RECRUITMENT OF MUD CLAM *Polymesoda erosa* (SOLANDER, 1876) IN A MANGROVE HABITAT OF CHORAO ISLAND, GOA

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Abstract

Habitat-specific settlement success results either from active habitat selection or differential mortality after non-selective settlement. The mud clam *Polymesoda erosa* (Solander, 1876) is an ecologically and economically important benthic invertebrate with high abundance in the mangrove forests of Chorao Island, Goa, India. A one-year study (Jul 2004-Jul 2005) was conducted to characterize the patterns of post-larval settlement and survival of *P. erosa* in the mangrove habitat. The mean density of settling post-larvae was 28 no.m^{-2} with a majority of settlers during Sept 04. The density of adult clams in the landward zone ranged from 7-12 no.m^{-2} (mean: 9 ± 6 sd; n=122). In the seaward region, adults were completely absent at the low tide level. Higher densities of juveniles observed at the low- and mid-tide levels were assumed to be due to frequent inundation which allowed the young individuals to feed adequately and attain the critical sizes at which vulnerability to physical and biological constraints is substantially reduced, whereas, at high-tide level, increased desiccation may account for the mortality of settlers. It is speculated that initially the settlers settle according to the hydrodynamic conditions for sedimentation; however, adult survival is affected by their recruitment in a suitable habitat (e.g. substrates near A*vicennia* sp.). Thus, habitat dependent viability during the post-settlement phase could be the best explanation for the non-random, patchy distribution of *P. erosa* observed in the Chorao mangrove swamp.

Resumo

Um assentamento larval bem sucedido resulta da seleção ativa do habitat pelas larvas ou da mortalidade diferencial destas após o assentamento não seletivo. Nos manguezais da ilha Chorao, Goa, India, a ostra do lodo *Polymesoda erosa* (Solander, 1876) é um invertebrado muito abundante e de importância econômica. O presente trabalho, realizado durante um ano (julho de 2004 a julho de 2005), visou caracterizar os padrões de assentamento pós-larval e a sobrevivência de *P. erosa* no ambiente do mangue. Os resultados mostraram que a densidade de larvas pós-assentadas foi de 28 indiv.m^{-2}, com a maioria dos assentamentos ocorrendo em setembro de 2004. A densidade de adultos fixados no lado terrestre variou de 7 a 12 indiv.m^{-2} (média: 9 ± 6 dp; n = 122). Na região voltada ao mar, os adultos estiveram ausentes no nível da maré baixa. As altas densidades de juvenis observadas nos níveis de maré baixa e média estão provavelmente relacionadas à inundação frequente da área, o que permite aos indivíduos jovens alimentarem-se adequadamente e atingirem os tamanhos críticos em que a vulnerabilidade aos estresses físicos e biológicos são substancialmente reduzidos. Além disso, na maré alta, o aumento da dissecação pode favorecer a mortalidade dos indivíduos recém-assentados. É lançada a hipótese de que o assentamento ocorre inicialmente devido às condições hidrodinâmicas da sedimentação, mas a sobrevivência do adulto é afetada pelo recrutamento em ambiente favorável (p. ex., em substratos próximos a *Avicenia* sp.). Desta forma, a viabilidade do habitat durante o período pós-assentamento pode ser a melhor explicação para a distribuição não randômica, em manchas, observada para *P. erosa* no manguezal da ilha Chorao.

Descriptors: Cages, Abundance, Mortality, Juveniles, Chorao Island, Goa.
Descritores: Gaiolas, Abundância, Mortalidade, Juvenis, Ilha Chorao, Goa.

Introduction

The processes that lead to the colonization of substrata by larval invertebrates are among the most important in determining the ecology of marine communities. A fundamental process shaping community structure in most habitats is recruitment. Many marine benthic organisms are associated with particular substrate types. Active habitat choice for a specific sedimentary environment, in the form of habitat selection by settling larvae, may increase the likelihood of placing the offspring into that habitat.

However, differences in larval supply through passive transport (BUTMAN, 1987) as well as post-settlement processes (WILSON, 1991) offer equally convincing reasons.

Capture fishery is collapsing all over the world (MYERS; WORM, 2003), with bivalve fishery being no exception. One of the most common reasons for this is the continuous degradation of the habitat. In view of this fact, the effective management of these resources in an age of escalating reclamation of their habitats, it becomes imperative to study the recruitment of an organism, as the success of recruitment shapes the population. In addition, recruitment studies also help in understanding the overall ecology of an organism (PAWLIK, 1992), which may be useful to maintain a satisfactory environment.

The mud clam *Polymesoda erosa* is found in the mangrove forests of tropical and subtropical regions around the world and in India it is found abundantly along the west coast (INGOLE et al., 1994, 2002). This clam provides the basis of artisanal fishery on many islands of tropical and sub-tropical regions (MEEHAN, 1982). Perusal of the available literature suggests that *P. erosa* is mostly found in the landward side of the high intertidal area of mangrove forests (MEEHAN, 1982; CLEMENTE; INGOLE, 2006) where it thrives in the extreme conditions under which it is inundated only during the highest spring tides. During emersion it achieves aerial respiration via mantle.

In view of the commercial importance of this species and its potential for aquaculture, information on its recruitment has implications for the selection of suitable sites for cultivation. Except for a preliminary account by CLEMENTE; INGOLE (2006), no study on the recruitment aspects of the clam *P. erosa,* has so far been reported.

In the Chorao mangrove forests, adult *P. erosa* show a non-random patchy distribution in the high tidal regions towards the landward side. Because *P. erosa* is generally found in the high intertidal regions of the mangrove forests it was hypothesized that *P. erosa* has a high recruitment in the high tidal region and that the species actively selects this habitat. The aim of this study was thus to investigate whether the settlers´/juveniles´ behavior influences the non-random patchy distribution of adult *P. erosa* in the high tidal area of the mangrove forests. This study describes the recruitment of *P. erosa* among a population on Chorao Island, Goa, India.

Materials and Methods

Field sampling was carried out monthly (July 2004-July 2005) on Chorao island (15°25' -

15°30'N Lat and 73°45'E - 73°59'E Long; Fig. 1). The tide in the estuary is of mixed, semi-diurnal nature with a maximum height of 2.3 m. The mean tidal heights at LT, MT and HT levels were 0.25 m, 1.1 m and 1.98 m, respectively. Chorao island is a protected bird sanctuary in the backwaters of the Mandovi estuary, with extensive mangrove vegetation towards the western, low-lying tip. The whole area has mangrove vegetation and is covered by a criss-cross network of water channels. The mangrove flora of this island is represented by 12 genera and 15 species. The dominant plants are *Rhizophora mucronata, Avicennia marina*, *Sonneratia alba* and *Excoecaria allagocha.* The faunal elements most commonly seen are many varieties of commercial fish, prawns, crabs and oysters. The interior zone of the HT level is inundated only by very high spring tides.

For sampling settlers, juveniles and adults, three transects were considered (covering the three intertidal levels (viz. low- (LT), mid- (MT) and high-tide (HT) levels)), approximately 500 m long and 20-40 m apart.

Settlers, juveniles and adults correspond, respectively, to the shell size classes <0.3, between 0.3 and 3, and >3 mm (CLEMENTE, 2007). To determine settlers, the shell length was measured to the nearest 0.01 mm with an ocular micrometer, whereas for juveniles and adults it was measured to the nearest 0.1 mm with Vernier calipers.

Settling Population (Field ᵉxperiment With Cages)

The successful use of artificial collectors of monofilament netting to monitor settlement, early growth and mortality of bivalves (KNUCKEY, 1995; CHAUVAUD et al., 1996), and establish patterns of distribution of benthic epifauna (ARDISSON; BOURGET, 1992) is well known. In the present study, for sampling the settlers, twelve metallic cages of 60x30x30 cm size were prepared with MS (Mild Steel) iron (0.5 mm∅) and a nylon net material of 200 µm mesh. These were set up in the field in July 2004, approximately a month prior to the main spawning period (CLEMENTE; INGOLE, 2009). The cages were set at randomly selected replicate sites covering the three tide levels (each transect represents one of the three tide levels). Four cages were set on each transect, separated by a distance of 10 m. Cages were deployed at a height of 10 cm above ground level (Plate 1), as settlers are actually organisms within the sediment collected in the cage. If the cages had to be deployed at ground level, then after sediment fills they would have been dragged further down (due to their increased weight), making it difficult to quantify the sediment from the cage itself.
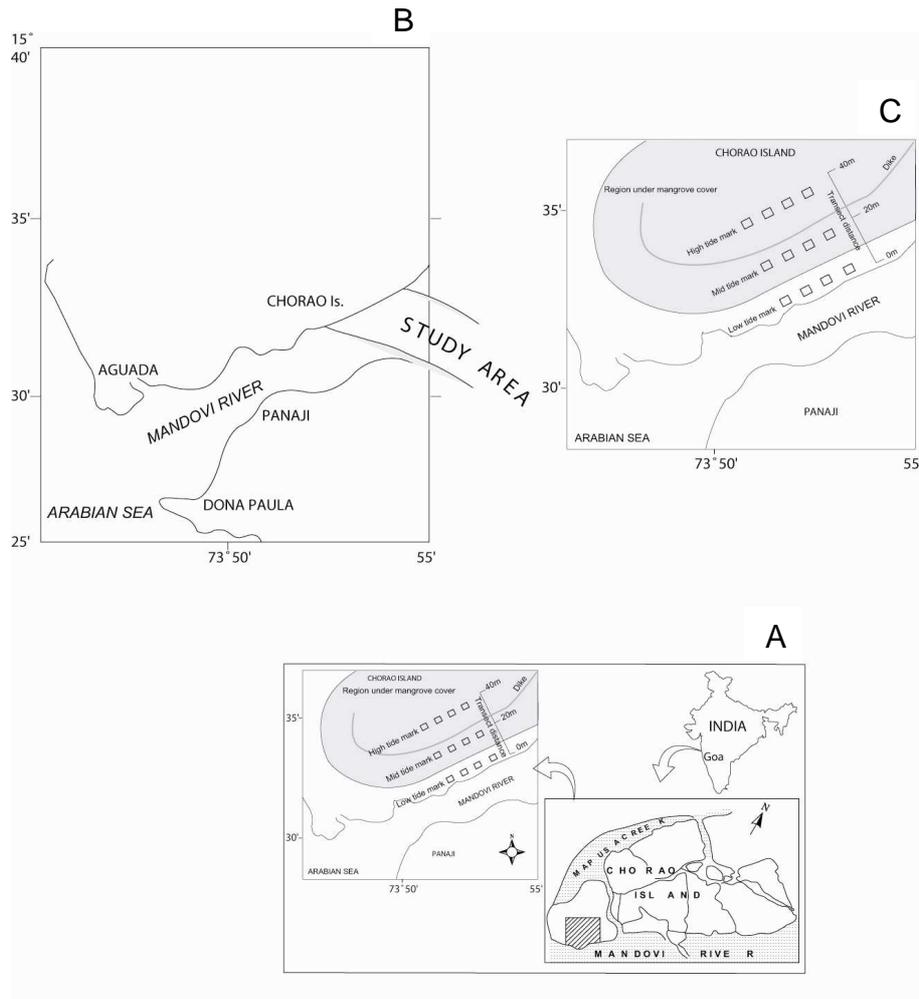
Fig. 1. Map of Chorao island showing the sampling site for *P. erosa.*

Retrieval of the cage material was undertaken monthly (CACERES-MARTINEZ et. al., 1994; GARCIA et. al., 2003; DOBRETSOV; WAHL, 2001) and it was then washed in a large tub, sieved on a 0.3 mm sieve and preserved in 10% buffered formalin Rose-bengal solution. In the laboratory, cage samples were again washed in running water and examined under stereo zoom microscope (Olympus B061).

Juvenile Population

Juveniles are found buried in the sediment and are aggregated largely within the upper 5.0 cm of the sediment. To collect juveniles, triplicate samples (from a marked area of 0.25 m^{-2}) from the upper 5.0 cm of sediment were collected with a hand held steel spatula in close proximity to each cage. Samples were then sieved through a 300 μm sieve mesh in the field and were fixed immediately with 5% buffered formalin Rose-bengal solution to facilitate sorting.

Adult Population

The adults of *P. erosa* ranged between 1.5 and 102 mm, have a lifespan of approx. 4 years and are mostly found lying on the sediment. Adult clams were recorded from 9 to 12 quadrants of 1 m^2 each month and collected by handpicking.

Data Analyses

The differences in settlement at different intertidal levels were examined by the density of settlers in the cages and were compared as between

transects. ANOVA was used to examine spatial and temporal variation in abundance of settler, juvenile and adult *P. erosa* in relation to different intertidal levels as well as among different months. For each significant ($p < 0.05$) ANOVA, factor level means were compared post hoc using Tukey's HSD. A significance level of $p < 0.05$ was considered throughout the study. The error bars in Figures 2 and 3 indicate standard deviation.

Plate 1. Cages in the field experiment to study *P. erosa* settlement.
(A) Cage at low-tide level (B) Cages at mid-tide level

RESULTS

The abundance of the *P. erosa* population on Chorao Island did not show any significant variation as between different months, intertidal levels or types. However, when the interaction of these factors was considered, it was seen that intertidal levels and *P. erosa* types (settlers, juveniles and adults) presented a significant effect (Table 1). Settlers were observed on all the three intertidal levels. Newly arrived settlers were found in the cages from Sept to Nov 2004. Their maximum abundance was recorded in Sept 2004 (28 ind. m^{-2}), which reduced subsequently to 4 ind. m^{-2} in Nov 2004 (Fig. 2). A comparison of the mean abundance of settlers indicates that, except on one occasion (Oct 2004) at one site, the seaward zone had a greater abundance of settlers than the landward zone (Fig. 2). Among intertidal levels in the seaward zone, the abundance of settlers was higher on the low- than on the mid-tide level. Settler abundance was approximately twice that on the mid-tide level and about 4 times higher than that recorded at the high-tide level (Fig. 2). Juveniles were found throughout the sampling period except in Sept 2004 and Mar 2005, with peak abundance in Aug and Oct 2004 (Fig. 2). The maximum abundance of 11 ind. m^{-2} was observed in Oct 2004 and the minimum of 1 ind. m^{-2} in Jan 2005, Apr 2005 and Jun 2005. More juveniles were observed at the low tide level than at mid- and high-tide levels (Tukey's HSD test, p<0.05; Table 2), except in Feb 2005. A comparison of seasonal changes in abundance of new settlers and juveniles shows that the abundance peak of juveniles during early Jul 2004 originated from new settlers in Jun 2004, while a peak in the juvenile population observed in Nov 2004 might have originated from that of the newly settled in Sept 2004. The abundance of juveniles in the seaward zone was threefold that in the landward zone (Fig. 2). Adult *P. erosa* were found throughout the study period in the Chorao mangrove forests. Their abundance did not fluctuate remarkably in different months (Fig.2 and Table 1). As far as the distribution of adults is concerned; it varied highly between the intertidal levels. The abundance of adults was significantly higher in the high-tide level but they were completely absent at the low tide level (Tukey's HSD test, p<0.05; Table 2). Adult *P. erosa* showed greater selectivity, being found exclusively in the landward region (MT and HT) inside the mangrove forest. The abundance of adult clams in the landward zone ranged from 7-12 ind. m^{-2} (mean: 9 ± 6 sd; n=12, Fig. 3). Even though high abundance of juveniles was observed towards the landward zone, there was a more or less similar pattern for the settlers and juveniles but the adults showed a completely different pattern. The abundance of adult *P. erosa* in the landward zone was approximately 4 times that of the settlers and twice that of the juveniles observed (Fig. 3).

Table 1. Results of ANOVA for *P.erosa* abundance between different types (settlers, juveniles & adults) along the three intertidal levels (LT, MT & HT) in different months on Chorao island.

Intertidal levels	Types	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}
		6.916667	0.6666667	0.000000	4.666667	3.000000	2.750000	1.833333	5.000000	9.250000
LT	NS {1}									
LT	J {2}	0.4154392								
LT	A {3}	0.2797972	0.9999997							
MT	NS {4}	0.9968523	0.891517	0.778228						
MT	J {5}	0.9025379	0.9959415	0.978726	0.999657					
MT	A {6}	0.8672881	0.9981898	0.987748	0.999016	1				
HT	NS {7}	0.688698	0.9999769	0.99931	0.985161	0.99998	1			
HT	J {8}	0.999016	**0.0460227**	0.707453	1	0.99865	0.99685	0.9703885		
HT	A {9}	0.9959415	0.0770802	**0.041438**	0.794644	0.41544	0.3614	0.1984317	0.8541	

Table 2. Tukey's HSD post hoc multiple comparison tests for differences in the abundance of *P.erosa* types (new settlers=NS, juveniles=J and adults=A) between different intertidal levels (LT, MT, HT) on Chorao island.

Source of variation	DF	SS	MS	F	p
Month	11	228.463	114.231	2.35994	0.100888
Intertidal level	2	149.852	74.926	1.54792	0.218915
Types	2	47.574	23.787	0.49142	0.613567
Month*Intertidal level	22	33.704	8.426	0.17407	0.951104
Month*Types	22	468.815	117.204	2.42135	0.054921
Intertidal level *Types	4	660.259	165.065	3.41013	0.012514
Month*Intertidal level *Types	44	146.685	18.336	0.3788	0.928985
Error	765	3920.75	48.404		

CLEMENTE AND INGOLE: RECRUITMENT OF *P. erosa* IN A MANGROVE HABITAT   159
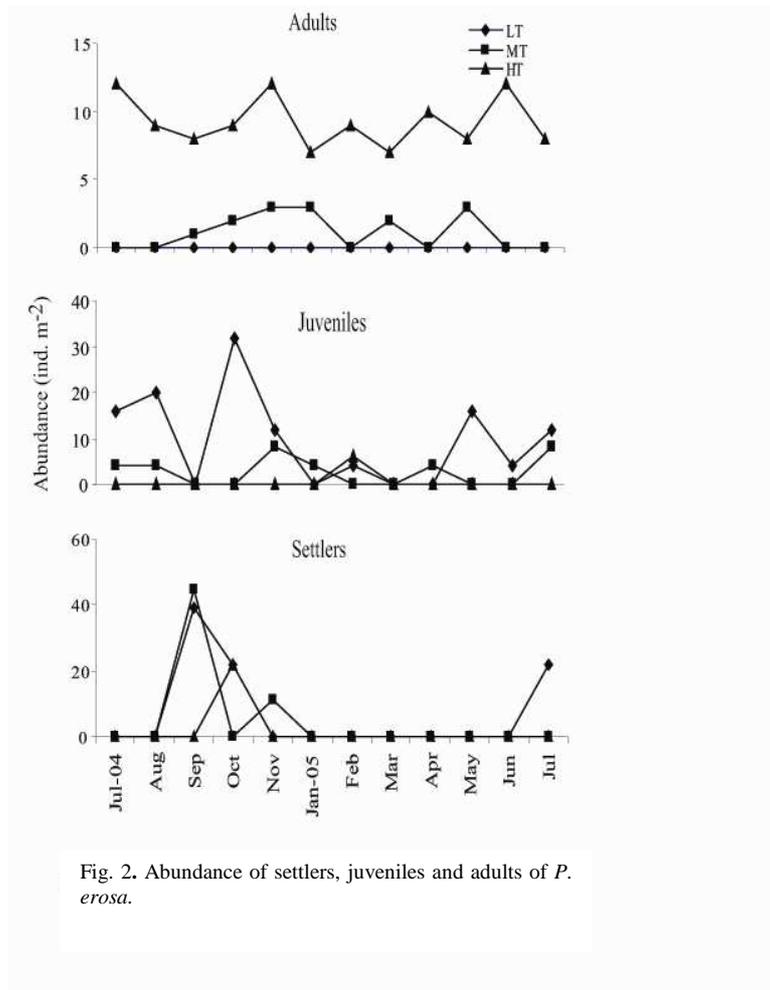

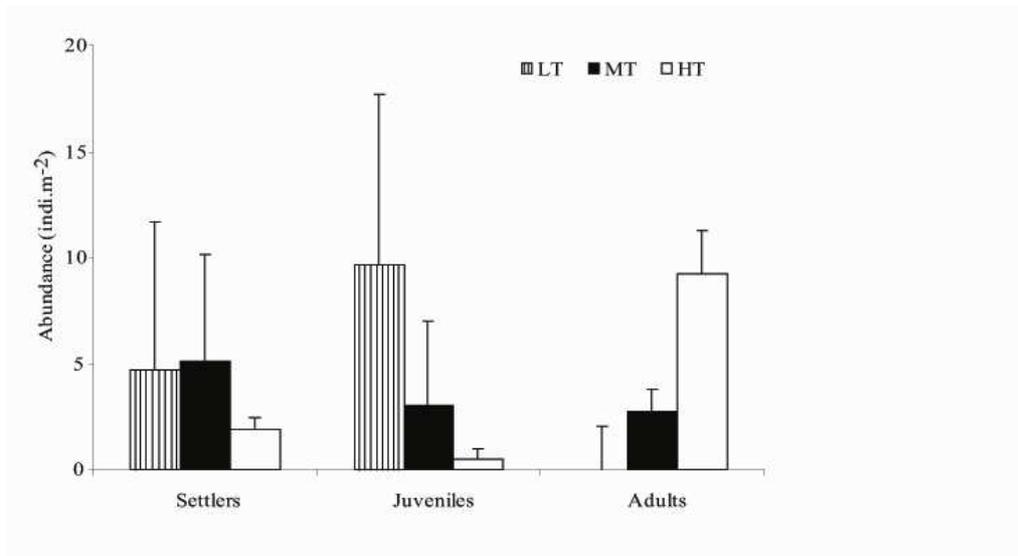Fig. 2. Abundance of settlers, juveniles and adults of *P. erosa.*

Fig. 3. Mean abundance of new settlers, juveniles and adults of the mud clam *P. erosa* at different intertidal levels.

DISCUSSION

In all months, the majority of the juveniles were confined to the seaward zone while adults were found conspicuously towards the landward zone. In contrast, settlers were found at comparable densities in the seaward and landward zones.

Bivalve larvae are known to act like passive particles entrained by hydrodynamic factors (BERTNESS et al., 1996), relatively unable to influence their distribution and abundance on the shore on a large spatial scale. Larval *P. erosa* may also be acting as passive particles, since the settlers were observed at all the tide levels. Hence, the same physical processes (BERTNESS et al., 1996) that maintain the distribution of sediments with similar fall velocities may be responsible for initial settlement and distribution of larval *P. erosa*.

It was seen that more juveniles were located on the low-tide level than in the mid- and high-tide levels although settlers were recorded at all the tide levels. The differential settlement of larvae with low abundance towards the landward region could be due to the initial mortalities of the settlers in an unfavorable area (GOSSELIN and QIAN, 1997). Reviews on mortality of juvenile invertebrates have suggested that desiccation and predation may often be the most important causes of mortality (GOSSELIN and QIAN, 1997; HUNT and SCHEIBLING, 1997).

Earlier studies have established the fact that juvenile mortality during the first hours or days may be due to a rapid elimination of individuals located in unfavorable areas and beyond this it is largely dependent on body size, a major determinant of vulnerability (GOSSELIN and QIAN, 1997). Rapid growth during the early juvenile period is considered to be an important strategy to reduce the likelihood of mortality by minimizing the time spent in the smallest, most vulnerable size classes (VERMEJI, 1987). Gaining maximum size in the shortest possible time requires the availability of food. Experimental studies have shown increasing growth with increased food concentration (PECHENIK et al., 1990). Being a filter feeder, *P. erosa* can feed only during immersion, and thus the presence of settling stages at low-tide level (where there is frequent inundation) will enable them to feed adequately and attain the critical sizes at which vulnerability to physical and biological constraints is substantially reduced. Hence, the observed distribution of juvenileson the low tide level could be due to the availability of food with frequent inundation. However, though the juveniles were recorded on the low- and mid-tide levels, the adults were found only in the high-tide region, with a few clams on the fringe of the mid-tide very close to the high-tide level. It is very interesting to note that the adult clams recorded even in the mid-tide region (dominated by *Rhizophora* mangroves) were found only near the *Avicennia*

species among other species of mangroves. The presence of few juveniles at the high-tide level can be explained by the fact that not all the larvae, which do settle, may recruit there and the high number of adults could be due to large numbers of older individuals from better recruitment years. Since juvenile abundance was higher than that of settlers, and adult abundance was still higher, it cannot be assumed that settlement is equal in intensity every year.

The most conspicuous difference between the low-tide and both the mid- and high-tide levels is the absence of vegetation or mangrove trees in the low-tide region. If the absence of vegetation were the only problem for the clams, then the mid-tide region with mangrove vegetation should have provided the ideal habitat. Typically very few or no clams were observed on the mid-tide level. An observation worthy of consideration here is that the mid-tide level is dominated by *Rhizophora* species. Generally the adult clam population was higher per unit area among *Avicennia* mangroves than among other mangrove species. Clearly some aspect of this species attracts or allows increased survival of young *P. erosa*. It is well known that each of the different species of mangrove plant presents a different structural environment in relation to number of stems, root/rhizome biomass, and stem basal area (CAPEHART; HACKNEY, 1989).

Given that *P. erosa* relies on aerial breathing during emersion for prolonged periods, characteristics of the substrate may play an extremely important role in its distribution. Substrates that facilitate aerial respiration will favor greater abundance of clams than those that hinder such activity. The rhizosphere of *Avicennia marina* is highly oxidized with virtually complete absence of sulphide (LYIMO et al., 2002). *Avicennia germinans* creates oxidized rhizospheres substantially larger than those described for other plant species (THIBODEAU; NICKERSON, 1986). Sediment type is another factor that is crucial in marine benthic communities, the importance of which for bivalves has been well established (e.g. VAN HOEY et al., 2004). Observations from this study indicate that density of adult *P. erosa* was higher at the sites with fine silt (HT) but absent at sites with a high sand content (LT). However, lack of sediment grain size data does not allow one to draw direct conclusions, which calls for thorough study in the future.

The differences in the physical structure of the mangrove forest in the present study included fewer pneumatophores and less compact sediments in areas with few or no clams. Studies have shown that more pneumatophores generally occur in the compacted sediments of *Avicennia* sp. areas (UNDERWOOD; CHAPMAN, 1998; SKILLETER; WARREN, 2000). This preference of *P. erosa* for habitats containing *Avicennia* sp. could to be related to the compacting of the sediment and the feeding mechanism. Sediment resuspension, a factor that clogs the filters of suspension feeders is likely to be more intense where wave energy more readily disturbs the bottom. Although it could not be accurately quantified in the present experimental study, areas without any mangrove vegetation or mats of roots will probably have lower abundance of clams or none at all. Hence, this may explain the absence of clams at low-tide level and low densities of clams in *Rhizophora* dominated zones due to gill clogging which, at extreme levels, is stressful to many organisms (RHOADS; YOUNG 1970; ROGERS, 1990). Even if sediment characteristics may not provide the active habitat selection criterion (HUXHAM; RICHARDS, 2003), they may give a measure of the correlated variables that influence habitat selection (SNELGROVE; BUTMAN, 1994). For example, sediment type can correlate with food availability, i.e. large grain sizes and fast current flow can correlate with increased phytoplankton and small grain sizes and slow current flow can correlate with higher densities of benthic algae (LOPEZ; LEVINTON, 1987). Adaptations to abiotic extremes do not preclude mangrove clams from living in habitats where physical conditions are better, such as unvegetated low tide habitats, but biotic factors, particularly vegetation, may limit their distribution in those habitats.

In addition, it is well known that the lower limit of distribution of intertidal organisms is mainly determined by the action of biotic factors such as competition for space or predation (CONNELL, 1961). Predation may prove to be a widespread and important structuring component of soft sediment communities accounting for the patchy distributions of many infaunal species (BYERS, 2002). The clam's ability to live relatively high up in the intertidal zone may limit predation by most species. The results also indicated the importance of the physical vegetative structures other than for refuge from predators since the forested *Avicennia* habitat had the greatest adult clam abundance regardless of some predator presence as observed by the effective predation within the *Avicennia* zone evidenced by broken shells. However, the importance of predation has yet to be tested for *P. erosa* on Chorao Island. Furthermore, to date no specific predator of *P. erosa* has been identified and documented in the literature.

Conclusion

Juvenile and adult distribution of *P. erosa* differ on Chorao island and these differences are attributable to post-settlement processes. It appears that *P. erosa* prefers substrates near the *Avicennia* in

the high intertidal region. Great differences in *P. erosa* abundance between sediments underlying stands of *Avicennia* sp. and other mangrove species in otherwise similar areas of mangrove forest may then be attributed to differences in tree root structure, the availability of microalgae, and the physical and chemical nature of the sediment surface. Given that this study is limited to a single experiment with no follow-up experiments, no clear conclusions can be drawn although a possible explanation of the recruitment process is provided. Further, to make generalizations about the importance of a specific mangrove plant species for the distribution of this clam, large data sets from a variety of mangrove forests in different geographical areas, substantiated with field experiments, will help to understand the role of a particular mangrove species in structuring the *P. erosa* community.

ACKNOWLEDGEMENTS

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