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NEW RECORDS OF MARINE WOOD BORERS (BIVALVIA: TEREDINIDAE AND ISOPODA: LIMNORIIDAE) FROM SÃO MIGUEL, AZORES, WITH A DISCUSSION OF SOME ASPECTS OF THEIR BIOGEOGRAPHY

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ABSTRACT

Specimens of the morpho-species *Lyrodus pedicellatus* (Bivalvia: Teredinidae) and *Limnoria tripunctata* and *L. quadripunctata* (Isopoda: Limnoridae) were extracted from wood samples collected during July 2012. *Limnoria tripunctata* and *L. quadripunctata* coexisted in the same wood piece, which is rare for limnoriids. All three species were recorded for the first time from São Miguel waters and *L. quadripunctata* was also recorded for the first time from the Azores. The recent recorded presence of these species in the Azores suggests a recent range expansion from southern Europe.

RESUMO

Espécimes da morfo-espécie *Lyrodus pedicellatus* (Bivalvia: Teredinidae) e espécimes das espécies *Limnoria tripunctata* e *L. quadripunctata* (Isopoda: Limnoriidae) foram extraídos de pedaços de madeira coletados durante o Workshop Sabrina, Mosteiros, São Miguel, Açores. *L. tripunctata* e *L. quadripuncta* foram encontradas a coexistir no mesmo pedaço de madeira, o que é uma observação rara em limnorideos. Este é o primeiro registo para estas três espécies em São Miguel e também o primeiro registo da espécie *L. quadripunctata* nos Açores. A ocorrência destas três espécies nos Açores, coincidente com o aumento da actividade destes organismos na última década na Europa, sugere uma recente expansão com origem no Sul da Europa.

INTRODUCTION

Marine wood borers are an heteregeneous group of xylotrophic (wood feeding) organisms, including bivalves (Teredinidae [Distel, 2003]) and Crustacea (Limnoriidae [Cragg, 2003]). They are considered serious pests due to the destruction they inflict on man-made wooden structures in the marine environment (Turner & Johnson, 1971). Indeed, economic and safety issues were the main motivation for the first scientific studies of the species in the 18th century, when outbreaks of wood borers in the wooden dykes of the Netherlands caused catastrophic destruction. Among the numerous reports produced on wood borers at the time (Clapp & Kenk, 1963), the most important was that of Sellius (1733) wherein he recognised three teredinid species, which were synonymised by Turner (1966) with *Teredo navalis* (Linnaeus, 1758), *Nototeredo norvagica* (Spengler, 1792) and *Psiloteredo megotara* (Hanley, 1848) and an isopod species, which was interpreted to be *Limnoria lignorum* (Rathke, 1799) (Clapp & Kenk, 1963).

Since these early studies, a large number of teredinids have been reported upon from European waters from cold Norway (Santhakumaran & Sneli, 1978; Borges, 2007) to the warm Mediterranean Sea (Bobat, 1995; Borges, 2007; Sivrikaya *et al.*, 2009). The large number of publications describing new teredinid species in the 18th, 19th and early 20th centuries created many synonyms. This situation left the systematics and taxonomy of the Teredinidae in a chaotic state. One of the reasons for this was probably the fact that teredinids are a particularly difficult group of bivalves

to identify. Whereas in the majority of bivalves morphological identification is based on shell features, in the case of the Teredinidae, the shells show high intraspecific variation and interspecific similarity and thus identification is almost entirely based on the morphology of the pallets (Turner, 1966). In the catalogue of the Teredinidae by Turner (1966), the taxonomy of the family was reviewed and six species were identified from the Atlantic and the Mediterranean coasts of Europe. In the last decade, however, the number of teredinid species in Europe has increased to nine, including two invasive species (Borges *et al*., submitted) and two cryptic species in the *pedicellatus*-like *Lyrodus* complex of species (Borges *et al*., 2012).

The Limnoridae includes wood and algae boring species. Of all the limnoriid species reported from Europe, five are wood borers. *Limnoria lignorum* was the first limnoriid species described by Rathke (1799) as *Cymothoa lignorum*. Later on, it was recognised by White (1857) as being synonymous with *Limnoria terebrans* Leach, but subsequent authors referred to the species as *Limnoria lignorum*, as it is now known. For many years, it was thought to be the only wood boring limnoriid species, which led to several erroneous identifications (Neves, 1962). One and a half centuries later, a second wood boring limnoriid, *Limnoria quadripunctata* Holthuis, 1949, was described from the Netherlands. Soon after, a third species, *Limnoria tripunctata* Menzies, 1951, was described from Southern California but was later found in southern Europe, in countries such as Portugal (Franco, 1962; Neves, 1962) up to the English Channel (Eltringham & Hockley, 1958). The last two limnoriid species, *Limnoria borealis* Kussakin, 1963 and *Limnoria carinata* Menzies & Becker, 1957 were reported from Europe but only in Icelandic waters and in the Mediterranean Sea, respectively. The taxonomic status of the latter was, however, considered uncertain (Cookson, 1990) but the species has now been re-described (Castelló, 2011).

Three teredinid species have been reported from the Azores in the early literature. *Nototeredo norvagica*, from São Miguel, Faial (Dautzenberg, 1889) and Pico Islands (Nobre, 1924) and both *N. norvagica* and *Psiloteredo megotara* were reported as occurring commonly in driftwood in the vicinity of the Azores (Morton *et al*., 1998). In the last decade, although *N. norvagica* is still recorded from São Miguel (Martins *et al*., 2009), the species occurring in the Azores seems to have changed. *Teredora malleolus* (Turton, 1822) was reported for the first time from São Miguel (Martins *et al*., 2009) and *Lyrodus pedicellatus* (Quatrefages, 1849) was reported also for the first time from Terceira waters (Borges, 2007). In the case of limnoriids, *Limnoria tripunctata* is the only species recorded from the Azores, at Terceira (Borges, 2007).

The malacological fauna of the Azores has been the subject of several studies (Gofas, 1990; Morton, 1995; Ávila *et al*. 1998, 2000; Martins *et al*., 2009). Similarly, there are a number of studies on the crustacean fauna of the Azores (Paula *et al*., 1992; Southward, 1998; Costa & Jones, 2000; Rubal & Larsen, 2012; Torres *et al*., 2012). No specific studies have, however, been undertaken either on teredinids or on limnoriids, probably because, in the Azores, contrarily to what happens in northern European countries, marine wood borers do not pose a threat to maritime structures, such as harbours, pontoons and jetties, which are usually constructed of concrete. These organisms are inconspicuous, due to the specific substrata they inhabit and thus they might easily be missed in general surveys, which is probably the reason for the paucity of information in the literature. The aim of the present work was, thus,

to investigate the diversity of teredinids and limnoriids occurring in São Miguel waters, as a contribution to knowledge of the local fauna.

MATERIALS AND METHODS

Wood pieces were collected during a dive at a depth of 10 metres at Aquário (station SAB2011.DI3), Mosteiros, São Miguel, Azores (37º53´N; 25º48´W), in July 2011, during the 'Sabrina' Workshop. Limnoriid specimens were collected from the wood surface, by carefully splitting the tunnels with forceps under a stereo dissecting microscope. After the limnoriids were collected, the wood pieces were split up to extract the teredinids. In the majority of cases whole specimens were removed but, in others, the soft tissues had rotten and only pallets and shells were found. Morphological identifications of teredinids were based on pallet characters according to the keys in Turner (1971) and the illustrations and descriptions in Turner (1966). In the case of limnoriids, morphological identifications were based mainly on the ornamentations of the pleotelson (tubercles), according to the keys in Menzies (1957) and the descriptions in Holthuis (1949). Complete specimens were preserved individually in 96% ethanol for future molecular analysis.

RESULTS

Twenty teredinid and twenty-nine limnoriid specimens were extracted from the wood. All complete teredinid specimens were identified as belonging to the morpho-species *Lyrodus pedicellatus*. Some specimens were lacking pallets and were identified only to family level, as without pallets further identification is not possible. Limnoriid specimens were identified as *Limnoria quadripunctata* and *Limnoria tripunctata*. Both species were found co-existing in the same piece of wood. Many specimens were identified only to genus level, *Limnoria* sp., due to damage to the pleotelson tubercles. All three species are reported for the first time from São Miguel and *Limnoria quadripunctata* is also reported for the first time from the Azores.

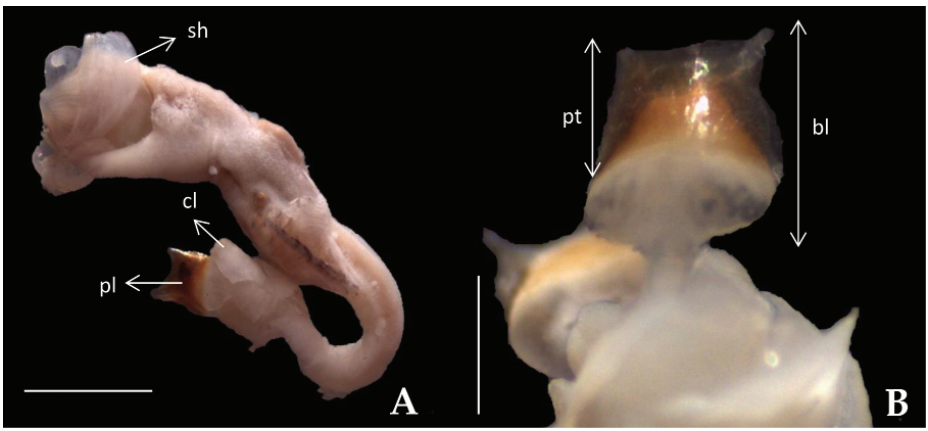

FIGURE 1. Specimen of the morpho-species *Lyrodus pedicellatus* extracted from wood collected in São Miguel, Azores (**A**); detail of the pallets (**B**). **bl**, blade of pallet; **cl**, calcareous lining; **pl**, pallets; **pt**, periostracum of pallet; **sp**, siphon;**st**, stalk of pallet. Scale bars: A= 2 mm; B= 0.5 mm.

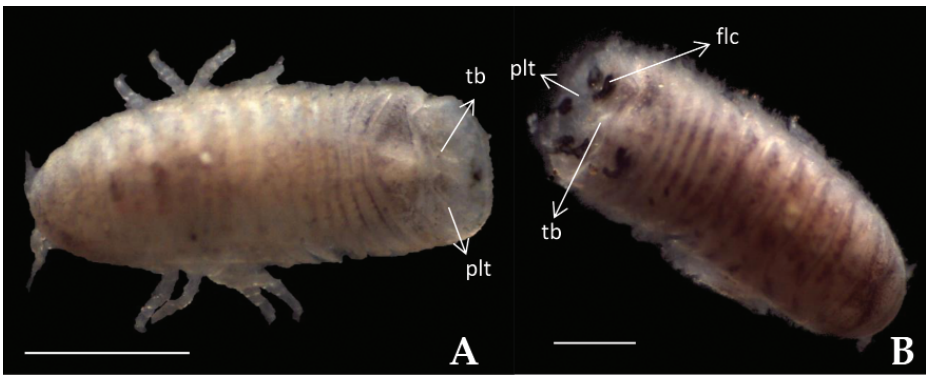

FIGURE 2. Specimens of *Limnoria quadripunctata* (**A**) and *Limnoria tripunctata* (**B**). **ml**, *Microfoliculina limnoriae* (epibiotic heterotrich cilliate); **plt**, pleotelson; **tb**,tubercle. Scale bars= 0.5 mm.

Bivalvia: Teredinidae

Lyrodus pedicellatus (Quatrefages, 1849)
Diagnosis: pallets non-segmented, composed of a single piece; calcareous portion of blade conical distally; upper portion of calcareous blade (distal half) enveloped by a periostracal cap, which varies from light to dark brown, almost black; periostracal cap more or less straight sided, with a distal margin U-shaped, extending as lateral horns (Figs. 1A, B).

Isopoda: Limnoriidae

Limnoria quadripunctata Holthuis, 1949
Diagnosis: fifth somite of pleon dorsally with an x-shaped carina on median line; pleotelson with four sharp tubercles on the median line; behind each of the posterior tubercles is a longitudinal ridge which is more evident in female specimens (Fig. 2A)

Limnoria tripunctata Menzies, 1951
Diagnosis: dorsal surface of fifth somite of pleon with two elevated nodes located anteriorly and a single posterior elevated area; pleotelson with an anterior tubercle located on the median line, followed by a pair of tubercles; behind each of the posterior tubercles is a longitudinal ridge (Fig. 2B).

DISCUSSION

In the present study, none of the teredinid species reported upon by Martins *et al.* (2009) and Nobre (1924) were found. It is not, however, possible to ascertain, either from the present study or from previous ones, if any of the reported species were or are established in local waters. Both *Lyrodus pedicellatus* and *Limnoria tripunctata* were considered to be established species in Terceira as they were collected from test panels exposed for a year in local waters. We do not know, however, whether the pieces of wood (present study) had been part of fixed maritime structures or if they were driftwood and in previous studies teredinid shells were identified from dredged sediment (Nobre, 1924; Martins *et al*., 2009). To find definitive evidence of established populations, therefore, would require collecting specimens either from fixed structures or from test panels exposed over a period of time.

The occurrence of *L. pedicellatus* in São Miguel seems to confirm the trend that this is the most common teredinid occurring in southern Europe, occurring as far north as the English Channel (Lebour, 1946; Morton, 1971). Indeed, this was the dominant species in test panels exposed in Terceira and Algarve (Borges, 2007) and in wooden piles retrieved from the Tagus Estuary (Borges *et al*., 2010). *Lyrodus pedicellatus* is also the dominant teredinid species in the Mediterranean, south of Turkey (Borges, 2007; Sivrikaya *et al*., 2009). A recent study by Borges *et al.* (2012), using molecular markers in addition to morphology, has shown, however, that the Atlantic and Mediterranean forms of *L. pedicellatus* are in fact cryptic species. Hence, in order to determine the probable origin of *L. pedicellatus* occurring in the Azores, we plan to obtain DNA sequences to compare with homologous sequences of *L. pedicellatus* from the Atlantic and the Mediterranean (Borges *et al*., 2012) and with GenBank sequences of specimens obtained from Florida (Distel *et al*., 2011).

Finding *Limnoria quadripunctata* and *Limnoria tripunctata* coexisting in the same piece of wood was unexpected. As far as we are aware, the coexistence of limnoriids in the same piece of wood has only been reported upon by Eltringham & Hockley (1958) in Southampton, southern England. In the Tagus Estuary, *L. quadripunctata* and *L. tripunctata* co-occur in the same area, Porto Brandão, but not in the same piece of wood (Borges *et al*., 2010). Since its description by Holthuis (1949), *L. quadripunctata* was known to occur only in the coastal waters of the Netherlands and England (Eltringham & Hockley, 1958). In the last decade, however, the distribution of *L. quadriunctata* seems to have expanded. The species was reported for the first time in Portsmouth, Bournemouth and Swanage, southern England, where it is, now, the most common limnoriid species (Borges, 2007). It was also reported for the first time along the Atlantic coast of France (Le Roux, 2009), in the Tagus Estuary (Borges *et al*., 2010) and in Viana do Castelo in 2009, northern Portugal (Borges, unpublished data).

Of the two limnoriid species found in São Miguel, the most abundant was *Limnoria tripunctata*. This was expected, as *L. tripunctata* is the most common limnoriid species in southern Europe. Indeed, it is the most destructive wood boring species in southern Turkey, in the south of Portugal and in Terceira (Borges, 2007). In Portugal, this species is found as far north as Aveiro (Borges, unpublished data). The recent observed proliferation of limnoriid activity in southern Europe, which rivals that of teredinids, might be related to an increase in salinity (Einsenreich, 2005) as limnoriids appear to be restricted to waters with salinities close to that of full seawater (Cragg *et al*., 1999).

Biogeographic considerations on the occurrence of wood borers in the Azores

Although prevailing currents in the Azores are from the Western Atlantic, several studies have shown that molluscan species in the Islands have greater affinity with European than with Western Atlantic species (Wirtz, 1998; Ávila, 2000; Sá-Pinto *et al*., 2008; Malaquias *et al*. 2009). It is probable that Azorean specimens might be the eastern Atlantic form of *L. pedicellatus* and have their origin in mainland Portugal. Indeed, a phylogeographic study on species of *Patella* (Mollusca: Gastropoda) in Macaronesia and mainland Portugal indicates that species of this genus, such as *Patella aspera*, in the Azores seem to have originated from mainland Portugal populations (Sá-Pinto *et al*., 2008).

Lyrodus pedicellatus is a long-term brooder, thus dispersal of this species

to the Azores was probably achieved by rafting adults in driftwood either carried by currents or in ballast water. Once the species is present in a certain area with suitable environmental conditions, which is the case of the Azores (Borges *et al*., submitted), the release of the larvae in such a late stage of development certainly maximises their chances of survival and settlement, when appropriate substrata are available. It is, therefore, probable that this species will become established in the area.

The dispersal capability of limnoriids is small compared to that of teredinids, as they have direct development and reduced swimming capabilities (Cragg *et al*., 1999). Mechanical transport by drift-infested wood (Johnson, 1935) or chance introductions due to human activities (Cragg *et al*., 1999) are, hence, still the most probable mechanisms for spread of limnoriid species to remote areas such as the Azores. Rafting, for instance, is known to be of particular importance for many coastal organisms without pelagic dispersal stages (Thiel & Gutow, 2005). In algae boring limnoriids, all life stages and both sexes have been found in floating holdfasts. This suggests that limnoriids can reproduce successfully during rafting, facilitating long-distance dispersal (Miranda & Thiel, 2008).

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