UNIVERSIDADE ESTADUAL DE CAMPINAS

INSTITUTO DE BIOLOGIA

PRISCILA DE ALMEIDA CANDIDO BARONI

MONITORAMENTO DE UMA PLANÍCIE DE MARÉ NA REGIÃO SUDESTE DO BRASIL COM BASE NA DINÂMICA POPULACIONAL DE ESPÉCIES DOMINANTES

MONITORING OF A TIDAL PLAIN IN THE SOUTHEAST REGION OF BRAZIL BASED ON THE POPULATION DYNAMICS OF DOMINANT SPECIES

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Tese apresentada ao Instituto de Biologia da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Doutora em Biologia Animal, na área de Biodiversidade Animal.

Thesis presented to the Institute of Biology of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Animal Biology, in the area of Animal Biodiversity.

Orientadora: Profª Drª Antonia Cecilia Zacagnini Amaral
Co-orientador: Dr. Guilherme Nascimento Corte

ESTE TRABALHO CORRESPONDE À VERSÃO FINAL DA TESE DEFENDIDA PELA ALUNA PRISCILA DE ALMEIDA CANDIDO BARONI ORIENTADA PELA PROFª ANTONIA CECILIA ZACAGNINI AMARAL.

CAMPINAS
2020

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca do Instituto de Biologia
Mara Janaina de Oliveira - CRB 8/6972

B268m Baroni, Priscila de Almeida Candido, 1991-
Monitoramento de uma planície de maré na região Sudeste do Brasil com base na dinâmica populacional de espécies dominantes / Priscila de Almeida Candido Baroni. – Campinas, SP : [s.n.], 2020.

Orientador: Antonia Cecília Zacagnini Amaral.
Coorientador: Guilherme Nascimento Corte.
Tese (doutorado) – Universidade Estadual de Campinas, Instituto de Biologia.

1. Dinâmica populacional. 2. Crustáceo. 3. Poliqueta. 4. Planícies de maré - Araçá, Baía do (São Sebastião, SP). I. Amaral, Antonia Cecília Zacagnini, 1948-. II. Corte, Guilherme Nascimento, 1984-. III. Universidade Estadual de Campinas. Instituto de Biologia. IV. Título.

Informações para Biblioteca Digital

Título em outro idioma: Monitoring of a tidal plain in the Southeast region of Brazil based on the population dynamics of dominant species
Palavras-chave em inglês:
Population dynamics
Crustacea
Polychaeta
Tidal flats -São Sebastião, Araçá Bay (São Paulo, Brazil)
Área de concentração: Biodiversidade Animal
Titulação: Doutora em Biologia Animal
Banca examinadora:
Antonia Cecília Zacagnini Amaral [Orientador]
Fosca Pedini Pereira Leite
Hélio Herminio Checon
Mônica Angélica Varella Petti
Leonardo Querobim Yokoyama
Data de defesa: 30-10-2020
Programa de Pós-Graduação: Biologia Animal

Identificação e informações acadêmicas do(a) aluno(a)
- ORCID do autor: https://orcid.org/0000-0001-8453-2271
- Currículo Lattes do autor: http://lattes.cnpq.br/6139134159705714

Campinas, 30 de outubro de 2020.

COMISSÃO EXAMINADORA

Profª Drª Antonia Cecilia Zacagnini Amaral

Dr. Hélio Herminio Checon

Dr. Leonardo Querobim Yokoyama

Profª Drª Fosca Pedini Pereira Leite

Drª Mônica Angélica Varella Petti

Os membros da Comissão Examinadora acima assinaram a Ata de Defesa, que se encontra no processo de vida acadêmica do aluno.

A Ata da defesa com as respectivas assinaturas dos membros encontra-se no SIGA/Sistema de Fluxo de Dissertação/Tese e na Secretaria do Programa de Pós-Graduação em Biologia Animal do Instituto de Biologia da Universidade Estadual de Campinas.

Agradecimentos

À Deus, pela vida.

À minha família que me apoiou e suportou minha ausência e meus lamentos por quatro anos. Aos meus pais, Angelina e José Luiz, que sempre apoiaram as minhas decisões não importando o lugar do mundo em que eu resolvesse me meter. A minha irmã Danila e meu cunhado Yargo por me acolherem aleatoriamente na frente do PlayStation por horas a fio e sempre me recomendarem e emprestarem livros que me ajudaram a manter minha mente em paz e sã. Ao meu noivo, Guilherme, que, se Deus quiser, quando eu defender essa tese, já será meu marido. Obrigada por me incentivar todos os dias, por me inspirar e ser minha maior alegria. Esse ano não foi fácil, mas ter você me deu forças e, grande parte do que consegui, foi por você sempre me dizer para continuar acreditando, ter calma, respirar fundo e não parar de escrever. Eu te amo.

À professora A. Cecília Z. Amaral pela orientação, paciência, correções, dicas e por muito mais do que isso. Pelos ensinamentos que me ajudaram a ser uma pessoa melhor e a olhar as coisas de forma diferente. Obrigada por não desistir de mim, mesmo quando eu quis fazer isso.

Ao meu coorientador Guilherme Corte por responder minhas mensagens confusas sobre curvas de crescimento e produção. Obrigada por me ajudar com análises e interpretações, pelas correções e incentivos.

Eu não poderia deixar de agradecer pessoas tão incríveis que se disponibilizaram a passar um tempinho na Baía do Araçá, todos os meses, com o pé na lama, na frente das peneiras, triando o material e molhando as pernas no frio. Vocês foram a base que eu precisei - física e emocionalmente - para conseguir passar por um ano de coleta. Obrigada Jaque, Rafa, Tati, Rodrigo, Bruno e, especialmente, Bia e Angélica. Vocês duas carregaram esse trabalho, literalmente, em forma de sacos de areia.

Deixo, também, um agradecimento ao Hélio por me ensinar as análises granulométricas no R e por seu bom humor nos dias de coleta.

À Silvana L. por me ensinar a identificação dos estágios reprodutivos de *Monokalliapseudes.*

Agradeço, especialmente, ao meu amigo Bruno. Uma das primeiras pessoas que tive contato no início do doutorado, alguém com quem pude conversar, trocar experiências e informações, além de pegar churrasco dos gregos, perder o jantar do congresso e passear por lugares incríveis além mar. Muito obrigada por todo o apoio que você e sua família me deram, pelo acolhimento e disponibilidade. Você, a Bia e a Joana tornaram esse período mais alegre.

Às minhas grandes amigas Carol, Camila e Dessa pelas conversas diárias no WhatsApp, as bobagens, risadas, pilates on-line e por me abraçarem mesmo à distância.

À minha ex-professora de ballet, Vanessa. Pode parecer algo simples e bobo, mas ter um lugar para onde ir nas noites em que morei sozinha em Campinas me ajudavam mais do que eu imaginei que seria possível.

À minha banca de qualificação: professores Fosca P. Leite, Flavio D. Passos e Paulo S. Oliveira por todos os questionamentos e contribuições importantes para este trabalho.

Ao Centro de Biologia Marinha da Universidade de São Paulo (CEBIMAR/USP) e todos os seus funcionários pelo suporte técnico e acolhimento.

Ao Instituto de Biologia da Universidade Estadual de Campinas (UNICAMP) pela infraestrutura.

Aos motoristas da Unicamp que nos auxiliaram no início do projeto, não só nos transportando, mas suportando nossa sujeira.

O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código de Financiamento 001.

À Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) pelo auxílio concedido por meio do Projeto Biota/Fapesp-Araçá (Proc. 2011/50317-5).

Ao Fundo de Apoio ao Ensino, à Pesquisa e à Extensão (FAEPEX) pelo financiamento de minha participação no *VIII International Sandy Beaches Symposium* (Creta - Grécia).

E a todos que ainda acreditam na ciência e que entendem que ela é uma das bases de nossa sociedade e que merece nossa atenção, dedicação e investimento.

Obrigada a você que, de alguma maneira, tornou essa tese possível.

Resumo

A distribuição espacial da fauna bentônica em planícies de maré depende do grau de exposição da área, do conteúdo de água intersticial e do teor de matéria orgânica. Nestes locais, organismos bentônicos demonstram sensibilidade à poluição e às alterações causadas ao ambiente onde vivem e podem atuar como indicadores de pressões ambientais. A Baía do Araçá constitui uma vasta planície de maré que sofreu constantes alterações que geraram determinadas perturbações que foram responsáveis por mudanças ambientais na região, como a diminuição da riqueza de espécies. A análise da dinâmica populacional de espécies dominantes em ambientes costeiros é essencial para compreender a comunidade e o ambiente e pode ser utilizada para fins de monitoramento. Este estudo é apresentado em dois capítulos e tem como objetivo avaliar a dinâmica populacional de duas espécies macrofaunais. O capítulo 1 mostrou que *Laeonereis acuta* apresenta um importante papel na produtividade secundária da Baía do Araçá, rápidas taxas de crescimento e reprodução e recrutamento de indivíduos contínuos ao longo do tempo que reforçam o seu comportamento oportunista. Já os resultados do capítulo 2 mostram que a população de *Monokalliapseudes schubarti* possui alta fecundidade com rápida e constante reprodução. A espécie é altamente predada, constituindo importante elemento da teia trófica e apresenta relações com certas características ambientais, por isso, é indicada para análises ambientais que visem avaliar alterações na composição e estrutura dos sedimentos dos ambientes em que ocorrem. Ambas as espécies demonstraram ser potenciais indicadoras da qualidade dos sedimentos, portanto, espera-se que este estudo possa ser utilizado como subsídio para futuras pesquisas e acompanhamento da qualidade dos sedimentos.

Abstract

The spatial distribution of the benthic fauna in tidal flats depends on the degree of exposure of the area, the content of interstitial water and the content of organic matter. In these places, benthic organisms demonstrate sensitivity to pollution and changes at the environment they live and can act as indicators of environmental pressures. The Araçá Bay is a vast tidal flat that has undergone constant changes that have generated certain disturbances that were responsible for environmental changes in the region, such as the decrease in species richness. The analysis of the population dynamics of dominant species in coastal environments is essential to understand the community and the environment in question and can be used for monitoring purposes. This study is divided in two chapters and aims to evaluate the population dynamics of two macrofaunal species. Chapter 1 showed that *Laeonereis acuta* plays an important role in the total secondary productivity of Araçá Bay, it shows rapid growth and reproduction rates and recruitment of continuous individuals over time that reinforce their opportunistic behavior. The results of chapter 2 show that the population of *Monokalliapseudes schubarti* has high fertility with rapid and constant reproduction. The species is highly predated, constituting an important element of the trophic web and has relations with certain environmental characteristics, therefore, it is indicated for environmental analyzes that aim to evaluate changes in the composition and structure of sediments in the environments in which they occur. Both species proved to be potential indicators of sediment quality, therefore, it is expected that this study could be used as a subsidy for future research and monitoring of sediment quality.

Sumário

Introdução geral

Planícies de maré constituem ambientes sedimentares formados pela deposição de partículas em áreas costeiras com baixa energia, cujas características sedimentológicas dependem, dentre outros fatores, da amplitude de maré e da ação de ondas (Debacker et al. 2010). Nestes locais, a distribuição espacial da fauna bentônica depende da do grau de exposição, do conteúdo de água intersticial e do teor de matéria orgânica (Pagliosa 2006). De acordo com Omena e Amaral (2000), o hidrodinamismo presente nestas regiões é o fator com maior capacidade de limitar a distribuição e estabelecimento de espécies bentônicas, com predomínio dos parâmetros físicos sobre os biológicos, porém é improvável que variáveis isoladas e únicas sejam responsáveis por toda a distribuição da fauna nestes ambientes, uma vez que diferentes espécies ocupam hábitats distintos (Rizzo, Amaral 2001). A macrofauna bentônica de regiões costeiras é constituída, em sua maioria, por poliquetas, moluscos e crustáceos que são influenciados pelas variáveis hidrodinâmicas do meio.

Nestes locais, organismos bentônicos demonstram sensibilidade, não apenas às diferentes escalas de seu habitat, mas também à poluição e às alterações de estado de seu ambiente (Resh, Jackson, 1993) e, de acordo com Borges et al. (2008), podem atuar como indicadores de pressões ambientais e da saúde do meio, uma vez que estão diretamente submetidos às constantes mudanças nos sedimentos em que vivem. Segundo Amaral et al. (2016), as comunidades biológicas de regiões entremarés são estruturadas principalmente pela energia das ondas (que afetam a composição granulométrica dos sedimentos), regime de marés, granulometria, salinidade e teor de matéria orgânica, com possíveis variações decorrentes de alterações antrópicas. Seu modo de vida junto ao fundo e o predomínio de formas de pouca mobilidade e com baixa capacidade de migração em resposta a condições adversas favorecem a utilização da fauna bentônica como bioindicadora da qualidade dos substratos (Pearson, Rosenberg 1978; Gesamp 1980; Lenat; Barbour 1994; Weisberg et al. 1997). Sendo assim, o estudo da biologia de integrantes da macrofauna bentônica constitui importante ferramenta para o monitoramento e manejo de ecossistemas costeiros permitindo a compreensão do meio (Omena, Amaral 2000; Arruda, Amaral 2003; Turra e Denadai 2015).

Dentre os estudos dessa natureza e associados à fauna bentônica realizados no Litoral Norte de São Paulo, destacam-se os desenvolvidos na região da Baía do Araçá associados ao Projeto Temático Biota/FAPESP-Araçá subsidiado pela Fundação de

Amparo à Pesquisa do Estado de São Paulo (FAPESP) que contou com participantes vinculados a diferentes instituições de ensino e pesquisa, nacionais e estrangeiras. Ao longo de sua duração, o projeto foi responsável por revelar um ecossistema de alta riqueza e diversidade de espécies (Amaral et al. 2015, Amaral et al. 2018). De acordo com Amaral et al. (2010), apesar de ter sofrido severas alterações por conta do soterramento para expansão portuária e do crescimento populacional humano, a baía possui um dos últimos remanescentes de manguezais de São Sebastião e apresenta elevada diversidade biológica, além de ser um local importante para atividades econômicas, sociais e culturais dependentes desse ecossistema e dos ciclos biológicos relacionados, tais como a pesca tradicional que visa a captura de peixes, crustáceos e moluscos para consumo e comercialização.

A Baía do Araçá, inserida na porção continental do Canal de São Sebastião (SP), constitui uma vasta planície de maré que sofreu constantes alterações em sua área durante a construção do Porto de São Sebastião e que comporta um emissário submarino para disposição de esgotos domésticos, fatores estes que geraram perturbações na região tais como enriquecimento orgânico, alteração na hidrodinâmica e contaminação por compostos químicos. Apesar dos impactos e mudanças gerados neste ecossistema, segundo Amaral et al. (2015), o mesmo possui grande biodiversidade e alta produtividade e abundância de organismos bentônicos, incluindo espécies novas para a ciência e espécies ameaçadas de extinção. Portanto, o seu estudo, conservação e monitoramento das alterações em suas características ambientais, tanto bióticas como abióticas são de suma importância.

Transformações e pressões que agiram na planície de maré da Baía do Araçá foram responsáveis por mudanças ambientais na região, como a diminuição da riqueza faunística (Amaral et al. 2010). Os processos bióticos e abióticos que já foram aferidos na baía, tanto naturais (referente ao próprio hidrodinamismo das planícies de maré) quanto induzidos, permanecem em curso. Tal fator torna necessário um acompanhamento e monitoramento das condições do ambiente ao longo do tempo, observando se a área sofre alterações e se estas interferem ou estão relacionadas aos padrões da fauna bentônica dominante, atestando-se, assim, se tais formas de avaliação permitem aferir sobre a condição do ecossistema.

Análises da qualidade dos sedimentos podem abranger três linhas de evidências principais: análises químicas, ecotoxicológicas e da estrutura da comunidade macrobentônica com o intuito de integrar as diferentes abordagens e gerar informações mais consistentes sobre a degradação induzida pelas ações humanas (Long, Chapman 1985; DelValls, Chapman 1998).

Para Giangrande, Lucciano e Musco (2005), dentre a macrofauna bentônica, algumas espécies de poliquetas são muito indicadas para análises ambientais, uma vez que sinalizam possíveis distúrbios. Esses animais possuem grande importância ecológica no funcionamento das comunidades por serem um dos grupos mais abundantes presentes em ecossistemas praiais e estuarinos, além de apresentarem uma diversidade de modos alimentares, alta biomassa e serem importantes componentes da teia alimentar nos ecossistemas marinhos (Giangrande, Lucciano, Musco 2005; Maccord, Amaral 2005; Rohr, Almeida 2006). Apesar de tais características relevantes e únicas que tornam poliquetas importantes para o uso em monitoramentos, este não é o único grupo que se destaca para esse tipo de análise. Alguns crustáceos são comumente utilizados como bioindicadores em muitos ambientes aquáticos, já que muitas vezes demonstram alterações em seus comportamentos populacionais e reprodutivos quando expostos a contaminações químicas e orgânicas provenientes de diferentes fontes (Rinderhagen et al. 2000, Resgalla Jr, Laitano 2002; Soroldoni et al 2020). Porém, análises integradas da qualidade de sedimentos visam a utilização das comunidades bentônicas como um todo, baseando-se na presença e ausência de certos grupos faunísticos (Long, Chapman 1985) e não em suas dinâmicas populacionais e na biologia de espécies. A utilização da comunidade bentônica se mostra muitas vezes suficiente para aferir sobre condições ambientais, porém, o uso limitado de identificações em nível de família ou gênero pode não ser tão efetivo para avaliar mudanças temporais (Checon, Amaral 2016).

Diante disso, surge a necessidade de novas ferramentas que auxiliem avaliações e monitoramentos ambientais com o propósito de elucidar efeitos de impactos antrópicos ao longo do tempo e não apenas com levantamentos pontuais. Portanto, a análise da dinâmica populacional de espécies dominantes em ambientes costeiros se torna uma alternativa para o acompanhamento de uma região, uma vez que é essencial para compreender a comunidade e o ambiente em questão (Rinderhagen et al. 2000; Leão et al. 2012), podendo ser utilizada para fins de monitoramento.

Para a Baía do Araçá, Checon et al. (2018) propuseram uma ferramenta para uso em programas de monitoramento que identificou hábitats bentônicos e permitiu a seleção de espécies indicadoras desses habitats para a região, tais como *Laeonereis acuta* e *Monokalliapseudes schubarti.* Com base em tais hábitats previamente identificados, duas áreas distintas no interior dessa baía onde estas as duas espécies ocorrem em manchas, foram selecionadas para este trabalho com o objetivo de avaliar as análises populacionais e de reprodução e dar suporte ao uso dessas espécies em programas de monitoramento ambiental que visem inferir sobre a qualidade sedimentológica de ecossistemas para sua conservação.

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Capítulo 1

Population dynamics of *Laeonereis acuta* (Treadwell, 1923) (Annelida: Nereididae) on a tidal flat

Abstract

Laeonereis acuta is a common macroinfaunal species on soft-bottom coastal ecosystems of the South American coast and it is considered a relevant tool for monitoring the environment, since it acts as a bioindicator of environmental quality due to its opportunistic nature. Yet, little is known about its population biology. Given the importance of this species, its population dynamics and secondary production were investigated in a tidal flat that has undergone constant changes (Araçá Bay, southeastern coast of Brazil). The samples were collected monthly in the upper mid-littoral region of the bay, between 2016 and 2017. All collected individuals were counted (N = 2296) and had the width of the 6^{th} setiger (W6S) measured as an indicator of size. Higher population densities were observed in autumn and winter, with an acute fall at the end of spring of 2017. This population produced five identified cohorts during the year. The growth rate was low, especially in organisms with higher age, with little seasonal variation (C = 0.31). The mortality rate (Z) was 3.44/year and the average secondary production was 1.9 mg AFDM.m^{-2}.$year^{-1}$. The highest production was observed in smaller individuals. Species abundance was positively related to chlorophyll *a* and phaeopigments content, while higher secondary production was related to higher temperatures and intermediate values of organic matter (~0.12g) and salinity (~26). The production/biomass (P/B) ratio was 2.83, indicating a big role of *L. acuta* at total productivity of the bay and its importance as food resource for higher trophic levels. The species' higher abundance and response to environmental changes reinforces the use of *L. acuta* as a potential tool to be used as an indicator in ecological monitoring programs, especially regarding tidal flats and organic contaminants.

Introduction

Laeonereis is a common macroinfaunal group of nereidid polychaetes on the Atlantic coast of the Americas with high occurrence in sandy substrates of coastal zones (Pettibone 1971; Amaral 1979; Omena, Amaral 2000; Santos, Lana 2001; Pamplim et al. 2007; Jesús-Flores, Salazar-Gonzáles, Salazar-Vallejo 2016; Weis et al. 2017). *Laeonereis* show a generalist nature, with rapid growth rates, numerous offsprings, and nonselective feeding behaviour (Pettibone 1971; Amaral 1979; Omena, Amaral 2000; Jumars, Dorgan, Lindsay 2015), and a fully benthic life cycle, occuring inside mucoid burrows where it spawns (Klesch 1970) and its larvae feed on microphytobenhtos until its complete development (Mazurkiewics 1975).

Over the past decades, several studies have demonstrated that anthropic impacts, such as metal and organic contamination, may influence the population dynamics of Laeonereis (e.g. Uc-Peraza; Delgado-Blas 2012; Mazurkiewicz 2009; Sardi et al. 2016; Díaz-Jaramillo et al. 2018). Campelo et al. (2017), for example, tested the influence of cadmium dichloride ($CdCl_2$) and suggested the use of *L. culveri* as a test organism considering its representativeness and sensitivity to this contaminant. Similarly, Müller et al. (2019) found that *L. culveri* significantly accumulated arsenic in its body and had DNA damage when exposed to dimethylarsinic acid (DMA), an organic form of arsenic detected in sediments and aquatic organisms (Zeng et al., 2018). Geracitano et al. (2004) found morphological variation, such as loss of the digestive epithelium, in *L. acuta* exposed to copper. The strong association of Laeonereis species with the sediment, generelist behavior and sensibility to anthropogenic action, have supported their use as good indicators in ecological assessments in coastal zones (Pagliosa, Barbosa 2006; Weis et al. 2017).

Along the Southeast coast of Brazil, two *Laeonereis* species have reported: *L. culveri* and *L. acuta*. Both species are very similar regarding its occurrence, behavior and even the maturation of its oocytes during the species' reproductive cycle (Santos, Florêncio, Florêncio 2002), which led to great taxonomic confusion. Nevertheless, a recent investigation combining morphological and molecular data showed that *L. acuta* is the only species in this region.

Despite its high potential to be used as an indicator species, information on *L. acuta* population attributes is limited, which can compromise its use in in ecological monitoring programs. Studies developed in recent years with the species (and, overall, the genre) focused mainly on morphological and taxonomic aspects (Barros et al. 2018), while investigations on its population dynamics were carried out mainly by Bloom (1983) and Omena and Amaral (2000). Therefore, to support the use of *L. acuta* in monitoring programs, it is essential to understand its population dynamics, which includes knowledge about their abundance, growth and productivity to give general information about the species and not just punctual results of their occurrences (Urban, Campos 1994; Corte et al. 2015).

Therefore, this work examines the population dynamics of *Laeonereis acuta* and the species seasonal distribution. It aims to enhance the knowledge about *L. acuta* and provides information to support its use in ecological monitoring programs. To achieve these goals, the analyses were performed over a year on a tidal flat in Southeastern Brazil. This coastal system has great ecological and social importance, but has undergone substantial changes due to the presence of a large and structured harbor (São Sebastião Harbor) and the largest oil terminal in Brazil (TEBAR) in the past decades (Amaral et al., 2010, 2016). This scenario is commonly seen across the world; therefore, this study may be used as support to be applied in other areas.

Methods

Study area

The Araçá bay, located at the continental side of the São Sebastião Channel (North Coast of the State of São Paulo) (23º49'S, 45º23'W), is a vast muddy-sand tidal flat dominated by tides, waves and winds, with an intertidal region that can reach 300 m of amplitude (Amaral et al. 2010; Amaral et al, 2018). The bay has six mangrove nuclei (Schaeffer-Novelli et al. 2018) and plays an important role at birds' establishments and feeding (Mancini et al. 2018). Primary organic sources, including phytoplanktonic activities, contribute significantly to the area's food web (Soares, Arantes, Pucci 2018b). The water circulation inside the bay is tide-dominated and its morphology has an accretionary behavior, that is, formed by the accumulation of sediments influenced by its confined characteristic due to anthropogenic constructions (Siegle et al. 2018).

Since the 1960s, the bay had its area altered during the construction of the Port of São Sebastião and the largest oil terminal in Brazil (TEBAR). It also comprises a submarine outfall for domestic sewage disposal, which came into operation in 1990 (Fig. 1). Altogether, these factors resulted in serious contamination from domestic sewage, with high levels of organic matter and hypoxia. Linked with human population growth in the surrounding areas and the history of oil spills, these factors led to the disfigurement and pollution of the environment (Weber, Bícego 1991; Zanardi et al. 1999; Gubitoso et al. 2008; Lamardo, Bícego, Weber 2013; Kim et al. 2018). A prospection made by Turra et al. (2017), indicates that anthropic impact and environmental alteration might increase if a port expansion occurred; affecting not only the bay's hydrodynamics and its biodiversity, but the surrounding areas as well.

Despite the impacts and environmental changes in this ecosystem, it still has great biodiversity and high productivity and abundance of benthic organisms, including new and endangered species (Amaral et al. 2016). This makes its study, conservation and monitoring highly important, such as demonstrated by a project developed previously at the area – the Biota FAPESP-Araçá Project (2012-2017). The project integrated multiple research fields and focused on the bay's current scenario (Amaral et al. 2018).

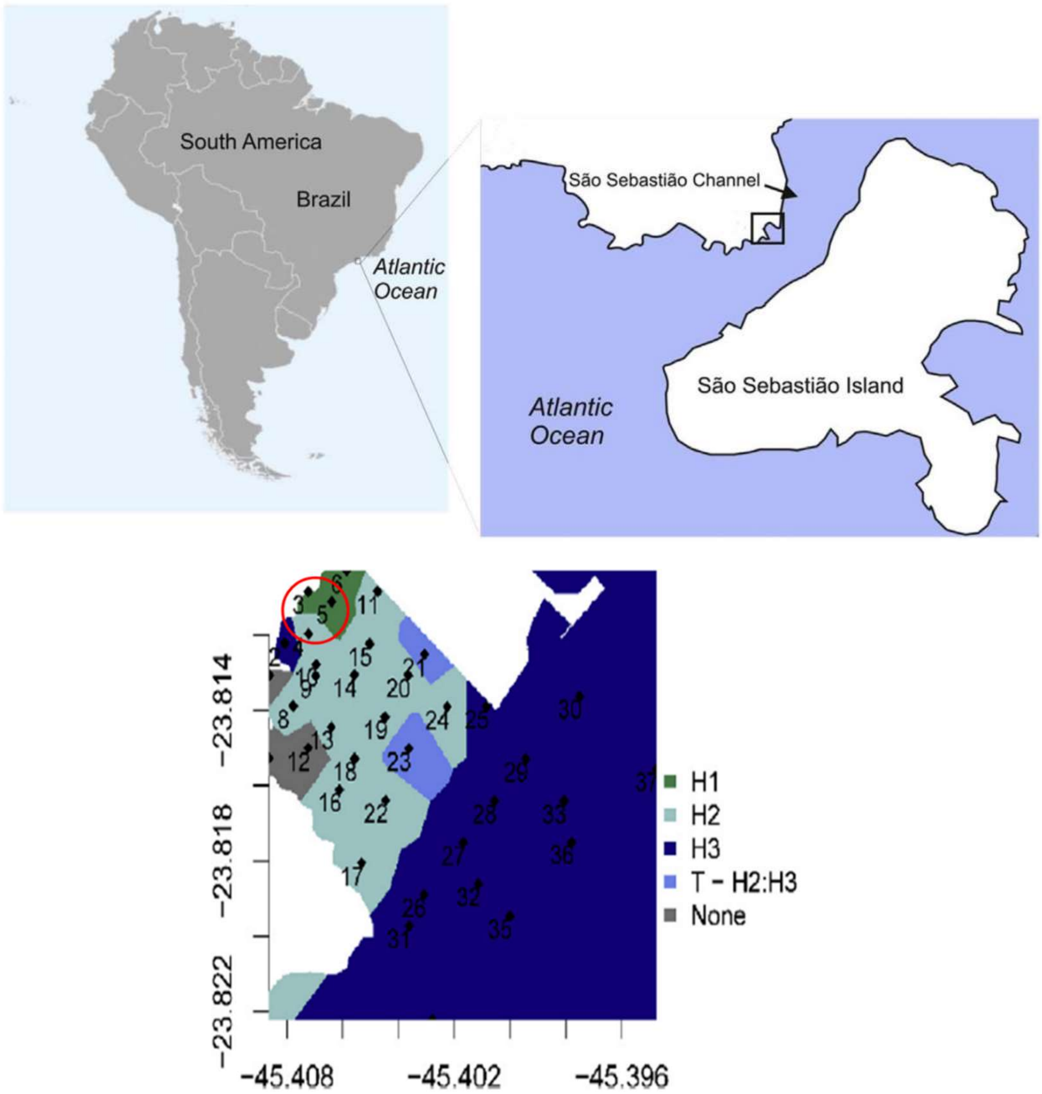

Figure 1. Araçá Bay (São Sebastião channel). Macrofauna habitats determined by Checon et al. (2018a). The circle indicate the sampling site. Upper map:Angelini et al. (2018); Lower map: Checon et al. 2018a (H1: Habitat 1; H2: Habitat 2; H3: Habitat 3). Maps adapted by the authors.

Sampling

Monthly samples were taken in the upper mid-littoral region of the Araçá bay's tidal flat (Fig. 1) from December 2016 to November 2017, during morning periods of low tide. Twelve sampling stations were chosen randomly in a fixed sector of 50 m² (23º48'49.9 "S 45º24'31.3" W). This sampling site correspond to an area inside Habitat 1 (Fig. 1), characterized by a higher amount of coarse sand (Checon et al. 2018). Samples were obtained with a cylindrical sampler (10 cm in diameter and depth) and specimens of *Laeonereis acuta* were separated from the sediment using 1.0 and 0.3 mm mesh size sieves in the coastal laboratory at the Center of Marine Biology of the University of São Paulo (CEBIMar/USP) and then preserved in 70% ethanol. Additionally, five sampling stations were randomly selected for environmental analyses. In each of those sampling stations, a sediment sample was collected with a 5 cm diameter cylindrical sampler, to a 10 cm depth. These samples were placed in plastic vials and immediately kept on ice for further organic matter analysis. An extra sample was obtained following the same procedures described above for granulometric studies. In these same regions, we collected five samples at the superficial layer of the sediment with the aid of a cylindrical acrylic tube to a depth of 1 cm, to obtain the microphytobenthic biomass. The substrate temperature measurements were obtained once, *in situ*, with an INCOTERM thermometer at the beginning of the samplings. One sample of interstitial water was obtained for further salinity analyses made with a LEICA refractometer.

Environmental parameters analysis

To investigate the influence of environmemntal characteristics on the population dynamics of *L. acuta*, we measured temperature, salinity and collected samples of sediment and microphytobenthos.

Granulometric analyses were done according to the dry sieving method for sandy fractions described by Suguio (1973) and the granulometric data were calculated in the Rysgran package of R 3.4.3 (R Development Core Team 2008). The organic matter content analysis followed the technical norm nº 13,600 of ABNT (1996), which consists of a drying process in a stove and muffle furnace and subsequent weighing.The microphytobenthic biomass was analyzed through the evaluation of photosynthetic pigments (chlorophyll *a* and phaeopigments) according to the method of spectrophotometric extraction and reading described by Plante-Cuny (1978) and adapted of David (1997). Margalef's Pigment Index was performed according to Margalef (1957) that considers values of 1 – 2 an indication of young individuals and 3 – 5 of older and senile organisms. All analyses were undertaken in the R environment (R Development Core Team 2008) using the mgcv (Wood 2012) package.

Population Structure and Mortality analysis

Abundance, density and population size structure were determined for each month. Density was estimated using the number of individuals obtained monthly.

Temporal variation in abundance was compared using generalized linear mixed model with months nested in season.

We used the width of the 6th setiger (W6S) of each individual as an estimate of total length, since it does not suffers influence of pharynx movements (Omena, Amaral 2001). Size-frequency histograms relating W6S to the number of individuals were constructed for each month. This measurement was performed at a binocular stereomicroscope.

Growth analysis consisted of separating the size frequencies using the Bhattacharya method followed by the NORMSEP routine in the FISAT II program (VBGC: Gayanillo et al., 2005), determining the ages of the cohorts (length-based) and constructing the age-length relationship. This data was used to adjust the von Bertalanffy model curve (modified for seasonal oscillation in growth) (von Bertalanffy equation) that was adjusted in Software R 3.4.3 and expressed in:

$$Wt = W_{\infty}\{1 - exp^{[-K(t-t_0)+\left(\frac{CK}{2\pi}\right)\sin(2\pi(t-t_s))-\left(\frac{CK}{2\pi}\right)\sin(2\pi(t_0-t_s))]}\}$$

where W_t is the width at time t; W_{∞} the asymptotic width; K the von Bertalanffy growth constant; t_0 time at width 0; C amplitude of seasonal oscillation of growth and t_s the starting point of oscillation regarding t=0.

The life expectancy was obtained from the inverted equation of Von Bertalanffy, using the length of which 99% of the population were represented (L99), according to Fonseca, Veloso and Cardoso (2000). To calculate the instantaneous mortality rate (Z) a simple negative exponential model was used by the converted catch curve method to the available length in the FISAT II program.

Production and Biomass Analysis

Approximately 260 randomly selected individuals from all size classes were dried at 80ºC for 24h, combusted at 500ºC for 4h and weighed to assess the ash-free dry weight (AFDW). The secondary production analysis followed Crisp (1984) through the equation:

$$P = \Sigma f_i G_i W_i \Delta t_i$$

where f_i is the average number of individual of a size class, Δt_i the period of time and G_i the growth rate, W_i the average body weight. Gi was determined by:

$$G_i = bK[\left(\frac{L\infty}{L_i}\right) - 1]$$

where b is the relation weight-size, K and $L\infty$ VBGC parameters and L_i the average size.

Annual biomass was calculated as:

$$\bar{B} = \Sigma f_i W_i \Delta t_i$$

Relationship between population attributes and environmental variables

Generalized Additive Models were used to investigate the relationship between environmental variables and abundance, production and biomass of *L. acuta*. The following environmental covariates were included: sediment organic matter (OM), chlorophyll a concentration (CHA), salinity (SAL), temperature (TEMP) and mean sediment grain size (GS). Phaeopigment concentrations were strongly correlated with chlorophyll *a* concentration (r = 0.99). Therefore, this variable was not included in the analyses to avoid collinearity. Models were based on a negative binomial for count data with overdispersion (abundance data) and gamma distribution continuous data (production and biomass) (Zuur et al. 2010). The significance of each variable was assessed using the test criterion (P α 0.05) and backward elimination of covariates until all remaining terms in the model were significant. Relationships between response variables and predictors were analyzed through the graphical output of GAMs.

Results

Environmental characterization

The granulometric analysis showed a sediment with predominance of very fine and medium sand, moderate selected and an overall low content of silt and clay (Table 1; Fig. 2).

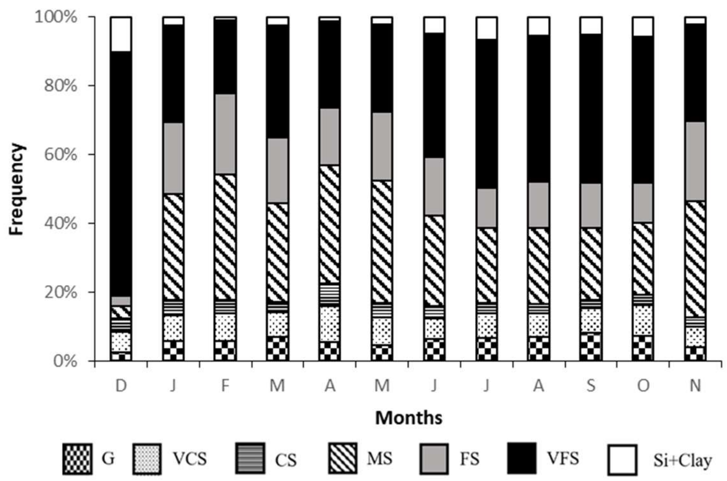

Figure 2. Sediment composition at sampling site in Araçá Bay. Gravel (G), Very Coarse Sand (VCS), Coarse Sand (CS), Medium Sand (MS), Fine Sand (FS), Very Fine Sand (VFS), Silt and Clay (Si + Clay).

The sediment temperature varied seasonally, with higher temperatures in summer and lower in winter. Some variables, such as interstitial water salinity ranged from 21.2 in June/17 to 34.8 in September/17. The average organic matter content varied between 0.01 ± 0.005 g and 0.13 ± 0.08 g with higher percentage in the summer (December 2016 and September 2017 – 0.13 and 20.8%) and a decrease in autumn (Table 1).

Table 1. Temporal variation of the environmental parameters and *Laeonereis acuta*'s density at the sampling sector in Araçá Bay from December 2016 to November 2017. GS: Mean grain size; T: Sediment temperature; Salinity: Interstitial water salinity; OM: Organic matter content; Chl a: Chlorophyll *a* biomass; Phae: Phaeopigments biomass; Density; Abundance (N = number of individuals)

	GS (phi)	**T (ºC)**	**Salinity**	**OM (g)**	**Chl a ($mg.m^{-2}$)**	**Phae ($mg.m^{-2}$)**	**Density ($ind.m^{-2}$)**	**Abundance (N)**
Dec/16	3.1	27.5	25.4 ± 3.0	0.13 ± 0.08	141.8±55.0	154.9±93.2	1,868.3±122.6	176
Jan/17	2.1	28.0	31.8 ± 2.4	0.10 ± 0.01	56.7±13.8	24.1±10.0	1,093.42±94.4	103
Feb/17	1.9	29.5	27.2 ± 4.4	0.03 ± 0.062	41.1±12.1	17.1±9.2	636.9±53.6	60
Mar/17	2.1	29.0	31.6 ± 3.9	0.01 ± 0.005	61.8±38.9	39.3±38.2	1,953.2±68.2	184
Apr/17	1.7	26.0	24.4 ± 5.2	0.01 ± 0.008	109.1±14.7	87.3±21.6	3,598.7±102.0	339
May/17	2.1	22.0	29.4 ± 1.7	0.02 ± 0.02	56.1±30.1	33.5±36.5	2,845.0±102.9	268
Jun/17	2.4	21.0	21.2 ± 7.9	0.08 ±0.05	125.3±31.1	111.1±47.5	2,961.7±95.4	279
Jul/17	2.5	22.5	33.2 ± 0.7	0.12 ± 0.02	189.1±36.1	276.9±76.6	1,910.8±79.2	180
Aug/17	2.5	19.5	32.3 ± 1.3	0.10 ± 0.03	206.8±51.1	281.7±114.5	2,515.9±95.3	237
Sep/17	2.3	23.5	34.8 ± 0.7	0.13 ± 0.03	208.8±65.1	306.3±153.2	3,089.1±88.9	291
Oct/17	2.2	23.5	33.0 ± 0.8	0.10 ± 0.02	75.92±39.6	54.6±48.3	1,825.9±86.8	172
Nov/17	2.3	24.5	24.2 ± 6.4	0.06 ± 0.04	50.0±17.8	22.0±14.0	424.6±34.4	40

The average values of chlorophyll *a* ranged between 41.1 $mg.m^{-2}$ (February/17) and 208.8 $mg.m^{-2}$ (September/17), whereas phaeopigments varied between 22.0 $mg.m^{-2}$ (November/17) and 306.3 $mg.m^{-2}$ (September/17) We observed higher microphytobenthic biomass in July, August and September, which correspond to the coldest months (Table 1). At these months, the amount of phaeopigments was higher than chlorophyll *a*. Chlorophyll *a* and phaeopigments ratio reached peaks in March and November (ratio of 3.3), which indicates high photosynthetic activity at those months. All months had a Margalef Pigment Index between 2.1 and 2.5, an indicative of younger communities.

Density

The density of *Laeonereis acuta* varied over time, ranging from 424.6 to 3598.7 ind.m^{-2} (Table 1). Higher number of individuals were found in autumn and winter (April to September 2017), while lower densities were observed in summer and spring (January, February and November 2017).

Population structure

During the study period, 2,329 specimens were collected and measured. The smallest individual had 0.18 mm W6S and the largest 2.28 mm. Nearly all size-classes were present throughout the study, except for the bigger ones (> 2 mm) which were observed only in February and March. At the beginning of the sampling, in December 2016, three main cohorts coexisted (Fig. 3). The Cohort 1, of larger individuals, probably recruited in the spring of 2016 almost disappeared in January and February 2017, while Cohort 2 was recruited in late spring and coexisted with the remaining cohorts until its disappearance at the end of autumn. The third cohort (Cohort 3), of younger and smaller individuals, dominated the population in December 2016.

New recruitment was observed in January 2017, which probably originated from the adults of Cohort 1, however, this new cohort (Cohort 4) almost disappeared during spring 2017. Another recruitment (Cohort 5), generated by the spawning of Cohort 2, occurred in March 2017 and remained until October 2017. Therefore, four recruitments were observed during the study period: two during spring and two during summer.

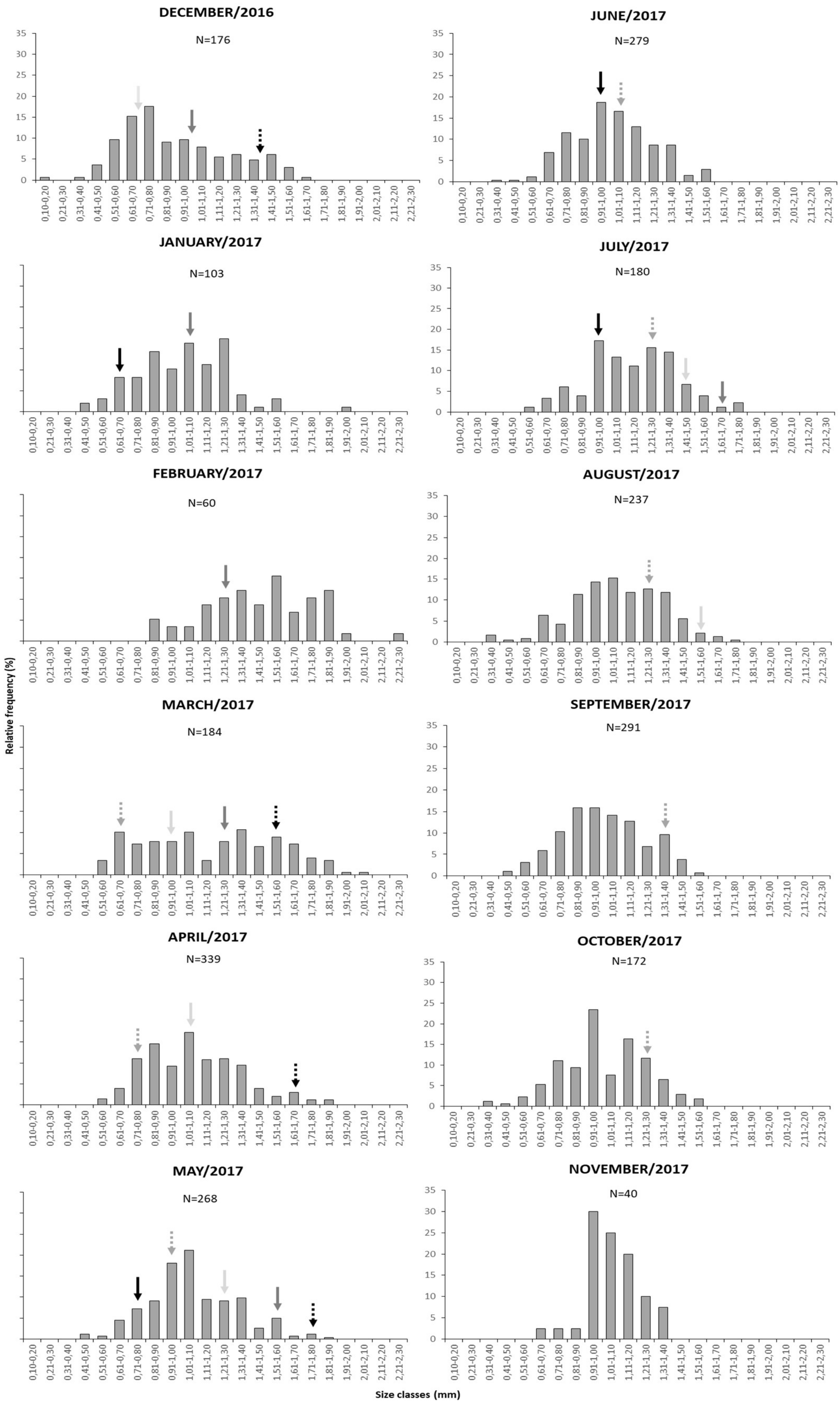

Figure 3. *Laeonereis acuta*. Relative frequencies of size classes (width of 6th setiger) at the sampling sector in Araçá Bay from December 2016 to November 2017. Arrows indicate the different cohorts: dashed black - cohort 1; dark gray - cohort 2; light gray - cohort 3; black - cohort 4; dashed gray - cohort 5.

Population growth

The population showed significant seasonal growth and rapid growth (Fig. 4). It is also possible to observe a higher growth rate in smaller sizes (individuals in whom reproduction occurs less frequently).

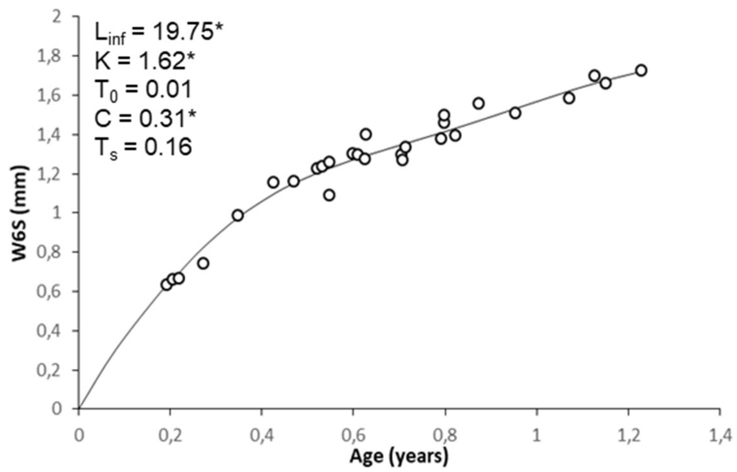

Figure 4. *Laeonereis acuta.* Growth curve estimated by seasonal function of von Bertalanffy at the sampling sector in Araçá bay from December 2016 to November 2017. W6S: width of the sixth setiger (used as estimation of size).K: growth rate; C: seasonal oscillation parameter. Asterisks denote significant values at $P < 0.05$.

Mortality and secondary production

The mortality rate (Z) was 3.44/year. The average secondary production was 1.92 mg $AFDM.m^{-2}.year^{-1}$ (Figure 5A). The highest production was observed in younger individuals (4.402 mg $AFDM.m^{-2}.year^{-1}$) and reduced in older (larger) individuals (Fig. 5B). The average biomass was 0.68 g $AFDM.m^{-2}$ and the turnover rate (productivity-biomass ratio, P/B ratio) was 2.83.

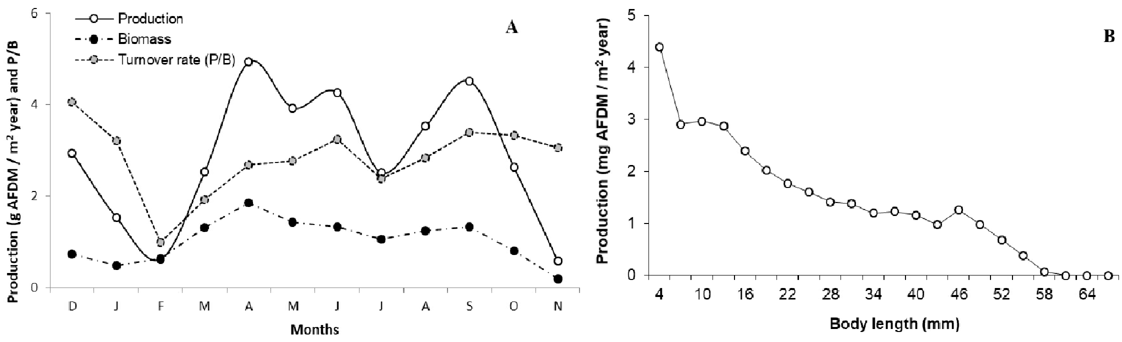

Figure 5. *Laeonereis acuta. A)* Secondary production, biomass ($g.m^{-2}$) and turnover rate *B)* Annual secondary production by the method of Crisp (1984), at the sampling sector in Araçá Bay from December 2016 to November 2017.

Environmental influence on population parameters

The chlorophyll *a* concentration was the only environmental variable significantly affecting abundance of *L. acuta.* Number of individuals was higher in sites with more than 100 $mg.m^{-2}$ of chlorophyll *a*, however a non-linear relation was observed with stabilization after 150 $mg.m^{-2}$ (Table 2, Fig. 6). The productivity of *L. acuta* was influenced by chlorophyll *a* concentration, temperature, total organic matter and salinity (Table 2). Higher values of productivity were observed in lower or higher concentrations of chlorophyll *a*, intermediate concentrations of total organic matter content, and salinity values from 24 to 30 (Fig. 7). Increases in temperature were directly related to increases in productivity. We found no relationship between the environmental variables and biomass of *L. acuta*.

Table 2. Generalized additive model outputs for the relationship between environmental variables and population parameters of *L. acuta*. CHA=chlorophyl a concentration, TEMP= temperature, OM= organic matter, SAL=salinity, Edf = estimated degrees of freedom, Ref.dr = reference df, R-sq.(adj) = adjusted r squared.

Source	edf	Ref.df	Chi.sq	F	P	Deviance	R-sq.(adj)
Abundance						37.4%	30.3%
s(CHA)	1.67	1.89	7.08		0.05		
Productivity						98.8%	98.4%
s(CHA)	2	2		24.6	0.01		
s(TEMP)	1.93	1.99		42.15	<0.01		
s(OM)	2	2		48.42	<0.01		
s(SAL)	2	2		34.18	<0.01		

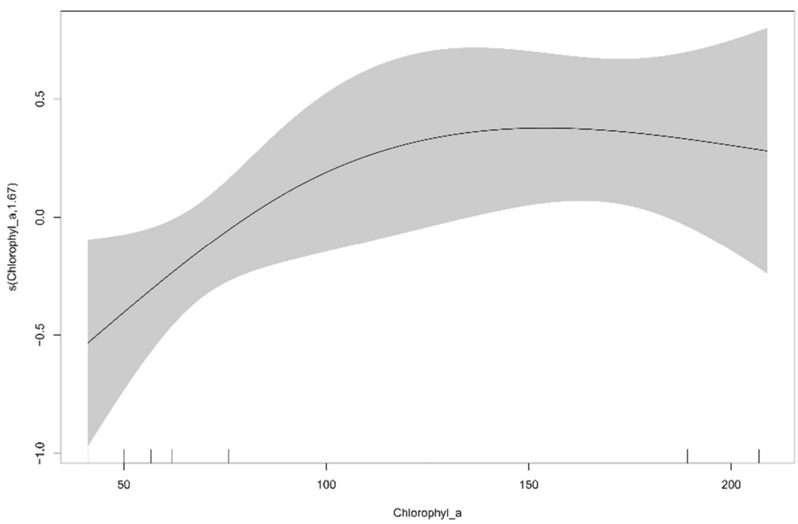

Figure 6. Smoothers curves (S) showing the relationship (solid line) between *L. acuta*'s abundance and Chlorophyll *a* concentration (mg/m^2). Shaded areas indicate standard errors of the smooth curve. The 'rug

plots' on the x-axis indicate the range of variables over which measurements were taken. Numbers after the variable name on the y-axis represent estimated degrees of freedom.

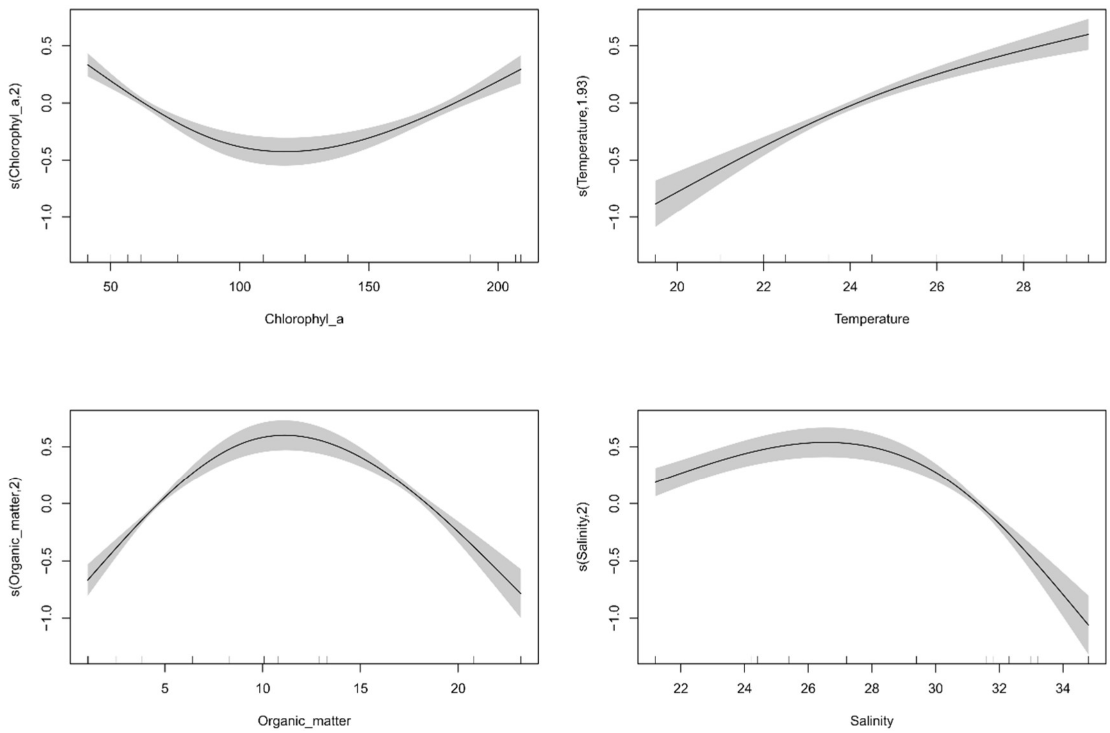

Figure 7. Smoothers curves (S) showing the relationship (solid line) between *L. acuta*'s productivity and the significant environmental variables (P<0.005). Shaded areas indicate standard errors of the smooth curves. The 'rug plots' on the x-axis indicate the range of variables over which measurements were taken. Numbers after the variable name on the y-axis represent estimated degrees of freedom.

Discussion

Our results bring important information on the population dynamics of *L. acuta*, highlighting its relevance as an important component of Araçá Bay, due to its high abundance and productivity. Moreover, our results provide important information to support the use of *L. acuta* in ecological monitoring programs.

The population structure analysis indicated that the species shows continuous reproduction and recruitment in Araçá Bay, since we observed individuals of small size-classes in almost all months. This corroborates the statement made by Santos, Florêncio and Florêncio (2002) that tropical polychaete species reproduce throughout the year due to constant light and food availability. For *L. acuta*, this was seen through five recruitment periods, a common behavior among nereidid polychaetes (Gillet 1990) and that has been previously observed for this species (Netto, Lana 1994; Omena, Amaral 2000) and for *Laeonereis culveri* (Martin, Bastida 2006). Despite this continuous reproduction, the abundance of *L. acuta* was higher in autumn and winter, likely a result from more intense reproductive effort in the summer months and higher availability of food, represented by microphytobenthos. We also noted high turnover rate (P/B) and a temporal fluctuation in density with clear peaks in autumn followed by subsidiary peaks in winter. These peaks seem to be a trend among the genre, as seen in Bloom (1983), however could also be linked to the amount of food.

Based on this, it is clear that environmental factors, such as temperature, have a high influence on Nereididae spawning and recruitment periods. The GAM analysis here performed evidenced higher production at higher temperatures, which coincides with the main recruitment events that occurred in the summer and spring months. This demonstrates that the increase in temperature (typical of summer) generated a stimulus to the spawning behavior and growth of individuals (as seen in Dales 1950 and Omena, Amaral 2000).

However, some small-sized polychaetes are known for having their reproduction affected not only by light but also by food resources that directly influence species abundance (Santos, Santos, Florêncio 2002). It is known that polychaetes from coastal areas rely at some levels on vegetable debris: mangroves, salt marshes and microphytobenthic activity (Netto, Lana 1999). At the study area, there is a tendency of a greater abundance of *L. acuta* to be linked to higher availability of food resources (i.e., chlorophyll *a* and phaeopigments) seen at the winter months. This larger amount of food resources may have allowed a large number of individuals to survive after settlement and reach larger size classes. This demonstrates the importance of microphytobenthos to *L. acuta* and coastal productivity.

As for the estimated growth parameters, we noted an intermediate growth rate (K = 1.6) when compared to previous studies. Omena and Amaral (2000), for example, found growth rates (K) of 1.4 and 2.2 for autumn and summer cohorts, respectively, in Enseada Beach (São Sebastião-SP). Similarly, Martin and Bastida (2006) (for *L. culveri* – very similar to *L. acuta*) observed growth rates (K) from 1.8 in autumn to 3.3 in summer in tidal flats of Buenos Aires Province (Argentine). Altogether, these results show that the species present rapid growth rates; yet, seasonal factors, such as differences in temperature and food availability, may exert a strong influence on its growth. The influence of seasonal variables is further highlighted by the seasonal oscillation parameter

(C), which was significant in all three studies – Omena, Amaral (2000): C = 1 (summer and autumn); Martin, Bastida (2006) (*L. culveri)*: C = 0.8 (summer) and 0.9 (autumn); this study C = 0.3 (spring, summer, autumn and winter).

The growth curve estimated was directly affected by the polychaetes' biology2. The growth rate was higher in younger individuals and decreased in organisms with greater age. This result is likely related to the semelparity of *L. acuta*, that is, the older individuals, who have achieved sexual maturity, cease investing resources in growth and survival during reproductive periods and prioritize the reproduction. Altogether, it can also explain the main reason why some cohorts disappeared at certain months. Smaller and, therefore, younger individuals were responsible for higher secondary production, since they demonstrate higher growth rates than the older ones that invest in reproduction rather than growth.

The turnover rate (P/B ratio) was situated within the average of the observed for other nereidid (Table 3). Larger species with a greater life span, such as *Nereis glandicincta* and *Nereis diversicolor*, demonstrate higher turnover rates than smaller ones (*Ceratonereis erythraeensis* and *Ceratonereis keiskama*) that were similar to *Laeonereis acuta* at previous studies.

Yet, *L. acuta* has great importance regarding the bay's productivity and this can be seen through the analysis of *Anomalocardia brasiliana*, a mollusk bigger than the polychaete (with an average shell size of 21.98 mm), that also lives at Araçá bay's sediment, but in a region with different characteristics than the ones found here. This species has a P/B ratio of 0.6 (Corte et al. 2017). If we compare both organisms, it is clear that the mollusk has reduced turnover rates when compared to *L. acuta* that demonstrated rapid development. This indicates that, even though *L. acuta* individuals have smaller size and biomass than other species, it plays an important role at the total productivity of Araçá Bay and, likely at other coastal ecosystems as well. In addtion, the P/B ratio of *L. acuta* was higher at this study when compared to Omena and Amaral (2000) (2.0 [previously attested] and 2.83 [present study]). This may reinforces the important role of the species in the productivity of Araçá Bay.

Table 3. Summary of published information of P/B ratio (turnover rate) in different Nereididae species.

Species	P/B	Site	Reference
Neanthes glandicincta	6.2	Mai Po - China	Shin (2001)
Nereis diversicolor	4.6	Loire Estuary - France	Gillet (1990)
Nereis oligohalina	4.5	Paranaguá Bay - Brazil	Pagliosa and Lana (2000)
Nereis diversicolor	3.0	Ythan estuary – Scotland	Chambers and Milne (1975)
Laeonereis acuta	2.8	Araçá Bay - Brazil	Present study
Laeonereis acuta	2.0	Enseada Beach - Brazil	Omena and Amaral (2000)
Laeonereis culveri	2.0	Río de la Plata - Argentine	Martin and Bastida (2006)
Ceratonereis erythraeensis	1.9	Burg River Estuary – South Africa	Kaletja (1992)
Ceratonereis keiskama	1.8	Burg River Estuary – South Africa	Kaletja (1992)

Besides growth parameter, the biomass of *L. acuta* registered in this study is very similar to Omena and Amaral (2000) what can be an indicator that this species is well adapted to the environmental conditions of Araçá Bay. As for environmental parameters, we noted that some abiotic characteristics, such as temperature, remained the same as previous years (Corte et al. 2018). Weis et al. (2017) observed that *Laeonereis acuta* increases in biomass and body sizes when exposed to urbanized environments, nevertheless, *L. acuta*'s biomass decreased under high concentrations of organic matter in the sediment at this study, suggesting that strong contamination levels may compromise its population attributes.

Animals' biology, productivity and behavior can be affected by environmental alteration, especially regarding benthic organisms. These animals are constantly in contact with the sediment, demonstrate sensibility to changes in different scales of their habitat and, therefore, will respond to alterations (Resh, Jackson 1993).

Sediments can accumulate high concentrations of contaminants, as compounds suffer reactions with particulate materials, assuming a toxic form. These materials can also be available at water column by the resuspension caused by tides, waves and anthropic action, such as dredging (Cesar et al. 2006). The areas hydrodynamics and its currents are the main factors that control the sediment particles distribution of Araçá Bay

(Alcántara-Carrió et al. 2018) and variations on these parameters can influence grain sizes, cause a variation on species and enhance contaminants availability (Day et al. 1989).

In previous works, it was found that the intertidal region of the upper part of Araçá Bay was mostly composed of sandy sediment, with more than 75% sand (Kim et al., 2018) and with a high contribution of coarse sand that can be correlated to *L. acutas*'s occurrence (Checon et al. 2018b). Nevertheless, a low contribution of coarse sand was observed in this study. Moreover, a recent investigation on contamination parameters at the bay showed that no individual metal value (i.e., aluminum [Al], arsenic [As], cadmium [Cd], chrome [Cr], copper [Cu], iron [Fe], manganese [Mn], nickel [Ni], lead [Pb], scandium [Sc], tin [Sn] and zinc [Zn]), exceeded the threshold effect level; however sewage contamination was detected, especially in the upper intertidal area (Checon et al. 2018b). This low concentration of metals could be one of the reason why *L. acuta* does not demonstrate high evidences of impacts.

In general, population dynamics of *L. acuta* suggest that the species is well adapted to the bay's conditions showing a short life cycle with rapid recolonization. If we add *L. acuta*'s capability of living in urbanized regions, its rapid growth, general opportunistic features and sensibility to sediment contamination (Geracitano et al. 2004; Pagliosa, Barbosa 2006), it is clear that the species should be used as an indicator of impact and alteration in ecological monitoring programs of tidal flats. High rates of organic matter decreased the productivity of *L. acuta*; if we add the species feeding behavior as a deposit feeder to this scenario, we could characterize the use of *L. acuta* as proper at studies of environmental impacts analyses regarding the enhancement of organic matter (derived from industrial or domestic outfalls). This statement is reinforced by the effect of high concentrations of organic matter in the species dynamics, whereFor a better and more concrete environmental quality evaluation, the population dynamics should be studied, for it shows the organism's behavior throughout time and space and provides solid information about the species responses to the environmental characteristics. Our results bring important information on population attributes of *L. acuta* that can be used to monitor further environmental changes at Araçá Bay, as well as support its use in coastal areas that face impacts from human activities.

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Capítulo 2

Growth and reproductive parameters of *Monokalliapseudes schubarti* (Mañe-Garzón, 1949) (Crustacea: Tanaidacea) on a tidal flat in Southeastern Brazil

Abstract

The population biology and reproductive parameters of *Monokalliapseudes schubarti* (Mañe-Garzón, 1949), an important tanaid of muddy-sand substrates, was studied in Araçá Bay (São Sebastião, São Paulo, BR). This region has suffered severe and constant changes throughout time due to anthropic activities; a scenario commonly found around the world. Therefore, *M. schubarti*'s analyses here performed focused on finding bases for the use of the species in monitoring programs. Samples were collected monthly from December 2016 to November 2017. Individuals were counted (N = 6916), measured (TL: total length) and had their sex and developmental stage identified. The population had a sex ratio with a predominance of females. Larval stages and non-reproductive individuals had high occurrence and were responsible for monthly fluctuation in density. The tanaid had a great number of eggs and five cohorts appeared during the studied period, which shows high fecundity and rapid and constant reproduction. The growth rate K was 1.94, mortality rate Z was 5.24/year, and the P/B ratio was 3.88, demonstrating high turnover and production of this species in Araçá Bay. A high concentration of organic matter and chlorophyll *a* (related to microphytobenthic activity) and lower mean diameter of sediment were the main drivers of total secondary production (389.96 g AFDM.m^{-2}.year^{-1}). The results performed in this study highlight the importance of *Monokalliapseudes schubarti* as important food resource for higher trophic levels and provide baseline informtion to support its use in monitoring or environmental evaluation programs that involves organic enhancement or changes in sediment structure and composition.

Introduction

Tanaids are abundant crustaceans on the continental shelf of different countries and have a significant influence on the structure of some benthic communities (Silva 2010). According to Leite, Turra and Souza (2003), few species of tanaids occur along the Brazilian coast, among which stands out *Monokalliapseudes schubarti* (Mañé-Garzón, 1949), a species that has high occurrence in soft substrates. The species occurs through the South and Southeast coast of Brazil (Lana; Guiss 1991; Blankensteyn; Moura 2002; Fonseca; D'Incao 2003; Brendolan 2004; Ferreira; Abilhoa 2005; Contente et al. 2007; Pennafirme; Soares-Gomes 2009; Branco; Junior 2009) and has great importance in the coastal trophic web as a food resource of fishes, other crustaceans, such as decapods, and aquatic birds (Pennafirme; Soares-Gomes 2009; Freitas-Júnior et al. 2013).

Monokalliapseudes schubarti's males also show two distinct forms of chelipeds with a greater distance between the two protuberances at the propodus, what characterizes two male morphotypes. Initially, this led to taxonomic confusion and the description of two different Brazilian species (Lang 1956; Bacescu 1979), however, researches on individuals characteristics showed that the two species were synonyms (Leite; Leite 1997; Drumm; Heard 2011).

Altogether, this generated another discussion. Some tanaids are known for reverting their genre (protogyny) as a reproductive strategy to supply the population's needs or as a survival behavior. Thus, it is possible to see juveniles developing into either females or males when adults, females turning into males (when males are absent) or small males incapable of competing with larger males due to their size, reproducing as females (Highsmith 1983; Modlin; Harris 1989). Therefore, the same was thought to be true about *M. schubarti* and its two male morphotypes. However, a morphometric study made with this species highlighted evidences that protogyny does not occur in this case, but rather morphologically distinct chelipeds on males at different developmental stages (Costa 2017).

As for its ecology, *M. schubarti* lives in galleries below the surface of muddy-sand sediments, normally dominated by very fine sand and great organic matter content (Nucci et al 2001). The species is considered r-strategist, with fast development, high reproductive activity and recruitment potential, what generates its high abundance and densities (Leite; Turra; Sousa 2003; Freitas-Júnior et al. 2013). Their high abundance is attributed not only to the species biology, but also to their wide tolerance to environmental variations (Leite; Leite 1997). Nevertheless, the distribution of this species may be influenced by environmental characteristics, such as food availability and sediment type, and by anthropogenic effects (Pennafirme; Soares-Gomes 2009). Some studies used *M. schubarti* as a test organism in toxicity analyses observing the species' sensibility and responses towards contamination, such as the ones generated by antifouling particles (Resgalla Jr; Laitano 2002; Soroldoni et al 2020). However, Abessa, Sousa and Tommasi (2006) showed that the tanaid demonstrates high rates of survival when exposed to some contaminated sediments, such as the ones found in Rio Cubatão. This area is highly contaminated by metals (such as mercury), trace elements and organic compounds generated by the industrial pole of Cubatão that has been characterized as one of most contaminated regions of the world (Luiz-Silva; Matos; Kristosch 2002; Luiz-Silva et al. 2006). Mottola, Schorck and Resgalla (2009) also noted that the species is highly resistant to contaminated sediments with some toxic compounds such as cadmium. These statements make it clear that the species is not indicated for toxicity tests. However, the same authors attested that it shows tolerance regarding organic matter enhancement with increases in their abundance.

M. schubarti has a clear preference for very fine sand substrates and their benthic behavior puts them in an intrinsic sediment dependency and in direct contact with organic contaminants present in the substrate since it burrows for the construction of galleries (Brendolan 2004). Their bioturbation can generate changes in sediment chemistry for mixing different zones and allowing oxygen and ammonia penetration, which alter the availability of contaminants (Remaili et al 2016; VanDer Meer et al. 2017). In addition, substrate's type and nature can influence chemical bioavailability inside this compartment making it easier to affect the fauna (Amato et al. 2016). This exposure can also be enhanced due to the species feeding habits, since burial deposit eater organisms are constantly exposed and demonstrate higher sensibility to organic changes (Simpson et al. 2016).

These characteristics give the species a great potential when used in monitoring programs specially regarding alteration in sediment characteristics and organic enrichment Thus, based on these evidences, this study aims to understand *M. schubarti*'s population dynamics and some of its reproductive behaviors on a tidal flat in Southeastern Brazil (an area that went through severe changes throughout time). This work also examines the relation between the tanaid's population to environmental variables in order to infer about its capacity of responding to environmental condition for reinforcing its use in monitoring programs.

Methods

Study area

This study was developed in Araçá bay (Fig. 1) , a tidal flat of muddy-sand with an intertidal zone that, due to its gentle slope, can reach 300 m of length (Amaral et al. 2010; Amaral, et al, 2018). The area has a history of impacts, such as port and an oil terminal construction and activities and contamination from domestic sewage linked to human population's growth in the surrounding areas (Weber and Bícego 1991; Zanardi et al. 1999; Gubitoso et al. 2008; Lamardo; Bícego; Weber 2013; Kim et al. 2018). Altogether, these historical impacts increased with port expansion and altered the bay's hydrodynamics, changing water circulation and accumulation of sediments (Siegle et al. 2018), and its biodiversity (Turra et al. 2017).

This ecosystem has six mangrove nuclei and is an important feeding site for birds and fishes. The high phytoplanktonic productivity in the area contributes significantly to the local food web and great biodiversity and abundance of benthic organisms, including new and endangered species (Amaral et al. 2016; Soares; Arantes; Pucci 2018; Checon et al.2018; Dias et al. 2018; Mancini et al. 2018; Schaeffer-Novelli et al. 2018; Soares et al. 2018a). Altogether, this makes its study, conservation and monitoring highly important (Amaral et al. 2018).

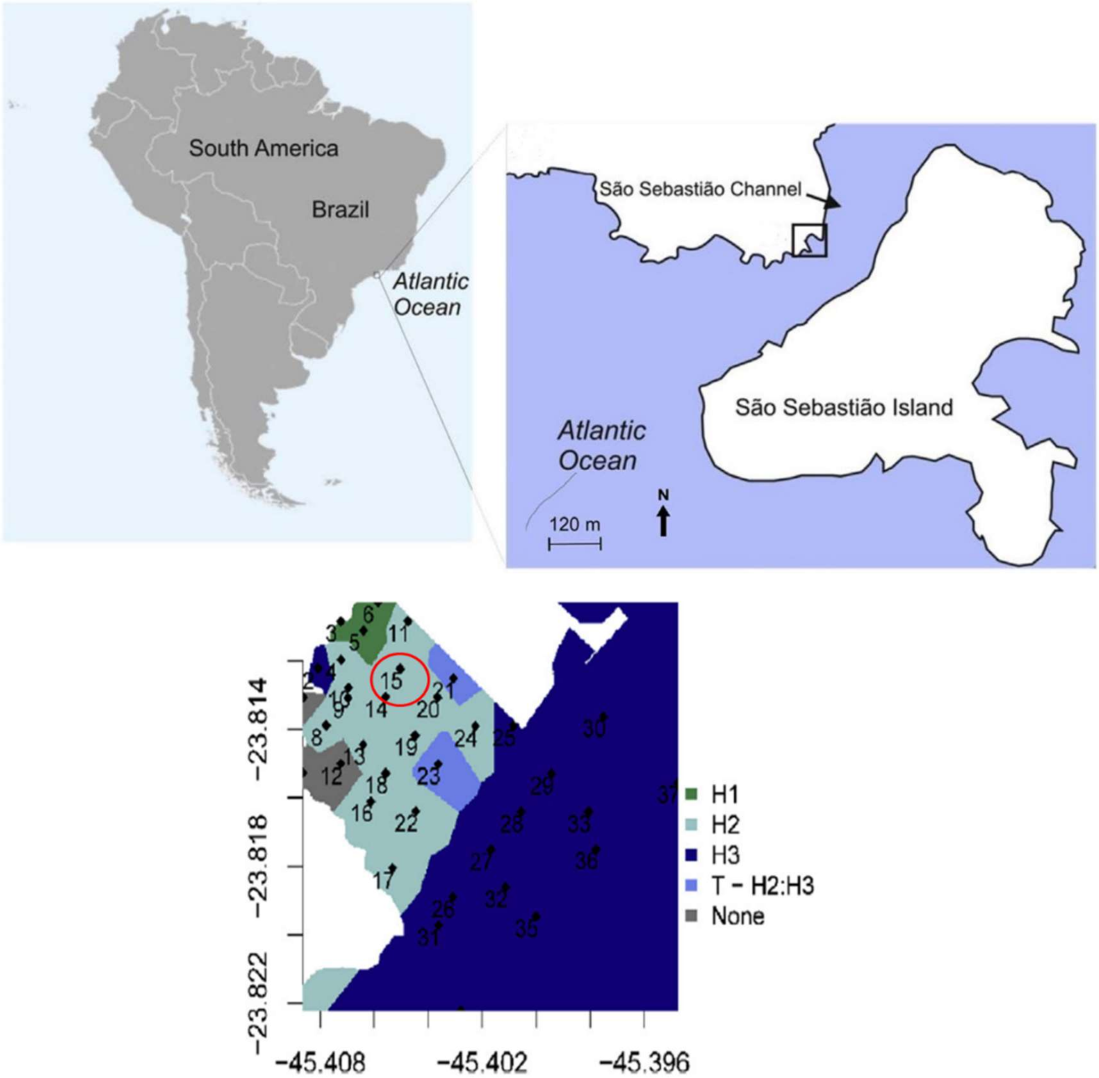

Figure 1. Araçá Bay (São Sebastião channel). Macrofauna habitats determined by Checon et al. (2018a). The circle indicate the sampling site. Upper map:Angelini et al. (2018); Lower map: Checon et al. 2018a (H1: Habitat 1; H2: Habitat 2; H3: Habitat 3). Maps adapted by the authors.

Sampling

Sampling was performed monthly from December 2016 to November 2017, during morning periods of low tide. At each sampling occasion, three samples were randomly collected in a fixed sector of 50 m² in the upper mid-littoral region of the Araçá bay's (23º48'49.9 "S 45º24'31.3" W). This sampling site correspond to an area inside Habitat 2 (Fig. 1), a shallower area, with high primary production and predominance of fine and very fine sand (Checon et al. 2018). Samples were randomly chosen inside this region and obtained with a cylindrical sampler (10 cm in diameter and depth) and specimens of *Monokalliapseudes schubarti* were separated from the sediment using 1.0 and 0.3 mm mesh size sieves in the coastal laboratory at the Center of Marine Biology of the

University of São Paulo (CEBIMar/USP) and then preserved in 70% ethanol. The sediment was wet during the sampling period.

Additionally, next to each sample for *M. schubarti* population analyses, five sediment sample were collected with a 5 cm diameter cylindrical sampler, to a 10 cm depth for organic matter analyzes. These samples were placed in plastic vials and immediately frozen. An extra sample was obtained following the same procedures described above for granulometric studies. In these same regions, we collected five samples at the superficial layer of the sediment with the aid of a cylindrical acrylic tube to a depth of 1 cm, to obtain the microphytobenthic biomass. The substrate temperature measurements were obtained once, *in situ*, with an INCOTERM thermometer at the beginning of the samplings. One sample of interstitial water was obtained for further salinity analyses made with a LEICA refractometer.

Environmental parameters analysis

Granulometric analyses were done according to the dry sieving method for sandy fractions described by Suguio (1973) and the granulometric data were calculated in the Rysgran package of R 3.4.3 (R Development Core Team 2008). The organic matter content analysis followed the technical norm nº 13,600 of ABNT (1996), which consists of a drying process in a stove and muffle furnace and subsequent weighing.

The microphytobenthic biomass was analyzed through the evaluation of photosynthetic pigments (chlorophyll *a* and phaeopigments) according to the method of spectrophotometric extraction and reading described by Plante-Cuny (1978) and adapted of David (1997). Margalef's Pigment Index was performed according to Margalef (1957) that considers values of 1 – 2 an indication of young individuals and 3 – 5 of older and senile organisms.

We used Generalized Additive Models to investigate the relationship between abundance, production and biomass of *M. schubarti* and the environmental variables sediment total organic matter, chlorophyll *a* concentration (CHA), phaeopigments concentrations (PHAE), salinity (SAL), temperature (TEMP), mean sediment grain size (GS), and selection coefficient of sediment (SEL). Phaeopigment concentrations were strongly correlated with chlorophyll *a* concentrations ($r = 0.99$). Therefore, we removed this variable from analyses. We assessed the significance of each variable using the test criterion ($P \alpha 0.05$) and backward elimination of covariates until all remaining terms in the model were significant. Relationships between response variables and predictors were analyzed through the graphical output of GAMs. All analyses were undertaken in the R environment (R Development Core Team 2008) using the mgcv (Wood 2012) package.

Population Structure and Mortality analysis

Abundance, density and population size structure were determined for each month. Density was estimated using the number of individuals obtained monthly and expressed in ind.m^{-2}. Temporal variation in abundance was compared using generalized linear model with months nested in season.

We measured the total length (TL) of the dorsal median region of each specimen (TL, from the tip of the carapace to the distal medial margin of the pleotelson) (Fig. 2) for defining size classes, cohorts and estimate the growth curve. This measurement was performed at a binocular stereomicroscope. Size-frequency histograms relating TL to number of individuals were constructed for each month.

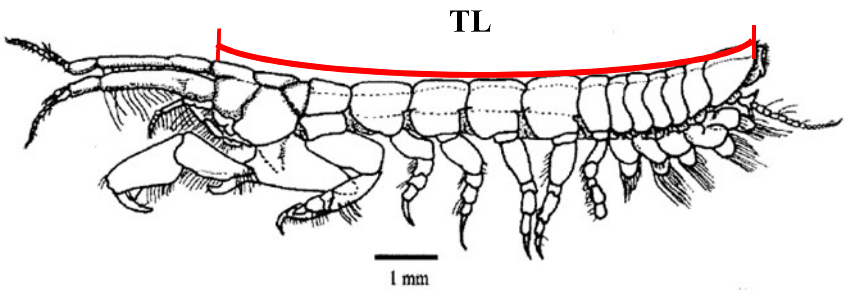

Figura 2. *Monokalliapseudes schubarti.* Drawing adapted from Montagnolli et al. 2004. Highlighted, the tanaid dorsal region used as a measure of the total length. TL: Total length

Growth analysis consisted of separating the size frequencies using the Bhattacharya method followed by the NORMSEP routine in the FISAT II program (VBGC: Gayanillo et al., 2005), determining the ages of the cohorts (length-based) and constructing the age-length relationship. This data was used to adjust the von Bertalanffy model curve (modified for seasonal oscillation in growth) (von Bertalanffy equation) that was adjusted in Software R 3.4.3 and expressed in:

$$Wt = W_{\infty}\{1 - exp^{[-K(t-t_0)+\left(\frac{CK}{2\pi}\right)\sin(2\pi(t-t_s))-\left(\frac{CK}{2\pi}\right)\sin(2\pi(t_0-t_s))]}\}$$

where W_t is the width at time t; W_{∞} the asymptotic width; K the von Bertalanffy growth constant; t_0 time at width 0; C amplitude of seasonal oscillation of growth and t_s the starting point of oscillation regarding t=0.

The life expectancy was obtained from the inverted equation of Von Bertalanffy, using the length of which 99% of the population were represented (L99), according to Fonseca, Veloso and Cardoso (2000). To calculate the instantaneous mortality rate (Z) a simple negative exponential model was used by the converted catch curve method to the available length in the FISAT II program.

Production and Biomass Analysis

Randomly selected individuals from all size classes were dried at 80ºC for 24h, combusted at 500ºC for 4h and weighed to assess the ash free dry weight (AFDW). The secondary production analysis followed Crisp (1984) through the equation:

$$P = \Sigma f_i G_i W_i \Delta t_i$$

where f_i is the average number of individual of a size class, Δt_i the period of time and G_i the growth rate, W_i the average body weight. Gi was determined by:

$$G_i = bK[\left(\frac{L\infty}{L_i}\right) - 1]$$

where b is the relation weight-size, K and L∞ VBGC parameters and L_i the average size.

Annual biomass was calculated as:

$$\bar{B} = \Sigma f_i W_i \Delta t_i$$

Reproduction

Separation by sex and stage of development was performed by analyzing the size and morphology of the antenna and chelipeds (adapted from Leite; Leite 1997). Females were classified as pre-ovigerous (with oostegites: plate-like processes that will later form the marsupium) and ovigerous females (carrying eggs, embryos or marsupium).

Males were identified according to cheliped morphology: more developed cheliped meropodite than females and broader and more developed protopodite, with two tooth-like elevations alternating with bristles or similar to the first form, but with meropodite with strong apophysis and most prominent curve (Fig. 3). Non-reproductive individuals were categorized according to cheliped morphology (female-like chelipeds, including immature males and females) - this classification, as in Leite et al. (2003), was used since males could not be differentiated from females until they developed wider antennae and chelipeds. Larval stages included both *manca* and *neutrum*, without distinction between them.

Figura 3. *Monokalliapseudes schubarti.* Examples of morphological differences at individuals' chelipeds. A) Female; *B e C)* Males (adapted from Leite; Leite 1997).

We analyzed the temporal variation of abundance and size distribution of juveniles, non-reproductive individuals, males, pre-ovigerous females, ovigerous females and post-ovigerous females. The frequency of eggs and ovigerous females carrying eggs, embryos or just marsupium was evaluated and the correlation of Pearson was obtained between the size of females and eggs and between the abundance of juveniles (larval stages) and ovigerous stages. To compare the sizes of immature females and ovigerous females we applied a Student t-test and a simple linear regression analysis to evaluate the relationship between the size of ovigerous females and the number of eggs inside the marsupium.

Results

Environmental characterization

Granulometric analyses demonstrated a predominance of very fine sand in all sampled months (Fig. 2).

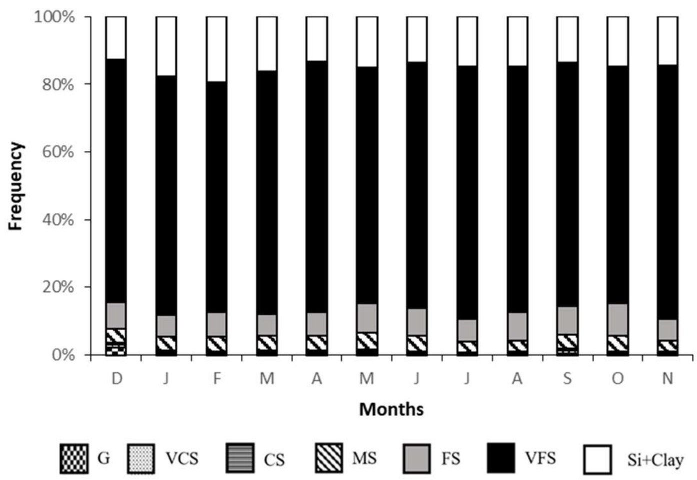

Figure 2. Sediment composition at sampling site in Araçá Bay. Gravel (G), Very Coarse Sand (VCS), Coarse Sand (CS), Medium Sand (MS), Fine Sand (FS), Very Fine Sand (VFS), Silt and Clay (Si + Clay).

Sediment temperature varied seasonally, with higher values in summer (29.5ºC) and lower during winter (19.5ºC). Interstitial water salinity variation was low between the sampled months, with the highest value of 35.6 in September and a sharp drop in November, reaching 12.3. The average organic matter content showed a slight variation over the months: between 0.20 ± 0.02 g and 0.38 ± 0.17 g, with the highest percentage observed in summer (January: 0.38 g) with a clear drop at fall (April: 0.20 g) (Table 1).

Table 1. Temporal variation of the environmental parameters and *Monokalliapseudes schubarti*'s density at the sampling sector in Araçá Bay from December 2016 to November 2017. GS: Mean grain size; T: Sediment temperature; Salinity: Interstitial water salinity; OM: Organic matter content; Chl a: Chlorophyll *a* biomass; Phae: Phaeopigment biomass; Density: Density of individuals; Abundance: *Monokalliapseudes schubarti*'s abundance (N = number of individuals)

	T (ºC)	Salinity	OM (%)	Chl a (mg.m^{-2})	Phae (mg.m^{-2})	Density (ind.m^{-2})	Abundance (N)
Dec/16	27.5	32.3±0.94	0.24±0.007	334.3±41.07	679.8±185.67	30,955.4±1,424.0	729
Jan/17	29.0	32.6±0.47	0.38±0.17	361.0±30.36	783.1±154.71	11,167.7±1,702.1	263
Feb/17	29.5	33.0±0.00	0.29±0.03	301.0±69.6	618.9±276.66	21,358.8±1,770.0	503
Mar/17	29.0	34.6±0.47	0.25±0.01	461.6±91,0	1321.1±447.72	16,900.21±3,075.0	398
Apr/17	26.0	33±0.00	0.20±0.02	396.9±911.2	922.2±40.95	29,087.0±4,108.2	685
May/17	22.0	34±0.00	0.26±0.02	414.8±10.3	1046.1±28.78	17,197.4±2,849.1	405
Jun/17	21.0	29±0.81	0.24±0.02	457.4±120.4	1365.6±546.87	13,460.7±200.1	317
Jul/17	21.0	35±0.00	0.22±0.01	451.8±53.8	1192.3±216.52	14,946.9±3,183.3	352
Aug/17	19.5	33.6±0.47	0.23±0.04	410.3±19.9	1100.7±139.69	27,600.8±3,091.7	650
Sep/17	23.0	35.3±0.47	0.25±0.008	336.7±59.1	746,0±242.60	41,698.5±2,005.3	982
Oct/17	23.0	35.0±0.00	0.26±0.01	263.3±81.5	538.5±270.15	33,970.2±1,946.6	800
Nov/17	25.5	12.3±0.47	0.23±0.03	296.2±36.4	606.6±163.78	35,329.0±2,620.4	832

The average values of phaeopigments ranged between 538.5 mg.m^{-2} (October/17) and 1365.1 mg.m^{-2} (June/17) and between 263.3 mg.m^{-2} (October/17) and 457.4 mg.m^{-2} (June/17) of chlorophyll *a*. Therefore, higher microphytobenthic activity occurred from March to July, during fall and winter, months with lower temperatures.

Density, population structure and growth

During the study period, 6,916 specimens were collected and measured. The density of *M. schubarti* ranged from 11,167.7 to 41,698,5 ind.m^{-2} (Table 1). September showed higher value, differing significantly from the other months. Population density tended to increase with peaks in December (30.955,4 ind.m^{-2}), October (33,970.2 ind.m^{-2}), November (35,329.0 ind.m^{-2}) and September (41,698.5 ind.m^{-2}). A decrease was observed in January (11,167.7 ind.m^{-2}) and in colder months such as June (13,460.7

ind.m^{-2}) and July (14,946,9 ind.m^{-2}). The smallest individual had 1.08 mm of total length and the largest 12.33 mm. The frequency of the different size classes had trimodals and bimodals distributions, with a predominance of peaks of small size classes' individuals, which indicates the presence of young organisms throughout the entire study period.

Five recruitment were observed during the year. At the beginning of the study, in December/16, two cohorts coexisted (Fig. 4). The Cohort 1, of smaller individuals, had good representativeness at the population, was probably generated at months before this study and showed clear growth until September/17 when it disappeared, while Cohort 2 was probably recruited in late spring and remained until summer. New recruitment was observed in February/17 (Cohort 3) and was generated by the adults of Cohort 2. Young individuals appeared in May/17 (Cohort 4) however, this new cohort disappeared for some months and did not demonstrate high growth, with individuals reaching between 7.51 mm and 8.0 mm before dying. The last recruitment happened in August/17 and lasted until the end of the study period.

Regarding its growth curve, the population showed C = 0.43 and K = 1.94 (Fig. 5) and demonstrated continuous recruitment.

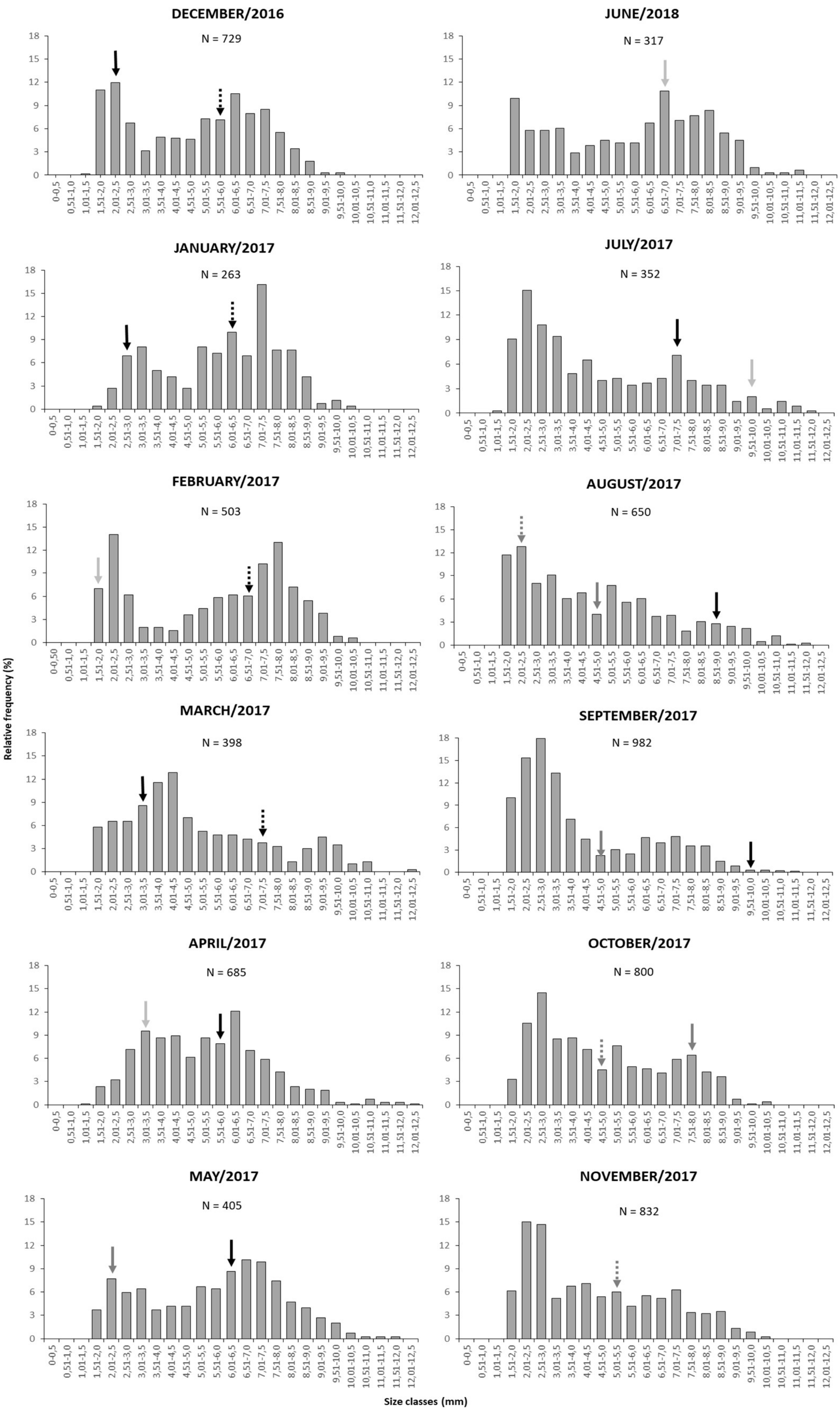

Figure 4. *Monokalliapseudes schubarti*. Relative frequencies of size classes (total length) at the sampling sector in Araçá Bay from December 2016 to November 2017. Arrows indicate the different cohorts: black - cohort 1; dashed black - cohort 2; light gray - cohort 3; dark gray - cohort 4; dashed gray - cohort 5.

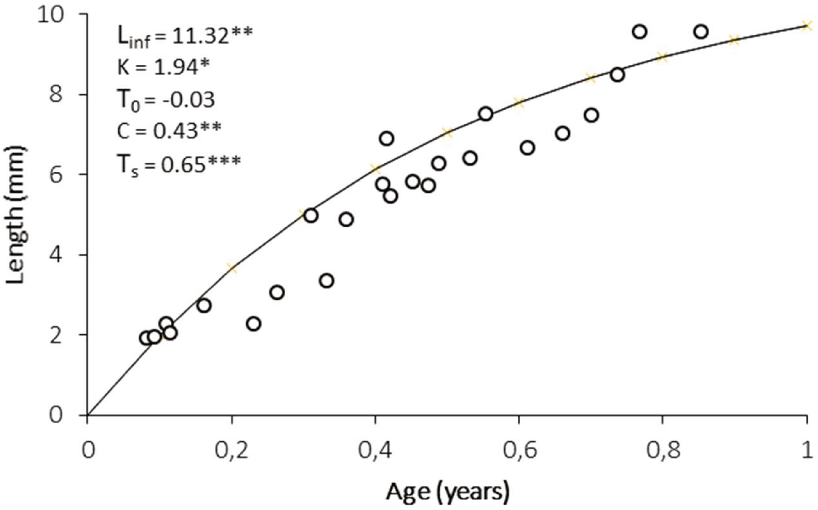

Figure 5. *Monokalliapseudes schubarti.* Growth curve estimated by the seasonal function of von Bertalanffy at the sampling sector in Araçá bay from December 2016 to November 2017. Length: total length. K: growth rate; C: seasonal oscillation parameter. Asterisks denote significant values; * at $p < 0.05$, ** $p<0.01$, *** $p<0.001$.

Mortality and secondary production

Average biomass was 2.25 g AFDM.m^{-2} and the turnover rate (productivity-biomass ratio, P/B ratio) was 3.88 (Fig 6A) Average secondary production was 368.96 mg AFDM.m^{-2}.year^{-1} (Fig. 6B) and higher values were observed for small and medium-size individuals. A clear drop on this production can be seen as individuals get older and bigger, after they reach around 7 mm of total length. The mortality rate (Z) was 5.24/year and was higher in older individuals.

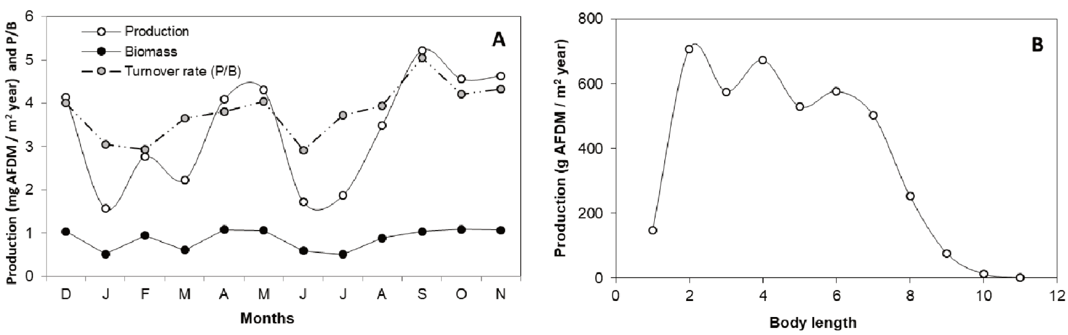

Figure 6. *Monokalliapseudes schubarti. A)* Secondary production (mg AFDM.m^{-2}.year), biomass (g.m^{-2}) and turnover rate *B)* Annual secondary production (g AFDM.m^{-2}.year) by the method of Crisp (1984), at the sampling sector in Araçá bay from December 2016 to November 2017.

Environmental influence on population parameters

Abundance of *M. schubarti* was higher in sites with a concentration of chlorophyll *a* lower than 350 mg/m^2, decreasing in higher values (Table 2, Fig. 7). A linear decrease in abundance of *M. schubarti* was related to increases in the organic matter content and lower mean diameter of sediment. The relation between biomass of *M. schubarti* and environmental variables were very similar to those recorded for abundance, with lower biomass in sites with high concentrations of chlorophyl *a* and organic matter, and low mean diameter. Also, biomass increased in sites with well-sorted sediments (Fig 8). Yet, contrasting patterns were registered for productivity. Higher values of productivity were observed in higher concentrations of chlorophyl *a*, and a linear increase of productivity was related to increases in total organic matter content, and lower mean diameter of sediment (Fig. 9).

Table 2. Generalized additive model outputs for the relationship between environmental variables and population parameters of *M. schubarti*. CHA=chlorophyll a concentration, OM=organic matter content, SEL=selection coefficient, MD = mean diameter, Edf = estimated degrees of freedom, Ref.dr = reference df, R-sq.(adj) = adjusted r squared.

Source	edf	Ref.df	F	P	Deviance	R-sq.(adj)
Abundance					84.4%	76.4%
s(CHA)	1.73	1.93	12.92	<0.01		
s(MD)	1	1	18.94	<0.01		
s(OM)	1	1	5.52	<0.05		
Production					80.7%	86.3%
s(CHA)	1.89	1.99	12.27	<0.01		
s(MD)	1	1	18.26	0.01		
s(OM)	1	1	11.97	<0.05		
Biomass					96.9%	98.7%
s(CHA)	1.99	2	102.6	<0.001		
s(MD)	1	1	116.28	<0.001		
s(OM)	1.36	1.59	87.88	<0.001		
s(SEL)	1.95	1.99	6.76	<0.05		

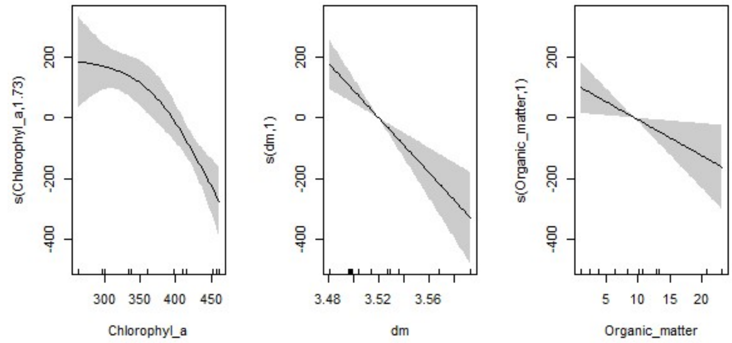

Figure 7. Smoothers curves (S) showing the relationship (solid line) between *M. schubarti*'s abundance and Chlorophyll a concentration (mg/m^2), mean diameter and organic matter content. Shaded areas indicate standard errors of the smooth curve. The 'rug plots' on the x-axis indicate the range of variables over which measurements were taken. Numbers after the variable name on the y-axis represent estimated degrees of freedom.

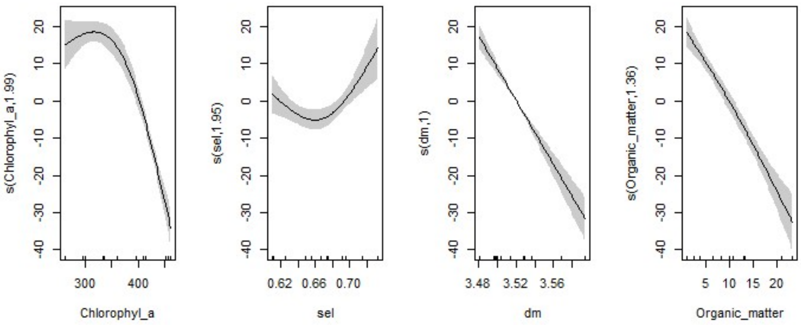

Figure 8. Smoothers curves (S) showing the relationship (solid line) between *M. schubarti*'s biomass and Chlorophyll a concentration (mg/m^2), selection coefficient, mean diameter and organic matter content. Shaded areas indicate standard errors of the smooth curve. The 'rug plots' on the x-axis indicate the range of variables over which measurements were taken. Numbers after the variable name on the y-axis represent estimated degrees of freedom.

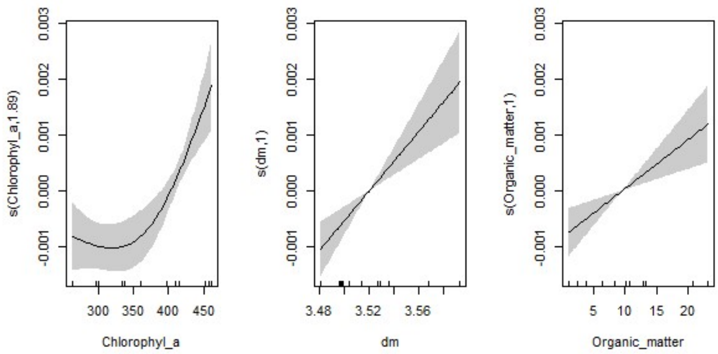

Figure 9. Smoothers curves (S) showing the relationship (solid line) between *M. schubarti*'s production and Chlorophyll a concentration (mg/m^2), mean diameter and organic matter content. Shaded areas indicate standard errors of the smooth curve. The 'rug plots' on the x-axis indicate the range of variables over which measurements were taken. Numbers after the variable name on the y-axis represent estimated degrees of freedom.

Reproduction

In most months, the frequency of larval stages was higher than other developmental stages, with lower incidence in January and April (13.02 and 16.37%, respectively) (Fig. 10). Non-reproductive individuals also had a high occurrence, dominating the population in March (46.32%) and April (40.78%). However, it is noteworthy that pre-ovigerous females also showed some representativeness in December/16 and January/17, with frequencies of 39.69 and 35.24%, respectively.

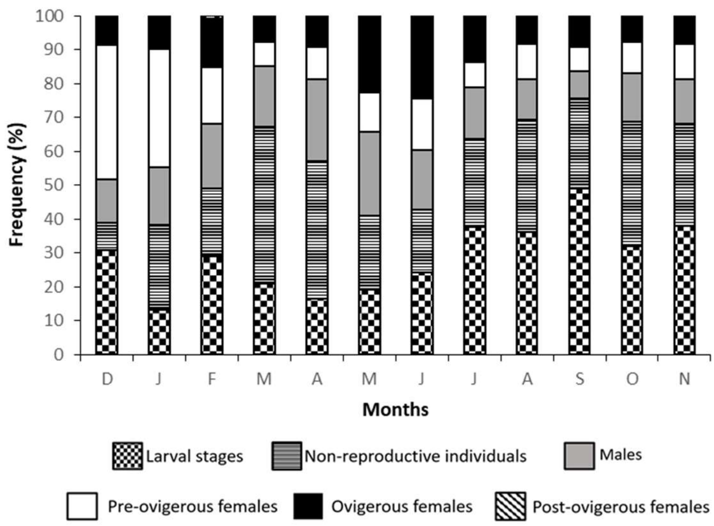

Figura 10. *Monokalliapseudes schubarti*. Relative frequency of development stages in Araçá Bay from December 2016 to November 2017.

Greater abundance of ovigerous females with embryos within the marsupium was observed when compared to females with only marsupium or eggs (Fig. 11A). There was a low correlation between the frequency of ovigerous females and the occurrence of larval stages (Pearson = - 0.261) (Fig. 11B). The number of females did not influence the number of larval individuals that were high in all months, reaching a peak in September/17. The number of eggs per month showed great variation not always related to the frequency of ovigerous females (Fig 11C). July / 2017 showed the lowest total number of eggs, but it was not the month with the lowest number of ovigerous females, which leads to the conclusion that factors other than biologicals may influence the number of eggs, such as environmental parameters. The number of eggs was higher in February/17

Average egg diameter did not show great variation in the different ovigerous females and there was no correlation between egg size and the average total length of the females (Pearson = - 0.183) (Fig. 11D).

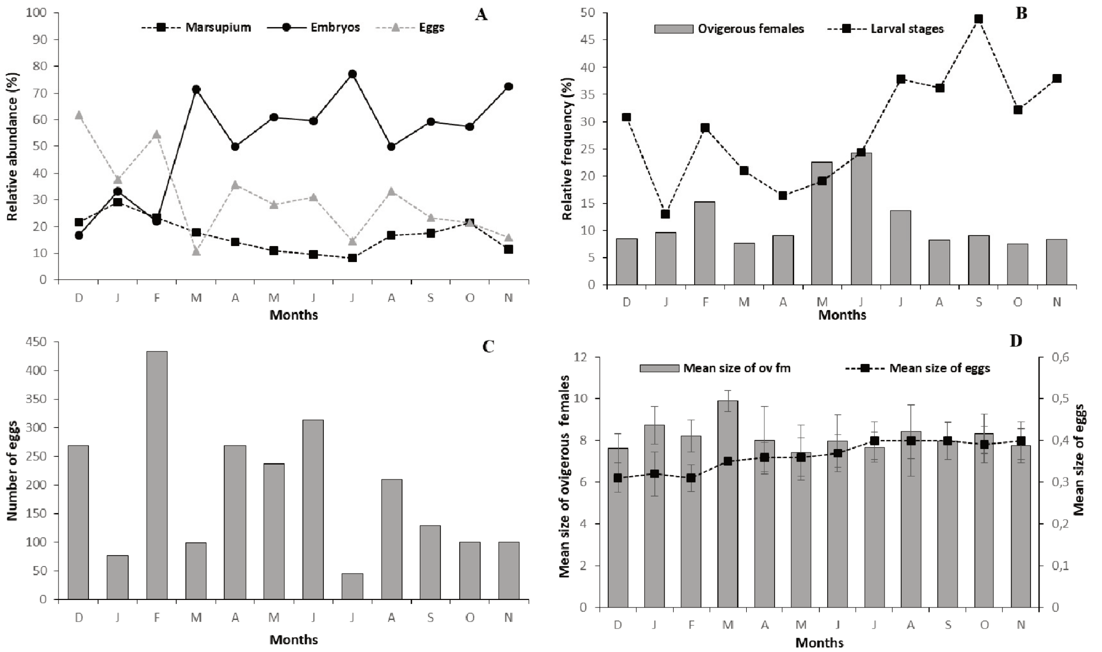

Figura 11. *Monokalliapseudes schubarti.* A) Relative abundance of ovigerous females with only marsupium, embryos or eggs; B) Relative frequency of ovigerous females and larval stages; C) Number of eggs per month; D) Mean size of ovigerous females (total length) and mean diameter of eggs. Bars represent the standard deviation.

Discussion

The results about the species' population biology and reproduction gives solid collaboration to the knowledge of *M. schubarti*'s biology. Despite some monthly fluctuations related to the increase of number of juveniles, the high values in density found, are common and expected in the Peracarida superorder, indicating periods of intense reproduction and recruitment (Pennafirme and Soares-Gomes 2009). The species showed a sex ratio with female numerical predominance, a typical tanaid behavior already observed for the species (Masunari; Zieg 1980; Leite; Turra; Sousa 2003). Larval stages and non-reproductive individuals also had a high occurrence and dominated the population at some months, another factor typically related to the species (Pennafirme; Soares-Gomes 2009).

Females, juveniles and larval phases had great representativeness throughout the study and new individuals constantly emerged in the population, occurrences linked to continuous reproduction. Greater abundance of ovigerous females with embryos within the marsupium was observed when compared to females with only marsupium or eggs, which shows that individuals do not take a large amount of time to develop into larval phases and reinforces the high fecundity and rapid reproduction that characterize their behavior as opportunistic, even facing the lower number of males.

Some studies indicates that the small number of males is attributed to the species reproductive behavior, since reproduction occurs inside females' tubes and, therefore, males are constantly moving between sediment particles and different depths being more exposed to predation since their movement may attract predators, as well as their presencial in more superficial layer (Leite; Turra; Sousa 2003; Fonseca; D'Incao 2006). Altogether, this reinforces the conclusion that the same male individual is responsible for fertilizing different females thoughout their life cycle, since there are less males than females, what corroborates the speculation made by Costa (2017) that males' morphotypes are just one type of male in different developmental stages that gets sexual mature as soon as it leaves the juvenile state, suffering morphological changes as it grows and gets older.

Different species of tanaids are known for their distinct morphological structure and reproductive behavior regarding males: in *Tanais cavolinii,* sexually mature males have enlarged chelipeds (Modlin; Harrris 1989), on the other hand, males of the species *Leptochelia savignyi* have two morphotypes and both can reproduce (Masunari 1983). Rather both *M. schubarti'*s male morphotypes are reproductively active or not, laboratory analyses with this purposes, haven't been developed yet, thus, an acurate statement regarding this matter would only be able through more specific and detailed analyses.

As for the females, the species seems to invest in a great number of eggs instead of in a large group of females reproducing at the same time. This was seen by the number of ovigerous individuals that were not as high as it could have been expected due to the species' high reproduction rates. Despite the relatively small number of females carrying eggs or embryos, new cohorts kept appearing during the study period, likely an indicator that juveniles entered and established themselves in the population after spawning and that females are capable of carrying a high number of eggs. The length of the first mature state female of *M. schubarti* in Araçá Bay was 5.94 mm. Individuals of this size took around four or five months after leaving the marsupium to reach this total length, as observed through analyzed cohorts and similarly seen by Fonseca and D'Incao (2003) and Freitas-Junior et al. (2013). This demonstrates the great investment in growth before reproduction, a biological parameter that prepares females for carrying a larger number of eggs (Fonseca; D'Incao 2003).

However, the number of eggs per month showed great variation not always related to the frequency of ovigerous females. July/17 showed the lowest total number of eggs, but it was not the month with the lowest number of ovigerous females, which leads to the conclusion that factors other than biological, such as environmental parameters, may influence the number of eggs. Additionally, at the developmental stage ratio, post-ovigerous females are barely seen. This shows that females do not die after releasing their eggs; conversely, after reaching sexual maturity, they keep reproducing immediately after spawning until they achieve a senile stage – bigger and with lower growth rate – and die. This behavior was seen through five recruitment periods (cohorts) noted for *M. schubarti* during the studied year, a common result among the species that, once more, denotes an intense and rapid development with constant reproduction until their deaths (Fonseca; D'Incao 2003: six cohorts; Leite; Turra; Sousa 2003: seven cohorts).

We attested peaks in density in spring and early summer months (as seen in Freitas-Junior et al. 2013), warmer periods were organic matter availability is higher. However lower densities were observed in January, February and March, summer months with no acute drop in organic matter content or microphytobenthic activity. Nevertheless, these months showed high temperatures, a limiting factor towards individuals' growth, establishments and survival when above 25ºC (Brendolan; Soares-Gomes 2006).

As for the estimated growth parameters, the tanaid did not demonstrate a growth velocity (K) as fast as it was expected. Leite, Turra and Sousa (2003) observed K = 3.0; here, K was 1.94. Different factors could have influenced this result: the great temperature at most months – that can affect individuals' establishments, as already discussed – and the acute drop in salinity observed during some periods, a factor that has already been shown as limiting for other populations (Fonseca; D'Incao 2006; Pennafirme; Soares-Gomes 2009). However, despite this low velocity, *M. schubarti* still demonstrated constant recruitment thoughout time, what was responsible for population renewal and the appearance of the five cohorts here attested.

Another factor linked to this scenario, is the natural mortality that exerts external stress on the population. *M. schubarti's* mortality rate (Z) was higher than other organisms studied in the same area, such as *Laeonereis acuta*, a polychaete that occurs at the upper mid-littoral region of Araçá bay (Z = 3.44/year; unpublished data). Fonseca and D'Incao (2006) have attested high mortality to this tanaid, indicating that it is heavily preyed upon throughout all seasons. Also, their small burial depths put them in a more vulnerable condition since they are more exposed to currents and waves' actions and predation (Rosa-Filho; Bemvenuti 1998).

Inside Araçá Bay, *M. schubarti* is considered food to some species of fish, such as *Diapterus rhombeus* and *Orthopristis ruber* (Soares et al. 2018), which can influence recruitment and growth, as observed in March and April, where no new cohorts appeared, even though there were ovigerous females at previous months. This leads to the thought that individuals were preyed on before spawning or reaching bigger sizes. Therefore, continuous reproduction becomes a survival strategy facing predation.

The species showed great importance regarding the bay's productivity indicated by its P/B ratio of 3.88, a bigger value than the one found for another benthic organism at the area: *Laeonereis acuta,* a polychaete that plays a great role at Araçá bay's total productivity (P/B=2.8 – unpublished data). This may indicate that *M. schubarti* is a important food resource for other organisms in Araçá Bay, since it shows a great productivity.

In addition, other external elements, such as environmental parameters, proved to be strong influences on the whole population. The species' productivity was related to three main factors: high concentrations of chlorophyll *a*, increases in total organic matter content and finer mean sediment diameter. It is known that sediment composition is the greatest limiting factor for *M. schubarti*'s occurrence and establishment. The species is frequently associated to sediments with fine sand since it is influenced by the number of small particles at this compartment (Rosa-Filho; Benvenuti 1998; Leite; Turra; Sousa 2003; Freitas-Junior et al. 2013; Ortega et al. 2018; Checon et al. 2018). Its preference for muddy-sand substrates is related to their burial behaviors and construction of galleries, where they use small sediment particles to make these structures stable (Rosa-Filho; Bemvenuti 1998).

As for the other limiting factor, it is known that deposit feeders, with filter characteristics, who ingests detritus of different sources, represent the family Kalliapseudidae; they feed on algae, diatoms, microphytobenthos or other particles that gets around their gallery openings (Ogle; Heard; Sieg 1982; Brendolan 2004; Drumm 2005). For such reasons, higher microphytobenthic activity and organic matter were related to higher *M. schubarti*'s productivity, since they use these food resources for generating energy for themselves.

Thus, it is clear that the tanaid can be influenced by changes at granulometric composition and by alteration at food availability. So, even though *Monokalliapseudes* *schubarti* is not indicated for toxicity tests (Abessa; Sousa; Tommasi 2006), the results performed in this study highlight the importance of using the species in monitoring or environmental evaluation programs that involves organic enhancement or changes in sediment structure and composition.

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Considerações finais

Os resultados aqui apresentados indicam que análises da dinâmica populacional e reprodução são importantes para inferir se algumas espécies podem ser recomendadas como indicadoras da qualidade ambiental em programas de monitoramento, uma vez que tornam possível a observação de características populacionais e suas relações com parâmetros ambientais que podem sofrer alterações causadas por ações antrópicas. Além disso, a dinâmica populacional denotou ser um estudo importante a ser incluído em programas de análise ambiental, muito mais do que apenas a ausência e/ou presença de uma espécie em um determinado ambiente.

Laeonereis acuta possui potencial em ser utilizada como indicadora de impacto em programas de monitoramento ambiental. A dinâmica populacional indicou que a espécie apresenta um importante papel na produtividade secundária total da Baía do Araçá, possui rápidas taxas de crescimento e reprodução e recrutamento de indivíduos contínuos ao longo do tempo, porém, fatores ambientais tais como fontes de alimento demonstraram grandes influências na população. Assim sendo, reforça-se o uso da espécie como uma boa ferramenta para programas de monitoramento ambiental, especialmente em planícies de marés e estudos relacionados à contaminação orgânica.

Já a população de *Monokalliapseudes schubarti* possui uma predominância de fêmeas, grande número de estágios larvais e indivíduos não-reprodutivos, além de um grande número de ovos. Esses fatores demonstraram estar conectados com a alta fecundidade e com a rápida e constante reprodução, o que caracteriza o comportamento da espécie como oportunista. A baixa taxa de crescimento se relacionou com a predação do tanaidáceo, uma vez que a espécie constitui importante elemento da teia trófica e está vulnerável por construir galerias próximas da superfície o que resultou em uma alta taxa de mortalidade. Já para as relações com o ambiente, a produção de *M. schubarti* se com altas concentrações de matéria orgânica, clorofila *a* (atividade microfitobentônica) e menores diâmetros dos grãos de areia. Estes registros indicam a importância desta espécie em análises ambientais que visem avaliar o enriquecimento orgânico e/ou alterações na composição e estrutura dos sedimentos.

Mediante as pressões antrópicas sofridas pela Baía do Araçá, é possível inferir que as populações estudadas têm demonstrado certa adaptabilidade às condições ambientais. Tanto o poliqueta quanto o crustáceo demonstraram sobrevivência e crescimento que potencializam o uso de tais espécies como indicadoras da qualidade ambiental. Porém, para o uso dessa abordagem como modelo em programas de monitoramento, mais estudos se tornam necessários, abordando uma discussão comparativa entre as distintas linhas de evidências para a análise de qualidade ambiental. No entanto, os resultados mostram as condições atuais das populações na baía e indicam que podem ser utilizadas como comparativos em futuros estudos e acompanhamento da qualidade ambiental e denotam a importância da dinâmica populacional nesse tipo de avaliação.

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Anexos

Anexo 1 – Declaração de Bioética e Segurança

UNICAMP
COORDENADORIA DE PÓS-GRADUAÇÃO
INSTITUTO DE BIOLOGIA
Universidade Estadual de Campinas
Caixa Postal 6109. 13083-970, Campinas, SP, Brasil
Fone (19) 3521-6378. email: cpgib@unicamp.br
IB

DECLARAÇÃO

Em observância ao **§5º do Artigo 1º da Informação CCPG-UNICAMP/001/15**, referente a Bioética, Biossegurança e acesso ao Patrimônio Genético, declaro que o conteúdo de minha Tese de Doutorado, intitulada "***Monitoramento de uma planície de maré na região Sudeste do Brasil através da dinâmica populacional de espécies dominantes***", desenvolvida no Programa de Pós-Graduação em Biologia Animal do Instituto de Biologia da Unicamp, não versa sobre:

(X) pesquisa envolvendo seres humanos
(X) animais
(X) temas afetos a Biossegurança
(X) acesso a patrimônio genético.

Se você deixou de assinalar alguma das opções acima deverá enviar (via SIGA) o documento do respectivo Comitê para a Secretaria..

Assinatura: ______________________
Nome do(a) aluno(a): Priscila Candido Baroni

Assinatura: ______________________
Nome do(a) orientador(a): Antonia Cecília Z. Amaral

Data: 12/11/2018

Anexo 2 – Declaração de não infração aos Direitos Autorais

Declaração

As cópias de artigos de minha autoria ou de minha co-autoria, já publicados ou submetidos para publicação em revistas científicas ou anais de congressos sujeitos a arbitragem, que constam da minha Dissertação/Tese de Mestrado/Doutorado, intitulada **"Monitoramento de uma planície de maré na região Sudeste do Brasil com base na dinâmica populacional de espécies dominantes"**, não infringem os dispositivos da Lei n.° 9.610/98, nem o direito autoral de qualquer editora.

Campinas, 30 de outubro de 2020

Assinatura : ______________________________
Nome do(a) autor(a): **Priscila de Almeida Candido Baroni**
RG n.° 38.085.941-5

Assinatura : ______________________________
Nome do(a) orientador(a): **Antonia Cecilia Zacagnini Amaral**
RG n.° 4153623