

## CHANGES IN POPULATION CHARACTERISTICS OF *Mytella falcata* (D'ORBIGNY, 1846) BEDS, AN EXPLOITED TROPICAL ESTUARINE MUSSEL

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### ABSTRACT

*Mytella falcata* is a heavily exploited mussel from Brazilian mangrove estuaries. Population density, spatial dispersion, shell length, dry weight and biomass of mussels were estimated from two exploited beds and one unexploited bed. In the latter, mussels were smaller due to lower tidal inundation frequency and thus had little economic value. Mussels were continually harvested from exploited beds until almost all individuals were removed and mussel spatial dispersion changed from aggregated to random as harvesting proceeded. Exploitation does not appear to be strongly size-selective as mean shell size and dry weight either remained high or increased during the harvesting season. In the unexploited bed, spatial dispersion remained aggregated but density decreased during the wet season perhaps as a result of low salinity. The population characteristics studied are simple but potentially important indicators of overexploitation for use in mussel bed management.

**Keywords:** Mussel; exploitation; mangrove; estuary

## MUDANÇAS EM CARACTERÍSTICAS POPULACIONAIS EM BANCOS DE *Mytella falcata* (D'ORBIGNY, 1846): UM MEXILHÃO TROPICAL ESTUARINO EXPLORADO

### RESUMO

*Mytella falcata* é um molusco intensamente explorado nos estuários de manguezais brasileiros. Densidade da população, dispersão espacial, comprimento da concha, peso seco e biomassa foram estimados em dois bancos explorados e em um banco inexplorado. Neste último, os moluscos apresentaram um tamanho menor devido a baixa frequência com a qual eram inundados pela maré, assim apresentaram pouco valor econômico. Nos bancos explorados a dispersão espacial mudou de agregada para aleatória. A exploração não parece ser um fator fortemente seletivo para o tamanho dos moluscos já que valores médios do comprimento da concha e o peso seco ou permaneceram altos ou aumentaram durante o período de exploração. No banco não explorado, a dispersão espacial permaneceu agregada, a densidade diminuiu durante a estação chuvosa provavelmente devido a diminuição da salinidade. As características populacionais estudadas são simples, mas potencialmente importantes indicadores de super-exploração para uso no manejo sustentável de bancos de mexilhões.

**Palavras-chave:** Mexilhão; exploração; manguezal; estuário

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## INTRODUCTION

The mangrove estuaries of northern Brazil are among those least impacted in terms of industrial pollution and urbanization (HERTZ, 1991). Their importance in both ecological (WOLFF *et al.*, 2000) and economic terms (GLASER, 2003; GLASER *et al.*, 2003; GLASER and OLIVEIRA, 2004; SAINT-PAUL, 2006) is very great. However, human migration towards the coast, the lack of employment opportunities and a rising urban demand for mangrove produce are increasing pressure on mangrove resources (GLASER *et al.*, 2003). Low quality of educational services, lack of employment, lack of health services, low prices for mangrove products, debt problems, lack of electricity and local leadership deficiencies were cited, in order of importance, by residents of mangrove villages as being major problems leading to precarious social conditions (GLASER, 2003) and thus greater dependence on coastal resources. Mangroves are exploited for their wood, the mangrove crab *Ucides cordatus*, fish and other crabs, shrimp and various molluscs (GLASER 2003; SAINT-PAUL 2006). Amongst the most commonly exploited mangrove molluscs is the estuarine mussel (*Mytella falcata* d'Orbigny 1846). This species lives in dense aggregations of up to several thousand individuals m<sup>-2</sup> in the surface layers of muddy sandy substrates of the lower regions of mangrove estuaries in northern Brazil (FERNANDES *et al.*, 1983). *M. falcata* may use the foot to slowly draw the anterior part of the shell into the substrate and produces byssus threads to anchor itself to solid particles in the mud (NARCHI and GALVÃO-BUENO, 1983), such as stones and other mussels. These bivalves have an important ecological role, transforming phytoplanktonic primary production into animal tissue that can be used by other organisms within the food web (DAME, 1996). Their protein content and nutritional value are very high (MARQUES, 1998) and are collected from natural mussel beds, especially in the northern (BLANDTT and GLASER, 1999; MUEDAS and MOREIRA, 2006) and north-eastern (PEREIRA-BARROS, 1987; PEREIRA-BARROS and PEREIRA-BARROS, 1988; NISHIDA *et al.*, 2006) coasts of Brazil. Diverse methods, from bare hands to agricultural tools including hoes, knives, hooks and rakes, are used to remove mussels, which are then washed and

separated from the byssus after reaching shore (NISHIDA *et al.*, 2006). Despite the economic and ecological importance of mussel beds, there are no studies of the impact of their unregulated exploitation. Residents of mangrove villages in the region point to overexploitation as the main cause of the scarcity and unpredictability of mussel beds (BLANDTT and GLASER, 1999). Studies of the population dynamics of *M. falcata* may contribute to the management of this species. Indicators of overexploitation that are easy to observe and measure may be developed for managed mussel beds. The use of such indicators might avoid the complete disappearance of mussel stocks and loss of income for mangrove residents. In this context, the present study aims to provide data on population density, spatial dispersion, dry weight, biomass, and population structure of exploited mussels in beds from a mangrove estuary in northern Brazil.

## METHODS

The study was carried out in the Emboraí mangrove estuary, near Nova Olinda, in the municipality of Augusto Corrêa in the State of Pará, northern Brazil. Three mussel beds were located in the estuary. Bed 1 (01°05'27.2''S, 046°28'28.6''W) was located on the right margin, measured approximately 30 x 8 m and consisted of a predominantly rocky substrate covered with a layer of fine muddy sediment. Bed 1 was regularly uncovered and covered by the tide. Bed 2 was located furthest down-river at the mouth of the estuary (01°00'55.7''S, 046°27'38.6''W), and measured approximately 105 x 50 m. Bed 3 was located midway between beds 1 and 2 on the left-hand margin of the estuary (01°04'19.5''S, 046°28'47.8''W) near an old wooden fishing *curral* (BARLETTA *et al.*, 1998), and measured approximately 30 x 15 m. Beds 2 and 3 consisted only of a muddy substrate and were submerged by the tide most of the time, being uncovered only during low spring tides.

The survey of the mussel beds was carried out over one year in monthly visits to the beds during the new or full moon phases when the beds were most likely to be uncovered during low tide. A total of 12 surveys were carried out in Bed 1 between June 2003 and June 2004, with the

exception of March 2004, when access to the site was impossible due to the rains. Bed 1 was not exploited at any time during the survey. Surveys of the other beds depended on the presence of mussels. In Bed 2, mussels were only present between August and November 2003, during which time 4 surveys were carried out. In Bed 3, mussels were only present between September 2004 and January 2005 during which time 6 surveys were carried out. Beds 2 and 3 were always exploited as long as mussels were present.

The survey involved simple random sampling of the mussel beds as these were relatively small and homogeneous in terms of substrate and mussel coverage. In Bed 1, sampling was done during low tide, using randomly chosen 1 m<sup>2</sup> quadrats (n=15) in which mussels were counted directly. As Beds 2 and 3 were usually covered by water, density was estimated using a PVC cylindrical corer, 110 cm in length by 10 cm in diameter, giving a sampling area of approximately 0.008 m<sup>2</sup>. The cylinder was pushed into the muddy substrate to a depth of 20 cm giving a sampling unit of sediment of 1.57 litres. The cylinder was used at 15 random coordinates within each bed. In each sampling unit, mussels were separated from the sediment and counted. Mean density (number mussels 0.008 m<sup>-2</sup> for beds 2 and 3 was recorded and converted to number mussels m<sup>-2</sup>) was calculated from the 15 replicate counts for each bed on each survey date. Mussel spatial dispersion (regular, random or contagious) was determined using the method described by ELLIOTT (1983). Total population size was estimated by multiplying the mean density (individuals m<sup>-2</sup>) by the bed area (m<sup>2</sup>). Casual observations of the numbers of people and methods of harvesting were made on each sampling occasion.

Two mussels were taken from the center of each quadrat in Bed 1 and two were chosen randomly from the sampling unit of sediment from beds 2 and 3 giving a total of 30 mussels from each bed for measurement of shell length (mm) and dry weight of the soft tissue (g) on each sampling occasion. Shell length along the anterior-posterior axis was measured to 0.1 mm using a Vernier calipers. Soft tissue was removed from the shell and dehydrated at 60°C for 24 hours and weighed to 0.01 g.

Mean mussel biomass, expressed in g.m<sup>-2</sup>, of each bed on each survey date was determined by multiplying the mean density (individuals m<sup>-2</sup>) by the mean dry weight (g). Total biomass of each bed on each survey date was obtained by multiplying the mean biomass (g.m<sup>-2</sup>) by the area of the bed (m<sup>2</sup>) and the value rounded to the nearest kg.

As each bed was sampled on different dates and beds 2 and 3 differed from Bed 1 in terms of substrate type, data for each bed was analyzed separately. Differences in mean values of density, shell length and dry weight between survey dates were thus verified separately for each mussel bed using one-way analysis of variance (ANOVA). Homogeneity of variances was checked using Cochran's C test (UNDERWOOD, 1997). Where variances were significantly different, data were transformed using the Box-Cox method (VENABLES and RIPLEY, 2002).

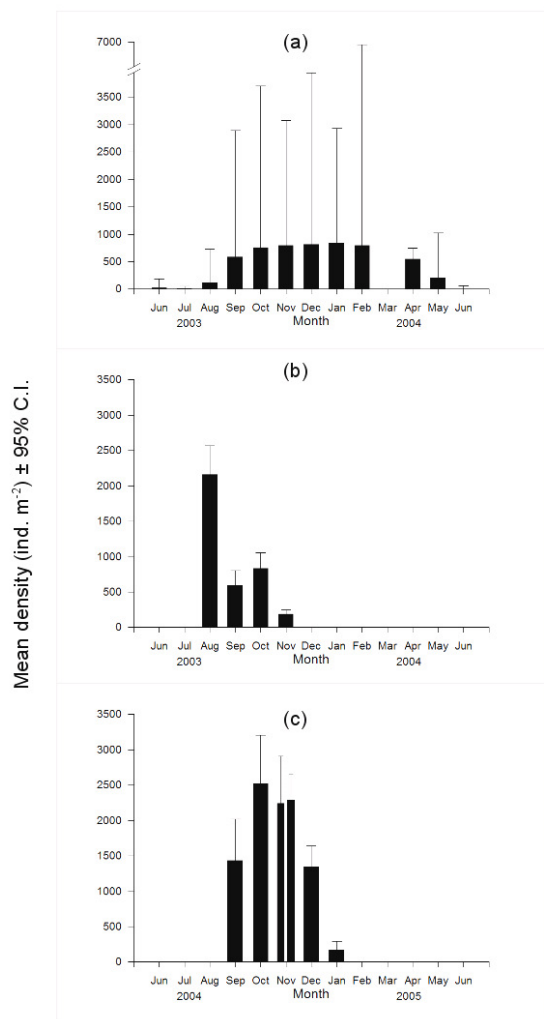
The relationship between shell length and dry weight was investigated using linear regression analysis. Length data were used to construct size-frequency distributions for each bed on each survey date. All data were analyzed using the software R (IHAKA and GENTLEMAN, 1996).

## RESULTS

Mean density at the unexploited Bed 1 (Figure 1a) was low in June and July but increased rapidly in August reaching highest values between October 2003 and February 2004. Thereafter, density declined rapidly to previously low values in June. Values in June, July and August of 2003 and June 2004 were significantly lower than values during the rest of the study ( $F_{11,168} = 35.2$ ,  $p < 0.001$ , Tukey,  $p < 0.05$ ). Mussel spatial dispersion remained aggregated during the entire study period. Mussels were not exploited at Bed 1. At Bed 2 (Figure 1b), mean density declined between August (2,157.5 ind m<sup>-2</sup>) and November 2003 (187.5 ind m<sup>-2</sup>). Significant differences in mean density occurred between all months at Bed 2 ( $F_{3,116} = 42.9$ ,  $p < 0.001$ , Tukey,  $p < 0.05$ ), with the exception of September and October. Mussels were spatially aggregated but became randomly dispersed in November 2003.

At Bed 2, on all sampling occasions, at least 50 people were involved in harvesting mussels, arriving at the bed by wooden paddle canoe or by

boat with a diesel engine. The majority of mussel harvesters were adult men, probably because of the remoteness of the site and the fact that the water was usually relatively deep (1 or more meters). However, a small number of women and children were also observed collecting at Bed 2. Mussels were removed usually by spade, straight-edged sickle or by hand and washed in a *paneiro* (wide mesh basket made of dried leaf strips). After washing away the silt, mussels were either bagged or placed directly in the bottom of the boat.



**Figure 1.** Mean mussel density (ind m<sup>-2</sup>) at Beds 1 and 2 between June 2003 and June 2004 (a, b), and at Bed 3 between June 2004 and June 2005 (c) on the Emboraí mangrove estuary. Note that Bed 3 was surveyed twice in November (16 and 26th)

At Bed 3 (Figure 1c), mean density was initially low (1,432.5 ind.m<sup>-2</sup>) in September 2004, increased in October 2004 but declined thereafter

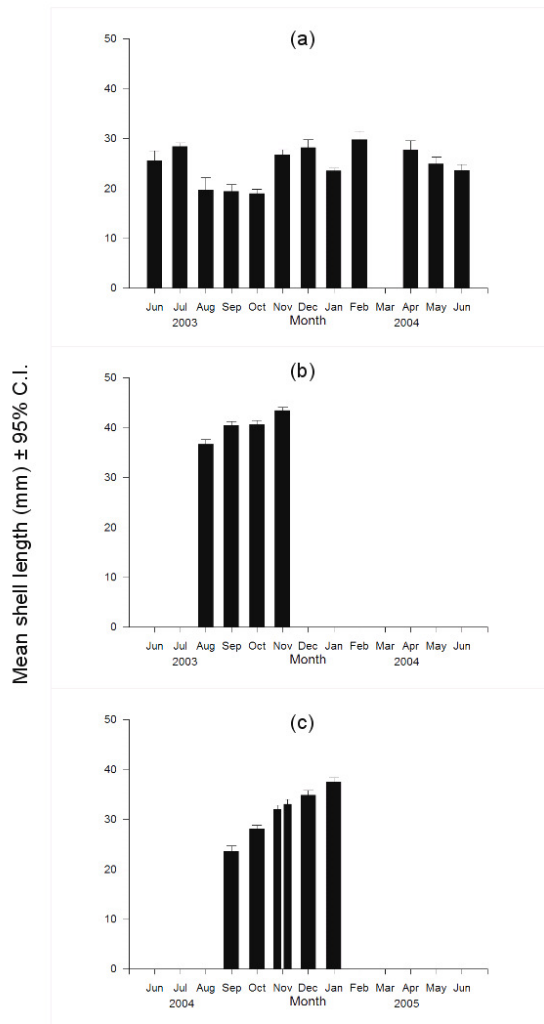
to 175.0 ind m<sup>-2</sup> in January 2005. At Bed 3, a significant difference in mean density ( $F_{5,84} = 14.2$ ,  $p < 0.001$ ) occurred between months where density was significantly lower in January 2005 and density in October was significantly different from values in September and December (Tukey,  $p < 0.05$ ). Mussel spatial dispersion was aggregated during the first three survey dates but became random thereafter. At Bed 3, which was relatively close to urban centers and not very deep at low tide, harvesting was observed from mid-October onwards with around 15 people involved, mostly women and children, arriving at the bed by wooden paddle canoe. Mussels were removed only by hand at this site and processed as described above for Bed 2.

Mean shell length differed significantly between months of the year ( $F_{11,348} = 28.56$ ,  $p < 0.001$ ) at Bed 1 (Figure 2a). Shell length was significantly lower between August and October 2003 and in January and June 2004 (Tukey,  $p < 0.05$ ). Size frequency distributions show evidence for recruitment in August, when mussels were found in smaller size classes and appears to correspond with the increase in density and the decrease in mean shell length described above. Subsequent growth of the mussels is shown by the increasing proportion of individuals in larger size classes, except for January and June 2004, when the proportion of larger individuals decreased.

At Bed 2 (Figure 2b), shell length increased from 36.6 mm in August 2003 to approximately 43.0 mm in November 2003. Significant differences in shell length were found between all survey dates ( $F_{3,326} = 41.4$ ,  $p < 0.001$ ) with the exception of September and October. In Bed 3 (Figure 2c), shell length increased from 23.7 mm in September 2004 to 37.5 in January 2005. Significant differences occurred between all survey dates ( $F_{5,174} = 133.9$ ,  $p < 0.001$ , Tukey,  $p < 0.05$ ) except those in November 2004.

Mean dry weight varied significantly between months at Bed 1 ( $F_{11,346} = 143.0$ ,  $p < 0.001$ ) with lowest values between June and August 2003 (Figure 3a). Dry weight increased in August and values remained high thereafter. Values in June, July and September were significantly lower than for other months (Tukey,  $p < 0.05$ ). At Bed 2 (Figure 3b), a significant increase in dry weight occurred between August and November ( $F_{3,236} = 50.7$ ,

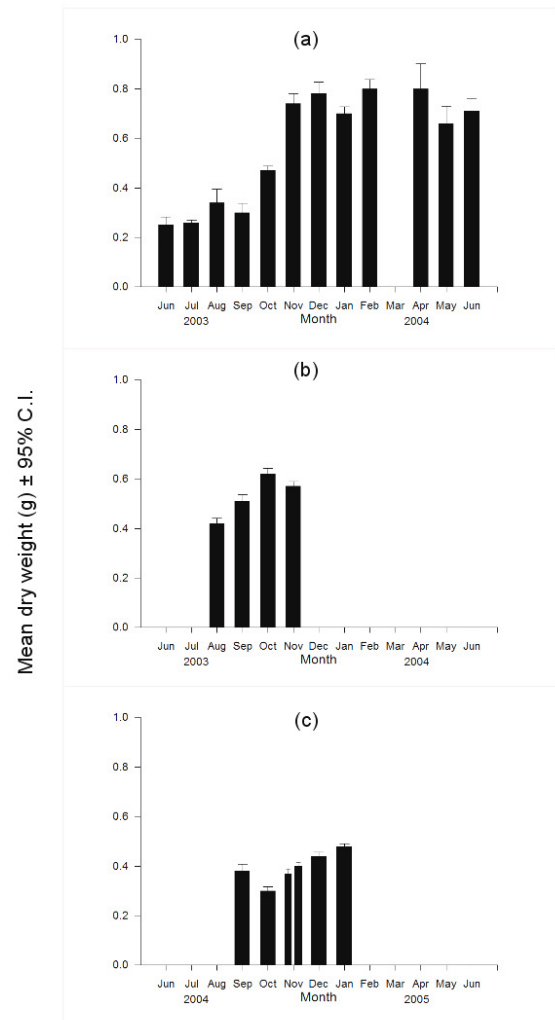
$p < 0.001$ , Tukey,  $p < 0.05$ ). At Bed 3 (Figure 3c), mean dry weight also differed significantly between survey dates ( $F_{5,174} = 42.9$ ,  $p < 0.001$ ) with a significant increase (Tukey,  $p < 0.05$ ) between September 2004 (0.38 g) and January 2005 (0.48 g). A significant decrease in dry weight occurred in October 2004.



**Figure 2.** Mean mussel shell length (mm) at Beds 1 and 2 between June 2003 and June 2004 (a, b), and at Bed 3 between June 2004 and June 2005 (c) on the Emboraí mangrove estuary. Note that Bed 3 was surveyed twice in November (16 and 26th)

Mean biomass ( $\text{g m}^{-2}$ ) varied between  $<1.0$  and  $650.0$  at Bed 1, between  $106.9$  and  $906.5$  at Bed 2, and between  $544.3$  and  $913.0$  at Bed 3. Total biomass (kg) and estimated population size (1,000 individuals) of each mussel bed on each survey date are shown in Tables 1-3. Biomass and population size increase and then decrease in Bed 1, which is not exploited, and decrease rapidly

over time in beds 2 and 3 which are exploited. Significant positive linear relationships between shell length (mm) and dry weight (g) were found for mussels in all beds (Table 4).



**Figure 3.** Mean mussel dry weight (g) at Beds 1 and 2 between June 2003 and June 2004 (a, b), and at Bed 3 between June 2004 and June 2005 (c) on the Emboraí mangrove estuary. Note that Bed 3 was surveyed twice in November (16 and 26th)

The appearance of smaller individuals occurred in August 2003 in Bed 1 (Figure 4) with subsequent growth shown by the increasing proportion of larger individuals between September and December 2003. At beds 2 and 3 (Figures 4 and 5), although there was no evidence for recent recruitment, growth of mussels occurred during the survey periods as the proportion of individuals in larger size classes increased.

**Table 1.** Total biomass (kg) and population size (1000 individuals) of *Mytella falcata* at Bed 1 in the Emboraí mangrove estuary, between June 2003 and June 2004

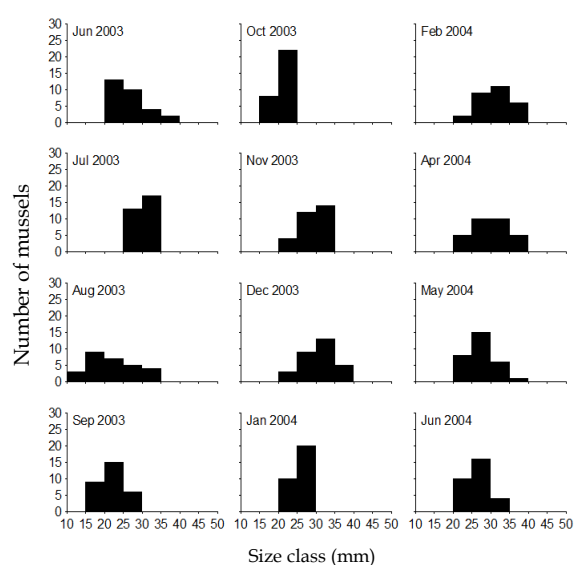
Month	Total biomass (kg)	Population size (1,000 individuals)
June 2003	1.5	6.0
July	1.0	3.8
August	10.0	29.5
September	42.4	141.4
October	85.7	182.5
November	141.8	191.7
December	151.8	194.6
January 2004	141.2	201.7
February	152.1	190.1
April	104.6	130.7
May	32.6	49.4
June	1.5	2.1

**Table 2.** Total biomass (kg) and population size (1000 individuals) of *Mytella falcata* at Bed 2 in the Emboraí mangrove estuary, between August and November 2003

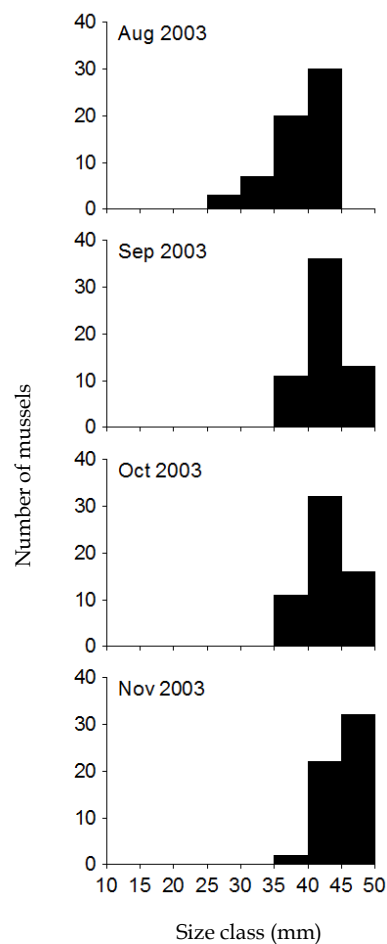
Month	Total biomass (kg)	Population size (1,000 individuals)
August 2003	4,759	90.6
September	1,595	25.0
October	2,712	35.0
November	561	7.8

**Table 3.** Total biomass (kg) and population size (1000 individuals) of *Mytella falcata* at Bed 3 in the Emboraí mangrove estuary, between September 2004 and January 2005

Survey date	Total biomass (kg)	Population (1,000 individuals)
30 Sep 2004	245	5.1
15 Oct 2004	341	9.0
16 Nov 2004	373	8.0
26 Nov 2004	411	8.2
11 Dec 2004	266	4.8
10 Jan 2004	38	0.6



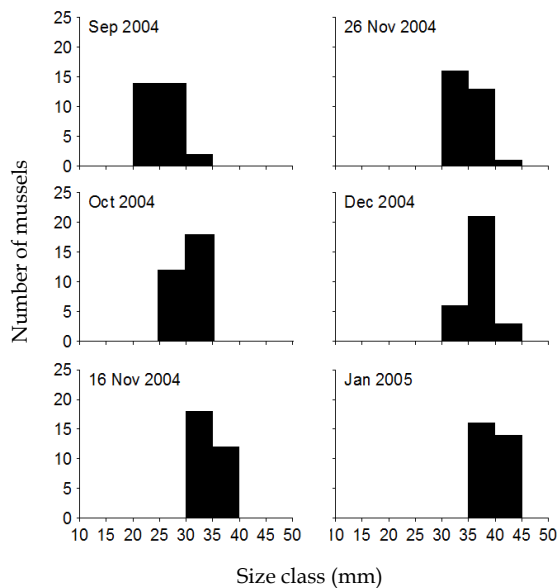
**Figure 4.** Mussel size frequency distributions at Bed 1 between June 2003 and June 2004 on the Emboraí mangrove estuary



**Figure 5.** Mussel size frequency distributions at Bed 2 between Aug 2003 and November 2003 on the Emboraí mangrove estuary

**Table 4** Relationship between shell length (mm) and dry weight (g) at the three mussel beds. Data were pooled over all survey dates

Mussel bed	Linear regression	Significance
1	$y = 0.0207x + 0.0447$	$F_{1,356} = 104, r^2 = 0.224, p < 0,001$
2	$y = 0.0227x - 0.3839$	$F_{1,238} = 338, r^2 = 0.585, p < 0,001$
3	$y = 0.0104x + 0.0704$	$F_{1,178} = 181.9, r^2 = 0.503, p < 0,001$

**Figure 6.** Mussel size frequency distributions at Bed 3 between September 2004 and January 2005 on the Emboraí mangrove estuary. Note that Bed 3 was surveyed twice in November (16 and 26th).

## DISCUSSION

### *Dependence of coastal populations on natural resources*

Human populations in coastal areas traditionally use the available natural resources from mangrove and estuarine habitats for a great diversity of purposes (GILBERT and JANSSEN, 1998; ALONGLI, 2002). In Maputo Bay, Mozambique, manual harvesting of large predatory crabs and oysters in intertidal areas is an important source of protein in an area where the raising of livestock is not widespread (BOER and PRINS, 2002). Coastal villages from the Pagbilao mangrove in the Philippines depend on artisanal methods to catch mud crabs (up to 75% of the value of the fishery), gastropods, marine crabs, fish and prawns (GILBERT and JANSSEN, 1998). In Zanzibar (Tanzania), between 10% to

30% of the population are involved in fishing and/or shellfish collection (SHUNULA, 2002). In Brazil, the Caeté mangrove estuary, close to the Emboraí mangrove estuary, is exploited by as many as 13,000 people in 21 communities where the majority depend on mangrove products for subsistence although there is significant commercial exploitation of crabs, fish, molluscs and mangrove wood (GLASER 2003; GLASER *et al.* 2003).

The exploitation of mussel beds in the Emboraí mangrove estuary is mirrored by similar situations in other parts of Brazil. In north-eastern Brazil, many people depend completely or partially on bivalve mollusc harvesting from mangrove estuaries in Maranhão (MUEDAS and MOREIRA, 2006), Paraíba (NISHIDA *et al.*, 2006) and Alagoas states (PEREIRA-BARROS and PEREIRA-BARROS, 1987). Even in relatively well-developed parts of Brazil, such as the state of São Paulo in the south east, fishermen during the off-season, and unemployed residents of coastal areas harvest the brown mussel (*Perna perna*) from rocky shores, which are then sold locally (HENRIQUES *et al.*, 2004).

The dependence on coastal habitats is growing since up to 55% of the global population now occupies such areas (ADEEL and POMEROY, 2002). Overexploitation of shrimp fry by poor fishermen and unemployed people for use in aquaculture in the Bay of Bengal is of concern (ISLAM and WAHAB, 2005). Increased coastward migration and the lack of alternative employment together with low costs and easy access has meant that the number of people involved in the exploitation of shellfish has increased (DIEGUES, 2004), despite decreases in income from these activities (GLASER and DIELE 2004). Although no data are available yet for mussel beds in Pará, an increase in their exploitation would be expected

for the same reasons. Such an increase has been observed in Maranhão (MUEDAS and MOREIRA, 2006). A predicted near-future decline in the rate of global population growth offers hope that the exploitation of mangroves will also decline thereafter (ALONGI, 2002).

#### *Indicators of overexploitation*

Many biological and ecological indicators of ecosystem damage or resource use have been proposed. For example, brachyuran crabs appear to reflect the past history and age of Malaysian mangroves such that oxypodids and grapsids (especially sesarmids) were abundant and diverse in younger, disturbed and older, mature stands, respectively (ASHTON *et al.*, 2003). BOER and PRINS (2002) did not find any evidence for an impact of human exploitation of mainly predatory crabs on a range of biological measures (density, biomass, richness, etc.) taken from an intertidal mud flat invertebrate assemblage in Mozambique. In this case, the low harvest rate (5%) in comparison to the available biomass, as well as the high motility and escape rate of target species, were cited as reasons for the lack of any impact.

Within mussel beds, however, animals are sessile, easily found and removed and thus they are more vulnerable to the effects of harvesting. Similar to our results, BLANDTT and GLASER (1999) observed a reduction in size and/or the disappearance of exploited mussel beds in the Caeté mangrove estuary. The exploitation of mussel beds may be monitored to allow management decisions to be taken regarding the intensity and timing of harvesting. Mussel density and spatial dispersion may be used as unbiased and easily measured indicators of the structural integrity of the mussel bed. Densities below 1 500 individuals m<sup>-2</sup> and dispersion patterns that deviate from contagiousness indicate a negative impact of exploitation and the need to reduce or halt harvesting.

Some studies have observed natural declines in abundance of *Mytella falcata* in the absence of exploitation. Laboratory studies have shown that *M. falcata* does not tolerate either very high (>35) or very low (<2) salinity and values between 5 and 15 are optimal for survival (PEREIRA-BARROS and MACÊDO, 1967). Mass mortality of *M. falcata* has been observed at Mundaú Lagoon, Alagoas

during the wet season (PEREIRA-BARROS, 1987), although this is a special case of a lagoon essentially becoming a freshwater lake. FERNANDES *et al.* (1983) found that at the beginning of the dry season in Maranhão state, mid-estuary stocks of *M. falcata* declined from over 10,000 m<sup>-2</sup> to under 1,600 m<sup>-2</sup> and in the lower estuary, stocks disappeared altogether. However, no abrupt variation in salinity had occurred and the authors believed the decline may have been due to natural predation. Intraspecific competition among mussels is another possible cause of declines in density since the concentration of phytoplanktonic food declines immediately above the bed and interference competition through physical pressure exerted by mussels on each other can reduce shell gape and thus food intake in dense patches of mussels (FRÉCHETTE *et al.*, 1989). The high variability in density in Bed 1 between September 2003 and February 2004, when densities increased, may have been the result of mortality due to intraspecific competition, thus increasing spatial heterogeneity.

We observed a natural, unexploited mussel bed and found that density declined between February and July, which period corresponds to the wettest part of the year when low salinity (0-10) prevails. However, not all mussels died, and dry weight and size remained high in surviving individuals, demonstrating the possibility of mussel beds remaining viable all year round, once exploitation is regulated.

Shell length may be used as an indicator of the growth of individuals in the bed, recruitment and the approximation to market size of mussels. In the Emboraí estuary, mussel length increases over time despite continual harvesting. This suggests that larger mussels are not especially selected for removal. The methods of removal, using rakes, shovels and other mainly agricultural implements, are very non-selective and so small mussels are also removed. Even small mussels (>12 mm) are sold in local markets along with the larger ones, the price depending on the average perceived size. However, this may be wasteful as these smaller mussels could reach market size (40 mm) in about 4-5 months (pers. obs.), and could also reproduce in the meantime. Non-selective collecting of *Mytella falcata* was also observed by NISHIDA *et al.* (2006) where bunches of mussels



are cut using a straight-bladed sickle and the mussels separated from the sediment and byssal threads only after returning to shore. The only non-exploited mussel bed in our study was composed of small individuals fixed to a small area of rocky substrate higher up the estuary (less time immersed during high tide) where there was a low return (small quantity of meat) for a greater harvesting effort (more difficult to remove).

#### *Management of exploited mussel beds*

Overexploitation of any resource leads to scarcity and results in costs for the users through increased harvesting effort (GILBERT and JANSSEN, 1998). The resource may disappear altogether, and, in this case, users have to go without that resource or look for alternatives. Such is the case with the mussel beds of the Emboraí estuary, where exploitation leads to the eventual disappearance of the mussels. Users must wait for the beds to recover, a process that may take up to 8 to 10 months. HENRIQUES *et al.* (2004) found that fishermen harvesting the brown mussel *Perna perna* in São Paulo were aware of the time necessary for recovery of the beds (also 8-10 months) and would often wait longer to guarantee the recovery process.

Mussel beds depend on the arrival of larvae, the abundance of which varies with time and location (GOSLING, 2003; MARQUES-SILVA *et al.*, 2006). Management of mussel harvesting could allow the beds to remain productive throughout most of the year. Management practices could include creating a limit to the size of the harvest per user, allowing a minimum density of mussels to remain in the bed after harvesting, permitting the use of certain approved techniques for the removal of mussels (to avoid damage to the sediment/bed structure) as well as the establishment of a minimum length of mussel that could be taken. NASCIMENTO (1968) found that spawning in *M. falcata* occurred from around 18 mm in length or between 2 and 3 months of age (NASCIMENTO, 1969). Throughout most of the year (9 months) the percentage of spawning individuals was at least 50% showing that year round reproduction and recruitment may occur in this species in warm, tropical waters. However, PEREIRA and GRAÇA LOPES (1995), in a two-year study, found that there was a single, very

well defined, pulse of settlement of *M. falcata* in December (southern hemisphere summer), with little or no settlement for the rest of the year in sub-tropical waters of São Paulo state.

Although very time-consuming, the use of more size-selective removal techniques is also encouraged. More precise cutting tools could allow removal of market sized individuals but leave behind smaller ones. These measures would maintain the adult mussel stocks for longer, allowing them to reach a larger, marketable size (40 mm) which would add both nutritional and economic value to the product. Establishment of a minimum size limit would also allow the adults to reproduce before being harvested and would thus enhance recruitment of juveniles to the beds (HENRIQUES *et al.*, 2001). Many larval bivalves are able to detect the presence of adult conspecifics and there is evidence to suggest that larval mussels prefer to settle on or near adults (GOSLING, 2003).

The maintenance of biodiversity is also important for habitat conservation. For example, in Malaysian mangroves, crab diversity was lower and species composition was different in stands that were heavily exploited for wood in comparison to less exploited ones. Due to activities such as burrowing, a diverse crab fauna appears to be important for the reestablishment of seedlings (ASHTON *et al.*, 2003). Management of mussel beds would also help conserve the diversity of the estuarine benthic community (diverse worms, other molluscs, crustaceans, benthic algae and microorganisms) usually associated with bivalve reefs (DAME, 1996). These organisms are important for nutrient cycling (DAY *et al.*, 1989; DAME, 1996), which enhances phytoplankton growth. In turn, mussel growth and reproduction is increased through filter-feeding on phytoplankton, thus contributing to the maintenance of the mussel beds. The organisms associated with mussel beds also serve as prey items for economically important species of fish and crab (DAME, 1996) as well as birds (DAME, 1996; DAY *et al.*, 1989). The diversity and abundance of the associated benthic fauna is a potential indicator of exploitation (BOER and PRINS, 2002) and should be investigated in *Mytella falcata* beds.

*Access rights, legislation and the future of bivalve exploitation*

Sustainable management of open-access natural resources is difficult and requires a great deal of commitment and cooperation between authorities, business and the local community (ALONGI, 2002). HENRIQUES *et al.* (2004) found that although mussel harvesters in São Paulo were aware of the benefits of leaving a mussel grow for longer before harvesting, the fear of a competitor removing the same mussel “during the next tide” was often an impediment to better management of the beds. There is therefore a good deal of both economic and political conflict over resource use and management (GLASER *et al.* 2003; GLASER and OLIVEIRA, 2004). Local common management, where resident users may exploit a resource, in a subsistence or small-scale manner is becoming common in mangrove communities of northern Brazil (GLASER and OLIVEIRA, 2004). Co-management of mangroves is also being carried out within diverse integrated management plans in various parts of the world (ADEEL and POMEROY, 2002), including Bangladesh (IFTEKHAR and ISLAM, 2004; ISLAM and WAHAB, 2005), Tanzania (SHUNULA, 2002) and Myanmar (OO, 2002). In contrast, mangrove conservation in Hong Kong tends toward protecting biodiversity and ecosystem function because of the widespread destruction of, and the lack of economic dependence on, mangroves (TAM and WONG, 2002).

Brazilian legislation, *Lei Federal No 4.771/65 (Código Florestal)*, makes it illegal to remove mangrove vegetation (GLASER *et al.* 2003), however, traditional activities such as the harvesting of shellfish and fishing in tidal channels are not prohibited by this law. On the other hand, Pará state laws (*Lei de Crimes Ambientais No. 9.605, 12/02/1998, Artigo 29*) prohibit the killing or capture of wild animals without due authorization. In Augusto Corrêa, recently proposed municipal environmental legislation (*Projeto de lei N.º 006/2007*) aims to protect and preserve the flora and fauna and inhibit activities that pose a risk to ecological function. It also specifies mangrove conservation as a priority as well as aiming to guarantee the exploitation of natural resources in an ecologically

balanced manner such that poverty is eliminated and social inequalities reduced.

The concept of protected areas called *reservas extrativistas* (RESEX) where resources could be traditionally exploited and managed by a local community also exists in Brazilian law (*Lei Federal No. 98.897*). The RESEX concept may allow a more sustainable approach to coastal resource management (GLASER *et al.*, 2003; DIEGUES, 2004; GLASER and OLIVEIRA, 2004). However, RESEXs may provide only a partial solution. Data are needed on the carrying-capacity of the mangrove in relation to human populations, and experience in other Brazilian ecosystems has shown that migration into RESEXs may reduce sustainability (SAINT-PAUL, 2006). In addition, as GLASER *et al.* (2003) point out, the conflict among the differing types of legislation must also be resolved. In Augusto Corrêa, the RESEX Araújo-Peroba was established in 2005 and includes the Emboraí estuary. Formal arrangements for the sustainable exploitation of the mussel beds may therefore be made by those communities within the RESEX.

Finally, production of fish or shellfish via aquaculture has been cited as an alternative to traditional exploitation (ISLAM and HAQUE, 2004; MUEDAS and MOREIRA, 2006) but the investment needed is often relatively high and usually tends to attract outsiders and not local residents (GILBERT and JANSSEN, 1998). In the Red River estuary, Vietnam, clams became an important export item from 1990, stimulating the expansion of clam culture by wealthy individuals to the exclusion of traditional clam gatherers (VAN HUE, 2003). Plant or animal cultures are not the same as natural stocks (GILBERT and JANSSEN, 1998) and are often viewed and treated differently (WALTERS, 2004). Finally, cultured stocks depend on natural ones, through the supply of larvae and juveniles (HENRIQUES *et al.*, 2001; Rönnbäck *et al.*, 2003; ISLAM and HAQUE, 2004; ISLAM and WAHAB, 2005), which must be managed anyway, along with the mangrove habitat (ISLAM and HAQUE, 2004). In Brazil, mussels may, however, be cultivated on a family-scale for subsistence, with relatively little investment (HENRIQUES *et al.*, 2001). By collecting spat on cords or netting and raising them in small cheap plastic containers, market-

sized *M. falcata* may be obtained in 4-5 months (pers. obs.). Small-scale mussel culture could supplement the harvest from natural beds once these are managed in a sustainable way and would also be compatible with RESEX management principles.

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