana*, **5**: 281–292.

MCNEIL, F. A. 1932. Crustacean boring pests in *Destruction of Timber by Marine Organisms in the Port of Sydney*, 18–23.

MENZIES, R. J. 1951. A new species of *Limnoria* from Southern California. *Bull. S. Calif. Acad. Sci.*, **50**: 86–88.

——— 1957. The marine borer family Limnoriidae (Crustacea Isopoda). *Bull. Mar. Sci. Gulf. Carribean*, **7**: 101–200.

——— AND G. BECKER 1957. Holzzerstorende Limnoria-Arten (Crustacea Isopoda) aus dem Mittelmeer mit Neubeschreibung von L. carinata. *Zeitschr. angew Zool.*, **44**: 85–120.

NIERSTRASZ, H. F. 1917. Die isopoden-Sammlung in Naturhistorischen Reichemuseum zu Leiden—II. Cymothoida. Sphaeromidae..... *Zool. Meded. 8s. Fijks. Mus. V. Nat. Hist., Leiden*, **3**: 87–120.

——— 1930. Isopoda (excl. Oniscoidea et Epicaridea). Resultats Scientf. Voyage aux Indes Orient. *Mem. Musse d'Hist. Nat., Belgique*, **3**: 1–17.

——— 1931. Isopoda Genuina. *Siboga Exped. Monogr.*, **32 C**: 123–233.

PARADICE, W. E. J. 1926. A note on the occurrence of a burrowing crustacean, *Sphaeroma quoyana*, at Cackatoo Island. *Austr. Zool. Sydney*, **4**: 319.

PFEFFER, G. 1887. Die Krebse von Sud-Georgien nach der Ausbeute der Deutschen Station 1882–83. 1. *Teil. Naturh. Mus. Hamburg Jahrb. Wiss. Aust. Hamburg.*, 43–105.

PILLAI, N. K. 1957. A new species of *Limnoria* from Kerala. *Bull. Res. Inst. Univ. Kerala*, **5**: 149–157.

——— 1961. *Wood-boring Crustacea of India*. Govt. India Press, Simla, 1–61.

RAY, D. L. AND J. R. JULIAN 1952. Occurrence of cellulase in *Limnoria*. *Nature*, **169**: 32–33.

RICHARDSON, H. 1904. Contributions to the natural history of the Isopoda. *Proc. U.S. Nat. Mus.*, **27**: 1–89.

——— 1905. A monograph of the Isopoda of North America. *Bull. U.S. Nat. Mus.*, No. **54**: 1–727.

——— 1909. Isopods collected in the north-west Pacific by the U.S. Bureau of Fisheries Steamer Albatross. *Proc. U.S. Nat. Mus.*, **37**: 75–129.

——— 1910. Report on isopods from Peru collected by Dr. R. E. Cocker, *Ibid.*, **38**: 79–85.

SHIINO, S. M. 1950. The marine wood-boring crustaceans of Japan. I. Limnoriidae. *Wasman J. Biol.*, **8**: 333–358.

——— 1957. The marine wood-boring crustaceans of Japan. II. Sphaeromidae and Cheluridae. *Ibid.*, **15**: 161–197.

STEBBING, T. R. R. 1904. Gregarious crustacea of Ceylon. *Spol. Zeylan.*, **2**: 1–29.

——— 1905. Marine crustaceans. XII. Isopoda with description of a new genus. *Fauna Geog. Mald. Laccad. Archip.*, **2**: 699–721.

——— 1905 *a*. Report on the isopoda collected by Prof. Herdmann at Ceylon. *Ceylon Pearl Oyst. Fish. Rep.*, **23**: 1–64.

——— 1910. Report on the Marine Biology of the Sudanese Red Sea. XIV. On the Crustacea, Isopoda and Tanaidacea. *J. Linn. Soc. Zool.*, **31**: 215–230.

——— 1911. Indian isopods. *Rec. Ind. Mus.*, **6**: 179–191.

THOMPSON, G. M. AND CHILTON, CH. 1887. Critical list of the Crustacea Malacostraca of New Zealand. *Trans. Proc. N.Z. Inst.*, **18**: 141–159.

TORELLI, B. 1930. Sferomidi del Golfo di Napoli. *Publ. Staz. Zool. Napoli*, **10**: 297–343.

WALKER, A. O. AND A. SCOTT 1903. Crustacea Malacostraca. II. Decapod and sessile eyed Crustaceans from [illegible]-el-Kuri. *Report Sokotra Exped.*, Liverpool Museum.

YOUNGE, C. M. 1927. The absence of cellulase in *Limnoria*. *Nature*, **119**: 855.