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BIOLOGIA POPULACIONAL DE *Nassarius vibex* (SAY, 1822) EM UMA PRAIA PROTEGIDA NO SUDESTE DO BRASIL

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Orientador: Dr. Ricardo Silva Cardoso

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RESUMO

Nassarideos tem distribuição mundial, sendo comuns em enseadas protegidas em zonas tropicais, subtropicais e temperadas, ocorrendo na zona entre-marés e no infralitoral. Espécies deste gênero são consideradas detritívoras e desempenhar importante papel na teia trófica, atuando como um elo entre a matéria orgânica não-viva e os consumidores dos níveis tróficos superiores. Os objetivos deste estudo foram: comparar o padrão de distribuição e a biologia populacional (crescimento e mortalidade) de machos e fêmeas de *Nassarius vibex*. Amostragens foram realizadas mensalmente, sempre em maré baixa de Setembro de 2007 a Fevereiro de 2009, na praia das Flexeiras, localizada no Estado do Rio de Janeiro (22°), sudeste do Brasil. Na região intermareal foram demarcados seis transectos perpendiculares à linha d'água, com 10 níveis equidistantes, de cada nível foi retirada uma unidade amostral (UA) (0,04 m²) enterrada a uma profundidade de 25cm, desde a base das dunas (UA10) até 9m a partir da linha d´água (UA1). Maiores abundâncias populacionais foram observadas na primavera em ambos os sexos. Foram observadas diferenças significativas na abundância entre os níveis, em ambos os sexos. Fêmeas de *N. vibex* apresentaram baixas abundâncias, crescimento mais rápido, alta taxa de mortalidade e baixa expectativa de vida quando comparadas aos machos. Variações nos parâmetros populacionais de *Nassarius vibex* podem ser reguladas através de um ajuste fenotípico as condições locais e aparentemente neste caso, a exposição por compostos orgânicos que induzem o imposex.

Palavras- chave: Biologia populacional, *Nassarius vibex*, Praia protegida, Brasil

ABSTRACT

Nassariids have a worldwide distribution, being most common in sheltered embayments in tropical, subtropical, and temperate zones occurring in intertidal and subtidal areas. Species of this genus are scavengers constituting a major link in the energy flow between carrion, independent of trophic levels, and the environment. The aims of this study are to compare the distribution pattern and the population biology (growth and mortality) of males and females of *Nassarius vibex*. Sampling was carried out monthly, at spring low tide, from September 2007 through February 2009 at Flexeiras Beach located in Rio de Janeiro State (22°), southeastern Brazil. Sampling was conducted according to a systematic design in which six transects perpendicular to the waterline were established, each with 10 equally spaced sampling units (SUs) were established, were extracted every 3 m, with a 0.04 m² metal sampler and to a depth of 25 cm, from the base of the foredunes (SU10) until 9 m below the waterline (SU1). Highest population abundances were observed in spring on both sexes. There were significant differences in abundance among the levels, in both sexes. Females of *N. vibex* had lower abundances, grew faster, and had higher mortality and smaller life span than males. Variations in population parameters of *Nassarius vibex* population might be regulated by phenotypic adjustment to local conditions, in food availability, and apparently, in this case, by exposure to organotin compounds inducing to the imposex.

Keywords: Population biology, *Nassarius vibex*, Sheltered beach, Brazil

APRESENTAÇÃO

Entre os invertebrados que são responsáveis por da macrofauna das praias, os moluscos podem atingir uma biomassa surpreendentemente alta em praias lamosas e areno-lamosas, ocupando diferentes níveis tróficos da teia alimentar destes ecossistemas. Neste grupo, os nassarídeos têm grande destaque pela sua dominância na fauna, e por desempenhar um papel ecológico importante como incorporadores da matéria orgânica na cadeia trófica.

Os estudos sobre o gênero *Nassarius* abordam temas relacionados à sistemática, alimentação e reprodução. Este gênero também é usado como bioindicador de poluição por TBT (tributilestanho, composto utilizado em tintas antiincrustantes aplicados em navios) causando o desenvolvimento do imposex (imposição de caracteres sexuais masculinos em fêmeas). Existem alguns estudos sobre a dinâmica populacional de espécies de nassariideos basicamente na Europa e Ásia, poucos estudos têm-se centrado nas espécies de *Nassarius* na América do Sul.

Dentre as espécies que habitam as praias arenosas, o gastrópode *Nassarius vibex* merece especial atenção por sua grande representatividade e por desempenhar importante papel na teia trófica, já que este gastrópode é detritívoro e atua como um elo de ligação entre a matéria orgânica não-viva e os consumidores dos níveis tróficos superiores. Existem poucos estudos sobre esta espécie e as informações disponíveis referem-se ao comportamento alimentar, a resposta de escape e ontogênese do sistema reprodutivo de populações do Atlântico Norte. O presente estudo visa preencher esta lacuna de conhecimento determinando: curva de crescimento; taxas de mortalidade e sobrevivência e expectativa de vida para machos e fêmeas de *Nassarius vibex* na praia das Flexeiras, baía de Sepetiba, RJ.

Amostragens mensais foram realizadas de setembro de 2007 a fevereiro de 2009, na praia das Flexeiras, ilha de Itacuruçá. Na região intermareal foram demarcados seis transectos perpendiculares à linha d'água, com 10 níveis equidistantes, de cada nível foi retirada uma amostra (0,04 m^2). O material coletado foi lavado em malha 0,5 mm e triado em laboratório. Os indivíduos de *Nassarius vibex* tiveram seus comprimentos de conchas medidos com o auxílio de um paquímetro de precisão 0,01 mm e agrupados, mensalmente, em classes de tamanho de 0,5 mm. Os organismos foram removidos da concha com o auxílio de um torno e indivíduos com presença de vesícula seminal e pênis foram identificados como machos, enquanto outros com vesícula seminal ausente foram identificados como fêmeas. A obtenção dos parâmetros de crescimento foi realizada baseando-se por meio da determinação mensal das modas de distribuição de frequência de comprimento com a Rotina NORMSEP do Programa FISAT.

Posteriormente, foram ajustados a curva de crescimento de von Bertalanffy com oscilação sazonal. A expectativa de vida foi calculada a partir do maior comprimento observado (Lmax) tanto para machos quanto para fêmeas. A taxa de mortalidade instantânea (Z) foi calculada por meio do método da curva de captura convertida de comprimento disponível na rotina ELEFAN II do programa FISAT. Z foi estimado segundo a fórmula: ln(N) = g-Z• t, onde N é o número de indivíduos, g é o intercepto da regressão, Z, em módulo, é a taxa de mortalidade instantânea, e t é a idade estimada para cada coorte.

A análise dos parâmetros de crescimento revelou que há variação significativa no crescimento individual entre os sexos. As fêmeas cresceram significativamente mais rápido do que os machos de *Nassarius vibex*, como corroborado pela análise de crescimento phi prima. O modelo VBGF com oscilação sazonal através do desempenho de crescimento não-linear explicou mais de 96% para fêmeas e mais de 97% para machos de *N. vibex*. Os parâmetros de crescimento estimados para fêmeas foram: (Linf) = 18,11 mm; (K) = 1,25 ano^{-1}; (C) = 0,66 e (WP) = 0,40; já os valores estimados para machos foram: (Linf) = 18,20 mm; (K) = 0,68 ano^{-1}; (C) = 0,36; e (WP) = 1,00.

A análise dos parâmetros estimados para machos e fêmeas de *N. vibex* e as curvas de crescimento derivadas destes, mostraram que as fêmeas cresceram mais rapidamente do que os machos, corroborando com o registrado para *N. reticulatus* em Portugal e no País de Gales (em condições de laboratório). Uma possível explicação pode ser devido à elevada porcentagem de fêmeas de *Nassarius vibex* afetadas pelo o imposex, como observado na população estudada (cerca de 85% das fêmeas). O crescimento de fêmeas imposexedas de *Nucella lapillus* foi muito mais acentuado do que em fêmeas normais. Esta diferença foi devido à energia destinada à reprodução mobilizada para o crescimento, uma vez que o TBT afeta a atividade gonadal, a energia é direcionada ao crescimento. Machos de *N. vibex* apresentaram padrão de crescimento sazonal e não houve crescimento da concha durante os meses de verão; isso é atribuído ao início da maturidade sexual, quando a energia é desviada do crescimento da para a reprodução, e indivíduos sexualmente maduros investem a maior parte da energia absorvida em atividade reprodutiva e não em crescimento.

As fêmeas de *N. vibex* exibiram redução do crescimento durante o outono. O ciclo gonadal de nassarideos tem um amadurecimento progressivo no outono com a maturidade alcançada no inverno. As fêmeas de *N. vibex* possuem poucas reservas de energia no período de maturação e a maior parte da energia adquirida pela alimentação é canalizada para a reprodução, mas não para o crescimento. Isso é comum nos moluscos que têm um ciclo de vida curto, alta fecundidade e uma curva de crescimento sigmoidal. O tamanho do menor indivíduo foi 5,33 mm para machos e 4,28 mm para fêmeas; já os maiores indivíduos tiveram os seguintes comprimentos: 17,44 mm e 17,56 mm para machos e fêmeas de *N. vibex*, respectivamente.

A expectativa de vida (Tmax) correspondentes a essas estimativas foram mais de 3,5 anos para machos e aproximadamente 3 anos para fêmeas de *N. vibex*. Diferentes expectativas de vida foram calculadas para os membros da família Nassariidae. *Nassarius vibex* tem uma expectativa de vida semelhante a *Nassarius festivus* (22-29 meses) em Hong Kong para tamanho máximo registrado de 16,1 mm e ambos têm uma curta expectativa de vida em relação à *Nassarius reticulatus* (15 anos) na Suécia para tamanho máximo registrado de 28,9 mm e no País de Gales (4 – 5 anos). Isto pode ser devido ao fato de *N. vibex* e *N. festivus* serem espécies subtropicais e *N. reticulatus* ser boreal (tanto a população da Suécia quanto à do País de Gales).

Resultados mostraram que fêmeas de *Nassarius vibex* tiveram uma mortalidade significativamente maior que machos (Z = 3,6 com desvio de 0,43•ano^{-1} para fêmeas e 3,44 com desvio de 0.37•ano- 1 para machos). As fêmeas de *N. vibex* da praia Flexeiras mostraram uma alta incidência de imposex sugerindo esterilidade e mortalidade de fêmeas causadas pela exposição a TBT e TPT. Isto foi observado também para as populações *Nassarius kraussianus* na África do Sul.

Concluímos que a biologia populacional de *N. vibex* parece ser afetada pelo imposex, uma vez que fêmeas de *N. vibex* tiveram uma menor abundância, cresceram mais rapidamente, e apresentaram maiores taxas de mortalidade e menores expectativas de vida em relação aos machos. Estes resultados podem ser explicados por alterações metabólicas causadas pela possível de TBT e TPT, além de compostos químicos que podem induzir a ocorrência de imposex.

Os resultados obtidos a partir de análise de estudos com outras espécies do gênero *Nassarius* fornece um forte apoio para a hipótese do gradiente latitudinal: espécies do gênero *Nassarius* de praias tropicais e subtropicais apresentaram maior crescimento, e as taxas de mortalidade e expectativa de vida menores do que as espécies de praias de clima temperado. Estas tendências latitudinais poderiam estar relacionadas a variações de temperatura, o que possibilita o que um agregado de variáveis, que ocasionam diferentes efeitos no ambiente (por exemplo, a disponibilidade de alimentos).

POPULATION BIOLOGY OF *Nassarius vibex* (SAY, 1822) ON A SHELTERED BEACH IN SOUTHEASTERN BRAZIL

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Short Running Head: Population Biology of *Nassarius vibex*

ABSTRACT

Nassariids have a worldwide distribution, being most common in sheltered embayments in tropical, subtropical, and temperate zones occurring in intertidal and subtidal areas. Species of this genus are scavengers constituting a major link in the energy flow between carrion, independent of trophic levels, and the environment. The aims of this study are to compare the distribution pattern and the population biology (growth and mortality) of males and females of *Nassarius vibex*. Sampling was carried out monthly, at spring low tide, from September 2007 through February 2009 at Flexeiras Beach located in Rio de Janeiro State (22°), southeastern Brazil. Sampling was conducted according to a systematic design in which biological samples were taken along six transects, equally spaced perpendicular to the shoreline. On each transect, 10 equally spaced sampling units (SUs) were established, the first (SU1) at the waterline, second last (SU9) on the drift line, and the last (SU10) 3 m above the drift line (supralittoral). Highest population abundances were observed in spring on both sexes. There were significant differences in abundance among the levels, in both sexes. Females of *N. vibex* had lower abundances, grew faster, and had higher mortality and smaller life span than males. Variations in population parameters of *Nassarius vibex* population might be regulated by phenotypic adjustment to local conditions, in food availability, and apparently, in this case, by exposure to organotin compounds inducing to the imposex.

Keywords: Population biology, *Nassarius vibex*, Sheltered beach, Brazil

INTRODUCTION

Among small invertebrates, which account for part of the macrofauna in beaches, mollusks can reach an astonishingly high biomass in mud flats (Cannicci, 2008) and sand beaches (McLachlan & Brown, 2006), occupying different trophic levels of the ecosystem food web (Arruda, Domaneschi & Amaral, 2003). In this group, nassariids have received special attention because they are one of the faunal dominants (Britton & Morton, 1994a), and play an important role in the recycling and reincorporation of decaying matter into the trophic chain of local estuarine ecosystems (Britton & Morton, 1994b).

The genus *Nassarius* has a worldwide distribution on the seabed and on soft shores, being most common in sheltered embayments in tropical, subtropical, and temperate zones, and occurring in intertidal and subtidal areas (Morton & Chan, 1999). Most of studies on this genus are related to the systematic (Cernohorsky, 1984) feeding behavior (Morton & Chan, 1999, 2003) and reproductive biology (Houston, 1978; Barnett, Hardy & Watson, 1980). This genus is used as a bioindicator of pollution by TBT (tributyltin, compound used in antifouling paints applied on ships) by the degree of imposex development (i.e, imposition of male sexual characters in females) in the coastal waters of Europe (Barreiro *et al*., 2001; Barroso *et al*., 2005).

There are few studies concerning the life span and population dynamics of nassariids species (Morton & Chan, 2003). Among the species most studied are highlighted *Nassarius reticulatus* (Linnaeus, 1758) (Tallmark, 1980; Barroso *et al*., 2005; Chatzinikolaou & Richardson, 2008); and *Nassarius festivus* (Powys, 1835) (Chan & Morton, 2001; Morton & Chan, 2003); but few studies have focused on *Nassarius* species of the South America coast (Demaintenon, 2001a, b; Cardoso, Caetano & Cabrini, 2009; Lima-Verde, Castro & Rocha-Barreira, 2010).

Nassarius vibex (Say, 1822) is one of the most important species in the macrofaunal intertidal communities of sheltered sand–muddy beaches on the São Paulo and Rio de Janeiro coast (Brazil) (Denadai, Amaral & Turra, 2005; Cardoso *et al*., 2011) and constitutes a major link in the energy flow between carrion, independent of trophic levels, and the environment (Britton & Morton, 1994a). There are few studies on this species and available information refers feeding behavior (Hurst, 1965), response to escape (Gore, 1966), and ontogeny of reproductive system (Demaintenon, 2001a; b). Concurrent studies have reported the imposex incidence in different populations of *N. vibex* (Cardoso *et al*., 2009; Cardoso *et al*., 2011; Lima-Verde *et al*., 2010) and feeding behavior (Cabrini & Cardoso, submitted). Apart from these studies, there is no further information about this species on the Atlantic coast of South

America. This study will compare the abundance, distribution pattern, and population biology of males and females of *Nassarius vibex*, common and abundant species in the sheltered beaches of Rio de Janeiro State.

MATERIALS & METHODS

Study Area, Sampling and Laboratory Procedures

Flexeiras Beach (22º56'S; 43º53'W) located at Itacuruçá Island, Sepetiba Bay, South coast of Rio de Janeiro state, Brazil, is characterized as sheltered beach using the McLachlan (1980) ranking system. This beach has a microtidal regime with a mean tidal range of 1.5 m, is 350 meters long and about 30 meters wide. Beach slope was of 1/30.6 m. The salinity of the water is nearly constant (35).

Sampling was carried out monthly at spring low tide in September 2007 through February 2009. Biological samples were taken along six transects, equally spaced perpendicular to the shoreline. On each transect, 10 equally spaced sampling units (SUs) were established, the first (SU1) at the waterline, second last (SU9) on the drift line, and the last (SU10) 3 m above the drift line (supralittoral). One sample was taken with a 0.04 m^2 quadrat sampler to a depth of 25 cm. Each SU was sieved through a 0.5 mm mesh. All individuals were preserved in 70% ethanol. Sediment samples for particle size analysis were taken with a plastic corer of 3.5 cm diameter to a depth of 10 cm at sampling unit 10 (supra), 5 (middle), and 1 (infra) in the transects 2 and 5.

In the laboratory, shell length of *Nassarius vibex* was measured with calipers (0.01 mm precision), with the results being grouped into 0.5 mm size classes; posteriorly, the shells were cracked in a vice, and the animals removed and examined for sex determination. Individuals having seminal vesicle were identified as males while other ones with seminal vesicle absent as females (Demaintenon, 2001b).

Sediment samples were dried in an oven at 70ºC and sieved through graded screens in order to determine mean particle size and sorting parameters for each level (Folk & Ward, 1957). After that, the mean particle size was calculated for these three strata. The beach face slope of each transect was measured by the height difference between drift line and waterline (Emery, 1961).

Data Analysis

To perform the growth analysis, the monthly length–frequency distributions discriminated by sex were used according to procedures suggested by Gómez & Defeo (1999). The procedure suggested by these authors consists of (1) separating normally distributed components of length–frequency distributions through the NORMSEP routine of the FISAT program (Gayanilo, Sparre & Pauly, 1996),

(2) assigning absolute ages to respective cohorts (lengths) and building an age-length key, (3) using the resulting age-length key for each sex to fit the von Bertalanffy growth function (VBGF) for seasonality (VBGF: Gayanilo *et al*., 1996) by nonlinear least squares:

$$L_t = L_\infty[1 - e^{[-K(t-t_0)+(KC/2\pi)\sin 2\pi(t-wp)-(KC/2\pi)\sin 2\pi(t_0-wp)]}]$$

where Lt is length at time t (mm); L∞ is the theoretical maximum length attained by the species; K is the curvature parameter; C accounts for the intensity of seasonal growth oscillations; to is theoretical age at zero length; and WP is the winter-point, *i.e*., period of growth reduction, expressed as a decimal fraction of the year. To compare the VBGF fitted for each sex, an analysis of the residual sum of squares (ARSS) was performed (Chen, Jackson & Harvey, 1992).

The standard growth index ϕ' (phi prime: Pauly & Munro, 1984) was used as a measure of overall growth performance: ϕ' = 2log10 (*L*∞) + log10 (K). Phi prime has been used successfully as a growth index in sandy beaches populations (Defeo, Sánches & Sánches, 1992).

The instantaneous mortality rate (*Z*) was calculated by the single, negative exponential model, using the length-converted catch curve method (Pauly, Munro & Abad, 1995) of the FISAT program (Gayanilo *et al*., 1996). Life span was estimated by an inverse von Bertalanffy growth equation, considering maximum length (Cardoso & Veloso, 1996).

A Student's t-test was used to compare abundance of males to females as well as to determine whether there were significant differences between the shell heights of males and females of N. vibex. A Nested ANOVA was used to test the null hypothesis that there was no significant difference in the abundance of the males and females of N. vibex between months nested within years, and also between levels nested within transects. Year and transect were fixed factors and month and stratum were random factors in the model. One-way ANOVA was performed to compare the spatial variability of mean grain size. Tukey's honest significant difference (HSD) test was used a posteriori to assess significant differences. Normality and homogeneity of variance was assessed using the Cochran.

The comparison test of slopes was used to compare mortality rates between males and females of *N. vibex* (Zar, 1999).

In all statistical analyses, a significance level of 5% was adopted (Zar, 1999).

RESULTS

Habitat Characterization

The mean grain size ranged from 0.25mm (medium sand) to 1.30mm (very coarse sand). One-way Anova indicated significant differences of mean grain size among strata (F= 4.57; df= 2/159; p<0.05), and Tukey's test detected differences only in upper strata (p<0.05). The beach had a gentle slope, ranging from 1/20 to 1/40m.

Population Structure

The highest population abundances of males and females of *Nassarius vibex* were registered in the spring (October 2007 and November 2008) Figure 1. The sex ratio between males and females differed significantly from 1:1 (t-test= 4.73; p<0.05). The males of *N. vibex* had higher abundance than females in most months. Between-month variation in population abundance was higher in males of *N. vibex*, ranging from 5.0 to 33.3 ind/m^2, while in females from to 3.3 to 21.5 ind/m^2. There was no significant difference in shell length between females and males of *N. vibex* (t-test= 0.47; p<0.64).

Distribution

The across-shore distribution of females and males of *Nassarius vibex* extended for 40m from the base of boulder wall to the lower limits of the swash zone (30cm water layer) Figure 2. Nested Anova indicated no significant differences between abundance of the males and the females of *N. vibex* between months nested within years (Years: $F(_{\text{males}})_{11,18}$= 1.51; p= 0.4098; Months (Years): $F(_{\text{males}})_{6.18}$= 1.54; p= 0.3468) and (Years: $F(_{\text{females}})_{12,18}$= 1.48; p= 0.2468; Months (Years): $F(_{\text{males}})_{3.18}$= 0.47; p= 0.8483); but significant differences between levels nested within transects were indicated (Levels (Transect): $F(_{\text{males}})_{50.60}$= 14.23; p= 0.0000 and (Levels (Transect): $F(_{\text{males}})_{50.60}$= 14.23; p= 0.0000 and Levels (Transect): $F(_{\text{females}})_{11.60}$= 13.19; p= 0.0004). Tukey's test showed that maximum abundance occurred closer to the lower part of the midlittoral (levels 4, 5 e 6), decreasing smoothly toward both extremes of the beach in both sexes

Populations Parameters

The analysis of growth parameters revealed that there is significant variation in individual growth between the sexes. Females grew significantly faster than males of *Nassarius vibex*, as verified by ARSS analysis ($F_{3,151}$ = 63.7; p< 0.05) and a variation of growth performance (ϕ'). The model VBGF with seasonal oscillation through nonlinear fitting explained more than 96% of the variance in females and more than 97% in males of *N. vibex*. The striking similarity between estimates of the VBGF determined that the statistical comparison through the ARSS did differ between sexes (F-ratio = 63.7; p< 0.0000).

Estimated growth parameters were statistically significant (p<0.0000; Table I), with the exception of to in males and females of *N. vibex* population. Weak intra-annual oscillations in growth reflected slower growth in the summer (December) in males (C = 0.36; WP = 1.00) and moderate intra-annual oscillations in growth reflected minimal growth in the autumn (April/May) in females of the scavenger (C = 0.66; WP = 0.40) (Figure 3). The size of the smallest individual (SL) of male was 5.33 mm, whereas those recorded in females of *Nassarius vibex* was smaller (i.e., 4.28 mm SL). The largest values were 17.44 mm and 17.56 mm in males and females of *N. vibex*, respectively. The life span (t_{max}) corresponding to these estimates was more than 3.5 years in males and approximately 3 years in females of *N. vibex*.

Comparison test of slopes showed that the mortality rate showed significant differences between the sexes (t-test = 4.15; p< 0.05). Females of *Nassarius vibex* (Z = 3.61 ± 0.43·yr-1) had significantly higher mortality than males (Z = 3.44 ± 0.37·yr-1) (Table II, Figure 4).

DISCUSSION

Population biology of both sexes of *Nassarius vibex* significantly differed. Females had lower abundances, grew faster, and had higher mortality and smaller life span than males. However, both sexes showed similar spatial distribution. These patterns were consistent in time.

The abundance peaks of males and females of *N. vibex* were recorded in spring. However, most studies with *Nassarius* species observed these peaks in summer (i.e., *Nassarius reticulatus* (Tallmark, 1980; Chatzinikolaou & Richardson, 2008) and *Nassarius festivus* (Morton & Chan, 2004)). All these studies registered only one peak per year. We believe that these unimodal peaks can be related to (a) the well-defined seasons in temperate zones or high-latitude regions; (b) or increased activity and feeding response during the warmer months and a decreased activity and response toward the catch during the winter. Tallmark (1980) observed that *N. reticulatus* became immobile in winter (temperatures below 4^{o}C) and thus, less vulnerable to predation. Thus, fluctuations in population abundance can indicate periods of intense reproduction and recruitment; it is frequent in benthic organisms.

The populations of *N. vibex* in Flexeiras beach were male-biased. Torres & Drummond (1999) suggested that if reproductive conditions are deteriorating, the differential costs between males and females may increase. This concept can be related to the environmental conditions typical of the study site. Sepetiba Bay should be regarded as the most dynamic, variable, and organically polluted area

(Gomes *et al*., 2009), thereby accounting for the greatest deviation in the sex ratio from 1:1. Cardoso *et al*., (2011) observed in this area, on beaches with high percentage of imposex (considered highly polluted), the sex ratio revealed significant deviations from 1:1 at three beaches, of the five analyzed.

Higher abundances of males and females of N. vibex occurred closer to the lower part of the midlittoral, decreasing smoothly toward both extremes of the beach. This distribution could be associated with grain size, since the middle and lower strata did not showed statistical differences, suggesting that Nassarius vibex occur most abundantly in coarse sands. However, *Nassarius iodes* (Dall, 1917) no showed preference by sediment type, occurring in fine sand and coarse sand (Cupul-Magaña & Téllez-Duarte, 1997). According to these authors, *Nassarius iodes* are governed more by their feeding habits than by their substrate preferences. Behavior can also influence the distribution, since *Nassarius vibex* population showed wide range over the surface of tidally exposed sandflats, in response to active foraging behavior. McKillup & McKillup (1997) also verified the same distribution to other Nassariids.

The high standard deviations in abundance of males and females of *N. vibex* by sampling levels (Fig. 2) suggest a clumped distribution of these species, mainly on intermediate area. Clumped distribution of *Nassarius vibex* population can be explained by aggregation around carrion in the intertidal zone, since this food is rarely naturally available, and when occurs, is in this zone (Britton & Morton, 1994b).

There was no significant difference in shell height between females and males of *N. vibex*, corroborating with observed for *N. reticulatus* (under laboratorial conditions) and *N. festivus* (Chatzinikolaou & Richardson, 2008; Chan & Morton, 2005).

Analysis of the estimated parameters for males and females of N. vibex and the growth curves derived from these (see Table I and Figure 3) show that females grew faster than males; corroborating with Barroso et al., (2005) to *N. reticulatus* in Portugal and Chatzinikolaou & Richardson, (2008), to *N. reticulatus* in North Wales (under laboratory conditions). A possible explanation may be due to the high percentage of females of Nassarius vibex affected by imposex, like observed in studied population (approximately 85% of females are affected by imposex—Cabrini unpublished). The low percentage of non-imposexed females impeded the construction of its growth curve. Son & Hughe (2000) observed that shell growth of imposexed females of *Nucella lapillus* (Linnaeus, 1758) populations was much more accentuated than for normal females. According to same authors, this difference was due to the energy meant for reproduction, being instead mobilized for the growth of the shell as TBT affects gonadic activity.

Males of *N. vibex* displayed a seasonal growth pattern, slower growth during the summer. Large males of *N. vibex* showed slower shell growth during the summer months and this is attributed to the onset of sexual maturity; when energy is diverted from shell growth to reproduction, this same pattern was also observed for *N. reticulatus* (Chatzinikolaou & Richardson, 2008). Females of *N. vibex* displayed growth reduction during the autumn that corroborated with the gonadal cycle of nassariids that progressively matured in autumn with maturity being achieved in winter (Chan & Morton, 2005). Females of *N. vibex* possess few energy reserves in period of maturation and the bulk of energy gained by feeding is channeled into reproduction but not for growth. This is common in mollusks, which have a short life cycle, high fecundity, and a sigmoid growth curve (Chia & Skeel, 1973).

Males of *N. vibex* showed weak growth oscillation while females of *N. vibex* showed moderate to high oscillation. Seasonal growth was also observed for *N. reticulatus* at a beach and a lagoon of North Wales, and for *N. festivus* at three beaches in Hong Kong (Morton & Chan, 2003). The interruption of growth of these species may be caused by ranges of ocean temperatures, alongshore currents, and climate. Other factors such as food availability have been observed to affect the growth of nassariids (McKillup & McKillup, 1997). Some authors suggest that rates of food supply or frequency of feeding opportunities influence feeding behavior of carnivorous snails, since carrion is generally a scarce source in mudflats and sandflats (McKillup & Butler, 1983; McKillup & McKillup, 1997).

Growth parameters of the VBGF $L\infty$ and K were significantly correlated with latitude (Table III). Some geographic trends emerged from the 12 growth estimates compiled from the literature: there is evidence for latitudinal gradients in both parameters, with $L\infty$ positively ($r = 0.62$; $p < 0.0306$) and K inversely ($r = -0.56$; $p < 0.0478$) correlated with latitude. Some 12 mm differences in $L\infty$ were found between the boreal species (28.6 mm CL) and subtropical species (16.6 mm CL).

Bivalves and crustaceans (Mazé & Laborda, 1988; Cardoso & Defeo, 2004; Defeo & Cardoso, 2002) grow faster at low latitudes. It is a consequence of an increased metabolic rate (higher oxygen consumption) observed at lower latitudes (Longhurst & Pauly, 1987). However, the genus *Nassarius* show no consistent geographical pattern to growth performance (phi prime). Since *N. vibex* is localized in low latitude (22º S), it showed value of phi prima lower than that of *N. festivus* (2.81 – 2.87) (Morton & Chan, 2003) in same latitude, and lower than that of *N. reticulatus* (2.76) in higher latitude (51º S)

(Chatzinikolaou & Richardson, 2008). This may be due to a great plasticity in life-history traits, which enables these species to survive under diverse environmental conditions (Brown, 1996).

Natural mortality in females was higher than in males of *N. vibex* population. It can be explained by females of *N. vibex* population of Flexeiras beach, showing a high incidence of imposex (Cabrini unpublished), suggesting that TBT is related to sterility and female mortality. This also was indicated for *Nassarius kraussianus* (Dunker, 1846) populations in South Africa (Marshall & Rajkumar, 2003).

The higher number of males than females of *Nassarius vibex*, in almost all months, could be explained by the greater life span of males over females (3.52 and 2.57, respectively), and thus they remain longer in the population. Life span differs within and among species of Nassariidae; males and females of *N. vibex* have a life span similar to *N. festivus* (22 – 29 mo) in Hong Kong (Morton & Chan, 2004) and both have shorter growing period than *N. reticulatus* (15 yr) in Sweden (Tallmark, 1980) and (4–5yr) in North Walles (Chatzinikolaou & Richardson, 2008). These data suggest that tropical species of *Nassarius* have shorter life spans than boreal species (Table III).

CONCLUSION

We can conclude that population biology of *Nassarius vibex* seems to be affected by imposex. Since females of *N. vibex* had lower abundances, grew faster, and had higher mortality and smaller life span than males. These results can be explained by alteration in the gonadic activity caused by possible presence of TBT or others chemical products that induced the occurrence of imposex.

Results obtained from applying a database of studies with other *Nassarius* species provided strong support to the latitudinal gradient hypothesis (LGH) (Defeo & Cardoso, 2002): *Nassarius* species from tropical and subtropical beaches exhibited higher growth and mortality rates and shorter life spans than species from temperate beaches. These latitudinal trends could be related to variations in temperature, which constitutes an “aggregate variable” that is correlated with different simultaneous effects in the near-shore surface zone environment (e.g., food availability).

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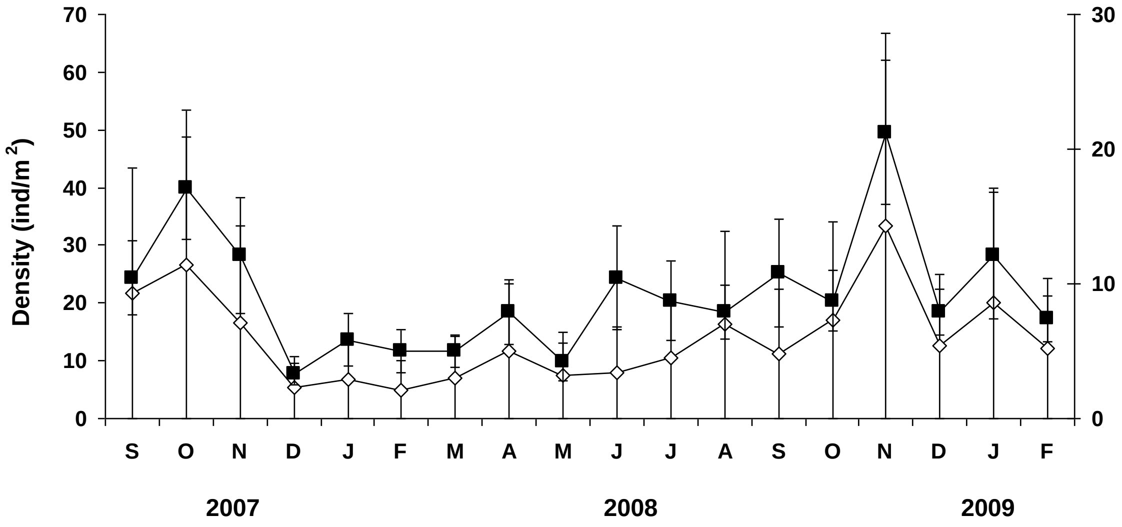

Figure 1. Monthly variations in abundance (ind m^2: mean ± 1SD) of the males (-■-) and females (-◊-) of *Nassarius vibex* for the period September 2007 to February 2009. Vertical bars represent standard deviation.

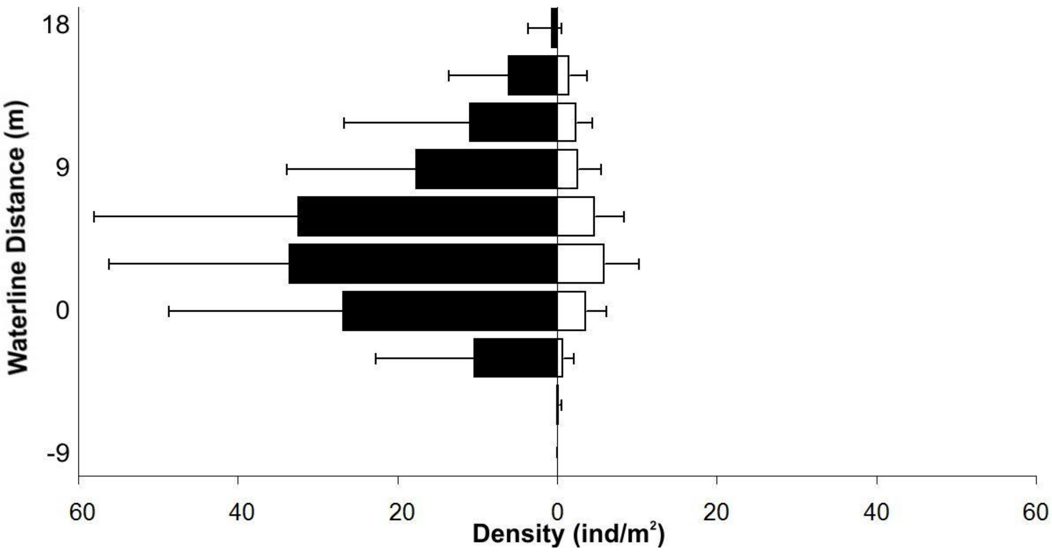

Figure 2. Across-shore variation in the mean abundance (± 1 SD) of the males (black bars) and females (white bars) of *Nassarius vibex* along the sampling strata for the period September 2007 to February 2009.

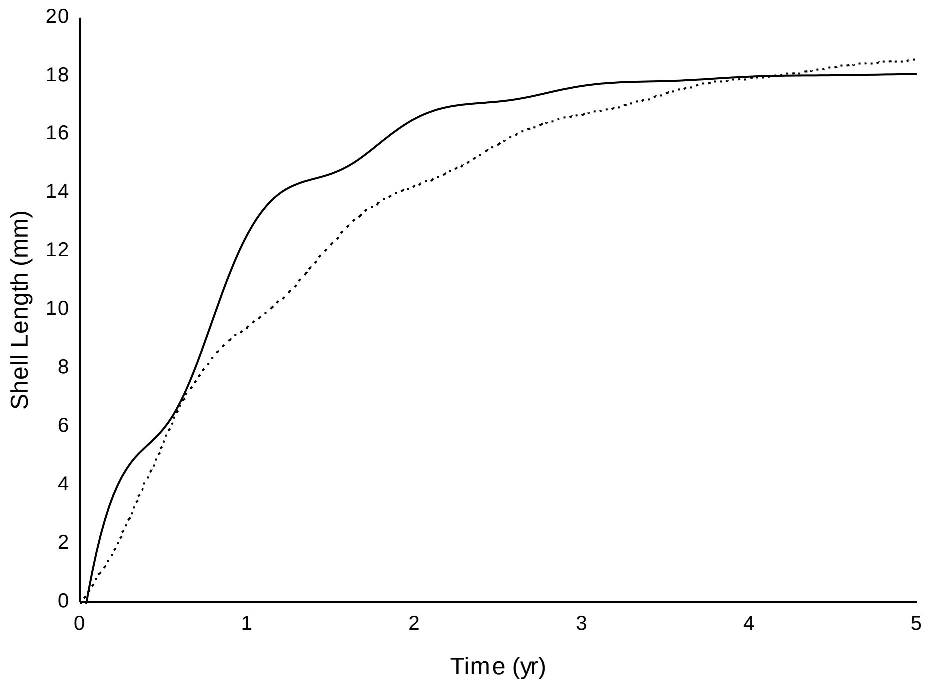

Figure 3. Seasonal growth curves fitted for males (- - -) and females (—) of *Nassarius vibex* for the period September 2007 to February 2009.

Table I. Growth parameters estimated by nonlinear least squares fit of the von Bertalanffy function for males and females of *Nassarius vibex*.

Nassarius vibex	Males		Females	
Parameter	Mean (SE)	P	Mean (SE)	P
$L\infty$ (mm)	19.20	0.0000	18.11	0.0000
K (y^{-1})	0.68	0.0000	1.25	0.0000
C	0.36	0.0018	0.66	0.0030
WP	1.00	0.0000	0.40	0.0000
T_0	0.01	0.9173	0.04	0.5671
r^2	0.99	0.0043	0.96	0.0015
ϕ'	2.40		2.61	
Largest (mm)	17.44		17.62	
t_{max} (mo)	3.52		2.97	

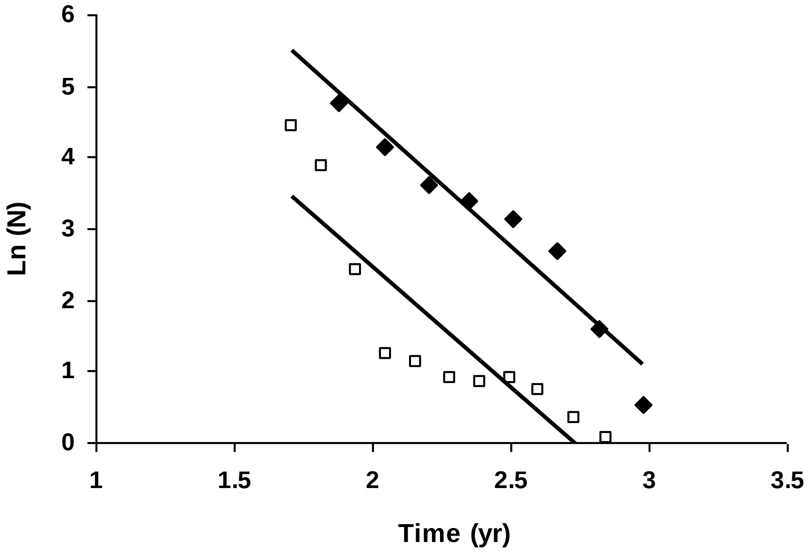

Figure 4. Length-converted catch curves for males (♦) and females (□) of *Nassarius vibex* during September 2007 to February 2009.

Table II. Mortality estimates (Z) for males and females of *Nassarius vibex*. Data are means and standard deviation (in parentheses) (g regression intercept; R^2 determination coefficient).

Parameters	Males	Females
g	11.35 (0.93)	9.71 (1.05)
Z	3.44 (0.38)	3.61 (0.43)
R^2	0.96	0.91

Table III: Parameters of the growth curve of von Bertallanfy to species of the family Nassaridae: asymptotic length (L∞), growth constant (K), growth performance index (ϕ').

Species	K (y^{-1})	L∞ (mm)	ϕ'	Latitude	Source
Nassarius vibex	0.68	19.20	2.40	(22° 56')	Present Study
Nassarius vibex	1.25	18.11	2.61	(22° 56')	Present Study
Nassarius vibex	1.22	18	2.60	(23° 37')	Yokoyama (2010)
Nassarius vibex	0.58	18.5	2.30	(23° 37')	Yokoyama (2010)
Nassarius festivus	2.7	16.6	2.87	(22°15')	Morton & Chan (2004)
Nassarius festivus	2.3	17.4	2.84	(22° 15')	Morton & Chan (2004)
Nassarius festivus	2.0	18	2.81	(22° 15')	Morton & Chan (2004)
Nassarius reticulatus	0.85	25.5	2.74	(53 °13')	Chatzinikolaou & Richardson (2007)
Nassarius reticulatus	0.70	28.6	2.76	(53 °13')	Chatzinikolaou & Richardson (2007)
Ilyanassa obsoleta	0.13	29.8	2.06	(38 ° 37')	Curtis *et al*., (2000)
Buccinanops globulosum	0.22	30.8	2.32	(40 ° 45')	Navarte *et al*., (2008)
Buccinanops globulosum	0.49	51.6	3.12	(40 ° 45')	Navarte *et al*., (2008)

ANEXO

Artigo científico derivado desta dissertação

Cabrini, T.M.B., Cardoso, R.S. 2012. Population Biology of *Nassarius vibex* (Say, 1822) on a sheltered beach in Southeastern, Brazil. Journal of Shellfish Research, v. 31, p. xx - xx.