

Comparative growth of the intertidal barnacle *Tetraclita stalactifera* (Thoracica: Tetraclitidae) in sites influenced by upwelling and tropical conditions at the Cabo Frio region, Brazil

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Abstract: Growth of the intertidal barnacle *Tetraclita stalactifera* was compared in two sites under upwelling and tropical influence at Cabo Frio region, Brazil. The hypothesis was that growth is higher at sites with an enhanced productivity. Five quadrates of 10 x 10 cm were cleared in an intertidal zone of each site to follow growth from recruitment and onwards. Base diameters were measured for 18 individuals at the tropical site (Ponta da Fortaleza) and 22 at the upwelling site (Ponta da Cabeça) using digitalized photos and ImageTool software. Mean growth rates were 0.07 mm/day at the tropical site and 0.06 mm/day at the site under upwelling influence. No effect of location, upwelling season or settlement time was found on barnacle growth rates. Other factors or synergic interactions such as temperature and food availability could influence *T. stalactifera* growth. Rev. Biol. Trop. 55 (Suppl. 1): 71-78. Epub 2007 June, 29.

Key words: Cirripedia, bottom-up effect, development, tropical region, temperature.

Coastal upwelling increases food availability and decreases water temperature. These are the two most important characteristics that link oceanographic conditions to organism behavior and physiology. Coastal upwelling can cause effects like an increment on diversity, abundance, and changes on physiological condition in filter-feeding organisms, including growth and survivorship (Pitts 1999, Menge 2000, Menge *et al.* 2002, 2003, Rutllant and Montecino 2002, Witman and Smith 2003, Soares-Gomes and Fernandes 2005). These environments also induce physiological responses of individuals to temperature variation and food availability (Menge *et al.* 2002, Brockington and Clarke 2005), and direct influences on reproduction or recruitment (Leslie *et al.* 2005).

Growth and development of larval stages of many marine invertebrates are affected by food availability and temperature (Anil *et al.* 2001, Desai and Anil 2004). Food availability affects also energy content in larvae and early development of adults (Anil *et al.* 2001, Giménez *et al.* 2004, Marshal and Keough 2004). Physiological response of individuals to temperature variation or food concentration has received little attention (mainly field observations). Some recent studies evaluate the role of environmental characteristics on physiological responses of species (Menge *et al.* 2002, Sanford 2002), using growth as a tool, mainly for barnacles and mussels (Sanford and Menge 2001, Phillips 2005).

Growth of many crustaceans depends on physiological conditions and energy content, and can be related to environmental

characteristics such as food availability, temperature, salinity and air exposure, among others (Hartnoll 2001).

Barnacles are good species for ecological modeling and monitoring programs since they can reflect environmental conditions; many species are widespread, easily identifiable and adequate knowledge of their life cycle is available. Their wide distribution allows comparisons among different regions and times.

Tetraclita stalactifera (Lamarck, 1818) is a typical intertidal barnacle species known from western Atlantic Ocean, Gulf of Mexico and eastern Pacific. They live attached to rocks, piers and many other hard substrata; their water temperature range is between 20 and 26 °C. Two subspecies are described for the Brazilian coast: *T. stalactifera stalactifera* and *T. stalactifera floridana* Pilsbry, 1916 (Young 1998), and a third subspecies, *T. stalactifera confines*, has been reported for the Gulf of California. On Brazilian shores, *T. stalactifera* distribution forms a fringe below high intertidal barnacle

Chthamalus spp. and above intertidal mussel *Perna perna*.

The present study, conducted at the Cabo Frio upwelling region, southeastern Brazil, aims to compare growth rates of intertidal barnacle *T. stalactifera* on sites under upwelling and under tropical influence. We tested the hypothesis that *T. stalactifera* growth is higher at the upwelling site (Ponta da Cabeça) due to an increase in food availability indicated by water temperature.

MATERIALS AND METHODS

At Cabo Frio region, we considered two sites with distinct upwelling influences (Guimaraens and Coutinho 2000), which were at a distance of 5 km from each other: Ponta da Cabeça (PC) (22°58.7' S, 42°02' W) under upwelling influence, and Ponta da Fortaleza (PF) (22°58.1' S, 42°00.8' W) under tropical influence (Fig. 1). Growth of *T. stalactifera* was

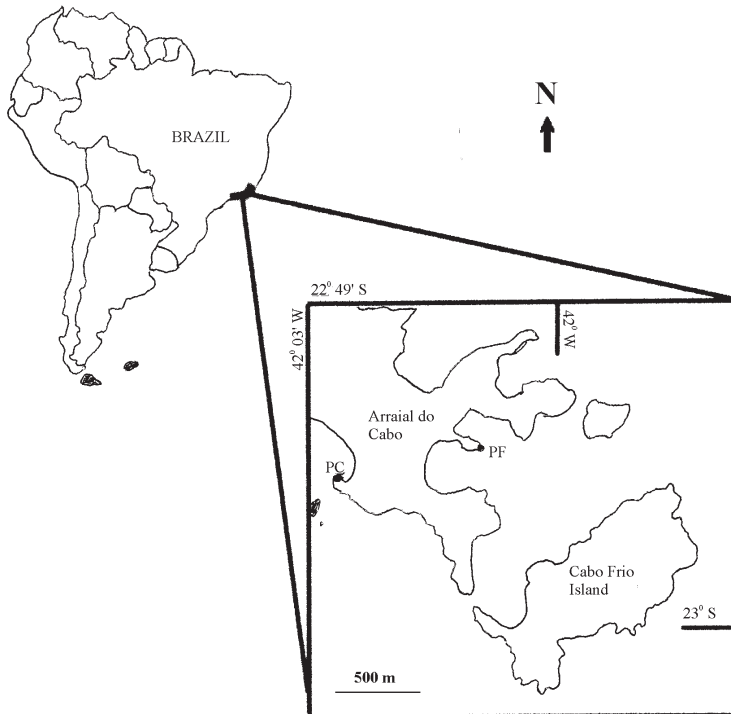


Fig. 1. Study site location and geographic coordinates from southeastern Brazil. Sampling sites: Ponta da Cabeça (PC), upwelling influence; Ponta da Fortaleza (PF), tropical influence.

monitored at both locations from November 2001 through September 2002.

At each site, five quadrates of 10 x 10 cm (100 cm²) were scraped and cleared to evaluate recruitment, substrate occupancy and growth of the intertidal barnacle *T. stalactifera*. Twice a month, sampling was carried out and photos were taken of each quadrate on ISO 200 film using a Canon EOS 3000 35 mm with 2X macro filters attached to a 35-80 mm lens. Distance between fixed points on quadrates was used to calibrate the measures. Photos were digitalized, each *T. stalactifera* individually recorded, and its base diameter was measured using the software ImageTool (UTHSCSA 2006). Base diameter was chosen, because (1) recruitment occurred at low densities at the beginning of the experiment, and (2) due to the small length of opercular aperture at that time. All individuals were measured from its recruitment to its death or until conclusion of the experiment in September 2002. For each individual we established the relation between size and age to estimate growth rate related to time. Surface water temperature was measured to correlate it with growth, allowing us to indicate upwelling and non-upwelling events. It was not possible to measure food availability due to logistical problems, but productivity in the region is related to thermal oscillation with higher productivity at

the upwelling site PC (Guimaraens and Coutinho 2000, Carbonel 2003)

We used 18 and 22 individuals from PF and PC, respectively, to evaluate growth of *T. stalactifera*. Age (days) and size (mm) were used to estimate daily growth rate (mm/day), and a T-test was used to compare growth rates at both sites and during early (summer = Nov-Apr) and latter (autumn/winter = Apr-Sept) settlement. We also performed a test to check normality and homogeneity of variances (Zar 1998). The relation between age and size was described by performing a linear regression analysis.

RESULTS

Substrate colonization by *T. stalactifera* barnacles started in January 2002 at Ponta da Fortaleza (tropical influence) and in February 2002 at Ponta da Cabeça (upwelling influence). Surface water temperature showed higher mean values at PF (23.3 °C) than at PC (19.9 °C), but water temperature was under seasonal influence. This pattern was observed in summer while from autumn to winter higher temperatures were measured at PC. During autumn-winter, water temperatures were always higher than 20 °C on both sites (Fig. 2).

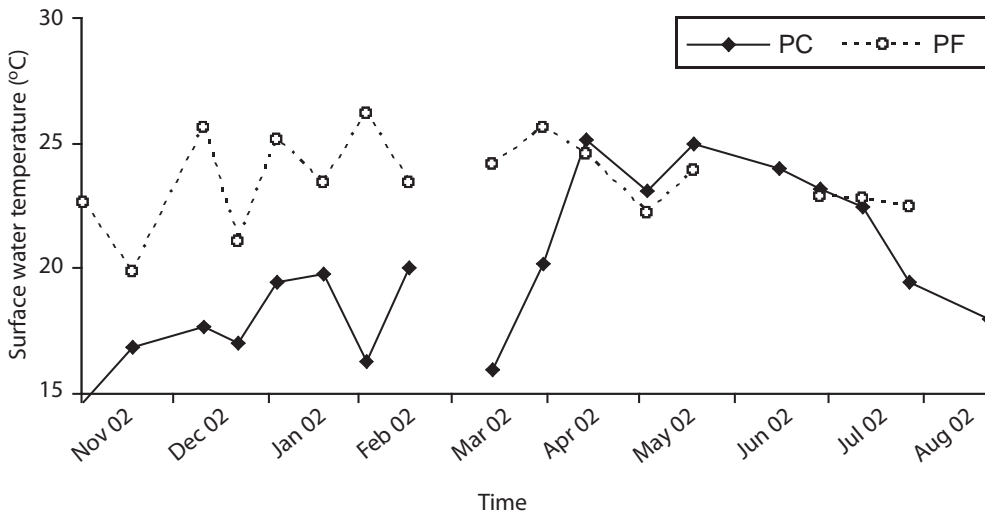


Fig. 2. Surface water temperature (°C) at Ponta da Cabeça (PC, upwelling) and Ponta da Fortaleza (PF, tropical) sites registered twice a month during experimental period. Empty spaces are missing values.

At the site under tropical influence (PF) we registered the largest individual with a base diameter of 16.67 mm. At the upwelling site (PC), the largest individual had a base diameter of 15.82 mm. Mean daily growth rate was higher at PF (0.07 ± 0.05 mm/day) than at PC (0.06 ± 0.03 mm/day), but this difference was statistically not significant (T-test, $p > 0.05$, $df = 35$). The highest individual growth rate of 0.12 mm/day was registered both at PF and PC for individuals who lived for 57 days.

If barnacle growth rate was size-dependent, a non-linear growth curve could be generated. This assumption was tested for the data from both sites for early (February-March) and late (April-May) settlement. Despite a mean growth rate of 0.07 mm/day at PF, growth rate for early and late settlers was 0.08 ± 0.06 and 0.06 ± 0.02 mm/day, respectively; however, this difference was statistically not significant (T-test, $p > 0.05$, $df = 39$). At PC site, overall mean growth rate was 0.06 mm/day, that for early and late settlers 0.08 ± 0.03 and 0.05 ± 0.03 mm/day, respectively. As for PF, there was no statistically significant difference between these cohort growth rates (T-test, $p > 0.05$, $df = 15$). Aside from the slight difference in growth rates between early and late recruiters, statistical analysis showed that growth rate was not related to size or settlement time. This is in agreement with the hypothesis that growth of *T. stalactifera* follows a linear model.

Comparison of growth rates at both sites on different settlement times showed no statistically significant difference (summer; T-test, $p > 0.05$, $df = 18$) (autumn/winter, T-test; $p > 0.05$, $df = 14$), indicating that season had no effect on the growth rates.

The growth curve for *T. stalactifera* at both sites (Fig. 3) did not reveal a limited growth, except for one individual at PF, which reached a plateau. Regression analysis showed a positive and significant relationship between size and age (Table 1), being higher at PF than at PC. Dispersion of points on the growth curves was more pronounced at the PC site, a location with more variable oceanographic conditions.

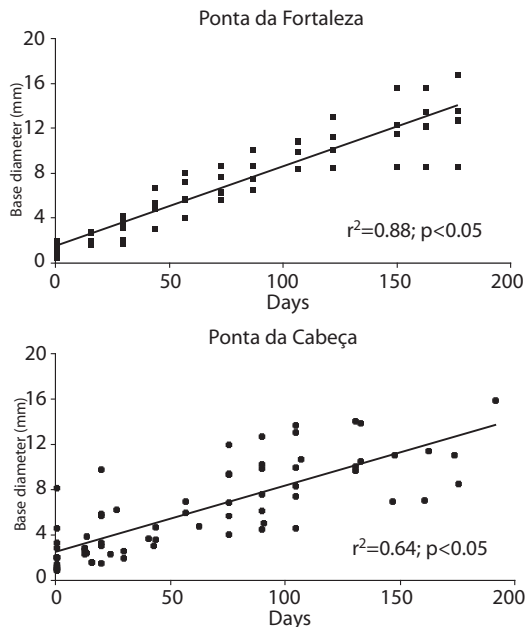


Fig. 3. Base diameter (mm) by age (days) and Pearson regression for intertidal barnacle *Tetraclita stalactifera* at Ponta da Fortaleza (square symbols= tropical influence) and Ponta da Cabeça (black points= upwelling influence). Continuous line is the adjusted linear regression.

TABLE 1
Results from linear regressions between base diameter (mm) and age (days) for barnacle *Tetraclita stalactifera*

| | X | | | | | |
|--------------------|-----------|-------------|----------------|-------|---------|----|
| | Intercept | Coefficient | r ² | F | p | df |
| Ponta da Cabeça | 2.44 | 0.06 | 0.64 | 118.5 | < 0.05* | 69 |
| Ponta da Fortaleza | 1.36 | 0.07 | 0.88 | 446.4 | < 0.05* | 64 |

* Significant difference

DISCUSSION

We studied growth rates of *T. stalactifera* at sites under different oceanographic conditions. Besides the numeric differences in mean growth rate, no statistically significant difference was noted between the site under tropical influence and the study location under upwelling influence. This result did not support our predictions, because we expected higher growth rates at the upwelling site due to a

higher availability of food (Valentin *et al.* 1987, Carbonel and Valentin 1999). No significant differences were found when we compared growth rates within the same site or for the same season but at different sites. Again, these findings were in opposite to those reported by other authors for *Balanus glandula* (Sanford and Menge 2001) and *Semibalanus balanoides* (Bertness *et al.* 1991), where higher growth rates were recorded at sites with higher upwelling influence and wave exposure or higher availability of food.

Our results agree partially with data published by Phillips (2005) who found higher growth rates for *B. glandula* at sites with decreasing upwelling. Phillips (2005) suggested that other factors (e.g., little variability in food availability among sites, off-shore transport of phytoplankton or water temperature, feeding behavior related to cirral activity) could have some influence on these results. These observations are quite similar to our findings, despite the fact that there was no difference concerning growth rate.

Mean growth rate of *T. stalactifera* at the Cabo Frio region during the first year was not limited by size or age and was similar to values reported for other intertidal barnacle species like *T. squamosa rubescens* (up to 0.03 mm/day; Villalobos 1979) and *S. balanoides* (up to 0.12 mm/day; Sanford and Menge 2001; up to 0.08 mm/day; Phillips 2005). Villalobos (1979) found a continuous decrease in growth rate starting with the first year which is typical for many crustaceans (Hartnoll 2001).

A higher dispersion of size-age data at upwelling sites compared to tropical sites may be related to environmental variability. At tropical sites, temperature remains more stable and larger changes occur seasonally. At upwelling sites, temperature could change in a few hours, and the effects over *Tetracilta* individuals are different. Despite the absence of statistical difference, this dispersion could be related to these differences in growth rate during upwelling and non-upwelling events (Sanford and Menge 2001, Phillips 2005) and may produce larger differences in long time series. Both behavior

and activity of suspension feeding depend on temperature. At 25 °C, cirral activity is high with 90 movements per minute, whereas at 15 °C cirral movement decreases to 30 per minute (Skinner, unpubl. data). Such a change in cirral activity and its effect on physiology and feeding has been reported previously (Southward 1955, 1957, Crisp and Bourget 1985). This reduction affects food intake and physiological condition of the animals (Brockington and Clarke 2005) and could affect growth as well.

In his review on crustacean growth, Hartnoll (2001) described how increasing temperature caused a decrease in intermolt duration and also affected metabolic processes leading to reserve accumulation. Food availability is also important, but for many species higher temperatures may have more positive influence on growth than high availability of food in cold waters. This could explain the differences between our sites, since the low food availability at PF would be compensated by a higher metabolic rate and activity of suspension feeding. In addition, the reproductive pattern could be related to food availability and temperature, and gonad development might be adjusted to this (Ventura *et al.* 1997).

In contrast to our predictions, early and late settlement at our upwelling site did not produce differences in growth rates, despite the fact that the autumn/winter settlers presented lower growth rates than earlier settlers. Further studies relating food availability, detailed measures of upwelling and non-upwelling events, rate of filtration at different temperatures, and growth marks on barnacles shell could help to determine the role of food availability and temperature on growth of intertidal barnacles.

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RESUMEN

El crecimiento del cirripedio intermareal *Tetraclita stalactifera* fue comparado en dos sitios influenciados por condiciones de resurgencia y tropicales en la región del Cabo Frio, Brasil. La hipótesis fue que el crecimiento es más grande en el sitio con más elevada producción. En esta región, cinco cuadrantes de 10 x 10 cm fueron raspados en el intermareal de las costas rocosas, en cada una de estas localidades, para estudiar el crecimiento de *T. stalactifera* desde el reclutamiento hasta finalizar el experimento o la muerte del individuo. El diámetro de la base de *T. stalactifera* fue medido para 18 individuos en el sitio tropical (Ponta da Fortaleza) y 22 en el sitio de resurgencia (Ponta da Cabeza) por medio de fotografías digitalizadas y el software ImageTool. Los resultados observados mostraron una mayor tasa de crecimiento en el área bajo la influencia tropical (0.07 mm/día) que en el área bajo influencia de resurgencia (0.06 mm/día). La localización del sitio, periodo de resurgencia o periodo del asentamiento no afectaron las tasas de crecimiento. Otros efectos o interacciones sinérgicas como la temperatura y la disponibilidad de alimento pueden afectar el crecimiento de esta especie en la región.

Palabras clave: Cirripedia, efecto bottom-up, desarrollo, región tropical, temperatura

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