Variation of populations densities between two species of barnacles (Cirripedia: Megabalaninae) at Guanabara Bay and nearby islands in Rio de Janeiro/RJ.

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Abstract

The Guanabara Bay is a very complex environment where anthropic influences take place since the beginning of the Brazilian colonization and even before. Some natural marine populations could possible be extinguished while others were introduced in this area. This study is an attempt to monitor the native species *Megabalanus tintinnabulum* (Linnaeus, 1758) and the introduced one *Megabalanus coccopoma* (Darwin, 1854) at some sites in the bay and also at two islands nearby. The objectives are to evaluate the potential of growth and colonization of this two species, as well as competitive aspects between them, considering their densities at different sites. The hypothesis is that under already stressed environments, non-indigenous species (NIS) could have a higher potential to survive, when compared with indigenous species. Data were taken from artificial substrata and natural rocky coast. Sampled organisms where measured and identified in the laboratory and also in the field. The results show that the NIS *M. coccopoma* is at higher densities compared with the native *M. tintinnabulum* at natural rocky coast and artificial substrata. This corroborates the hypothesis that NIS has a great potential to adapt and develop under stressed environments.

Key words: Brazil, Cirripedia, Guanabara Bay, *Megabalanus*, Non-indigenous species (NIS), Recruitment.

Introduction

Cirripeds are organisms widely used on intertidal and subtidal rocky shores' studies. As a sessile invertebrate, they may cover substantial area of the substratum where space is an important resource for competition (Apolinário, 1999a, b; Davis and Ward, 1999). These aspects make this group important in studies on recruitment, growth and mortality rates, as well as, determining and monitoring environmental impacts in coastal areas (Connell, 1972; Underwood and Fairweather, 1989; Sutherland, 1990).

The Guanabara Bay, located SW in the State of Rio de Janeiro, Brazil, is a very complex environment where anthropic influences have taken place since the beginning of the Brazilian colonization. Some natural marine populations could possibly be extinguished while others were introduced in this area. Also, not only is an organism's living environment spatially and temporally changing, but also, is an open system into which various species are moving, specially for many marine organisms that spend their larval period floating in the open seas (Shigesada and Kawasaki, 1997).

The subtidal zone along this bay is called the "mussel's belt" and there is the place where the native species *Megabalanus tintinnabulum* (Linnaeus, 1758) used to occur in high densities since the first field surveys (Leuderwaldt, 1929; Oliveira, 1940, Lacombe and Monteiro, 1974; 1941). However, a more recent survey, showed the presence of the non-indigenous species (NIS) *Megabalanus coccopoma* (Darwin, 1854) occurring at the subtidal space (Young, 1994). *M. coccopoma* is considered an opportunistic species easily adapted to recruit an survival in stressed environments and artificial structure (Newman and MacConnaughey, 1987). Newman and Stanley (1981), argue that balanids are reducing the diversity of chthamalids through time. Also, among balanids, competition for space among native and NIS is the main reason for the drastic effects on the composition of rocky coast and artificial substratum subtidal communities at stressed environments. Shigesada and Kawasaki (1997) point three possible strategies whereby a NIS can persist: (1) it takes over the native species' habitat through direct competition; (2) competition with the native species is not so aggressive that it coexists with the native species after establishment; (3) even though competitively weak, it survives by moving to open spaces that arise either occasionally or periodically. Seen from a biological time scale, against the large geological time scale from Cox and Moore (1993), native Megabalaninae species from the Guanabara Bay are possibly struggling for surviving under strategy (1) above.

This study is an attempt to monitor the native species *M. tintinnabulum* and the NIS *M. coccopoma* at some sites in the Guanabara Bay and also at two islands nearby. The objectives are to evaluate the potential of growth and colonization of these two species, as well as, competitive aspects between them considering their densities at different sites. The hypothesis is that at already stressed environments, NIS could have a higher potential to recruit and survive, when compared with indigenous species.

Material and Methods

Samplings were carried out at three sites inside the Bay (Ponte, Morcego and Urca) starting June 1999 and at two more sites at Pai and Comprida Islands starting December 1999. *M. tintinnabulum* and the NIS *M. coccopoma*, occur below the lowest tidal level within mussel belts (*Perna perna*), and the access for the quadracts is by free diving, using a boat to get close to the rocky shores and to the bridge-tie number 92 (at site Ponte). Since the sampling design is based on five sites, samples at all sites were taken at about 2 weeks interval (according to the weather conditions) so that the same site could be visited again at about 2 months interval.

A 900-cm^2 quadract is the reference for scrapping and taking the samples based on a random experimental design (Table I). Before June 1999, several samples were taken to measure the relationship between the standard deviation and the number of replicates at each site, determining the number of five replicates for each treatment, at each site (Pielou, 1974). The software EDGAR (Experimental Design Generator And Randomiser) available at "http://www.jic.bbsrc.ac.uk/services/statistics/edgar.htm" provided a Randomised Complete Blocks design (Table II).

Some adults and recruits were taken to the laboratory for the measurement of rostrum-carina sizes and an accurate identification of the organisms. Also, non-destructive technique was used to count numbers of individuals and size in the field, by free diving and taking note in a waterproof note pad.

Table I: Sampling design for three types of quadracts.

Type	Name	Date
Not cleared	Control	Adult population
Cleared at the beginning	Succession	Survivorship of recruits
Cleared at the beginning and after each new visit	Recruits	Recruitment

Table II: Randomised Completed Bolcks Design created by the software EDGAR.

Block 1	Block 2	Block 3	Block 4	Block 5
Succession	Recruits	Succession	Succession	Control
Recruits	Succession	Control	Control	Succession
Control	Control	Recruits	Recruits	Recruits

Study Site

Located at the State of Rio de Janeiro (RJ), Brazil, the Guanabara Bay (22° 37' and 22° 57' S - 43° 02' and 43° 16' W) covers a perimeter of 130 km and an area of 370 km^2 approximately, respectively, with a maximum depth of almost 30 m (Fig. 1).

A particular geographic characteristic of the State of Rio de Janeiro is that its littoral is almost E-W oriented, and the Guanabara Bay is N-S oriented. Comprida and Pai islands are approximately 5 and 2 km distant from the entrance to the bay, respectively.

Comprida Island is situated at the archipelago of Cagarras, just in front of Ipanema beach, in Rio de Janeiro City and Pai Island is located in front of Piratininga beach in Niterói City. They represent sites off the bay where the marine invertebrate fauna could be less influenced by the anthropic impacted waters from the Guanabara Bay.

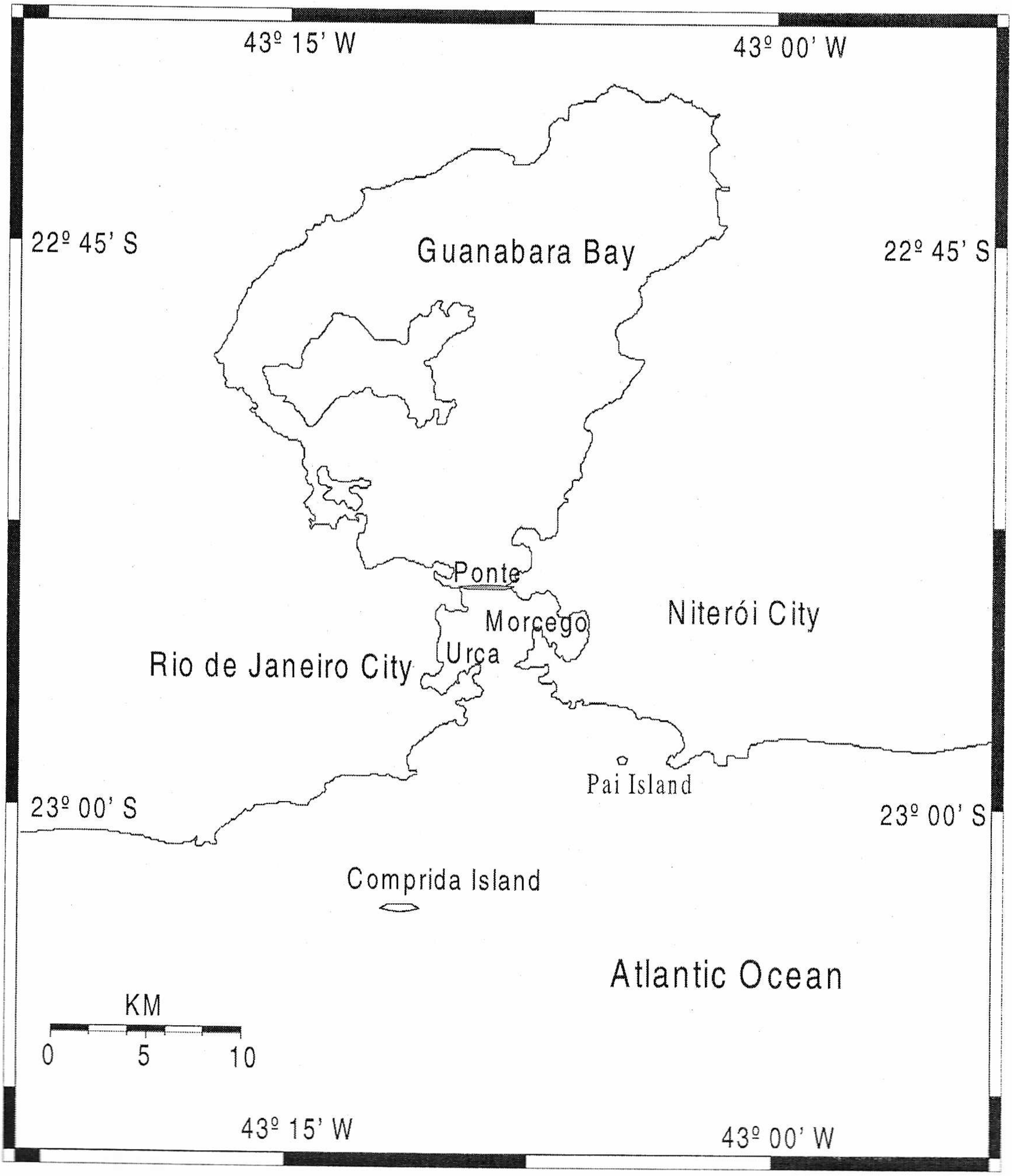


Figure 1: The Guanabara bay, RJ, Brazil and the sampling site locations. Image source: On Line Map Creation available at http://www.aquarius.geomar.de/omc.

Data Analysis

A two-way ANOVA (repeated measures) formed the basis for data analysis using the factors Time and Site. Also, a linear correlation was calculated for the number of recruits of *M. coccopoma* and *M. tintinnabulum* against the mussel *P. perna*. Data underwent square root transformation to ensure the equality of the variances, before being transformed into frequency data, followed by arcsine transformation to run ANOVA (Underwood, 1997). The first surveys at each site were conducted from February/March to May/June 1999. At this time, the exact sampling location was determined, according to logistical aspects such as access facility, wave impact and human interference. The next step was to find out the appropriate number of replicates for each treatment at each site. A total number of ten quadracts were sampled and the standard deviation was calculated to find a best number of quadracts necessary to sample with a stable SD (Fig. 2). Considering the trend, especially for *M. coccopoma*, a total of five quadracts was assumed to be representative and logistically viable for this study. Along with both species of *Megabalanus*, four others species of *Balanus* were sampled at the five sites. They are also important Cirripedia incrusting fauna, but not considered in this study (Table III). Figures of these species as well as general observations of barnacles are available at "http://www.geocities.com/barnacles_br".

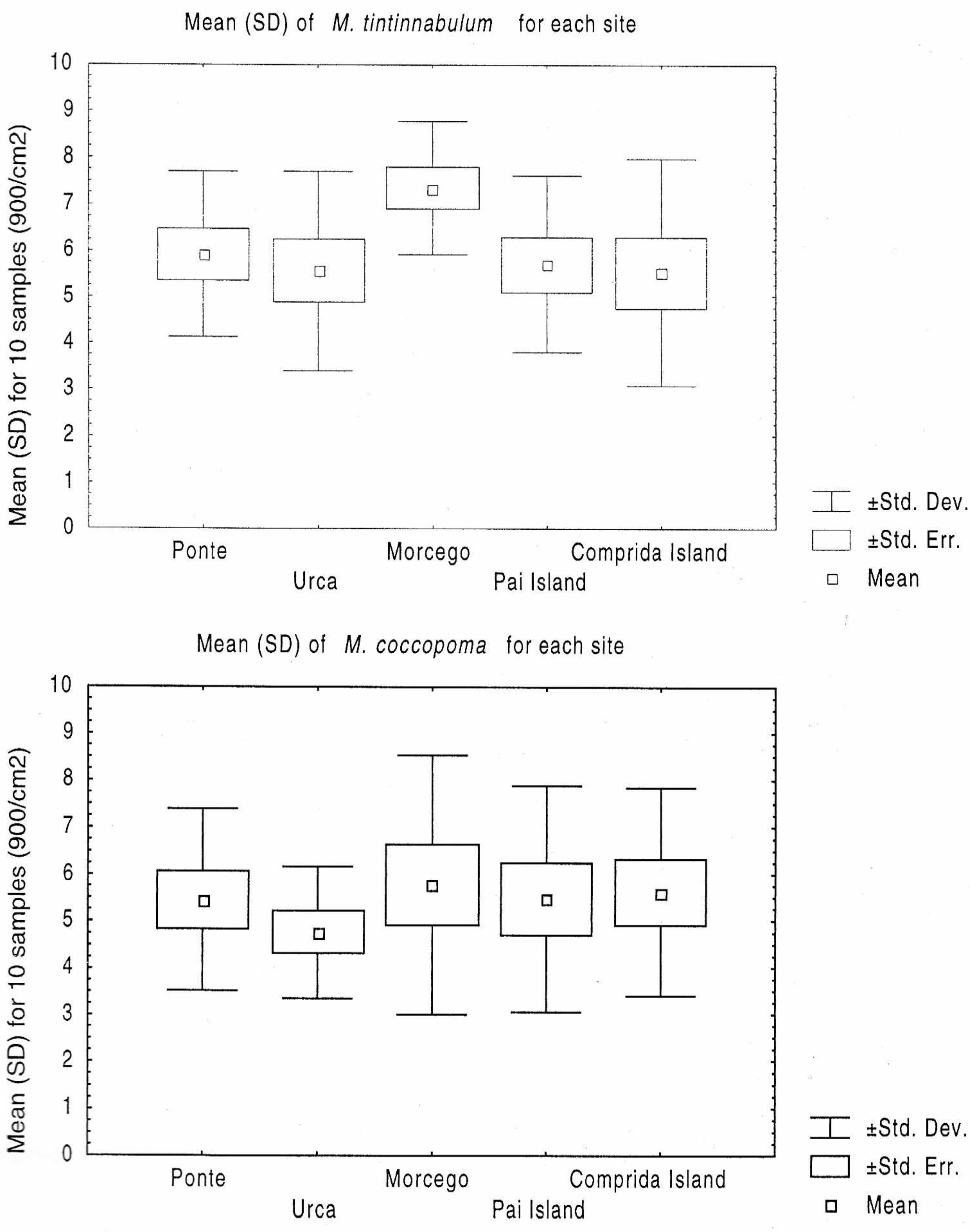


Figure 2: Mean (SD) of *M. coccopoma* and *M. tintinnabulum* for each site, sampled for 10 quadracts of 900 cm^2 each.

Table III: Frequency of Balanidae found at sites Ponte, Urca, Morcego Pai Island and Comprida Island. "0" = absent, "+" = sampled only once, "++" = sampled more than twice, "+++" = sampled all the times.

Taxa	Sites				
	Ponte	Urca	Morcego	Pai Island	Comprida Island
Subclass Cirripedia					
Order Thoracica					
Suborder Balanomorpha					
Superfamily Balanoidea					
Family Balanidae					
Balanus amphitrite Darwin, 1854	+++	0	0	+	+
B. eburneus Gould, 1841	+++	+	0	+	+
B. improvisus Darwin, 1854	+++	+	+	++	++
B. trigonus Darwin, 1854	++	+	+	++	++
Subfamily Megabalaninae Newman, 1979					
Megabalanus coccopoma (Darwin, 1854)	+++	+++	++	+++	+++
M. tintinnabulum (Linnaeus, 1758)	++	+	+	++	++

Results

The adult population does not varied significantly among sites Ponte, Urca, Comprida Island and Pai Island, for both species. However, site Morcego shows a very low density of barnacles. Also, great difference between the densities of both species seems to be the major results that express how competitive the NIS is (Fig. 3). The recruitment of *M. coccopoma* shows different patterns among the sites. Inside the bay, site Urca got important peaks of recruitment by the end of 1999. On the other hand, site Ponte was quite stable through time and site Morcego with almost zero recruitment. At the two islands nearby the bay, important peaks of recruitment were observed by the end of 1999, followed by a decline in the beginning of 2000 and another peak by August 2000. *M. tintinnabulum* shows a small recruitment activity at the five sites through time, with just a small trend of recruitment to be considered at sites Pai and Comprida Islands (Fig. 4). See also the summary the results of the two-way repeated measures ANOVA for each treatment (Table IV).

Another important result is summarized in figure 5. It shows how recruits of *M. coccopoma* are associated with the presence of the mussel *P. perna*. The value of $r = 0.64177$ for this figure (on the top) could be more expressive if we do not consider the first months of the study when the two sites at Pai and Comprida Islands were not included. *M. tintinnabulum* shows no association with *P. perna*, suggesting an important adaptive characteristic of the NIS.

Table IV: Summary of results from the two-way ANOVA for adult population and recruits.

Source		df	P
Adult population	Time	7	0.2540 NS
	Sites	4	0.001 *
	Time vs. Sites	3	0.1687 NS
Recruits	Time	7	0.1350 NS
	Sites	4	0.001 *
	Time vs. Sites	3	0.2650 NS

$^{*}\alpha = 0.05$

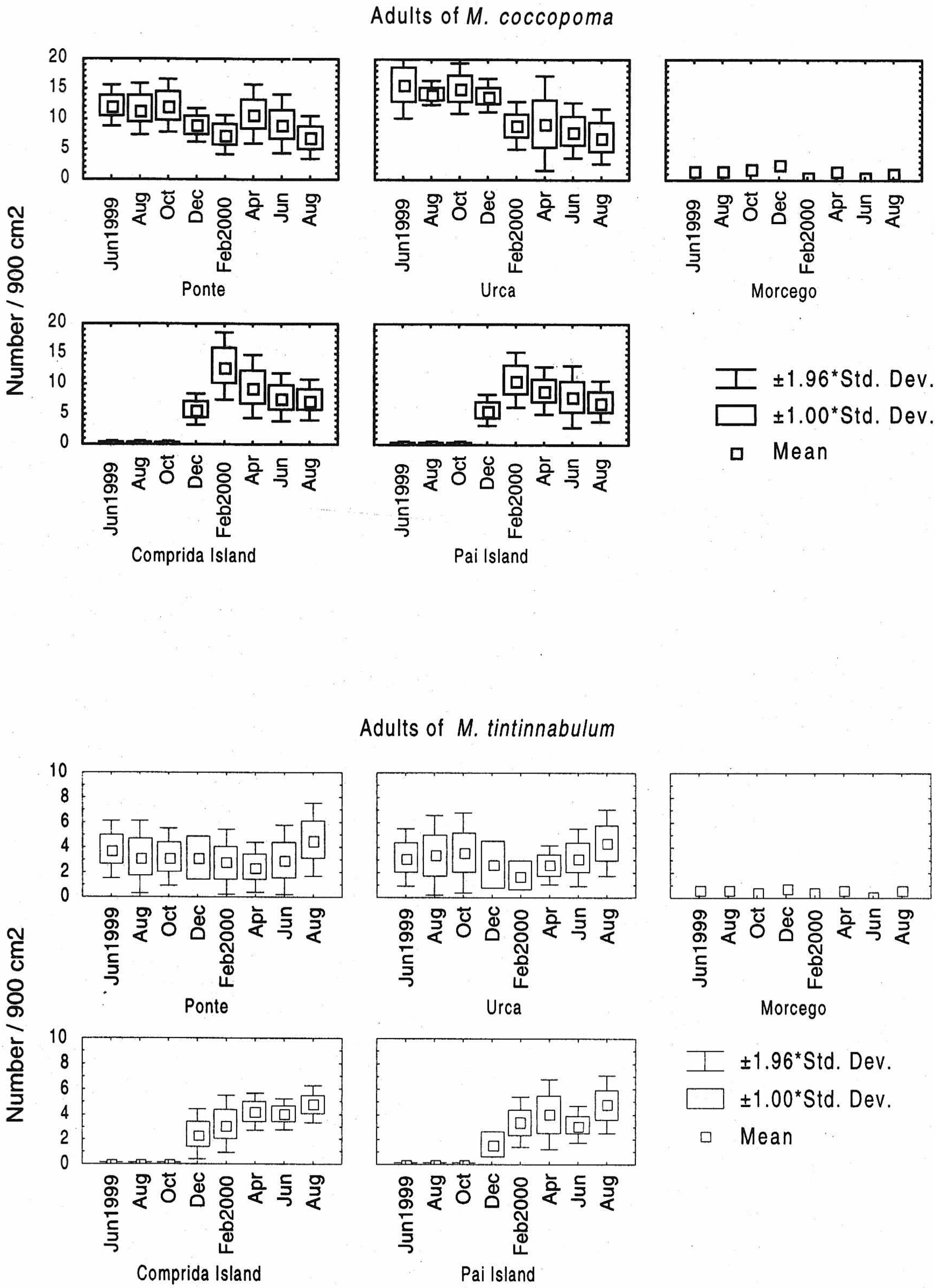


Figure 3: Mean (SD) variation of adults of *M. coccopoma* and *M. tintinnabulum* for each site.

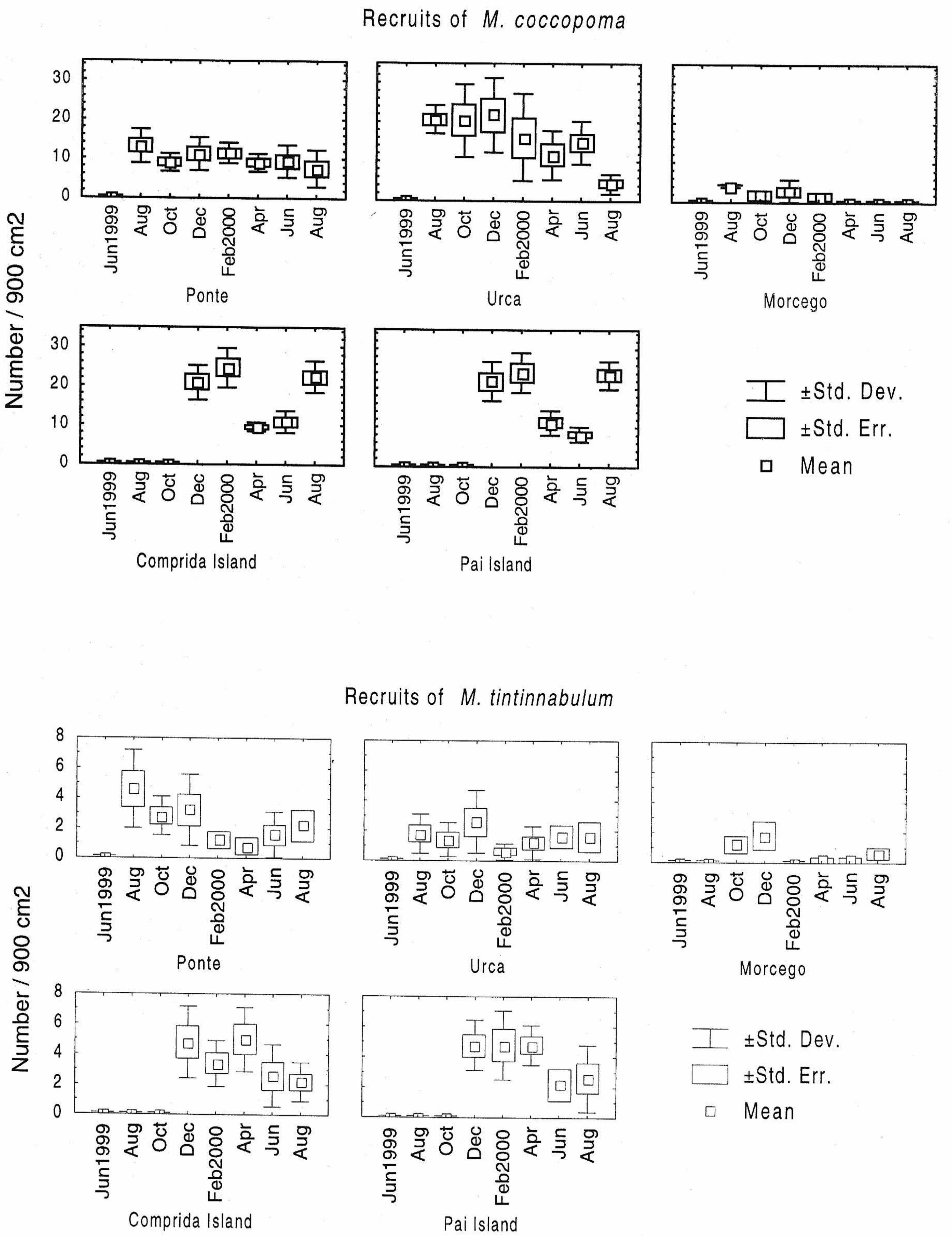
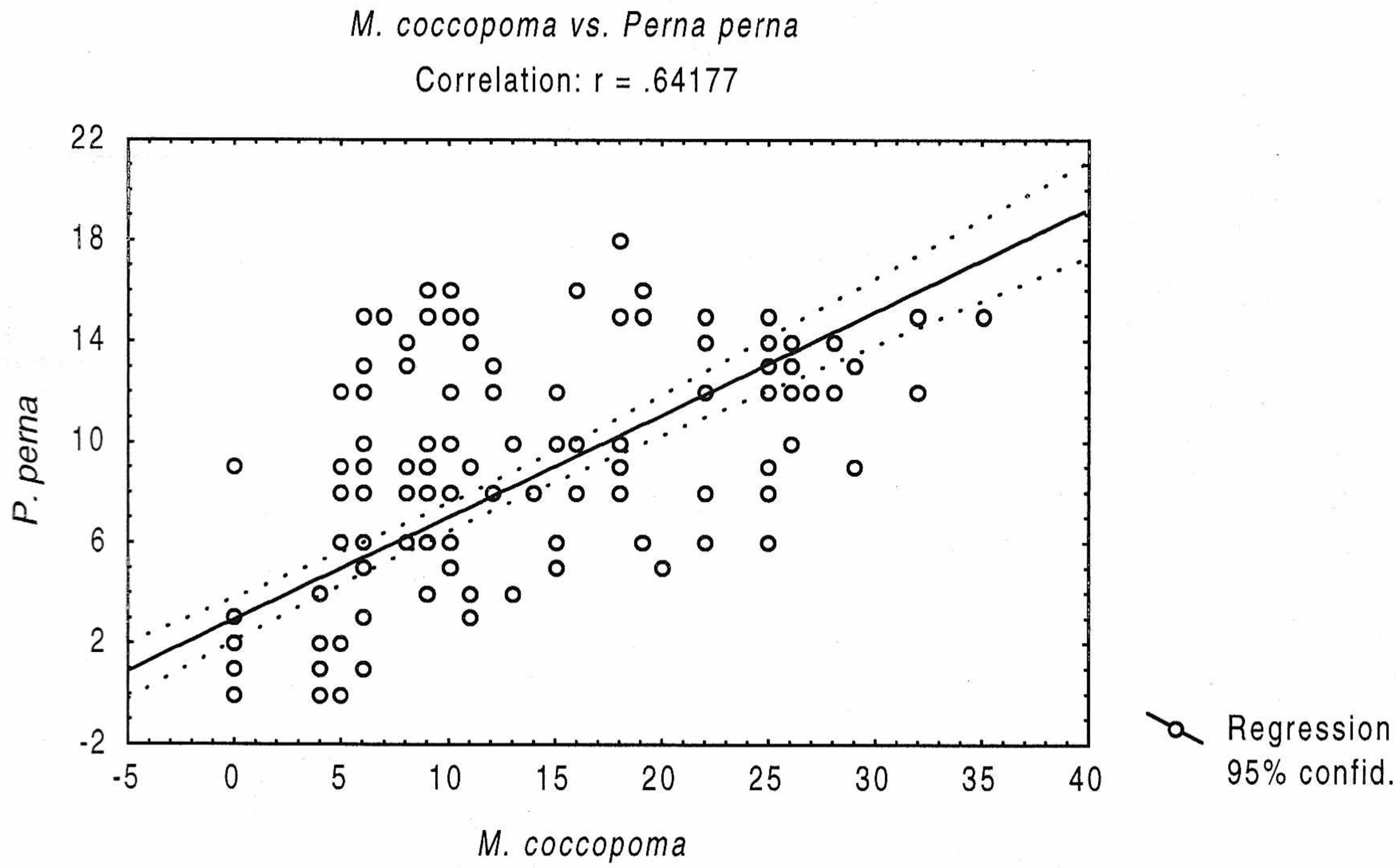


Figure 4: Mean (SD) variation of recruits of *M. coccopoma* and *M. tintinnabulum* for each site.



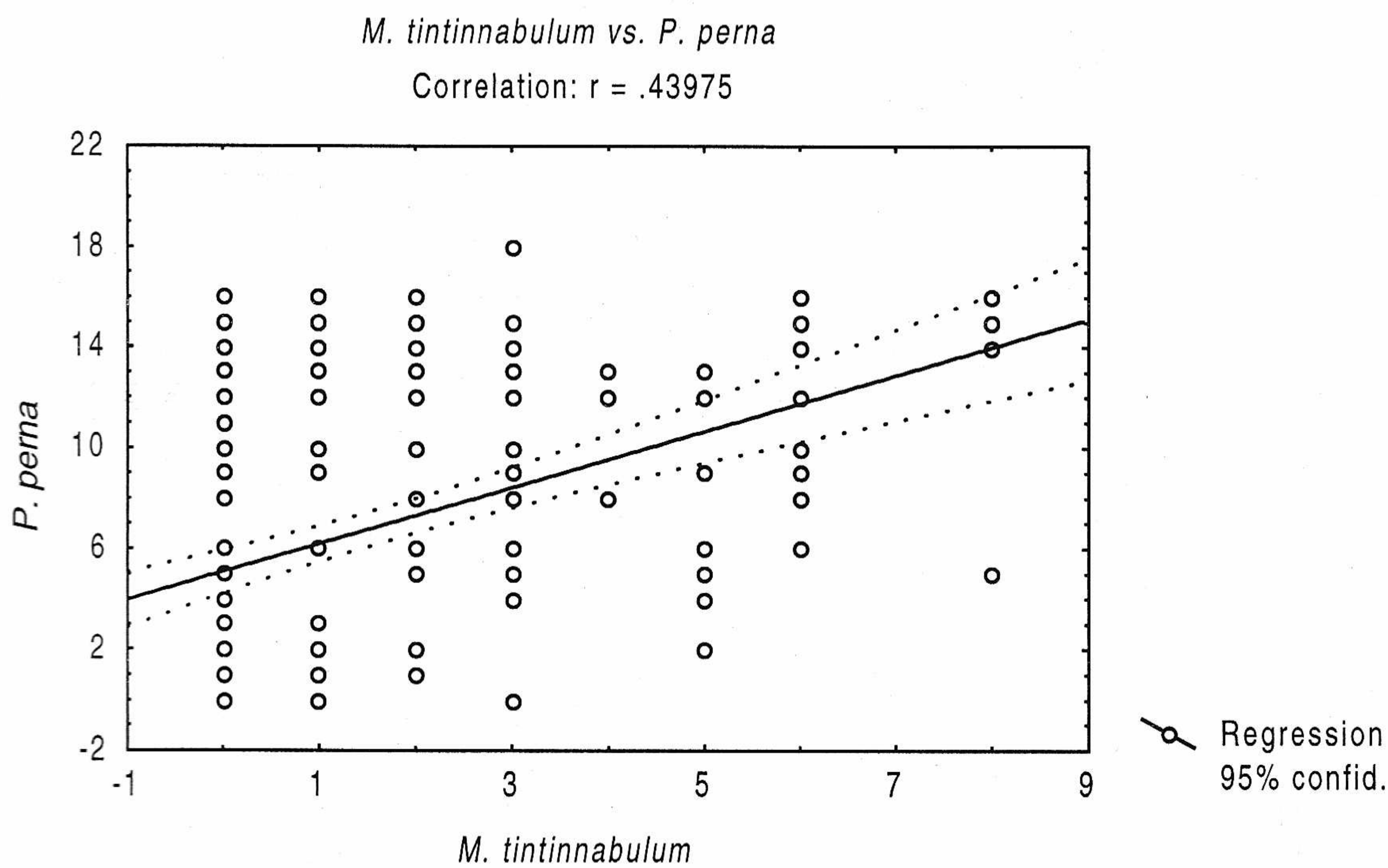


Figure 5: Linear correlation of *M. coccopoma* and *M. tintinnabulum* by *P. perna*.

Discussion

Differences in densities between *M. coccopoma* and *M. tintinnabulum* are clear for all sites, being the NIS (*M. coccopoma*) in a much higher density, through time. Patterns of variation of adult population and recruits show the establishment of the NIS at this environment, supporting the initial assumption that NIS would have a higher potential to recruit and survive in a already stressed environment. Böhme (2000) and Enserink (1999), also support the view that invaders often grow quickly and have short reproductive cycles. These important aspects are to be considered in a separate work, after concluding the sampling program (by March 2001), giving reasons for the successful establishment of the NIS at Guanabara bay.

Another important fact is the great number of the NIS recruiting over the mussel belt (*P. perna*). According, with Underwood (2000), competitive interactions on rocky shore are of three general types: pre-emptive, where one species prevents another one from settling from the plankton (e.g. Underwood and Denley, 1994); interference competition, or contest competition, where the use of space directly affects the other species (*e.g.* Connell, 1961; Menge, 1976); and finally exploitative or scramble competition, where several species need the same space to feed (*e.g.* Underwood, 1984). The model of competition that I suggest for these studied populations would be the pre-emptive, due to the fact that the NIS recruits better at the mussel belt, using the space available more efficiently. Following this line of thought, the mussel belt seems to be one of the key factors of the NIS success, since the barnacle could find habitat on and amongst mussels in a better way than it would on the rocky surface, providing the NIS a competitive advantage.

The aspects regarding the supply of larvae through time should also be considered to explain different abundances of recruits from both species. However, difficulties to distinguish between cypris larvae from *M. coccopoma* and *M. tintinnabulum* were considered at this study. Hence, assuming that those populations are part of a complex meta-population system, and the supply of larvae could come from a distant or close related population, methods of molecular genetics should be the best alternative to investigate the importance of short- or long-term larval dispersion (Gosling and McGrath, 1990; Gallardo and Carrasco, 1996). The molecular approach is already being carried out and will add more accurate information about the dynamics of those populations.

In conclusion, this study reveals the way how a NIS makes better use of the resource (space) in comparison with a native species, in a particular environment influenced by urban centers. No attempt or further assumptions of the illness of this process were made. Vermeij (1991) suggest that species ranges have fluctuated as a result of climate and biological interactions, in a natural way. However, the role of anthropic influences in biological introductions, especially after the 50's, is a major concern and topic of must investigations for researches the entire world. Terms like "Macdonaldization of biosphere" (Lövei, 1997) and "global McEcosystem" (Enserik, 1999) are unquestionable indications of the impacts of this problem in our society and the need for further investigations.

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References

Apolinário, M. 1999a. Temporal variations in community structure in and around intertidal barnacles (*Chthamalus challengeri* Hoek) patches on a plebby shore in Japan. Revista Brasileira de Biologia 59(1): 43-53.

Apolinário, M. 1999b. The role of pre-recruitment processes in the maintenance of a barnacle (*Chthamalus challengeri* Hoek) patch on an intertidal pebble shore in Japan. Revista Brasileira de Biologia 59(2): 225-237.

Böhme, W. 2000. Are non-indigenous species "ecological malignancies"? Ethology Ecology and Evolution, 12: 323-328.

Connell, J. H. 1961. The influence of interespecific competition and other factors on the distribution of barnacle *Chthamalus stellatus* . Ecology 42: 710-723.

Connell, J. H. 1972. Community interactions on marine rocky intertidal shores. Annual Review of Ecology and Systematics. 3: 169-192.

Cox, C. B. and Moore, P. D. 1993. Biogeography. An ecological and evolutionary approach, 5th ed. Blackwell, Oxford.

Davis, A R. and Ward, D. W. 1999. Does the large barnacle *Austrobalanus imperator* (Darwin, 1854) structure benthic invertebrate communities in SE Australia? Memoirs of the Queensland Museum 44: 125-130.

Enserik, M. 1999. Biological invaders sweep in. Science 285: 1842.

Gallardo, M. H. and Carrasco, J. I. 1996. Genetic cohesiveness among populations of *Concholepas concholepas* (Gastropoda: Muricidae) in Southern Chile. Journal of. Experimental Marine Biology and Ecology 197: 237-249.

Gosling, E. M. and McGrath, D. 1990. Genetic variability in exposed-shore mussels, *Mytilus* spp., along an environmental gradient. Marine Biology 104: 104-113.

Lacombe, D and Monteiro, W. 1974. Balalídeos como indicadores de poluição na baía de Guanabara. Revista Brasileira de Biologia, 34 (4): 633-644.

Leuderwaldt, H. 1929. Resultados de uma excursão científica à ilha de São Sebastião no litoral de estado de São Paulo em 1925. Revista do Museu Paulista, São Paulo, 16: 1-79.

Lövei, G. L. 1997. Global change through invasion. Nature 388: 627-628.

Menge, B. A. 1976. Organization of the New England rocky intertidal community: role of predation, competition and environmental heterogeneity . Ecological Monographs 46: 335-393.

Newman, W. A. and McConnaughey, R. R. 1987. A tropical eastern pacific barnacle, *Megabalanus coccopoma* (Darwin), in southern California, following El Niño 1982-83. Pacific Science, vol. 41: 31-36.

Newman, W. A. and Stanley, S. M. 1981. Competition wins out overall: Reply to Paine. Paleobiology, 7(4): 561-569.

Oliveira, L. P. H. 1940. Contribuição ao conhecimento dos crustáceos do Rio de Janeiro. Catálogo dos crustáceos da baía de Guanabara. Memórias do Instituto Oswaldo Cruz, 35(1): 137-151.

Oliveira, L. P. H. 1941. Contribuição ao conhecimento dos crustáceos do Rio de Janeiro. Sub-Ordem "Balanomorpha" (Cirripedia: Thoracica). Memórias do Instituto Oswaldo Cruz, 36(1): 1-31.

Pielou, E. C. 1974. Population and community ecology: principles and methods. Gordon and Breach, New York.

Shigesada, N. and Kawasaki, K. 1997. Biological invasions: theory and practice. Oxford University Press.

Sutherland, J. P. 1990. Recruitment regulates demographic variation in a tropical intertidal barnacle. Ecology 71(3): 955-972.

Underwood, A. J. 1984. Vertical and seasonal patterns in competition for microalgae between intertidal gastropods. Oecologia (Berl.) 64: 211-222.

Underwood, A. J. 1997. Experiments in Ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, 504 pp.

Underwood, A. J. 2000. Experimental ecology of rocky intertidal habitats: what are we learning? Journal of. Experimental Marine Biology and Ecology 250: 51-76.

Underwood, A. J. and Denley, E. J. 1994. Paradigms, explanations and generalizations in models for the structure of intertidal communities on rocky shores. In Strong, D. R., Simberloff, D., Abele, L. G., Thistle, A. (Eds.), Ecological communities: conceptual issues and the evidence. Princeton University Press, New Jersey, pp. 151-180.

Underwood, A. J. and Fairweather, P. G. 1989. Supply-side ecology and benthic marine assembles. Trends in Ecology and Evolution. 4: 16-20.

Vermeij, G. J. 1991. When biotas meet: understanding biotic interchange. Science 253: 1099-1104.

Young, P. S. 1994. Superfamily Balanoidea Leach (Cirripedia: Balanomorpha) from the Brazilian coast. Boletim do Museu Nacional, 356: 1-36.

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