

Seasonal abundance of the shipworm *Neoterredo reynei* (Bivalvia, Teredinidae) in mangrove driftwood from a northern Brazilian beach

Carlos S. Filho¹, Claudia H. Tagliaro¹ & Colin R. Beasley²

1. Laboratório de Conservação e Biologia Evolutiva, Universidade Federal do Pará, Campus de Bragança, Alameda Leandro Ribeiro s/n, Bairro Aldeia, 68600-000 Bragança, Pará, Brazil. (tagliaro@ufpa.br)

2. Laboratório de Moluscos, Universidade Federal do Pará, Campus de Bragança, Alameda Leandro Ribeiro s/n, Bairro Aldeia, 68600-000 Bragança, Pará, Brazil.

ABSTRACT. Shipworms are important decomposers of wood, especially in mangrove forests where productivity is high. However, little emphasis has been given to the activity of shipworms in relation to the export of nutrients from mangroves to adjacent coastal areas. As a first step to obtaining such information, the frequency of colonized mangrove driftwood as well as shipworm density and length were studied by collecting washed up logs during a year at Ajuruteua beach, state of Pará, northern Brazil. A single species, *Neoterredo reynei* (Bartsch, 1920), was found colonizing driftwood. Although large colonized logs were most common on the beach, shipworm density was higher in small logs, especially during the dry season. In general, however, density was higher during the wet season (January to April) and lowest in July. Overall shipworm mean length was 9.66cm. In large logs, mean length increased between the wet and dry seasons. However, there was no difference in length among log size categories. Mean shipworm length was similar throughout most of the year but tended to be greater in July. Although salinity varied between 10.9 and 40 during the year, no relationship was found between salinity and density or length. The results suggest that shipworm activity in driftwood logs is relatively constant throughout the year. Increased air humidity and rainfall may promote survival during the wet season. Large logs may take longer to colonize and thus have lower densities than small ones which are scarce probably because they are destroyed rapidly by shipworm activity. However, data on the disintegration of logs would be necessary to test this hypothesis. Larger size of shipworms in the dry season may be related to growth after an earlier recruitment period. Shipworms in large logs during the dry season may be better protected from dessication and high temperatures by the insulating properties of the larger volume of wood.

KEYWORDS. Teredinidae, shipworm, mangrove, driftwood.

RESUMO. Abundância sazonal do turu *Neoterredo reynei* (Bivalvia, Teredinidae) em madeira de mangue à deriva de uma praia da Costa Norte do Brasil. Turus são importantes decompositores de madeira, especialmente em manguezais, onde a produtividade é alta. Entretanto, pouca ênfase tem sido dada à atividade de turus em relação à exportação de nutrientes de manguezais para as áreas costeiras adjacentes. Como um passo inicial para obter tais informações, a frequência de madeira do mangue à deriva colonizada por turus, bem como a densidade e comprimento de turus, foram estudados através da coleta de troncos encalhados durante 12 meses na praia de Ajuruteua, Estado do Pará, norte do Brasil. Uma única espécie, *Neoterredo reynei* (Bartsch, 1920), foi encontrada colonizando a madeira à deriva. Embora troncos grandes colonizados fossem mais comuns na praia, a densidade de turus foi maior nos troncos menores, especialmente na estação seca. Em geral, a densidade foi maior durante a estação chuvosa (janeiro a abril) e menor em julho. O comprimento médio geral de turus foi de 9,66cm e, em troncos grandes, o comprimento médio aumentou entre as estações chuvosa e seca. Entretanto, não houve nenhuma diferença em comprimento entre as categorias de tamanho dos troncos. O comprimento médio dos turus foi semelhante ao longo do maior parte do ano, mas a tendência foi de comprimentos maiores em julho. Embora a salinidade tenha variado entre 10,9 e 40 durante o ano, nenhuma relação entre salinidade e densidade ou comprimento foi encontrada. Os resultados sugerem que a atividade de turus em madeira à deriva é relativamente constante ao longo do ano. Maior umidade do ar e precipitação podem promover sobrevivência durante a estação chuvosa. Troncos maiores podem levar mais tempo para serem colonizados e portanto podem ter densidades menores do que nos troncos menores. Estes últimos são incomuns talvez porque sejam rapidamente destruídos pela atividade dos turus. Dados sobre a desintegração de troncos, entretanto, seriam necessários para corroborar esta hipótese. O tamanho maior de turus na estação seca possivelmente esteja relacionado ao crescimento após um período anterior de recrutamento. Na estação seca, turus em troncos grandes podem ser melhor protegidos da dessecação e de altas temperaturas pelas propriedades isolantes do maior volume de madeira.

PALAVRAS-CHAVE. Teredinidae, turu, manguezal, madeira à deriva.

The wood-boring Teredinidae (“shipworms”) are highly specialized boring bivalves (TURNER, 1966), most of which colonize wood during the free-swimming larval stage and have both economic (TURNER, 1984; TANAL & MATLIN, 1997) and ecological importance (TURNER, 1984; KOHLMAYER *et al.*, 1995). A detailed account of Brazilian Teredinidae is given in MÜLLER & LANA (2004). Studies carried out in Brazil show that the burrowing activity of Teredinidae varies to differing degrees in a wide range of different types of wood (STILLNER & PEDROSO, 1977; JUNQUEIRA *et al.*, 1991; REIS, 1995) and is responsible for damage to wharfs, boats and other man-made structures (FERNANDES & COSTA, 1967). This is especially important in coastal areas of developing countries where the use of

wood for housing, fishing boats and fish traps is very common (BARLETTA *et al.*, 1998; KRAUSE & GLASER, 2003).

On the other hand, shipworms cause the breakdown of wood into finer organic material thus contributing to nutrient recycling and reducing the buildup of woody debris in coastal areas and estuaries (TURNER, 1984). Cellulose degrading and nitrogen fixing bacteria associated with the gills of shipworms (WATERBURY *et al.*, 1983) along with morphological evidence (TURNER, 1966) suggest that wood is used as a food by shipworms. However, although all shipworms bore into wood, the ability to use wood as a food source may vary among species (TURNER, 1966). The detritivorous action of shipworms is extremely important in mangroves (KOHLMAYER

et al., 1995) where there is a high level of production of woody biomass (GONG & ONG, 1990). Within the mangrove, much of this biomass, composed of fallen trunks, branches, and even aerial roots (SANCHEZ-ALFEREZ & ALVAREZ-LEON, 2000), may be colonized *in situ* by shipworms. There is some evidence that shipworms may enter living trees (NAIR & SARASWATHY, 1971; REIS, 1995) but it is suggested that this may occur only after the bark has been removed and the wood initially colonized by bacteria and fungi (KOHLMAYER *et al.*, 1995). However, the impact of live colonization on tree survival remains to be quantified. The colonized woody biomass may remain in the mangrove until it becomes completely decomposed. Experimental work in mangroves has shown that this may take up to two to three years (GONG & ONG, 1990; KOHLMAYER *et al.*, 1995) and test panels (1" thick) may be destroyed by Teredinidae in less than six months in tropical waters (TURNER, 1947). ROJAS & SEVEREYN (2000) found that *Psiloteredo healdi* (Bartsch, 1931) was able to decompose up to 58% of the mass of pine test panels in five months at Lago Maracaibo, Venezuela. Alternatively, colonized woody biomass may be removed from the mangrove by tidal action and eventually be transported to the adjacent coastal area. Shipworms may remain in the floating logs until all the woody material is decomposed and/or eroded by wave action. However, the logs may be transported back towards the estuary and mangrove forest, as well as become washed up on nearby sandy beaches. In the case of the former habitats, shipworms may continue to grow and reproduce whereas in the latter, exposure to the sun and wind at the high tide mark may cause death of the shipworms relatively quickly. In controlled experiments in Rio de Janeiro, 50% mortality of Teredinidae occurs after 56 hours of exposure to the air (OMENA *et al.*, 1990). Although shipworms are able to close off their burrow during low tide, some studies suggest that the wider the piece of wood, the better the protection from dessication and overheating (RIMMER *et al.*, 1983). Nevertheless, eventually all such woody material along with shipworm biomass is decomposed and may provide an important source of organic material and nutrients for organisms in the coastal area food web (GONG & ONG, 1990).

At Ajuruteua beach, on the northeastern coast of the state of Pará, northern Brazil, large quantities of mangrove woody biomass containing shipworms are observed after high tide. The beach is surrounded by mangrove vegetation (KRAUSE & GLASER, 2003). Previous studies about the contribution of benthos to nutrient cycling/transport in northern Brazilian mangroves have emphasized the importance of the role of land crab *Ucidus cordatus* Linnaeus, 1763 in processing leaf litter (WOLFF *et al.*, 2000; KOCH & WOLFF, 2002). Teredinids are common in mangroves in the region (BEASLEY *et al.*, 2005) and as a contribution towards knowledge of the fate of exported mangrove detritus to coastal areas, the present study aims to quantify variation in the frequency of colonized mangrove driftwood logs, and the density and size of shipworms colonizing these, during a one-year period at Ajuruteua beach.

MATERIAL AND METHODS

Between January and December 2003, searches for mangrove driftwood logs were carried out each week

during low tide over a 4km stretch of Ajuruteua beach (00°50'S, 46°36'W), municipality of Bragança, Pará. The mangrove forest is the overwhelmingly predominant vegetation type in the region and immediately surrounds the beach. Mangrove poles are used to construct fish-traps and, although there are few in the vicinity of the beach, it is possible that some of the driftwood may have come from such constructions. Logs washed ashore on the day that sampling took place remain along the tide mark and these were collected and sorted into three size categories regarding the circumference: small (up to 10cm), medium (10-20cm) and large (20-50cm). All logs were sawn to a standard 40cm length. The logs were numbered and five logs in each size category, a total of 60 logs per month, were randomly selected for examination for Teredinidae.

The logs were initially opened using a hammer and a wood-chisel, and a forceps was used from then on, in order to avoid damaging shipworms that might be inside. The bivalves were removed carefully with the forceps and in many cases, larger specimens could be removed without damage by inverting the log and allowing the animal to slide out through the gallery tube.

Shipworms were identified using TURNER (1966), RIOS (1994) and MORAES & LOPES (2003). The volume of each log was calculated using the formula $v = \pi \cdot r^2 \cdot h$, where r is the radius of the log and h is the length of the log. The number of individuals was counted per log and density was expressed as the number of individuals per cm^3 . Shipworm length (cm) was measured from the shell to the pair of pallets at the posterior end of the body. Salinity was measured weekly with an optical refractometer, using the Practical Salinity Scale.

Associations between the presence or absence of shipworms and log size and season were tested using Chi-square (χ^2) (ZAR, 1999). Two-way analysis of variance (ANOVA) was used to determine differences in mean density (in colonized logs only) and mean length of shipworms between seasons and log size categories. Density and length data were tested for homogeneity of variances using the Cochran C test (UNDERWOOD, 1997) and if significant differences occurred, the data were transformed appropriately. Where a significant difference was detected by ANOVA, Tukey tests were carried out, *a posteriori*, to assess pairwise differences between means (ZAR, 1999). Due to significant differences in variances after transformation and unbalanced sample sizes (different numbers of colonized logs per month) it was not possible to carry out a robust test (UNDERWOOD, 1997) for differences in density and length between months of the year. Instead, these data were presented graphically using box-and-whiskers plots (DALGAARD, 2002). The relationship between salinity and density and length was analyzed using Spearman Rank correlation. Data are presented as means \pm standard error (S.E.) unless otherwise stated. All analyzes used a critical level of significance of $\alpha=0.05$ and were carried out using the R statistical package (IHAKA & GENTLEMAN, 1996).

RESULTS

A single species, *Neoteredo reynei* (Bartsch, 1920), was found in driftwood logs during the entire study. Of the total of 720 logs examined, only 87 (12.08%) contained *N. reynei*, with a total of 744 specimens.

There was a significant association between the presence or absence of shipworms and log size category. There were fewer small logs colonized and more large logs colonized than expected ($\chi^2=65.3$, d.f.=2, $p<0.001$; Tab. I). Large colonized logs were found throughout the year, medium sized colonized logs were less frequent, whereas small colonized logs were rare (Tab. II). In terms of season, there was no difference in the overall frequency of colonized logs between the wet and dry seasons ($\chi^2=2.5$, d.f.=1, n.s.; Tab. I).

The density of *N. reynei* in driftwood logs varied between 0.000160 cm^{-3} and 0.025650 cm^{-3} , with an overall mean of 0.003607 cm^{-3} . Mean density was not significantly different between seasons (Tab. III; wet season: $0.00402 \pm 0.00053\text{ cm}^{-3}$, dry season: $0.00302 \pm 0.00079\text{ cm}^{-3}$). Between log size categories there were highly significant differences in mean density (Tab. III). The mean density in small logs ($0.01101 \pm 0.00383\text{ cm}^{-3}$) was significantly higher than in both medium ($0.00439 \pm 0.00075\text{ cm}^{-3}$) and large ($0.00273 \pm 0.00043\text{ cm}^{-3}$) logs (Tukey, $p<0.05$); these last two categories were not significantly different from each other (Tukey, $p<0.05$). Interaction between season and log size category was significant (Tab. III, Fig. 1) with density in small logs increasing between the wet and dry seasons whereas density decreased in the same period in both medium and large logs. Density was highest at the beginning of the wet season (January to April) but decreased during the transition period (May

Table I. Number of colonized and non-colonized logs by log size category and season, Ajuruteua beach, northern Brazil in 2003. Expected frequencies of logs from Chi-square tests are given in parentheses.

Log Size Category and Season	Colonized	Non-colonized
Small	5 (29)	235 (211)
Medium	21 (29)	219 (211)
Large	61 (29)	179 (211)
Wet	51 (43.5)	309 (316.5)
Dry	36 (43.5)	324 (316.5)

Table II. Number of small, medium and large logs colonized by *Neoteredo reynei* (Bartsch, 1920) by month and by season, Ajuruteua beach, northern Brazil in 2003. A total of 20 logs in each category were collected per month.

Month/Season	Log Size Category		
	Small	Medium	Large
January	0	3	7
February	3	1	6
March	1	5	7
April	0	1	2
May	0	1	6
June	0	1	7
Wet season total	4	12	35
July	0	0	4
August	1	1	7
September	0	4	6
October	0	2	3
November	0	2	5
December	0	0	1
Dry season total	1	9	26

to July) between the wet and dry seasons. Shipworm densities were lowest in July (Fig. 2), increasing again slightly between August and October.

The length of *N. reynei* varied between 1 and 113cm with a mean of 9.66cm. Mean length was significantly different between seasons (wet season: $9.17 \pm 6.07\text{ cm}$; dry season: $11.28 \pm 10.28\text{ cm}$) but not among log size categories (small: $7.57 \pm 7.61\text{ cm}$; medium: $10.72 \pm 7.10\text{ cm}$; large: $9.45 \pm 7.45\text{ cm}$; Tab. IV). However, interaction between both factors was significant (Tab. IV, Fig. 3) so there was no general seasonal effect on length. Mean length of *N. reynei* in large logs increased between the wet and dry seasons whereas in medium and small logs, mean length decreased (Fig. 3). Shipworm length was relatively similar during months of the year but was highest in July and lowest in February (Fig. 4).

Mean monthly salinity varied between 10.9 and 40 during the study (Fig. 5). However, there was no significant relationship between either salinity and shipworm density ($r_s=-0.2697$, d.f.=12, n.s.) or salinity and shipworm length ($r_s=0.412$, d.f.=12, n.s.).

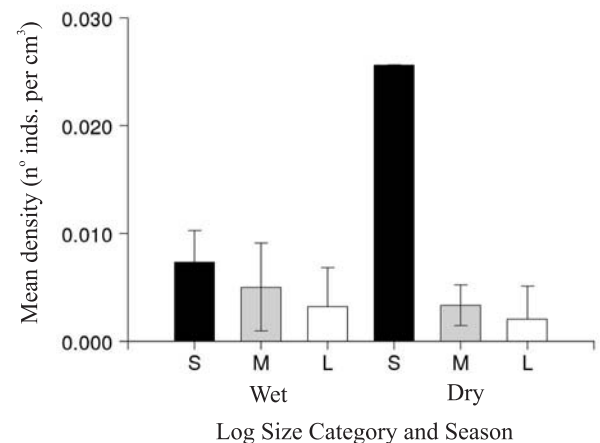


Fig. 1. Mean density \pm S.E. (number of individuals per cm^3) of *Neoteredo reynei* (Bartsch, 1920) in small, medium and large mangrove driftwood logs at Ajuruteua beach, northern Brazil, during the Wet (January to June) and Dry (July to December) seasons in 2003.

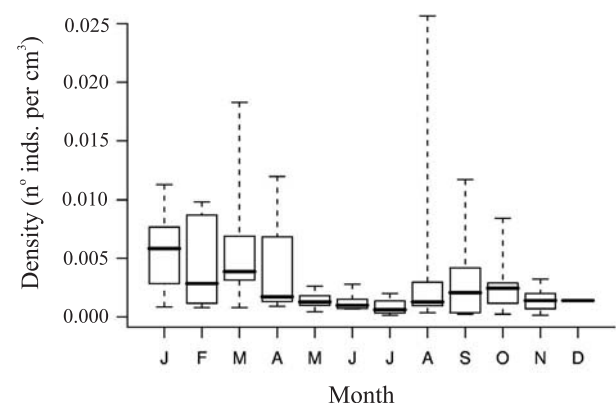


Fig. 2. Box-and-whiskers plot of density (number of individuals per cm^3) of *Neoteredo reynei* (Bartsch, 1920) in mangrove driftwood at Ajuruteua beach, northern Brazil, in each month of the study period (January to December 2003). (Horizontal bar, median; box, quartiles; dashed error bars, smallest and largest observations).

Table III. ANOVA summary of the effects of season and log size category on mean density of *Neoterredo reynei* (Bartsch, 1920) (untransformed data) in driftwood logs, Ajuruteua beach, northern Brazil in 2003. No differences in variances were detected prior to ANOVA (Cochran C=0.32; d.f.=6,4; n.s.).

Effect	d.f.	Sum Squares	Mean Square	F	p
Season (S)	1	0.00002091	0.00002091	1.86	n.s.
Log size category (L)	2	0.00031916	0.00015958	14.23	<0.001
Interaction S:L	2	0.00029586	0.00014793	13.19	<0.001
Error	81	0.00090837	0.00001121		

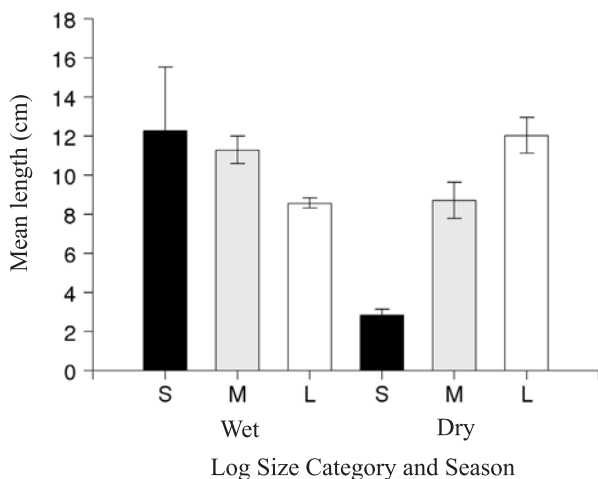


Fig. 3. Mean length \pm S.E. (cm) of *Neoterredo reynei* (Bartsch, 1920) in small, medium and large mangrove driftwood logs at Ajuruteua beach, northern Brazil, during the Wet (January to June) and Dry (July to December) seasons in 2003.

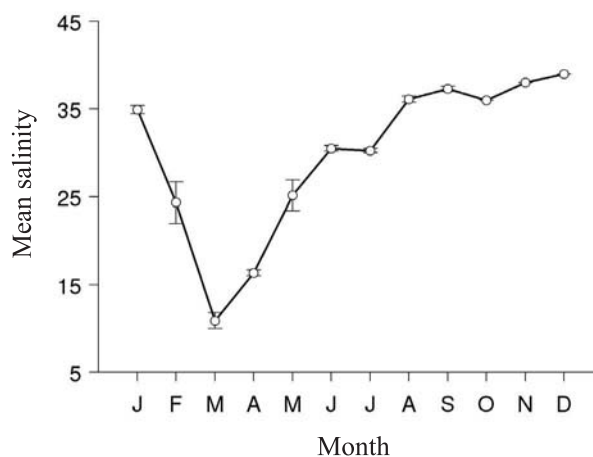


Fig. 5. Mean salinity \pm S.E. at Ajuruteua beach, northern Brazil, in each month of the study period (January to December 2003).

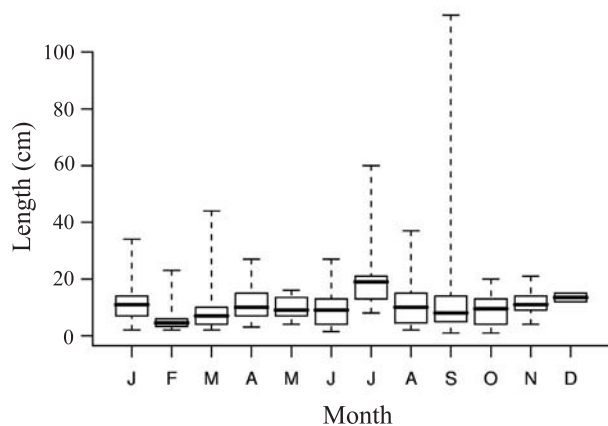


Fig. 4. Box-and-whiskers plot of length (cm) of *Neoterredo reynei* (Bartsch, 1920) in mangrove driftwood at Ajuruteua beach, northern Brazil, in each month of the study period (January to December 2003). (Horizontal bar, median; box, quartiles; dashed error bars, smallest and largest observations).

Table IV. ANOVA summary of the effects of season and log size category on mean length of *Neoterredo reynei* (Bartsch, 1920) (untransformed data) in driftwood logs, Ajuruteua beach, northern Brazil in 2003. No differences in variances were detected prior to ANOVA (Cochran C=0.396; d.f.=6,7; n.s.).

Effect	d.f.	Sum of Squares	Mean Square	F	p
Season (S)	1	538	538	10.26	<0.01
Log Size Category (L)	2	299	149	2.85	n.s.
Interaction S:L	2	1,215	607	11.59	<0.001
Error	738	38,648	52		

DISCUSSION

Several species of Teredinidae have been recorded from the northern coast of Brazil (RIOS, 1994; MÜLLER & LANA, 2004) but *N. reynei* was the only shipworm found in mangrove driftwood logs in the present study. Perhaps competitive interactions may explain the absence of other shipworm species. *Neoterredo reynei* is a common species in mangroves of both the Eastern and Western Atlantic and occurs along most of the Brazilian coast (MÜLLER & LANA, 2004). SANTOS *et al.* (2005) recorded six species of Teredinidae (*N. reynei*, *Bankia fimbriatula* Moll & Roch, 1931, *Bankia gouldi* (Bartsch, 1908), *Nausitora fusticula* (Jeffreys, 1860), *Teredo bartschi* Clapp, 1923, and *P. healdi*) in the mangroves of the Pará coast. In both of these studies, *N. reynei* was the dominant species. Similarly, *N. reynei* predominated in mangroves of Paranaguá Bay, southern Brazil (MÜLLER & LANA, 1986). In contrast, LEONEL *et al.* (2002, 2006) found *N. reynei* to be either least dominant (0.2 to 0.7%) or absent in mangroves of northeastern Brazil. LOPES & NARCHI (1993) found *N. reynei* to be the second most abundant shipworm in naturally occurring wood in mangrove forest at Praia Dura, state of São Paulo. However, in the same area, experiments using wooden collecting panels found very low numbers of *N. reynei* settling (LOPES & NARCHI, 1997). Finally, surveys by JUNQUEIRA *et al.* (1989) and JUNQUEIRA & SILVA (1991) showed *N. reynei* to be absent from diverse localities along the Rio de Janeiro coast, although 10 other shipworm species were found. In a later study at one of these localities, Ilha Grande Bay, BARRETO *et al.* (2000) found 11 species of Teredinidae but *N. reynei* remained absent.

Mean densities of *N. reynei* in mangrove habitat in the Ajuruteua Peninsula varied between 0.004 and 0.022 individuals per cm³. At Ilha Canela beach, densities were lower and ranged between 0.0015-0.0051 individuals per cm³ (BEASLEY *et al.*, 2005) and these values are very similar to those at Ajuruteua beach, possibly indicating the harsher environmental conditions of beach habitats. High variation in density among individual logs occurred in our study showing that shipworms are very patchily distributed. Densities of shipworms ranged from 0.006 to 2.12 individuals per cm² at locations along the Rio de Janeiro coast and factors such as the wood supply, especially that of wood already colonized by shipworms, the abundance and diversity of the encrusting fauna as well as salinity are responsible for the variation in shipworm infestation within and between localities (JUNQUEIRA *et al.*, 1989).

Only a small proportion of the mangrove driftwood examined in the present study was colonized by Teredinidae and only one species, *N. reynei*, was found. This result contrasts with our observation that pieces of wood in the mangrove forest are always colonized by shipworms, predominantly *N. reynei*. It may be that much of this driftwood is exported from the mangrove before shipworms are able to colonize it. As there is extensive removal of mangrove wood for housing, fish-traps and firewood in the region (KRAUSE & GLASER, 2003), debris from such logging may be rapidly exported by the tides and washed up, uncolonized, on nearby beaches.

The availability of wood is a fundamental requirement for the establishment of shipworm populations (TURNER, 1966). Mangrove wood appears to be a suitable substrate for shipworm species (LEONEL *et al.*, 2002, 2006) and although abundant at Ajuruteua, much of it is free of shipworms and therefore other factors may affect their ability to colonize driftwood.

RIMMER *et al.* (1983) found that wider stumps of wood were colonized to a greater height by *Bankia australis* (Calman, 1920) and suggested that the larger volume of wood afforded greater protection through insulation against dessiccation and heat stress during low tide. JUNQUEIRA *et al.* (1991) registered highest densities of shipworms in solid collecting panels than in thin sheet panels. In contrast, the density of *N. reynei* was significantly lower in large logs in the present study, possibly because the wood in large driftwood logs may take longer to colonize than in small ones. LOPES & NARCHI (1997) found that settlement of shipworm larvae on 25cm long mangrove wood collectors was greater and occurred more rapidly on thin (0.3cm) sheets than on thick (2.4cm) cylinders. The ability to colonize wood may be dependent on its moisture content and permeability and also on the formation of a microbial coating (NAIR & SARASWATHY, 1971), which, because of the smaller surface-area to volume ratio, may be lower in large logs. Smaller logs may absorb water more easily and thus may be appropriate for colonization by shipworm larvae after a relatively shorter period of time in the water than larger logs. Once colonized, small logs may soon be destroyed by shipworm activity, thus explaining the relatively low number of small colonized logs found in this study.

The chemical content of some tree species as well as the presence of bark, which contains high concentrations of chemical components (NAIR & SARASWATHY, 1971), may cause mortality in larvae attempting to penetrate certain types of wood (TURNER, 1976). However, LOPES & NARCHI (1997) found almost no shipworm settlement in experiments with artificial collectors made of pine, whereas settlement was greater in those collectors made of native mangrove wood.

Prior to settlement, changes in planktonic food supply (MANN & GALLAGER, 1984a), temperature or salinity may delay or stop development of free-swimming larvae (TURNER & JOHNSON, 1971; NAIR & SARASWATHY, 1971) and larvae may therefore be unable to penetrate the wood. Shipworm density was greater in the months of the wet season, when humidity and precipitation are greater, and may be related to ease of colonization as well as higher survivorship in logs out of the water. *Neoteredo reynei* is an euryhaline species found in waters that range in salinity between 0.6 to 14 in mangroves in Pará, northern Brazil (REIS, 1995) and between 2 and 35 in mangroves from Paraíba (LEONEL *et al.*, 2002). LOPES & NARCHI (1993) registered higher densities of *N. reynei* in the upper section of the Rio Comprido estuary (São Paulo) corresponding to a salinity of 0 to 5. Thus, it is unlikely that the much lower densities observed during the transition period between the wet and dry seasons (May and July) are related to mortality caused by a reduction in salinity. Lower salinity between March and April may be linked to a reduction in reproductive output in *N. reynei* perhaps as a result of higher levels of mortality during the planktonic stage, and consequently lower numbers of recruits in the following months. However, to date, nothing is known of the reproductive cycle of *N. reynei* in northern Brazil. LEONEL *et al.* (2006) reported highest densities of shipworms immediately following the period of lowest salinity in Paraíba. Data on Teredinidae in Paraíba show that reproduction may be influenced by seasonal changes; spawning occurs during periods of low salinity and lower temperatures in *N. fusticula* and in periods of high salinity and warmer temperatures in *B. fimbriatula* (LEONEL *et al.*, 2002). Many of the Australian Teredinidae can breed and settle throughout the year but, even in warmer latitudes, seasonal changes in shipworm reproductive activity occur (IBRAHIM, 1981). The experiments of SARASWATHY & NAIR (1974) show that *N. hedleyi* Schepman, 1919 (from Cochin Harbour, India, where salinity varies between 0.5 and 38.3) cannot survive in salinities higher than 29. However, although some individuals in the natural environment were able to tolerate higher salinities, this species reproduces only during the rainy period when salinity is optimal (11.2 to 14.5) for egg development (NAIR & SARASWATHY, 1971). Adults and larvae of two incubatory species of Teredinidae from a tropical estuary in Papua New Guinea can tolerate experimental salinities different from those found in the estuary (RAYNER, 1979). This author suggested that the most important factor affecting shipworm distribution may be the salinity tolerance range of settling and metamorphosing larvae.

Neoteredo reynei is one of the largest species of shipworm in Brazil and has been known to attain 1.80m in

length (MÜLLER & LANA, 2004). Although the largest specimen measured in the present study was 1.13m, the mean length of *N. reynei* in mangrove driftwood at Ajuruteua Beach was much smaller. Larger size of shipworms in the dry season may be the result of growth following an earlier settlement event in the wet season. Shipworms in large logs were longer in the dry season than in the wet one, those in medium and small logs were shorter. Insulating properties of the larger volume of wood may favor survivorship in beached driftwood and in turn allow growth and, perhaps after a high tide, reproduction may even occur. MANN & GALLAGER (1984b) showed that *Teredo navalis* Linnaeus, 1758 and *B. gouldi* could grow and reproduce in an experimental wooden substrate in the absence of a phytoplankton supplement. In experiments carried out by OMENA *et al.* (1990), 100% survival was recorded after 72 hours out of the water for *Nototeredo knoxi* (Bartsch, 1917) and appears to be related to adaptations in the pallets that better seal the burrow, as well as gas exchange via the mantle. *Neoterredo reynei* is known to have morphological adaptations that promote its survival out of water; a pair of highly vascularized dorsal lappets occur at the posterior end of the body near the burrow opening and are probably involved in cutaneous gas exchange (MORAES & LOPES, 2003). Modifications of the appendix, anal canal, ctenidia and labial palps, as well as food grooves, indicate that *N. reynei* is less dependent on phytoplankton and feeds predominantly on wood (TURNER, 1966; LOPES *et al.*, 2000; MORAES & LOPES, 2003). Thus, it may be possible for *N. reynei* to resist dehydration and overheating and continue feeding in upper intertidal zones of mangroves, estuaries and beaches, for some time, especially if colonizing a large log. Indeed, our own observations (BEASLEY *et al.*, 2005) and those of MORAES & LOPES (2003) and LOPES & NARCHI (1993) show that *N. reynei* is able to thrive in mangrove habitat with a low frequency of tidal inundation.

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REFERENCES

- BARLETTA, M.; BARLETTA-BERGAN, A. & SAINT-PAUL, U. 1998. Description of the fisheries structure in the mangrove-dominated region of Bragança (State of Pará, North Brazil). *Ecotropica* 4(1-2):41-53.
- BARRETO, C. C.; JUNQUEIRA, A. O. R. & SILVA, S. H. G. 2000. The effect of low salinity on teredinids. *Brazilian Archives of Biology and Technology* 43(4):399-407.
- BEASLEY, C. R.; FERNANDES, C. M.; GOMES, C. P.; BRITO, B. A.; SANTOS, S. M. L. & TAGLIARO, C. H. 2005. Molluscan diversity and abundance in coastal habitats of northern Brazil. *Ecotropica* 11(1-2):9-20.
- DALGAARD, P. 2002. *Introductory statistics with R*. New York, Springer. 267p.
- FERNANDES, L. M. B. & COSTA, A. F. 1967. Notas sobre organismos marinhos incrustantes e perfurantes das embarcações. *Boletim da Estação de Pesca* 7(3):8-26.
- GONG, W.-K. & ONG, J.-E. 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. *Estuarine, Coastal and Shelf Science* 31(5):519-530.
- IBRAHIM, J. V. 1981. Season of settlement of a number of shipworms (Mollusca: Bivalvia) in six Australian harbours. *Australian Journal of Marine and Freshwater Research* 32(4):591-604.
- IHAKA, R. & GENTLEMAN, R. 1996. R: a language for data analysis and graphics. *Journal of Computational and Graphical Statistics* 5(3):299-314.
- JUNQUEIRA, A. O. R. & SILVA, S. H. G. 1991. Estudo experimental dos Teredinidae Rafinesque, 1815 (Mollusca: Bivalvia) do estuário da Lagoa da Tijuca, Rio de Janeiro, RJ, Brasil. *Revista Brasileira de Biologia* 51(1):113-126.
- JUNQUEIRA, A. O. R.; OMENA, E. P. & SILVA, S. H. G. 1991. A comparative study of the methods used to evaluate the activity of Teredinidae molluscs. *Journal of Experimental Marine Biology and Ecology* 150(1):107-115.
- JUNQUEIRA, A. O. R.; SILVA, S. H. G. & SILVA, M. J. M. 1989. Evaluation of the infestation and diversity of Teredinidae (Mollusca, Bivalvia) along the coast of Rio de Janeiro state, Brazil. *Memórias do Instituto Oswaldo Cruz* 84(suppl. 4):275-280.
- KOCH, V. & WOLFF, M. 2002. Energy budget and ecological role of mangrove epibenthos in the Caeté estuary, North Brazil. *Marine Ecology Progress Series* 228:119-130.
- KOHLMEYER, J.; BEBOUT, B. & VOLKMAN-KOHLMEYER, B. 1995. Decomposition of mangrove wood by marine fungi and teredinids in Belize. *Marine Ecology* 16(1):27-39.
- KRAUSE, G. & GLASER, M. 2003. Co-evolving geomorphical and socio-economic dynamics in a coastal fishing village of the Bragança region (Pará, North Brazil). *Ocean and Coastal Management* 46(9-10):859-874.
- LEONEL, R. M. V.; LOPES, S. G. B. C. & AVERSARI, M. 2002. Distribution of wood-boring bivalves in the Mamanguape River estuary, Paraíba, Brazil. *Journal of the Marine Biological Association of the United Kingdom* 82(6):1039-1040.
- LEONEL, R. M. V.; LOPES, S. G. B. C.; MORAES, D. T. & AVERSARI, M. 2006. The interference of methods in the collection of teredinids (Mollusca: Bivalvia) in mangrove habitats. *Iheringia, Série Zoologia*, 96(1):25-30.
- LOPES, S. G. B. C. & NARCHI, W. 1993. Levantamento e distribuição das espécies de Teredinidae (Mollusca-Bivalvia) no manguezal da Praia Dura, Ubatuba, São Paulo, Brasil. *Boletim do Instituto de Oceanografia* 41(1/2):29-38.
- _____. 1997. Recrutamento larval e crescimento de Teredinidae (Mollusca-Bivalvia) em região entremarés de manguezais. *Revista Brasileira de Oceanografia* 45(1/2):77-88.
- LOPES, S. G. B. C.; DOMANESCHI, O.; MORAES, D. T.; MORITA, M. & MESERANI, G. L. C. 2000. Functional anatomy of the digestive system of *Neoterredo reynei* (Bartsch, 1920) and *Psiloteredo healdi* (Bartsch, 1931) (Bivalvia: Teredinidae). In: HARPER, E. M.; TAYLOR, J. D. & CRAME, J. A. eds. *The evolutionary biology of the Bivalvia*. London, The Geological Society of London. p.257-271.
- MANN, R. & GALLAGER, S. M. 1984a. Physiological and biochemical energetics of larvae of *Teredo navalis* L. and *Bankia gouldi* (Bartsch) (Bivalvia, Teredinidae). *Journal of Experimental Marine Biology and Ecology* 85(3):211-228.
- _____. 1984b. Growth, morphometry and biochemical composition of the wood boring mollusks *Teredo navalis* L., *Bankia gouldi* (Bartsch), and *Nototeredo knoxi* (Bartsch) (Bivalvia, Teredinidae). *Journal of Experimental Marine Biology and Ecology* 85(3):229-251.
- MORAES, D. T. & LOPES, S. G. B. C. 2003. The functional morphology of *Neoterredo reynei* (Bartsch, 1920) (Bivalvia, Teredinidae). *Journal of Molluscan Studies* 69(4):311-318.
- MÜLLER, A. C. P. & LANA, P. C. 1986. Teredinidae (Mollusca, Bivalvia) do litoral do Paraná, Brasil. *Nerítica* 1(3):1-147.
- _____. 2004. *Manual de identificação de moluscos bivalves da família dos teredinídeos encontrados no litoral brasileiro*. Curitiba, UFPR. 146p.
- NAIR, N. B. & SARASWATHY, M. 1971. The biology of wood-boring teredinid molluscs. In: RUSSELL, F. S. & YONGE, M. eds. *Advances in Marine Biology*. London, Academic. v.9. p.335-509.
- OMENA, E. P.; JUNQUEIRA, A. O. R. & SILVA, S. H. G. 1990. Resistência de Teredinidae Rafinesque, 1815 (Mollusca: Bivalvia) a diferentes períodos de exposição ao ar. *Revista Brasileira de Biologia* 50(3):701-707.

- RAYNER, S. M. 1979. Comparison of the salinity range tolerated by Teredinids (Mollusca, Teredinidae) under controlled conditions with that observed in an estuary in Papua New Guinea. **Australian Journal of Marine and Freshwater Research** 30(4):521-533.
- REIS, R. E. M. L. 1995. Moluscos bivalves perfuradores de madeira do Estado do Pará, Brasil: caracterização taxonômica, distribuição e resistência de madeiras. **Boletim do Museu Paraense Emílio Goeldi, Série Zoologia**, 11(2):125-203.
- RIMMER, M. A.; BATTAGLENE, S. L. & DOSTINE, P. L. 1983. Observations on the distribution of *Bankia australis* Calman (Mollusca, Teredinidae) in the Patonga Creek mangrove swamp, New South Wales. **Australian Journal of Marine and Freshwater Research** 34(2):355-357.
- RIOS, E. C. 1994. **Seashells of Brazil**. Rio Grande, FURG. 492p.
- ROJAS, J. E. & SEVEREYN, H. 2000. Wood decay rate by *Psiloteredo healdi* (Bivalvia: Teredinidae) in Lake Maracaibo, Venezuela. **Revista de Biología Tropical** 48(1):153-158.
- SANCHEZ-ALFEREZ, A. S. & ALVAREZ-LEON, R. 2000. *Neoteredo reynei* (Bivalvia: Teredinidae) in mangrove swamps of the Colombian Caribbean. **Revista de Biología Tropical** 48(2-3):720-720.
- SANTOS, S. M. L.; TAGLIARO, C. H.; BEASLEY, C. R.; SCHNEIDER, H.; SAMPAIO, I.; SANTOS FILHO, C. & MÜLLER, A. C. P. 2005. Taxonomic implications of molecular studies on northern Brazilian Teredinidae (Mollusca, Bivalvia) specimens. **Genetics and Molecular Biology** 28(1):175-179.
- SARASWATHY, M. & NAIR, N. B. 1974. Influence of salinity on a tropical estuarine shipworm *Nausitora hedleyi* Schepman (Bivalvia - Teredinidae). **Hydrobiologia** 44(4):397-411.
- STILLNER, F. J. & PEDROSO, O. 1977. Verificação da atividade de moluscos do gênero *Teredo* no litoral oceânico do Rio Grande do Sul. **Roessleria** 1(1):131-142.
- TANAL, V. & MATLIN, A. 1997. Marine borer attack on submerged timber structures: investigation, protection and control. **Port Technology International** 5:185-191.
- TURNER, R. D. 1947. **Collecting shipworms**. Cambridge, Limnological Society of America, Special Publication Nº.19. 4p.
- _____. 1966. **A survey and illustrated catalogue of Teredinidae (Mollusca, Bivalvia)**. Cambridge, Museum of Comparative Zoology, Harvard University. 265p.
- _____. 1976. Some factors involved in the settlement and metamorphosis of marine bivalve larvae. In: SHARPLEY, J. M. & KAPLAN, A. M. eds. **Proceedings of the 3rd International Biodegradation Symposium**. London, Applied Science. p.409-416.
- _____. 1984. An overview of research on marine borers: past progress and future direction. In: COSTLOW, J. D. & TIPPER, R. C. eds. **Marine biodeterioration: an interdisciplinary study**. London, E. & F. N. Spon. p.3-16.
- TURNER, R. D. & JOHNSON, A. C. 1971. Biology of marine wood-boring molluscs. In: JONES, E. B. G. & ELTRINGHAM, S. K. eds. **Marine borers, fungi and fouling organisms of wood**. Paris, Organisation for Economic Co-operation and Development. p.259-301.
- UNDERWOOD, A. J. 1997. **Experiments in ecology: their logical design and interpretation using analysis of variance**. Cambridge, Cambridge University. 504p.
- WATERBURY, J. B.; CALLOWAY, C. B. & TURNER, R. D. 1983. A cellulolytic nitrogen-fixing bacterium cultured from the gland of *Deshayes* in shipworms (Bivalvia: Teredinidae). **Science** 221(4618):1401-1403.
- WOLFF, M.; KOCH, V. & ISAAC, V. 2000. A trophic flow model of the Caeté Mangrove estuary (North Brazil) with considerations for the sustainable use of its resources. **Estuarine, Coastal and Shelf Science** 50(6):789-803.
- ZAR, J. H. 1999. **Biostatistical analysis**. Upper Saddle River, Prentice Hall. 663p.