Spatial and temporal variations on intertidal barnacle abundance in a tropical bay

Junqueira, A. O. R.; Falcão, A. P. C.; Mayer-Pinto, M.; Viana, M. S. and Silva, S. H. G.

Departamento de Biologia Marinha, UFRJ, 21949-900. Rio de Janeiro, Brasil e-mail: ajunq@biologia .ufrj.br

Abstract

Spatial and temporal variations on intertidal barnacle abundance were established in 4 areas with different eutrophication levels in Guanabara Bay. The inner areas (Paquetá and Governador) were considerably more polluted than the outer areas (Boa Viagem and Urca). Barnacle percentage cover was evaluated from December 1997 to December 1999, in 3-4 months intervals, in fixed transects in each area. Seven species of Balanomorpha were found: *Chthamalus bisinuatus, Tetraclita stalactifera, Balanus amphitrite, Balanus eburneus, Megabalanus coccopoma, Fistulobalanus citerosum* and *Euraphia rizophorae*. The first two species were remarkably absent in the inner areas while the last two were restricted to Governador. *C. bisinuatus* was the dominant species in the outer stations. *B. amphitrite* was the dominant species, occupying higher levels in one of the inner stations. A consistent pattern of temporal variation in abundance was evident exclusively in the inner stations, mainly Governador. A trend of increasing mortality after periods of high pluviosity was noted. Populations of *C. bisinuatus* showed more stability in abundance and lower mortality than *B. amphitrite.*

Key words: Barnacles, spatial variation, temporal variation, eutrophication, Guanabara Bay

Introduction

Changes in the structure of benthic assemblages can result from the recruitment of numerically dominant sessile organisms. This process, however, may be completely unrelated to human interference (Dye, 1993). Distinguishing natural fluctuations from those induced by anthropogenic factors has been the main challenge in the most recent environmental studies (Underwood and Petersen, 1988; Wiens and Parker, 1995).

Barnacles are the most common sessile invertebrates in the mid and high level rocky shores in Guanabara Bay (Lacombe and Monteiro, 1974; Brum and Absalão, 1989). Large scale studies on the temporal and spatial variations in barnacle abundance have shown the importance of reproductive periodicity, availability of larvae, nearshore current patterns and coastal topography (Hawkins and Hartnoll, 1982; Kendall *et al.*, 1985; Gaines and Roughgarden, 1985; Gaines *et al.*, 1985; Scheltema, 1986; Farrell *et al.*, 1991; Connolly and Roughgarden, 1999). On a local scale, several factors such as substratum heterogeneity, abiotic variables and biological interactions may change the expected patterns (Raimondi, 1988; Denley and Underwood, 1979, Kendall *et al.*, 1985; Leonard, 1999).

The appropriate description of pattern is a crucial requirement to understand causal processes (Benedetti- Cecchi *et al.*, 2000). The present study is part of a long term monitoring program being conducted in Guanabara Bay, which is related to a Pollution Control Project. It aims to detect evolutional trends in the structure and functioning of the biotic system of Guanabara Bay. In order to detect changes related to pollution abatement we had to establish the seasonal fluctuations in the benthic assemblages.

This paper provides data from the spatial and temporal variations on intertidal barnacle abundance in areas with different eutrophication levels in this tropical bay.

Materials and methods

Study area

Guanabara Bay, localized in Rio de Janeiro State (381 km^2), represents one of the most important estuarine systems on the Brazilian coast (Fig.1). It is a typical environment subject to a fast process of degradation since it is characterized by a shallow water system that receives continuous inflows of domestic sewage and periodical inflows of fresh water by a large drainage basin (4.000 km^2) that exists around it (Silva *et al.*, 1989). Thirty-five rivers, none of them of significant discharge, flow into the bay, bringing sediment, organic matter and industrial waste. Other sources of pollution, such as oil and garbage disposal, also affect the biota.

Water quality of Guanabara Bay is not uniform and some gradients can be observed in many of the hydrobiological characteristics, like higher salinities towards the mouth and an increase of pollution levels towards the inner regions. Circulation is controlled by tides and winds allowing water inflow from the ocean (width of the bay mouth = 1.8km^2). Tides are semi-diurnal with maximum amplitude of 1.4m. This system is subject to a remarkable dry season (May to September) and a rainy one (December to April).

Despite very few natural rocky substrata in the inner areas, Guanabara Bay presents many artificial substrata available to epibenthos.

Methodology

Observations were carried out in the intertidal zone (between 0,2m and 1,4m tidal levels) in four areas of Guanabara Bay (Fig. 1): Urca, Boa Viagem (both located near the mouth of the Bay), Governador and Paquetá Islands (located in the inner area).

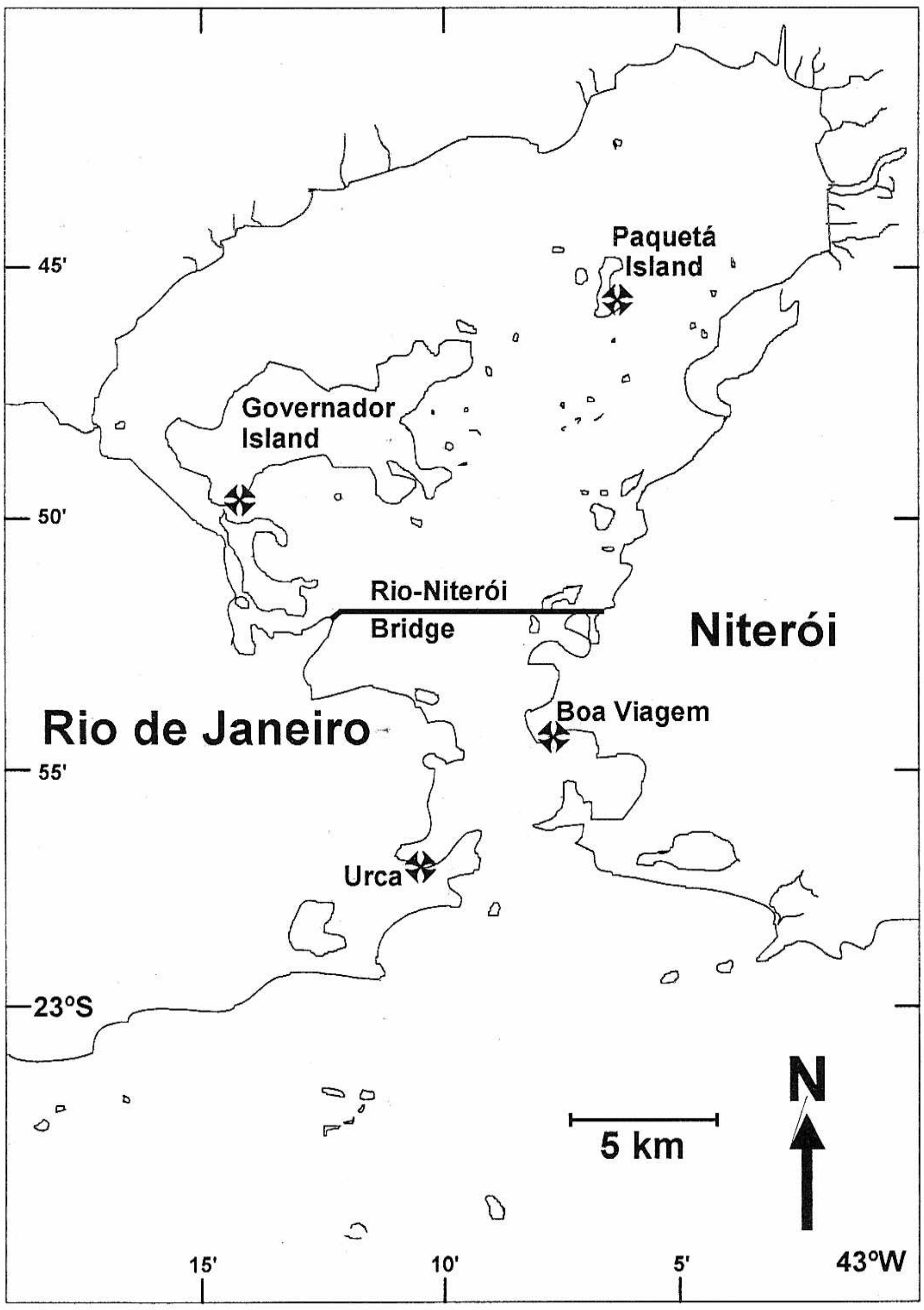

Figure 1: Guanabara Bay map showing the four studied areas.

The percentage cover of barnacles was estimated by the Intersection Method (Sutherland, 1974) in five fixed vertical transects, randomly chosen in the first sampling. Each transect comprised five quadrats, each one with 400cm^2 and one hundred intersections. The community was monitored each four months from December/1997 to December/1998 and trimonthly in 1999. Only the superior stratum of the community was considered. Barnacle relative mortality (dead barnacle percentage cover/ total barnacle percentage cover) was also evaluated.

In the characterization of the water conditions in outer and inner areas, weekly data of temperature, salinity, dissolved oxygen, turbidity, chlorophyll *a*, ammonia, nitrite, nitrate, total N, phosphate, total P were used from Urca and Governador. Pluvial influence was evaluated using total rainfall in the anterior trimester of each sampling period (data provided by the Governmental Agency, GeoRio).

Species composition, abundance and mortality of barnacle community were compared among the four areas in Guanabara Bay, considering only the most representative quadrats for each species. The vertical distribution of the most abundant or frequent species was done by calculating the percentage cover mean values of the same quadrats along the two years. Temporal variations in abundance and relative mortality of the most representative species, for each area, and spatial variations of these species were compared using Student t-tests or ANOVA for repeated measures and *a posteriori* Tukey test (Zar, 1996).

Results

Species distribution

Seven species of Balanomorpha were found in the 4 stations monitored in Guanabara Bay from Dec/97 to Dec/99 (Table II). *Chthamalus bisinuatus* Pilsbry, 1916 was the dominant species in the outer stations. There was a remarkable absence of *C. bisinuatus* and *Tetraclita stalactifera* (Lamarck, 1818) in the inner and more polluted stations (Table II). *Balanus amphitrite* Darwin, 1854 was found in all stations and was the dominant species in the inner ones. *Balanus eburneus* Gould, 1841 was also observed in all stations but with a very low percentage cover. *Megabalanus coccopoma* (Darwin, 1854) occurred only in Urca while *Fistulobalanus citerosum* (Henry, 1974) and *Euraphia rhizophorae* (Oliveira, 1940) were exclusively found in Governador (Table I).

Only the dominant species, *C. bisinuatus* and *B. amphitrite*, were considered in the next sections.

Vertical distribution

There were some differences in the vertical distribution of *B. amphitrite*. In one of the inner stations (Paquetá) this species had a broader distribution in the eulittoral zone occupying higher levels than in the outer stations (Fig. 2). The highest percentage cover was detected at the 0.8m tide level in Urca and Governador. In Paquetá the highest abundance was at 1.0m while in Boa Viagem it was found at the 0.6m level.

The broad distribution of *C. bisinuatus* in Boa Viagem was quite evident with the highest abundance in the levels 1.0m and 0.8m. This species had a very limited vertical distribution in Urca (Fig. 2).

Spatial distribution

Boa Viagem showed a significantly ($p<0.0001$) lower abundance of *B. amphitrite* in relation to the other stations (Tables I and III). Its reduced percentage cover in Boa Viagem may be due to the massive presence of *C. bisinuatus* in the high and mid levels (Fig. 2) and also to the presence of the green algae *Ulva* spp. in the lower levels. *Chthamalus bisinuatus* showed a significantly ($p=0.001$) higher abundance in Boa Viagem (Tables I and III). At this station *C. bisinuatus* presented a lower mortality than in Urca (Table 4). The relative mortality of *B. amphitrite* was significantly ($p=0.006$) higher in Urca and Governador (Tables III and IV).

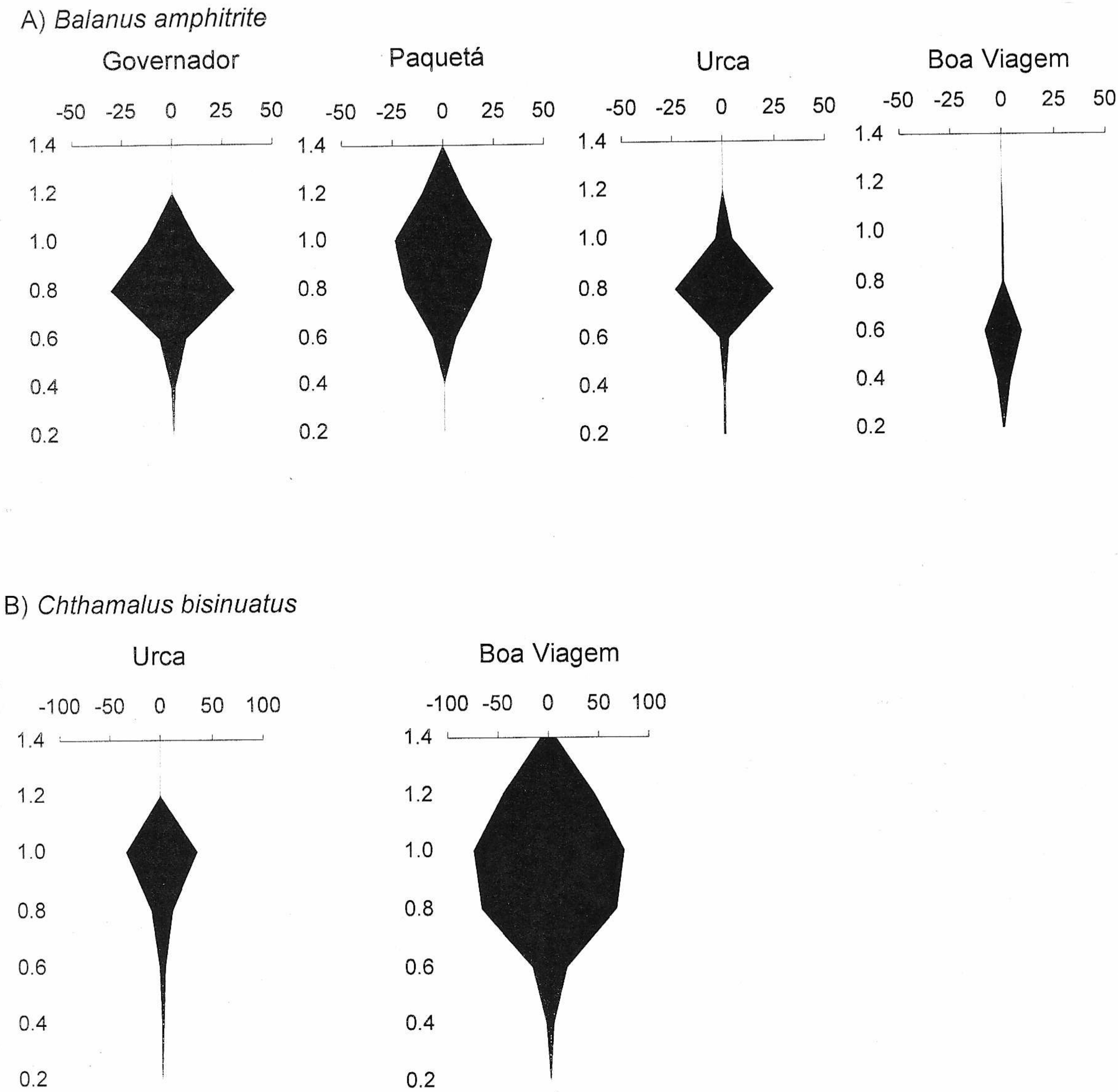

Figure 2: Vertical distribution of (A)*B. amphi*trite and (B) *C.bisinuatus* at the four areas of Guanabara Bay during the studied period. Mean percentage cover values were used. Minimum and maximum tidal levels(m) were showed at the figure left side.

Table I: Mean percentage cover (± SE) in the four studied areas of Guanabara Bay.

Species	Boa Viagem	Urca	Paquetá	Governador
Chthamalus bisinuatus	71.21 ± 2.27	34.99 ± 3.96	0.00	0.00
Balanus amphitrite	5.93 ± 3.33	24.33 ± 5.23	21.23 ± 7.53	30.55 ± 5.21
Balanus eburneus	0.20 ± 0.20	0.83 ± 0.40	4.73 ± 1.45	30.55 ± 5.21
Tetraclita stalactifera	2.20 ± 1.00	1.48 ± 0.27	0.00	0.00
Megabalanus coccopoma	0.00	< 0.1	0.00	0.00
Fistulobalanus citerosum	0.00	0.00	0.00	< 0.1
Euraphia rizophorae	0.00	0.00	0.00	< 0.1

Table II: Hydrobiological characterization of the study areas (mean data ± SE).

Environmental variables	Governador	Urca
Salinity (S)	26.0 ± 0.6	33.3 ± 0.2
Temperature (°C)	26.2 ± 0.4	23.5 ± 0.4
Turbidity (mg/l)	40.9 ± 0.4	19.7 ± 0.3
Dissolved oxygen (mg/l)	1.8 ± 0.1	3.2 ± 0.1
Ammonia (μm)	96.5 ± 2.4	7.8 ± 0.3
Nitrite (μm)	1.9 ± 0.1	1.1 ± 0.0
Nitrate (μm)	0.5 ± 0.1	4.2 ± 0.1
Total N (μm)	194.3 ± 3.9	26.5 ± 0.8
Phosphate (μm)	8.9 ± 0.1	1.2 ± 0.0
Total P (μm)	14.2 ± 0.2	2.5 ± 0.1
Chlorophyll *a* (μg/l)	108.2 ± 6.9	13.0 ± 0.6

Temporal variation

Balanus amphitrite

Governador was the only station where this species showed a consistent pattern of temporal variation with an increase of abundance in the months of December (Fig. 3A) and high mortality in the months after a period of high atmospheric precipitation (Apr/98 and Mar/99; Figs. 3B and 4A). Although the month of Aug/98 was not preceded by a period of high pluviosity it showed high mortality probably due to the persistence of shells attached to the substratum after death.

Balanus amphitrite presented a significant ($p<0.0001$) increase in abundance in September and December 1999 in Paquetá following a significant ($p<0.001$) decrease in relative mortality from 40% to 8.5% (Figs. 3A and .3B; Table III). A significantly ($p<0.01$) higher abundance was also found in Dec/97 (Table III). The highest mortalities at this site, as in Governador, were observed in months preceded by high pluviosity (Figs. 3B and 4A).

Significant ($p=0.03$) temporal changes of abundance occurred in Urca although Tukey Test didn't show differences among the months (Table III). The highest abundances were found in months where the lowest mortalities were registered (Apr/98, Mar/99 and Jun/99; Figs. 3C and 3D) but there was no clear pattern in temporal fluctuations.

There was no temporal variability in the abundance of *B. amphitrite* in Boa Viagem (Fig. 3C) even though a significant ($p<0.001$) mortality occurred in Apr/98 (Table III; Fig. 3D).

Chthamalus bisinuatus

This species presented more stable populations with mortality indices lower than those found for *B. amphitrite* populations. Nevertheless some significant temporal fluctuations of abundance ($p<0.05$) were still detected in Boa Viagem and Urca (Table III). In the former, the lowest abundances were related to a mortality increase in April and August 1998 (Figs. 3E and 3F). This month had experienced extreme low tides (Fig. 4B). The only significant change of abundance in Urca was observed in September 1999 (Table III) when 35% of the individuals died after a heavy oil deposition on the rocky shore (Fig. 3F).

Discussion

The absence of *C. bisinuatus* and *T. stalactifera* in the inner parts of the bay may be related to the decreasing salinity and/or to the increasing eutrophication (Brum and Absalão, 1989). The sensitivity of

T. stalactifera to low salinity was suggested by Oliveira (1947) and Lacombe and Monteiro (1974) to explain its distribution in Guanabara Bay. These latter authors also related the increasing pollution to the restriction of *T. stalactifera* to the bay mouth. The high salinities preference of *C. bisinuatus* was also observed by Lacombe and Monteiro (1974) although they have found some specimens in inner localities of the bay. The presence of this species in Paquetá and Governador was also documented by Brum and Absalão, 1989.

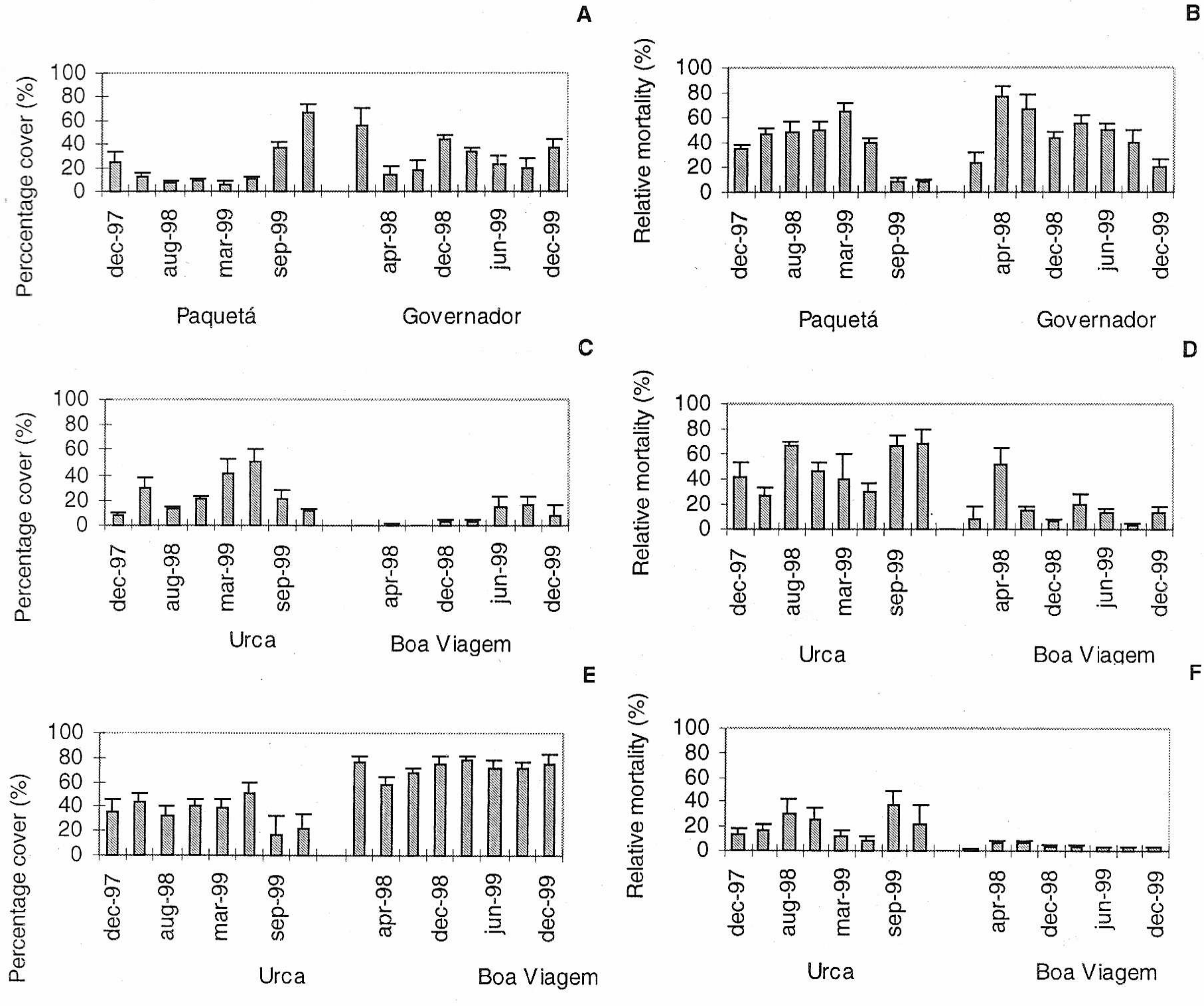

Figure 3: Mean percentage cover and relative mortality of *B. amphitrite* (A, B, C and D) and *C. bisinuatus* (E and F).

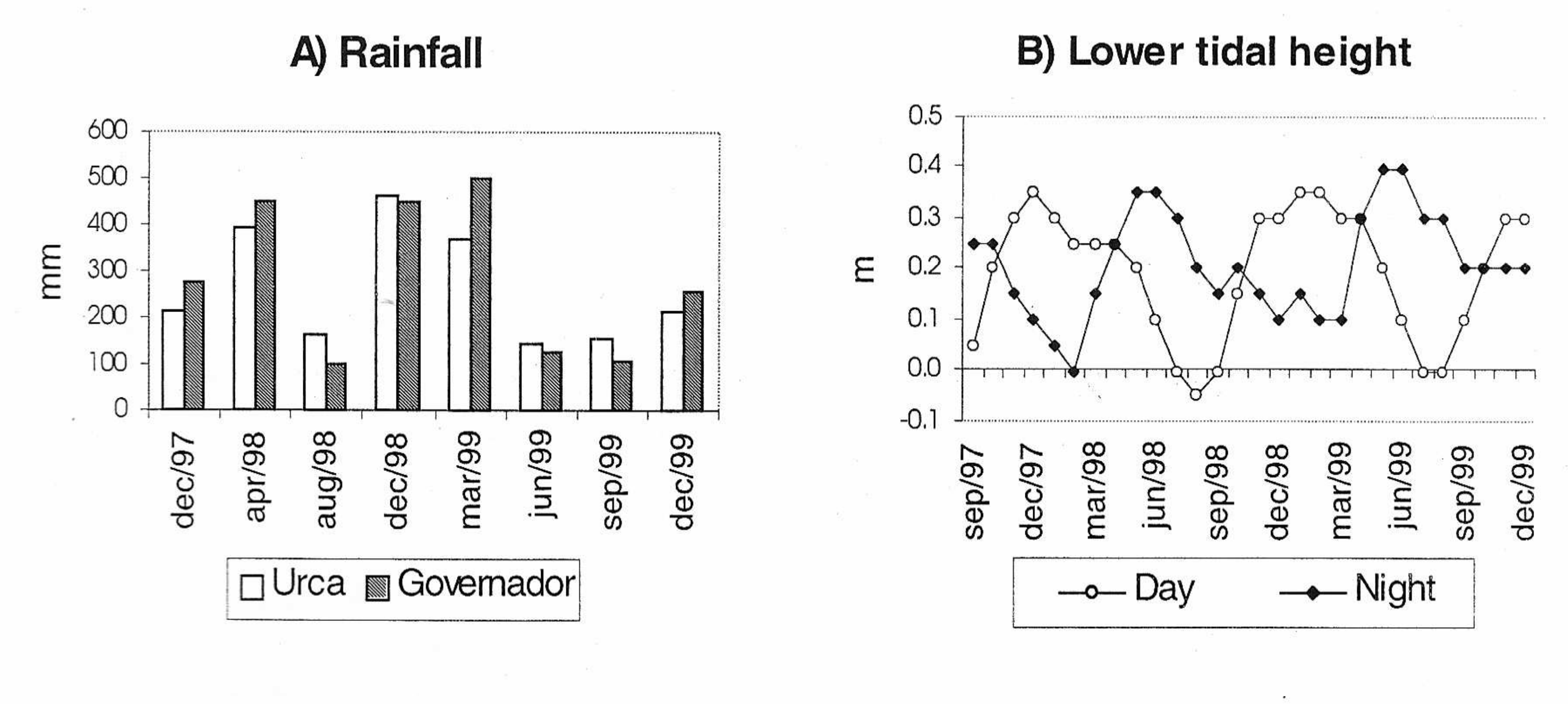

Figure 4: A) Trimonthly rainfall indices (months indicates the upper limit of the trimester) and B) Monthly lower tidal height registered during the studied period.

Table 3: Statistical results of temporal and spatial variations in abundance and relative mortality of *C. bisinuatus* and *B. amphitrite*. (M=March; AP=April; J=June; A=August; S=September; D=December). * Not significant ** Heterocedastic variances.

TEMPORAL VARIATION

ABUNDANCE

Chthamalus bisinuatus	ANOVA	TUKEY
Boa Viagem	F=3.126; p=0.014	M99 D97 D98 D99 J99 S99 A98 AP98
Urca	F=4.423; p=0.004	J99 AP98 D98 M99 D97 A98 D99 S99

Balanus amphitrite	ANOVA	TUKEY
Boa Viagem	F=3.650; p=0.160	**
Urca	F=2.840; p=0.030	*
Paquetá	F=63.927; P<0.001	D99 S99 D97 AP98 J99 D98 A98 M99
Governador	F=5.520; p=0.001	D97 D98 D99 M99 J99 S99 AP98 A98

RELATIVE MORTALITY

Chthamalus bisinuatus	ANOVA	TUKEY
Boa Viagem	F=3.137; p=0.014	A98 AP98 M99 J99
Urca	F=1.855; p=0.116	**

Balanus amphitrite	ANOVA	TUKEY
Boa Viagem	F=7.667; P<0.001	AP98 M99 J99 A98
Urca	F=4.062; p=0.003	D99 S99 A98 D9:
Paquetá	F=9.990; P<0.001	M99 D98 A98 AP:
Governador	F=6.227; P<0.001	AP98 A98 M99 D9:

SPATIAL VARIATION

ABUNDANCE

	Test	Result	TUKEY
Chthamalus bisinuatus	T-TEST	t=6.022; p=0.001	
Balanus amphitrite	ANOVA	F=16.941; p<0.0001	Boa Viagem ≠ Urca, Paquetá, Governador

RELATIVE MORTALITY

	Test	Result	TUKEY
Chthamalus bisinuatus	T-TEST	T=2.187; p=0.006	
Balanus amphitrite	ANOVA	F=27.073; p<0,001	Boa Viagem = Paquetá; Urca = Governador

The confirmed eurihalinity (Crisp and Costlow, 1963; Anil *et al.*, 1995; Qiu and Qian, 1999) and resistance to high eutrophication (Calcagno *et al.*, 1998) explain the presence of *B. amphitrite* in all sampling stations and its dominance in the inner areas of the bay (Lacombe and Monteiro, 1974; Brum and Absalão, 1989). Although this species showed a higher mean percentage cover in Urca than in Paquetá, its vertical distribution was more restricted in the former.

The restricted vertical distribution of *B. amphitrite* in the outer stations may be explained by the pre-emption of the substratum by other species: *C. bisinuatus* in the higher levels (mainly in Boa Viagem) and macroalgae in the lower ones. This is a common process limiting settlement of barnacle larvae (Denley and Underwood, 1979; Gaines and Roughgarden, 1985; Minchinton and Scheibling, 1993; Benedetti-Cecchi *et al.*, 2000). The extension of *B. amphitrite* to the high intertidal zone in one of the inner stations of Guanabara Bay (Paquetá) may indicate that the pre-emption of space by *C. bisinuatus* limits its distribution in the entrance of the bay. In the intertidal zone of the Suez Canal the early dominance of *B. amphitrite* has been reduced by the subsequent colonization of other organisms such as *Chthamalus* and *Cellana* (Por,1978 *apud* Shalla *et al.*,1995). Thus, although being physiologically able to survive in the upper intertidal zone *B. amphitrite* seems to be competitive inferior to *C. bisinuatus* at these levels of the shore. Experimental studies to verify this hypothesis deserve to be done. The classical ecological model for rocky intertidal communities predicts that competition will be greater lower on the shore than higher up (Connell, 1961; 1972; but see Underwood and Denley, 1984).

A consistent pattern of temporal abundance of *B. amphitrite* was evident exclusively in the inner stations, mainly Governador. The increase in the abundance of this species in summer (December months in the present study) was also documented in previous studies conducted in the southern hemisphere (Calcagno *et al.,* 1998) as well as in the northern hemisphere (Shalla *et al.*, 1995). A trend of increasing mortality after periods of high pluviosity in Guanabara Bay was noted. However, this trend was sometimes obscured by two factors. First, the persistence of shell plates on the substratum after death. The mean persistence reported for the same species in Argentina was 177 days, varying with season and age (Calcagno *et al.*, 1998). The second factor was the long sampling interval (between 3 and 4 months) which has underestimated postsettlement mortality.

The absence of a temporal variation pattern in the outer stations may reflect different biotic and abiotic effects which may account for a "background noise" (Dye, 1993) in recruitment and mortality.

Populations of *C. bisinuatus* showed more stability in abundance and lower mortality than *B. amphitrite.* Menge (2000) reported that *Chthamalus dalli* and *Balanus glandula* had differential susceptibilities to postrecruitment processes and observed that *Chthamalus* had high survival during periods of high *Balanus* mortality.

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