UNIVERSIDADE FEDERAL DO PARÁ
NÚCLEO DE ECOLOGIA AQUÁTICA E PESCA DA AMAZÔNIA
PROGRAMA DE PÓS-GRADUAÇÃO ECOLOGIA AQUÁTICA E PESCA

TESE DE DOUTORADO

EFEITOS DAS ATIVIDADES RECREACIONAIS SOBRE A FAUNA BENTÔNICA EM PRAIAS ARENOSAS AMAZÔNICAS

Thuareag Monteiro Trindade dos Santos

Belém-PA
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Tese apresentada ao Programa de Pós-Graduação em Ecologia Aquática e Pesca da Universidade Federal do Pará, como parte dos requisitos para a obtenção do título de Doutorado.

Orientadora: Dra. Virág Venekey
Co-orientador: Dr. Marcelo Petracco

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Thuareag Monteiro Trindade dos Santos

Efeitos das atividades recreacionais sobre a fauna bentônica em praias arenosas amazônicas

Tese de doutorado apresentada à comissão do Programa de Pós-Graduação em Ecologia Aquática e Pesca da Universidade Federal do Pará, como parte dos requisitos para a obtenção do título de Doutor em Ecologia Aquática e Pesca.

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Dedico essa tese à minha família, aos meus amigos e a todos que lerem.

“*A ciência, meus caros, é feita de erros, mas de erros benéficos, já que conduzem pouco a pouco à verdade*”

Jules Verne

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Resumo

Praias arenosas são ambientes de fácil acesso para a população humana e por conta disso estão sujeitas a diversas pressões antrópicas, que em sua maioria estão ligadas a atividades turísticas. As praias amazônicas atraem uma grande quantidade de turistas ao longo do ano e, até o momento, não existem trabalhos avaliando impactos ambientais relacionados ao turismo na fauna bentônica para a região. Diante desse cenário, o presente trabalho avaliou os efeitos das atividades recreativas (pisoteio e tráfego de veículos) na macrofauna (Capítulo 1), assim como na meiofauna e na nematofauna (Capítulo 2). Para isso, três praias com diferentes níveis de pressão recreativa (Atalaia: intensidade alta e veículos permitidos; Farol-Velho: intensidade moderada e veículos permitidos; e Corvinas: intensidade baixa e sem permissão de veículos), localizadas em Salinópolis (NE paraense), foram analisadas em 4 períodos (1 mês antes, durante, 1 mês depois e 2 meses depois da alta temporada de verão – julho de 2017). A macrofauna apresentou uma drástica redução na densidade e na riqueza principalmente nas praias do Atalaia e Farol-Velho durante a alta temporada. Por outro lado, a praia das Corvinas permaneceu sem grandes alterações durante todo o estudo. A recuperação da fauna foi observada 2 meses após a alta temporada. Além disso, a densidade e a riqueza dos poliquetos *Scolelepis squamata* e *Paraonis* sp. são indicadores de impactos negativos quando diminuídas, uma vez que são espécies mais vulneráveis às atividades de recreação. Por sua vez, tanto a meiofauna quanto a nematofauna apresentaram padrões similares aos da macrofauna, em que grandes reduções na densidade e na riqueza foram observadas nas praias com intensidade de recreação moderada e alta durante a alta temporada. Entretanto, a recuperação da fauna foi observada 1 mês após a alta temporada. Além disso, Copepoda, Tardigrada e os gêneros de Nematoda, *Daptonema* e *Chromadorita*, responderam às atividades recreativas com significativas variações dos parâmetros analisados, podendo ser usados como potenciais indicadores de impactos ambientais.

Palavras-chave: Atividades recreativas; Costa amazônica; Fauna bentônica; Impactos antrópicos; Praias arenosas.

Abstract

Sandy beaches are environments of easy access for the human population and therefore they are subject to several anthropic pressures, which are mostly linked to tourist activities. The Amazonian beaches attract a large number of tourists throughout the year and so far, there are no studies assessing environmental impacts related to tourism in the benthic fauna for the region. Thus, the present study investigated the effects of recreational activities (trampling and vehicle traffic) on the macrofauna (Chapter 1), as well as on meiofauna and free-living nematodes (Chapter 2). For this purpose, three beaches with different levels of recreational pressure (Atalaia: high intensity and vehicles permitted; Farol-Velho: moderate intensity and vehicles permitted; and Corvinas: low intensity and without vehicle permission) located in Salinópolis (NE Pará) were analyzed in 4 periods (before, during, 1 month after and 2 months after the high summer season – July 2017). The macrofauna showed a drastic reduction in density and richness, mainly at Atalaia and Farol-Velho beaches during high season. On the other hand, Corvinas beach remained largely unchanged throughout the study. The recovery of the fauna was observed 2 months after the high season. In addition, the vulnerability of the polychaetes *Scolelepis squamata* and *Paraonis* sp. to the recreational activities found in the study, indicates that they may be potential indicators of recreational impacts in this environment. On the other hand, meiofauna and free-living nematodes showed similar patterns to those of macrofauna, where large reductions in density and richness were observed on Atalaia and Farol-Velho beaches during high season. However, fauna recovery was observed 1 month after the high season. In addition, Copepoda, Tardigrada and the nematode genera *Daptonema* and *Chromadorita* showed vulnerability to recreational activities and can be used as potential indicators of environmental impacts.

Key-words: Amazon coast; Anthropic impacts; Benthic fauna; recreational activities; Sandy beaches.

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Considerações gerais

A tese está no formato de um texto geral integrador e artigos científicos, os quais correspondem a capítulos deste manuscrito e uma parte final com as conclusões gerais. Esta organização obedece ao Regimento Geral do Programa de Pós-Graduação em Ecologia Aquática e Pesca, Resolução nº 4.782/2016 (Art. 67).

A parte introdutória possui uma introdução geral onde são apresentados os principais aspectos dos impactos causados pelo turismo em praias arenosas, além de uma revisão sobre o estado atual de conhecimento dos impactos do turismo na macrofauna bentônica, na meiofauna assim como na nematofauna ao longo das praias brasileiras. Além da introdução geral são apresentados os objetivos e o material e métodos de forma mais detalhada.

O capítulo 1 apresenta um artigo submetido ao periódico "*Estuarine, Coastal and Shelf Science*" e visa descrever os efeitos das atividades recreativas na comunidade macrobentônica em três praias com distintos níveis de uso e ocupação por atividades turísticas na região amazônica.

O capítulo 2 apresenta um artigo submetido ao periódico "*Journal of Marine Environmental Research*" e visa descrever os efeitos das atividades recreativas na comunidade meiobentônica e na nematofauna em três praias com distintos níveis de uso e ocupação por atividades turísticas na região amazônica.

Por fim, são apresentadas as principais conclusões e perspectivas para futuros estudos em praias arenosas, os quais se fazem necessários para uma melhor compreensão dos impactos sofridos por essa fauna nesse ambiente, de modo a incentivar a elaboração de políticas direcionadas para o manejo e conservação do ecossistema.

Sumário

1. Introdução Geral

Praias arenosas oceânicas constituem um dos ambientes mais dinâmicos do planeta, estando presentes em mais de dois terços da costa mundial, uma vez que a sua ocorrência independe de fatores físicos, como a temperatura e o regime de marés (McLachlan & Defeo, 2017). Esses ecossistemas estão na transição entre os ambientes terrestre e marinho, e por conta disso, os depósitos sedimentares presentes sofrem constante retrabalhamento por processos biológicos, eólicos e hidráulicos (Hoefel, 1973). Por estarem constantemente se ajustando a flutuações dos níveis de energia locais, as praias atuam como zonas-tampão, protegendo a costa da ação direta da energia provinda dos oceanos, sendo esta considerada sua função mais importante (Hoefel, 1998). Outras funções ecológicas e socioeconômicas das praias arenosas são ciclagem de nutrientes, fornecimento de área para abrigo e desova da fauna marinha (aves costeiras e tartarugas), berçário para recursos pesqueiros exploração mineral, pesca, turismo e recreação (Defeo *et al.*, 2009; McLachlan & Defeo, 2017)

A biota de praias arenosas varia de microorganismos a vertebrados, com representantes endêmicos, facultativos, marinhos e terrestres (McLachlan & Defeo, 2017). As zonas entremarés das praias proporcionam habitats para diversos organismos (Defeo *et al.*, 2009) e nelas a fauna bentônica está representada por praticamente todos os filos animais (McLachlan & Defeo, 2017). A macrofauna (invertebrados > 0,5 mm) e a meiofauna (invertebrados com dimensões entre 0,044mm e 0,3 mm) são os principais animais endêmicos em praias arenosas (Harris *et al.*, 2014). Entre os organismos da meiofauna, o filo Nematoda é o mais abundante e diverso (Heip *et al.*, 1985; Giere, 2009; Moens *et al.*, 2013), chegando a representar 90% dos organismos da meiofauna em diversas praias (Kotwicki *et al.*, 2005). Além disso, diversos vertebrados (ex: peixes e aves marinhas) utilizam as praias ao menos temporariamente, como área de abrigo e alimentação (Lasiak, 1986; Hubbard & Dugan, 2003) e os insetos que habitam o supralitoral são os principais representantes terrestres que habitam as praias arenosas (Koop & Griffiiths, 1982).

As comunidades bentônicas em praias arenosas são estruturadas principalmente pelas características físicas (ex: ondas, marés, correntes, temperatura, granulometria) e químicas (ex: Ph, EH, O_2, salinidade) do ambiente (McLachlan & Defeo, 2017). Consequentemente, a biota varia de uma praia para outra, e as alterações ambientais, sendo elas naturais e/ou antropogênicas, podem influenciar a estrutura e o funcionamento das comunidades biológicas presentes (Defeo *et al.*, 2009; Amaral *et al.*, 2016). Em praias arenosas, a fauna bentônica desempenha importante papel na ciclagem de nutrientes e atua como elo entre níveis tróficos (McLachlan & Dorvlo, 2005; McLachlan & Defeo, 2017) ao servir de alimento para diversos invertebrados, aves e peixes (Hockey *et al.*, 1983; Neuberger-Cywiak & Mizrahi, 1990; Takahashi *et al.*, 1999). Desta forma, praias arenosas são consideradas ecossistemas chave tanto para o mar quanto para o continente, pois controlam importantes processos físico, químicos e biológicos (Gheskiere *et al.*, 2005).

Por ser um dos ambientes marinhos de mais fácil acesso para os seres humanos (Amaral *et al.*, 2016; McLachlan & Defeo, 2017) as praias são lugares muito populares para recreação (Klein *et al*., 2004, Amaral *et al*., 2016; McLachlan & Defeo, 2017), e há séculos têm sido exploradas comercialmente (McLachlan & Defeo, 2017). Os impactos causados pelos humanos em praias arenosas tiveram início há pelo menos dois séculos (Nordstrom, 2000) e há previsão de intensificação dos mesmo ao longo das próximas décadas (Brown *et al.,* 2008), devido principalmente ao contínuo e intenso crescimento demográfico em áreas costeiras (Carter, 1988; Schlacher *et al.,* 2007). Praias arenosas, por serem ambientes preferenciais para lazer e recreação, têm ainda passado por severo processo de urbanização para atender a demanda turística (Defeo *et al*., 2009). Nesse sentido, esses ambientes possuem relevante papel socioeconômico, uma vez que diversas populações litorâneas dependem das atividades comerciais e recreativas ligadas a esse ambiente (de Ruyk et al., 1995; Orams, 2003)

A urbanização desordenada em praias arenosas em todo o planeta tem trazido prejuízos ambientais para o ecossistema e ameaçado sua integridade (Defeo *et al*., 2009; Harris *et al*., 2014). Como consequência do investimento prioritário em infraestrutura para atender a economia do turismo as praias têm sofrido com múltiplas perturbações, como construções sobre dunas, engorda praial, estabilização da linha de costa, em conjunto com seus impactos associados, como luz artificial, limpeza de praia e supressão de dunas, poluição por lixo (rejeitos sólidos e líquidos), pisoteio e tráfego de veículos (Defeo *et al.*, 2009). Dentre as diversas atividades recreativas realizadas em praias arenosas (Priskin, 2003), o tráfego de veículos automotores e o pisoteio estão entre as mais comuns e impactantes (Defeo *et al.*, 2009; McLachlan & Defeo, 2017), causando efeitos de diferentes tipos e graus (Brown & McLachlan, 2002).

O tráfego de veículos é comum em praias ao redor do mundo (Godfrey & Godfrey, 1980; Priskin, 2003; Schlacher & Thompson, 2007) e os impactos causados são numerosos, incluindo mudanças geomorfológicas e nas características do sedimento como o tamanho médio do grão, grau de seleção e compactação (Anders & Leatherman, 1987; Priskin, 2003), assim como impactos sobre os organismos presentes (vertebrados e invertebrados) resultando em menor sucesso reprodutivo e declínio da população (Hosier *et al.*, 1981; Buick & Paton, 1989; Williams *et al.*, 2004). Por sua vez, o pisoteio é originado principalmente pela execução de atividades recreativas (ex: caminhada, prática de esportes, acampamento) ao ar livre (Liddle, 1997) e seus efeitos, quando intensos, contribuem para modificações nas comunidades marinhas (Casu *et al.*, 2006a,b; Huff, 2011; Schiel & Taylor, 1999) e terrestres (Liddle, 1997). Assim como o tráfego de veículos, o pisoteio afeta diretamente o sistema de dunas e a região do entremarés, provocand diversos impactos físicos sobre o substrato, os quais influenciam a umidade do solo, causam erosão e mudança na morfologia e propriedades do sedimento além da morte e/ou desaparecimento de organismos presentes (Liddle & Moore, 1974; Liddle & Greg-Smith, 1975).

Ainda que sua importância ecológica seja evidente, as praias são ambientes reconhecidos pela população, e por governantes, quase que exclusivamente por seu valor turístico e/ou recreacional (Schlacher *et al.*, 2008). As perturbações relacionadas à essas atividades variam entre praias (Meuhe, 2001) e em diferentes escalas espaciais e temporais (Defeo *et al.*, 2009; McLachlan & Defeo, 2017). Esses distúrbios podem diferir em duração e intensidade, sendo comumente classificados como pulso (impactos de curta duração) ou pressão (impactos crônicos) (Glasby & Underwood, 1996). Um estressor pode causar distúrbio de pulso ou pressão dependendo da escala temporal em que esteja agindo (Defeo *et al*., 2009). Modificações em vários níveis da organização biológica (ex: de indivíduos a ecossistemas) e em escalas espaciais e temporais já foram descritos (Costa *et al*., 2018; Reyes-Martínez *et al*., 2014). Entre essas modificações, o desaparecimento de organismos e/ou a diminuição da abundância, assim como mudanças no comportamento de invertebrados bentônicos, tem sido atribuídas tanto a distúrbios de pulso quanto de pressão em praias arenosas (McLachlan & Defeo, 2017).

A necessidade de estratégias de monitoramento, manejo e conservação da biodiversidade é premente em praias arenosas (Harris *et al.*, 2014). Pesquisas ecológicas de longo prazo, ainda que recomendadas, são de difícil condução em razão da natureza dinâmica do ecossistema, necessidade por decisões rápidas e limitação de recursos financeiros (Caro, 2010). Por conta disso o uso de espécies e comunidades de praias arenosas como indicador de impactos recreativos tem se intensificado (Veloso *et al.*, 2008; Schlacher *et al.*, 2016; Machado et al., 2017; Costa & Zalmon, 2019a,b,c; Costa et al., 2020a), uma vez que são fáceis de monitorar e respondem previsivelmente a alterações ambientais (Market et al., 2003). Os critérios para a seleção de espécies indicadoras incluem, (1) facilidade de amostragem; (2) sensibilidade ao impacto; (3) abundância no local; e (4) conhecimento acerca da sua biologia (Sidding *et al*., 2017).

A maioria dos organismos bentônicos em praias arenosas são infaunais, ocupando a zona de entremarés, onde a maior parte do tráfego de pessoas e veículos está concentrada (Schlacher & Thompson, 2007) sendo assim potencialmente vulneráveis aos impactos causados por essas atividades (Wolcott & Wolcott, 1984; Schlacher *et al.*, 2007; Bessa *et al*., 2013). Consequentemente, os atributos do ecossistema, a estrutura da comunidade, as características da população (ex. abundância, idade, proporção de sexo) e características individuais (ex. comportamento) mostraram um potencial para seu uso como indicadores ecológicos adequados de estresse ambiental (de Matthaeis *et al.*, 2000; Fanini *et al.*, 2009; Schlacher *et al.*, 2016b)

Praias arenosas ocorrem ao longo de mais de 8 mil quilômetros da costa brasileira (Klein & Short, 2016). No entanto, os conhecimentos sobre esses ambientes, particularmente sobre a biodiversidade, são ainda insuficientes para garantir sua conservação (Amaral *et al.*, 2016). Alguns estudos sobre o impacto do desenvolvimento desordenado na macrofauna bentônica de praias arenosas já foram realizados, contudo se concentram em algumas regiões geográficas (Vieira *et al.*, 2012) e focam poucas espécies, particularmente crustáceos, como anfípodas (ex: Viana, 2006; Veloso *et al.*, 2006; Veloso *et al.*, 2008; Veloso *et al.*, 2009), isópodas (ex: Veloso *et al.*, 2010) e o caranguejo *Ocypode quadrata* (ex: Blankensteyn, 2006; Neves & Bemvenuti, 2006; Vieira, 2011; Costa *et al*., 2020b). São poucos os trabalhos que utilizaram as comunidades macrobentônicas (ex: Machado *et al.*, 2017; Mendes *et al*., 2017; Costa et al., 2020a). Por sua vez, estudos utilizando a meiofauna como indicadora de impactos do turismo em praias são praticamente inexistentes (ex: Moellmann & Corbisier, 2003), e quase sempre se limitam a ambientes consolidados como recifes de coral (ex: Sarmento *et al.*, 2011; Junior, 2015). Em geral esses trabalhos mostraram que a fauna bentônica tem sido afetada negativamente pelos impactos oriundos das atividades recreativas, sendo a mais sensível à pressão humana em praias arenosas brasileiras (Veloso *et al*., 2006; Cardoso *et al*., 2016).

A zona costeira amazônica representa aproximadamente 35% de toda a zona costeira brasileira (Isaac & Barthem, 1995; Klein & Short, 2016) e possui um regime hidrodinâmico altamente peculiar em comparação com outras áreas costeiras do mundo

(Souza-Filho et al., 2009; Pereira et al., 2016; Souza-Félix et al., 2020). Nesta área, o regime de macromarés (> 4 m), a grande quantidade de sedimentos transportados pelos rios para o litoral e a alta hidrodinâmica em águas rasas favorecem a ocorrência de praias com diferentes tipos de sedimentos, morfologia e exposição às ondas (Rosa Filho et al., 2011; Klein & Short, 2016). De maneira geral, estas praias estão localizadas em enseadas ao longo da costa, embora apenas alguns locais possam ser acessados por via terrestre (Bernardes et al., 2012; Kjerfve & Lacerda, 1993). A maioria dessas praias é rural ou semiurbana e inclui paisagens naturais e áreas que foram ou estão sendo ocupadas sem um planejamento adequado (Szlafsztein, 2012; Cardoso et al., 2014).

O litoral do nordeste do Pará perfaz uma extensão de 600 km (Costa *et al.,* 1991) e as características naturais das praias presentes atrai grande número de visitantes, principalmente nas férias escolares de julho e em diversos feriados prolongados (Pessoa *et al.,* 2013; Sousa *et al.,* 2011, 2013, 2014), bem como dos setores econômicos públicos e privados, com sua infraestrutura concomitante, sujeitando essas áreas a uma crescente exploração (Hardiman & Burgin, 2010; Szlafsztein, 2012). No NE do Pará, as praias do município de Salinópolis recebem boa parte desses visitantes, sendo um dos locais mais frequentados por turistas em todo o estado o que contribui para um intenso crescimento urbano (Ranieri & El-Robrini, 2016). Contudo, o intenso uso dessas áreas tem afetado suas características ambientais originais (Oliveira *et al.,* 2011; Pinto *et al.,* 2011; Silva *et al.,* 2011), e, devido a devastação dos ecossistemas costeiros, vem acelerando a erosão costeira (Ranieri & El-Robrini, 2016). Outro problema sério das praias paraenses é o intenso tráfego de veículos nas praias, sobretudo na praia do Atalaia, que pode intensificar ainda mais os problemas ambientais presentes.

De fato, diversos estudos realizados nessas praias têm mostrado que problemas ambientais, como a contaminação das águas por emissários clandestinos e entulho flutuante, assim como a contaminação da areia por resíduos sólidos e esgoto não tratado, se intensificam durante os períodos de férias (Souza-Felix *et al*., 2017). Apesar disso, as instalações destas praias são precárias, sendo necessário um grande investimento por parte das autoridades locais e do setor privado para garantir, a longo prazo, a qualidade destas praias (Pereira *et al.,* 2014, 2016). Infelizmente, a falta de um planejamento adequado das atividades recreativas tem contribuído para a redução da qualidade dessas praias e uma análise detalhada dos inúmeros problemas ambientais e sociais é urgente (Sousa *et al.,* 2017).

Apesar de suas características ambientais singulares e de grande importância econômica e ecológica, a fauna bentônica presente nas praias arenosas da região tem sido pouco estudada. Até o momento, apenas estudos voltados à caracterização e descrição espaço-temporal dessa fauna foram realizados sobre a fauna bentônica de praias arenosas amazônicas, e em geral, esses estudos têm sugerido que fauna bentônica da região é influenciada por mudanças sazonais de características ambientais como chuvas, vento, salinidade, regimes de ondas, granulometria e estado morfodinâmico (ex: Gomes & Rosa Filho, 2009; Rosa Filho *et al.*, 2009, 2011; Santos & Aviz; 2018; Baia & Venekey, 2019; Santos & Aviz; 2020). Sendo inexistente até o momento estudos verificando a influência das atividades recreativas na fauna bentônica das praias da região.

Assim, o presente estudo buscou preencher algumas dessas lacunas de conhecimento na ecologia de praias arenosas na região, com o objetivo de colaborar com a avaliação das condições ambientais desse ambiente, servindo como base para determinar os danos e as consequências que as atividades recreativas causam. Além disso, os resultados do presente estudo também buscam encontrar espécies indicadoras que possam ser utilizadas para avaliação desses tipos de impactos no futuro. O trabalho produzirá dados que podem incentivar a elaboração de políticas direcionadas para o manejo e conservação do ecossistema.

2. Objetivos

2.1. Objetivo geral

Descrever o impacto das atividades recreativas (pisoteio e tráfego de veículos) na estrutura das comunidades bentônicas (macrofauna, meiofauna e nematofauna) em praias arenosas amazônicas, com foco no Município de Salinópolis, Pará, Brasil.

2.2. Objetivos específicos

- **Capítulo 1**

Avaliar o impacto das atividades recreativas na estrutura e composição da macrofauna bentônica de três praias arenosas amazônicas com diferentes níveis de intensidade de atividades recreativas, em momentos distintos do ano (antes, durante e após períodos de grande movimento turístico ocupação - (férias de julho).

- Hipóteses:

A alta intensidade de atividades recreativas (pisoteio e tráfego de veículos) provoca alterações na estrutura e composição das comunidades da macrofauna bentônica, alterando a composição taxonômica e reduzindo a riqueza e densidade de espécies.

- **Capítulo 2**

Avaliar o impacto das atividades recreativas na estrutura e composição da meiofauna bentônica e na nematofauna em três praias de arenosas de macromaré amazônica com diferentes níveis de turismo (alto, intermediário e baixo) antes, durante e após um episódio de alta ocupação turística (férias em Julho).

- Hipóteses:

A alta intensidade de atividades recreativas (pisoteio e tráfego de veículos) (1) causa mudanças na estrutura e composição da comunidade meiobentônica e nematofauna ao diminuir a riqueza e densidade de espécies, particularmente na praia urbana durante o período de alta ocupação turística (julho); e (2) causa mudanças no padrão de distribuição da meiofauna e da nematofauna.

3. Metodologia Geral

3.1. Área de estudo

A zona costeira do Estado do Pará situa-se entre as baías de Marajó e a baía de Gurupi, fazendo parte da Costa Norte Brasileira (Klein & Short, 2016). É uma costa de submersão, baixa e recortada, com características fluvio-estuarinas, direção geral NW-SE e amplitudes de maré entre 5-7 m (El-Robrini, 1992). A zona costeira paraense pode ser dividida em cinco setores: Setor 1 ou Marajó Ocidental; Setor 2 ou Marajó Oriental; Setor 3 ou Continental-Estuarino; Setor 4 ou Flúvio-Marítimo; e Setor 5 ou Costa Atlântica Paraense (SEMAS, 2020). O clima da região é classificado como quente e úmido (Clima Equatorial Amazônico) (Köppen, 1948), possuindo um período mais chuvoso (dezembro a maio) e outro menos chuvoso (de junho a novembro), alta taxa de umidade relativa do ar com média anual em torno de 80% a 90% (Martins & Luz, 2004) e temperatura média de 27°C (CPTEC, 2014).

O Município de Salinópolis (0°36’49” S e 47°21’22” W) localiza-se no setor 5 da região costeira paraense, regionalmente chamada de Salgado Paraense. O município dista aproximadamente 220 km da capital Belém (Figura 1) e tem aproximadamente 40.000 habitantes (IBGE, 2018). Além disso, durante o período de veraneio (junho-agosto) o município recebe mais de 280,000 turistas (IBGE, 2018). As praias possuem características morfodinâmicas e sedimentológicas semelhantes sendo classificadas como dissipativas, apresentando características oceânicas com declives suaves, ondas deslizantes e granulometria variando de areia grossa a muito fina (Ranieri & El-Robrini, 2015). Contudo, apesar dessa semelhança morfológica e morfodinâmica, as praias apresentam unidades fisiográficas distintas, possuindo uma costa bastante diversificada quanto às características naturais e antrópicas (Ranieri & El-Robrini, 2016). Assim, é possível encontrar setores naturais e setores com urbanização consolidada e/ou em crescente expansão ao longo da costa (Ranieri, 2015).

Para determinar o efeito das atividades antrópicas em praias amazônicas, foram realizadas amostragens em três praias no Município de Salinópolis com um gradiente de pressão antropogênica: Atalaia, Farol-Velho e Corvinas (Figura 1). A praia do Atalaia possui um alto nível de desenvolvimento urbano (ex. restaurantes, bares, hospedagens e casas) e alto nível de ocupação por turistas durante o verão, sendo um dos locais mais frequentados por turistas em todo o estado (Ranieri & El-Robrini, 2016). A zona do retropraia (antigo pós-praia - *backshore*; ver Meuhe, 2019 para revisão), é ocupada por diversas construções e infraestrutura para turismo (ex. estacionamentos, ruas asfaltadas), que destruíram o sistema de dunas e a vegetação presente. Por outro lado, a praia das Corvinas é um setor mais preservado com pouco nível de ocupação na praia e com um sistema de dunas preservado e vegetação de manguezal presente (Silva *et al*., 2010). Além disso, o acesso para essa praia só ocorre a pé (Martinelli Filho & Monteiro, 2019).

A praia do Farol-Velho é um setor intermediário localizado entre as praias do Atalaia e das Corvinas. Essa praia é urbanizada com baixo nível de ocupação pelo turismo. Entretanto, a zona do retropraia inclui diversas construções, principalmente domiciliares, e baixa infraestrutura para turismo. A entrada de veículos só é permitida nas praias do Atalaia e Farol-Velho, contudo o maior influxo ocorre no Atalaia. As amostragens ocorreram nos meses de junho, julho, agosto e setembro de 2017, visando coletar amostras em épocas com atividades turísticas distintas, sendo julho considerado o período com maior atividade turística, junho o mês antes do pico, e agosto e setembro os meses depois do período de pico de usuários, incluindo veículos (exceto na Corvinas).

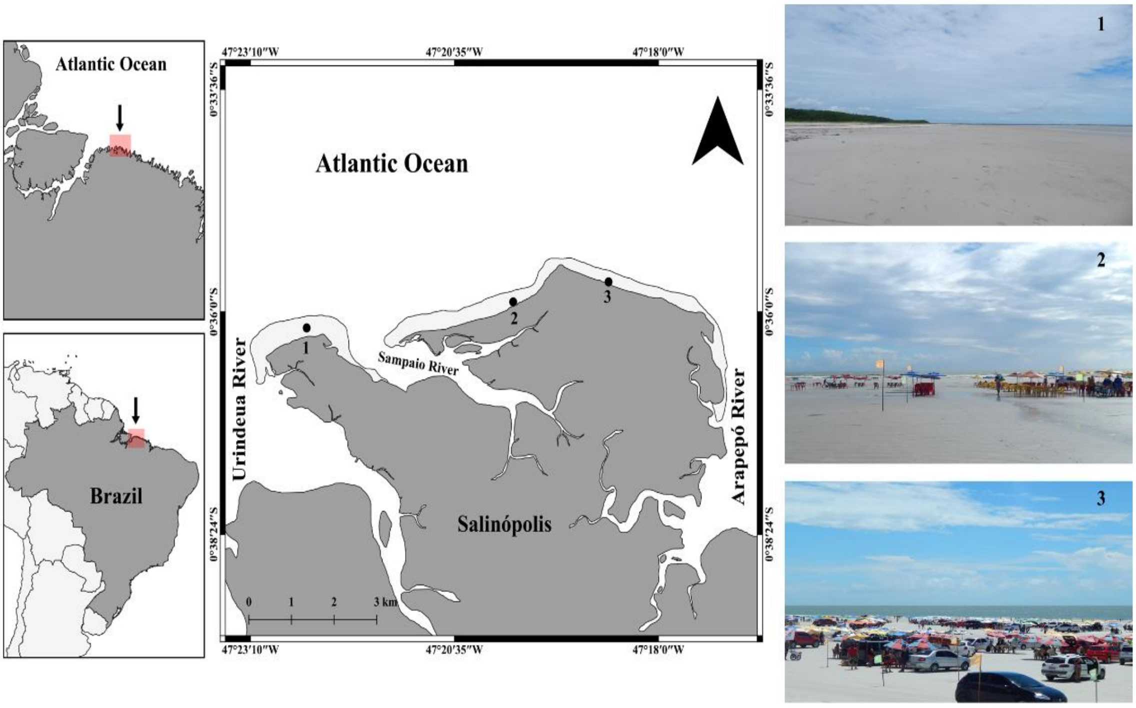

Figura 1: Mapa da área de estudo com identificação das praias estudadas (1 – Corvinas; 2 – Farol-Velho; 3 – Atalaia). (Foto: arquivo pessoal)

3.2. Procedimentos gerais de campo

3.2.1. Coleta da macrofauna

Em cada praia, as amostragens foram realizadas ao longo de dois transectos perpendiculares à linha d’água (distantes 100 m). Em cada transecto, as amostragens ocorreram em oito pontos (A – G) equidistantes (~50 m) se iniciando no supralitoral e abrangendo as regiões do médiolitoral superior, médiolitoral médio e médiolitoral inferior (Figura 2). Em cada ponto de coleta foram retiradas 4 amostras utilizando amostrador cilíndrico de 10 cm de diâmetro enterrado 20 cm no substrato. Após coletadas, as amostras foram lavadas em campo utilizando malha com abertura de 0,3 mm e os organismos retidos fixados em álcool 70% e posteriormente acondicionadas em sacolas plásticas.

Figura 2: Desenho amostral utilizado para a coleta das amostras da macrofauna bentônica nas praias estudadas e método de coleta. (Foto: arquivo pessoal)

3.2.2. Coleta da meiofauna

Em cada praia, as amostragens ocorreram ao longo de um transecto perpendicular à linha d’água. As amostragens ocorreram em oito pontos (A – G) equidistantes (~50 m) se iniciando no supralitoral e abrangendo as regiões do médiolitoral superior, médiolitoral médio e médiolitoral inferior (Figura 3). Em cada local de coleta foram retiradas 3 amostras utilizando amostrador cilíndrico de 3 cm de diâmetro enterrado 10 cm no substrato. Após coletadas, as amostras foram fixadas em formol a 4% e acondicionadas em potes plásticos

Figura 3: Desenho amostral utilizado para a coleta das amostras da meiofauna bentônica nas praias estudadas e método de coleta. (Foto: arquivo pessoal)

3.2.3. Coleta dos parâmetros ambientais

Paralelo à coleta de material biológico, em cada ponto de coleta foram retiradas três amostras de sedimento, para determinação dos parâmetros texturais (tamanho médio do grão, grau de seleção) e o teor de matéria orgânica (M.O). Por sua vez, o nível de compactação do solo foi determinado utilizando penetrômetro manual (Kg.f/cm²) e a temperatura (°C) utilizando termômetro de solo. Além disso, visando medir a intensidade das de atividades recreativas nas praias estudadas, em cada período de coleta, foram aferidos os níveis de perturbação da superfície praial. Para isso, foram quantificadas, *in situ*, a circulação de carros e pedestres presentes dentro da área de coleta por 10 minutos a cada 30 minutos (Figura 4) durante a duração da coleta (aproximadamente 4h). Foram ainda determinadas por local: a salinidade da água de superfície (utilizando refratômetro manual).

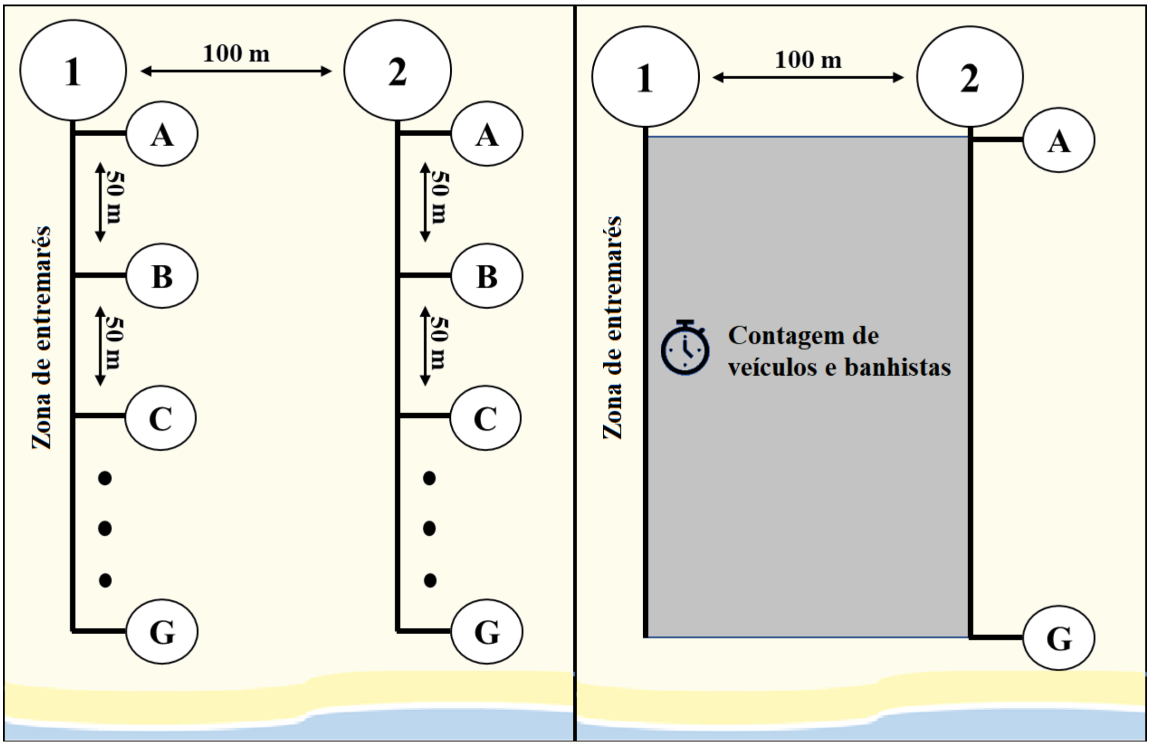

Figura 4: Desenho amostral utilizado para a coleta das amostras para cada praia estudada.

3.3. Procedimentos gerais de laboratório

3.3.1. Macrofauna

As amostras foram lavadas sob água corrente, sendo passadas por uma malha de 0,3 mm de abertura para a retirada do excesso de sedimento. Posteriormente o material retido na malha foi triado com o auxílio de microscópio estereoscópico e de microscópio óptico, quando necessário. Os organismos foram contados e identificados ao menor nível taxonômico possível e preservados em álcool etílico a 70%.

3.3.2. Meiofauna

Os organismos foram separados do sedimento por flotação com sílica coloidal de densidade de 1,18g/cm^3 (Somerfield *et al.,* 2005) utilizando peneiras de 0,3 e 0,045 mm de abertura. Os organismos retidos na peneira de 0,045 mm foram corados com rosa de bengala, colocados em placa de Dollfus, contados e identificados ao nível de grandes grupos zoológicos, com o auxílio de microscópio estereoscópico. Posteriormente, 50 Nematoda por amostra foram diafanizados e montados em lâminas permanentes, seguindo o protocolo proposto por de Grisse (1969) e Cobb (1917). Os Nematoda foram identificados a nível de gênero utilizando a chave pictórica de Warwick *et al.,* (1998), assim como a bibliografia específica da Seção de Biologia Marinha da Universidade de Ghent (Bélgica) e da página eletrônica do Nemys (Bezerra *et al.*, 2020).

Os Nematoda foram classificados quanto ao grupo trófico seguindo a proposta de Wieser (1953). Essa classificação leva em consideração a morfologia da cavidade bucal para classificar os organismos em: grupo 1: sem armaduras bucais, com - 1A: detritívoros seletivos e 1B: detritívoros não-seletivos; e grupo 2: com armaduras bucais, com - 2A: alimentam-se no epistrato/raspadores e 2B: predadores ou onívoros. Para a confecção da lista taxonômica, a classificação proposta por de Ley & Blaxter (2004) foi adotada

3.3.3. Parâmetros do sedimento

A granulometria foi determinada através do método de peneiramento dos sedimentos grosseiros como proposto por Suguio (1973). Os parâmetros estatísticos (média do diâmetro dos grãos, grau de seleção e proporções de areia, silte e argila) foram calculados utilizando as equações propostas por Folk & Ward (1957) e os sedimentos forma classificados de acordo com a escala de Wentworth (Buchanan, 1984). Por sua vez, o teor de matéria orgânica do sedimento foi determinado pelo método da calcinação (Dean, 1974).

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Capítulo 1 - How do recreational activities affect sandy beach macrobenthos? A study case in the Amazonian coast.

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Resumo

Relatamos pela primeira vez os efeitos das atividades recreativas nas comunidades macrobentônicas de praias arenosas amazônicas. As amostragens foram realizadas em três praias contrastantes: uma praia urbana com elevado número de banhistas e tráfego de veículos (Atalaia), uma praia intermediária com baixo tráfego de veículos (Farol-Velho) e uma área controle com baixo número de banhistas e tráfego de veículos proibido (Corvinas). A amostragem foi realizada mensalmente, representando quatro períodos com diferentes intensidades de visitação (antes, durante as férias e dois após o período de férias). As variáveis físicas do sedimento permaneceram constantes ao longo do tempo em todas as áreas, enquanto diferenças foram encontradas na intensidade da atividade recreativa e compactação de sedimentos entre as áreas ao longo dos períodos. Diferenças de densidade e riqueza entre os períodos foram observadas nas áreas Urbana e Intermediária, especialmente nas estações de amostragem superiores, onde se concentram as atividades recreativas. No entanto, a área de controle permaneceu constante durante todo o período de estudo. Além disso, a vulnerabilidade dos poliquetas *Scolelepis squamata* e *Paraonis* sp. indica que eles podem ser indicadores potenciais do impacto da atividade recreativa.

Palavras-chave: Praia arenosa; impactos ambientais; turismo; macrofauna; costa amazônica.

Abstract

We report for the first time the effects of recreational activities on macrobenthic communities of Amazonian sandy beaches. Samples were carried out in three contrasting beaches: an Urban beach with a high number of beachgoers and vehicle traffic, an Intermediary beach with a low level of vehicle traffic, and a Control area with a low number of beachgoers and prohibited vehicle traffic. Sampling was performed monthly, representing four periods with different visitation intensities (before, during vacation, and two after the vacation period). Physical sediment variables remained constant over time in all areas, whereas differences were found in recreational activity intensity and sediment compaction among areas over the periods. Differences in density and richness among periods were observed in the Urban and Intermediary areas, especially at the upper sampling stations where recreational activities are concentrated. However, the Control area remained constant throughout the study period. Furthermore, the vulnerability of the polychaetes *Scolelepis squamata* and *Paraonis* sp. indicates that they might be potential indicators of recreational activity impact.

Key words: Sandy shores; Environmental impacts; Tourism; Macrofauna, Amazon coast.

1.Introduction

Beach recreation is considered a significant form of human impact on sandy beaches (Davenport and Davenport, 2006; Schlacher et al., 2007a) and involves a wide range of activities, such as camping (Hockings and Twyford, 1997), use of vehicles (Schlacher and Thompson, 2008), and other recreational pursuits (Fanini et al., 2014). This intensive human use of beaches has been recognized as an activity that negatively affects beach fauna and the specific impact of recreational activities are well documented worldwide. Overall, these activities can dramatically alter the natural physical characteristics of beaches through compaction, rutting, and disturbance to the sand matrix (Anders and Leatherman, 1987; Priskin, 2003), which affects benthic communities directly (*e.g.* by removing individuals) and/or indirectly (*e.g.* by affecting biological interactions) (Brosnan and Crumrime, 1994; Brown and Taylor, 1999).

Changes in sandy beaches morphology and sediment characteristics are particularly troublesome for the benthic fauna, which is controlled primarily by the physical environment, with ecosystem functioning, zonation, and community structure being mainly linked to beach morphological state (see McLachlan and Defeo, 2018 for review). Additionally, beach species are not usually found in other environments as they often exhibit unique adaptations to the dynamic system where they inhabit (Schlacher et al., 2008). Thus, changes in physical features can alter species distribution patterns, which can result in a significant loss of biodiversity (Defeo et al., 2009).

Macrobenthic communities on sandy beaches are represented by most invertebrate phyla and play a major role in beach ecosystem functioning (McLachlan and Defeo, 2018), as they are involved in nutrient regeneration (Cisneros et al., 2011), and energy transfer between marine and terrestrial systems (Dugan, 1999; Lercari et al., 2010). Macrobenthos are also a pivotal economic asset for many traditional communities (Maguire et al., 2011), since artisanal shelfish fisheries (*e.g.* sandy beach clams and ghost shrimps) have important socioeconomic relevance worldwide (McLachlan and Defeo, 2018). Moreover, macrobenthic species, populations and communities have been recommended as bioindicators of beach health, due to their intrinsic relationship with the sediment, range of physiological tolerance to stress, behavioral plasticity, and diversity of life-histories (Veloso et al., 2008).

The effects of recreational activities on faunal communities have been assessed in different marine ecosystems, such as rocky shores (Ferreira and Rosso, 2009; Mendez et al., 2017), coral reefs (Rodgers and Cox, 2003; Sarmento et al., 2011), and mudflats (*e.g.*

Rossi et al., 2007). However, on sandy beaches, this issue has been neglected from different perspectives (Reyes-Martinez et al, 2015). The effect of these activities at the population level has been studied on species that are considered more susceptible, such as supralittoral talitrid amphipods (*e.g.* Weslawski et al., 2000; Ugolini et al., 2008; Veloso et al., 2008, 2009), ocypodid decapods (*e.g.* Barros, 2001; Neves and Bemvenuti, 2006; Lucrezi et al., 2009; Schlacher et al., 2015; Costa et al., 2018, 2020), and cirolanid isopods (*e.g.* Veloso et al., 2010). However, few studies have addressed the effects of recreational activities at community level (*e.g.* Schlacher and Thompson, 2012; Reyes-Martinez et al., 2015; Machado et al., 2017; Mendes et al., 2017), and their results have showed that these activities generally cause negative effects on the macrobenthic community and populations.

Historically, Brazilian economic development has consisted of poorly planned exploitation of natural resources, which has subjected Brazilian beaches to several types of human impacts (Amaral and Jablonsky, 2005; Scherer, 2013; Amaral et al., 2016). Despite their wide geographical extent, knowledge on Brazilian beaches is reduced and information available on their biodiversity, particularly in northern Brazil (Amazonian coast), is insufficient to guarantee their preservation (Amaral et al., 2016). Sandy beaches of the Brazilian Amazonian coast, distributed along more than 3900 km, have considerable touristic potential, since they are very safe for bathing, and most them have almost pristine nature (Pereira et al., 2016a, 2016b). Studies have shown that Amazonian sandy beaches are overcrowded during vacation (July) and some bank holidays (Sousa-Felix et al., 2017). Therefore, the present study evaluated the impact of recreational activities on macrobenthic fauna structure and composition of three Amazonian sandy beaches with different intensities of recreational activities, at distinct moments of the year (before, during and after periods of high tourist occupancy - July vacation). The following hypothesis was tested: high intensity of recreational activities (trampling and vehicle traffic) alters the structure of macrobenthic communities, changing taxonomic composition, and reducing richness and density.

2.Material and methods

2.1.Study area

The study area is located in the Atlantic Coastal Sector of North Brazil, one of the most densely populated areas of the Amazonian region (Sousa et al., 2011) with about 40.000 residents, where economy is based on fishing and tourism, which may receive > 280,000 beachgoers during July (IBGE, 2018). Local climate is equatorial humid with annual mean temperature and rainfall of 26-27°C and 2500-3000 mm, respectively, and approximately 75-85% of rainfall during rainy season (January - May) (Martorano et al., 1993; INMET, 2009).

This study was conducted on three beaches located in Salinópolis (0°36’49” S and 47°21’22” W), 220 km far from the city of Belém (Fig. 1A) with a variable anthropogenic pressure gradient; Atalaia (High activity – urban area), Farol-Velho (Intermediate activity – urban area), and Corvinas (Low activity – protected area). The Atalaia beach has a high level of urban development (*e.g.* restaurants, housing, and hotels) and high human occupancy during the summer season. The backshore is occupied by constructions and tourism infrastructure (*e.g.*, parking spaces, streets), which have destroyed the vegetation cover and the dunes system. In contrast, Corvinas beach is a pristine sector with low level of disturbance with a well-preserved dune system and mangrove vegetation in the backshore area (Silva et al., 2010). This beach can only be reached on foot (Martinelli Filho and Monteiro, 2019).

The Farol-Velho beach is an intermediate sector located in the transitional area between the Atalaia and Corvinas. This beach is urbanized with low level of tourism occupancy and the backshore includes constructions and low tourism infrastructure. Vehicles are only allowed on Atalaia and Farol-Velho beaches; however, the highest influx occurs on Atalaia beach. The main hydrodynamic features of the studied beaches are: macrotides (4 - 6 m), strong coastal currents (up to 1.5 m/s), and wave energy modulated by wave attenuation on sand banks during low tide (Monteiro et al., 2009; Pereira et al., 2009). The beaches have similar sedimentological and morphodynamic characteristics: dissipative exposed state, gentle slope, spilling waves, and sediment comprised mainly of fine to very-fine sand (Ranieri and El-Robrini, 2015).

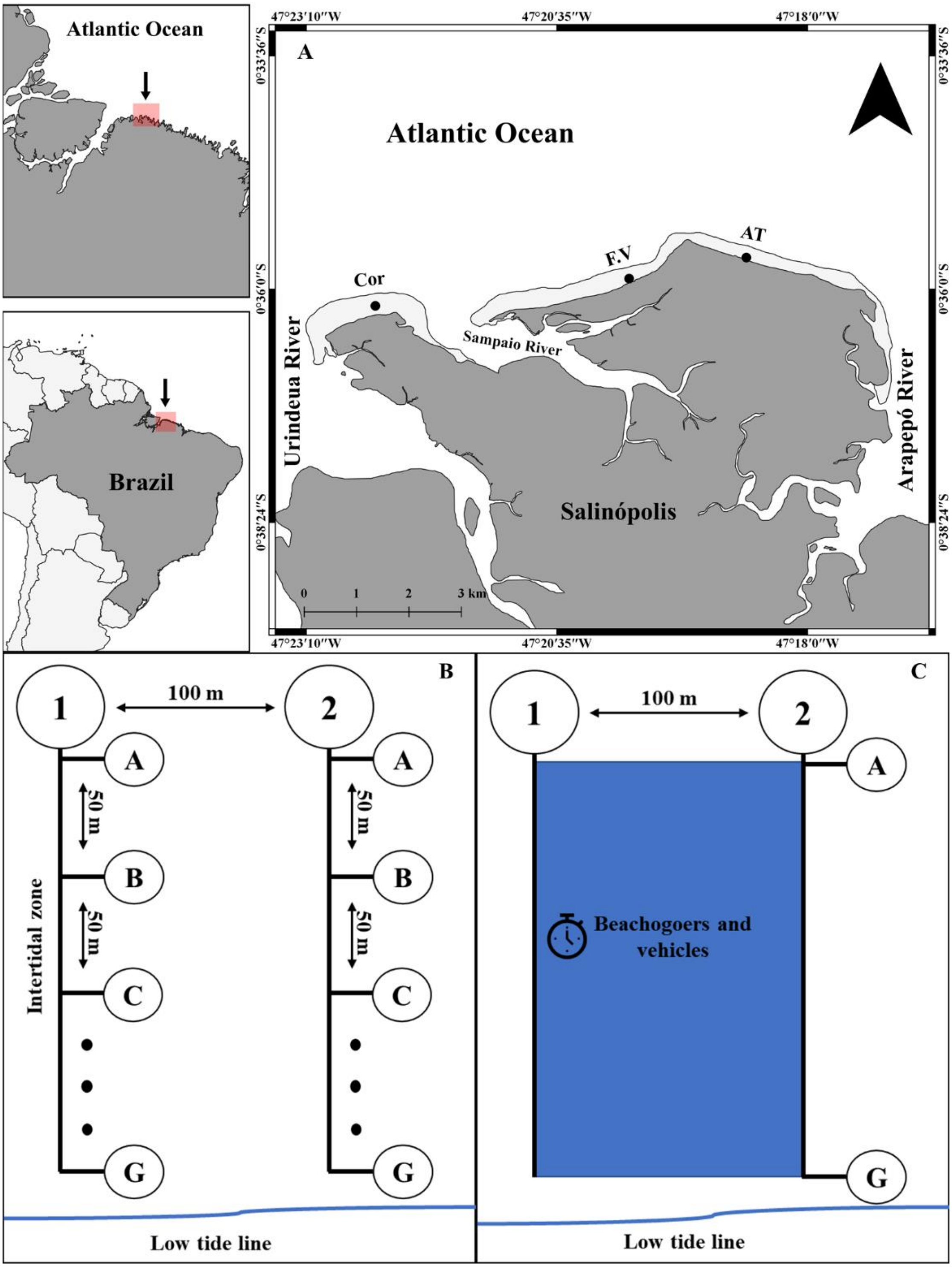

Fig. 1. Map showing the location of Salinópolis and the three sandy beaches studied A (Ata: Atalaia – Urban area; F.V: Farol-Velho – Intermediary area; Cor: Corvinas – Control area) and schematic representation of sampling on the three sandy beaches studied: B – Macrobenthos; C – Recreational activities.

2.2.Sampling and laboratory procedures

The largest tourist influx on Amazonian beaches occurs during vacation (July), and to evaluate its effects on macrofauna, four sampling campaigns were conducted on each beach during spring tides: June 2017 - Before Vacation, July 2017 - Vacation, August 2017 – After 1 (one month after vacation), and September 2017 - After 2 (two months after vacation) (Fig. 2). Macrofauna sampling was carried out in the intertidal zone of each beach along two across-shore transects (100 m distant from each other). Seven equidistant sampling stations (A - G), were established 50 m apart from each other at each transect, from the high tide mark to the swash zone (Fig. 1b). Four samples were collected at each sampling stations with a cylindrical corer (10 cm diameter and 20 cm height). After collection samples were sieved through a 0.3 mm mesh screen and preserved in 70% ethanol stained with Rose Bengal.

Simultaneously to biological sampling, sediment samples were collected from each sampling station for granulometric analyses and analysis of organic matter content measurement. Sediment compaction was determined at each station using a manual penetrometer (. Seawater salinity was determined using a sample of surface water from the infralittoral, with a manual refractometer. Also, the intensity of recreational activities was estimated based on disturbance levels of beach surface. Surface disturbance was estimated using the number of vehicles and beachgoers observed on each beach. For this purpose, four census campaigns were conducted (1 campaign per month on each beach) along with biological sampling procedures. In each campaign, vehicles and beachgoers were counted in an area between two across-shore transects along the intertidal zone for 10 minutes every 30 min within a 4-h period (a total of 8 counts/beach/sampling campaign) (Fig. 1c).

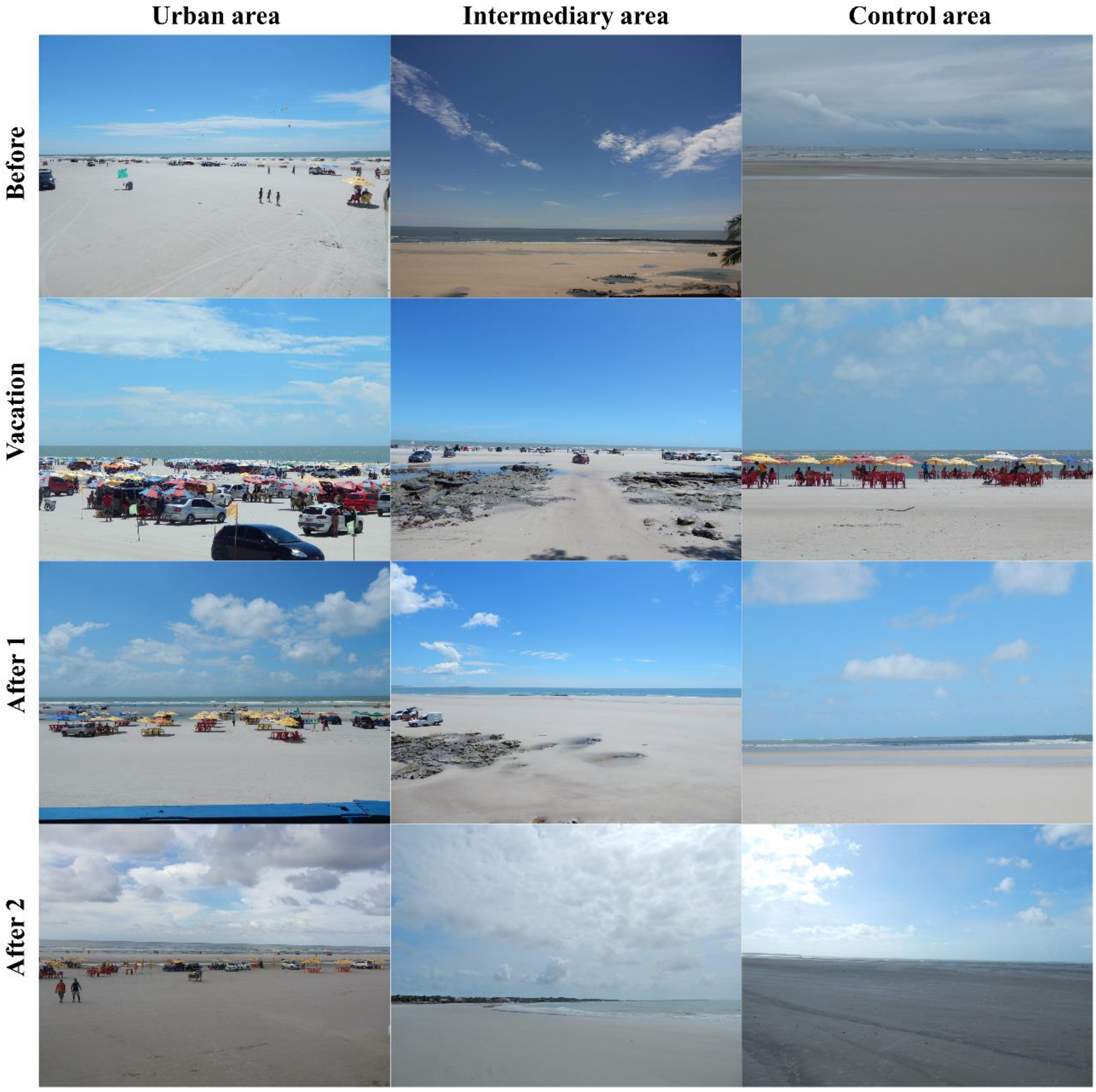

Fig. 2. Visitors at the three sandy beaches (Atalaia – urban area, Farol-Velho – intermediary area and Corvinas – control area) at the different periods (Before vacation, during vacation, After vacation 1 and 2).

In laboratory, biological samples were examined under a stereoscopic microscope, and organisms were counted and identified to the lowest taxonomic level possible. The granulometric analysis was conducted by sieving out the coarse sediments and pipetting the fine sediments, as proposed by Suguio (1973). Grain sizes were determined by sieving the sediment in an automatic shaker and classifying the grains according to the Wentworth scale (Buchanan, 1984). Water content was initially estimated as water loss after sediment drying for 24 h at 60 °C. Dried samples were combusted at 550 °C for 4 h to determine organic content (Dean, 1974).

2.3.Statistical analysis

For each sample species richness (total taxa) and density (inds. m^{-2}) were determined. These descriptors were compared among treatments using a three-way (period: before vacation, during vacation, after 1 and 2; area: Urban, Intermediary and Control; and sampling stations: A - G) analysis of variance (ANOVA) after checking normality (Kolmogorov–Smirnov's test) and homogeneity of variance (Levenes's test). When necessary data were fourth-root transformed. When ANOVA results were significant Tukey's test were used for pairwise comparisons. The validity of our *a priori* grouping (period, areas, and sampling stations) was analyzed using a three-way permutational ANOVA (PERMANOVA), designed using the same layout as the ANOVA. The contribution of each taxon to the dissimilarity among groups was assessed using the SIMPER (similarity percentage) routine. A 5% significance level was considered in all tests

The mean number of beachgoers and vehicles at each beach (mean number of the 8 counts) was used as a proxy for the beach use (recreational activities) at each sampling campaigns. Textural parameters (mean grain size, sorting, sand, and gravel percentages) were calculated using the equations of Folk and Ward (1957) in Sysgran (Camargo, 2006). Abiotic variables (mean sediment grain size, sorting, % sand and % fine, % organic matter, % water content, and compaction) and human beach use (mean number of beachgoers and vehicles) had the same configuration as ANOVA in order to detect changes in abiotic variables and human beach use among areas and periods. Abiotic variables were also analyzed using multivariate methods (Clarke and Gorley 2006). Environmental parameters were log (x+1) transformed, normalized, and analyzed using Principal Components Analysis (PCA). Multiple regression analyses were performed to assess the relationship between human beach use (number of beachgoers and vehicles) and sediment parameters, and the relationship of human beach use and sediment parameters with macrobenthos density and richness

3.Results

3.1.Environmental parameters and human beach use

The number of beach users (vehicles and beachgoers) was generally higher during Vacation in all areas. These variables were significantly higher in Urban and Intermediary in Vacation. There were no significant differences between Control and Intermediary areas in other periods. In all beaches Vacation had significantly more beachgoers (Fig.

3). The number of vehicles was significantly higher at Vacation in Urban and Intermediary beaches. Data for all environmental parameters are shown in Supplementary Material 1.

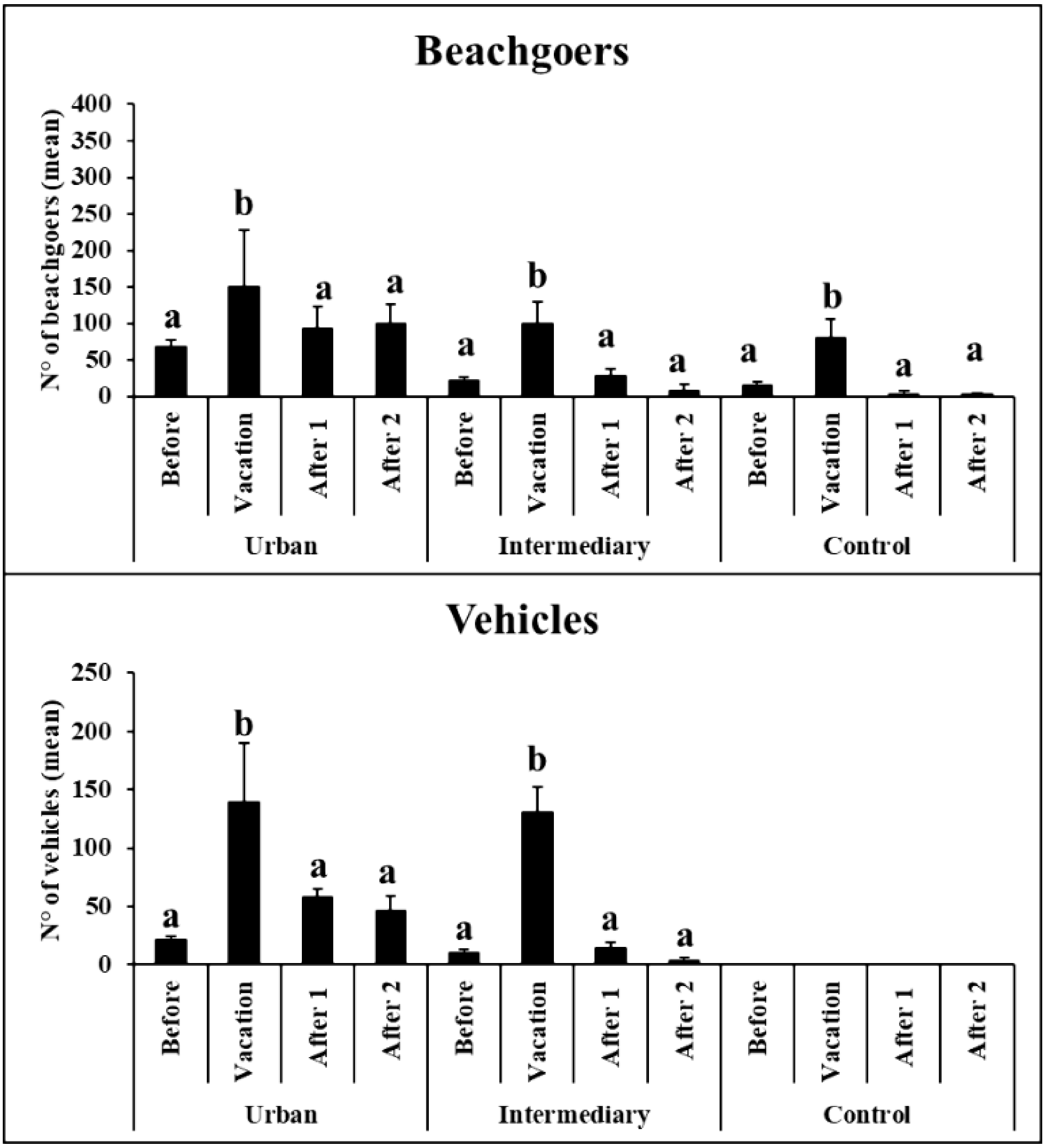

Fig. 3. Number of beach beachgoers (upper graph) and vehicles (lower graph) counted (mean ± SE) in each area in the different study periods (Before vacation, during Vacation, After vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

In all beaches, sediment was composed of well-sorted, fine to very-fine sand (Supplementary Material 1). Sediment characteristics (mean grain size, sorting, and organic matter) did not differ among beaches and sampling campaigns (Table 1). Sorting, on the other hand, significantly varied among periods and areas, with highest values in the Urban area during Vacation (Supplementary Material 1). Organic matter (OM) varied among areas ($F_{(2.84)}$=7.03, $p<0.05$), with higher values in the Control area. Significant differences between sampling stations ($F_{(6.86)}$=19.72, $p<0.05$) were detected in the Urban and Intermediary areas only during Vacation, when the lowest OM values were found at the higher sampling stations (A and B) in both areas (Supplementary material 1).

Overall, higher sand compaction was recorded during Vacation in all areas (Table 1). However, significant differences were only found between Before and Vacation (Supplementary material 1). There were significant differences in compaction among areas, with higher values found in the Urban area in all periods. Urban and Intermediary areas had similar compaction among sampling stations, with significantly higher values at the higher sampling stations (A – B), whereas the Control area had higher values at the lowest sampling stations (F – G).

Table 1. Summary of ANOVA results for sediment characteristics from sandy beaches of the Amazonian coast.

		OM		**Grain size**		**Sorting**		**Compaction**	
Factors	**df**	**F**	***p***	**F**	***p***	**F**	***P***	**F**	***P***
Period (Pe)	3	6.38	0.00*	18.65	0.00*	36.67	0.00*	45.89	0.00*
Area (Ar)	2	7.03	0.00*	6.87	0.00*	18.57	0.00*	167.19	0.00*
Sampling stations (S)	6	19.72	0.00*	1.48	0.19	6.45	0.00*	2.66	0.02*
Pe x Ar	6	1.26	0.28	17.89	0.00*	8.16	0.00*	8.93	0.00*
Pe x S	18	2.16	0.00*	0.56	0.91	3.51	0.00*	2.51	0.00*
Ar x S	12	1.80	0.05	1.37	0.19	1.94	0.04*	6.91	0.00*
Pe x Ar x S	36	1.02	0.44	0.66	0.91	1.34	0.13	1.13	0.30
Error	84								

*p<0.05; df = degrees of freedom; OM: organic matter.

Based on environmental variables, the first two principal components (PC) explained 37.6% of the variance between treatments (Fig. 4). Axis 1, which explained 19.2% of data variance, shows a clear separation of samples of 'Before Vacation' from the other periods. All areas had finer (very-fine sand, % fine) and better-sorted sediments with higher OM content Before vacation. On the other hand, the other periods had a more compacted sediment with larger grain size and a higher number of vehicles and beachgoers. The lower part of Axis 2, which accounted for 18.4% of the explanatory power of the analysis, was better associated with the periods Vacation and After 1. Samples from the period during Vacation had the maximum values of compaction and human beach use (vehicles and beachgoers). Multiple regression showed negative correlation between recreational activities (number of beachgoers and vehicles) and sediment characteristics; however, only sediment compaction had significant relationships (Table 2).

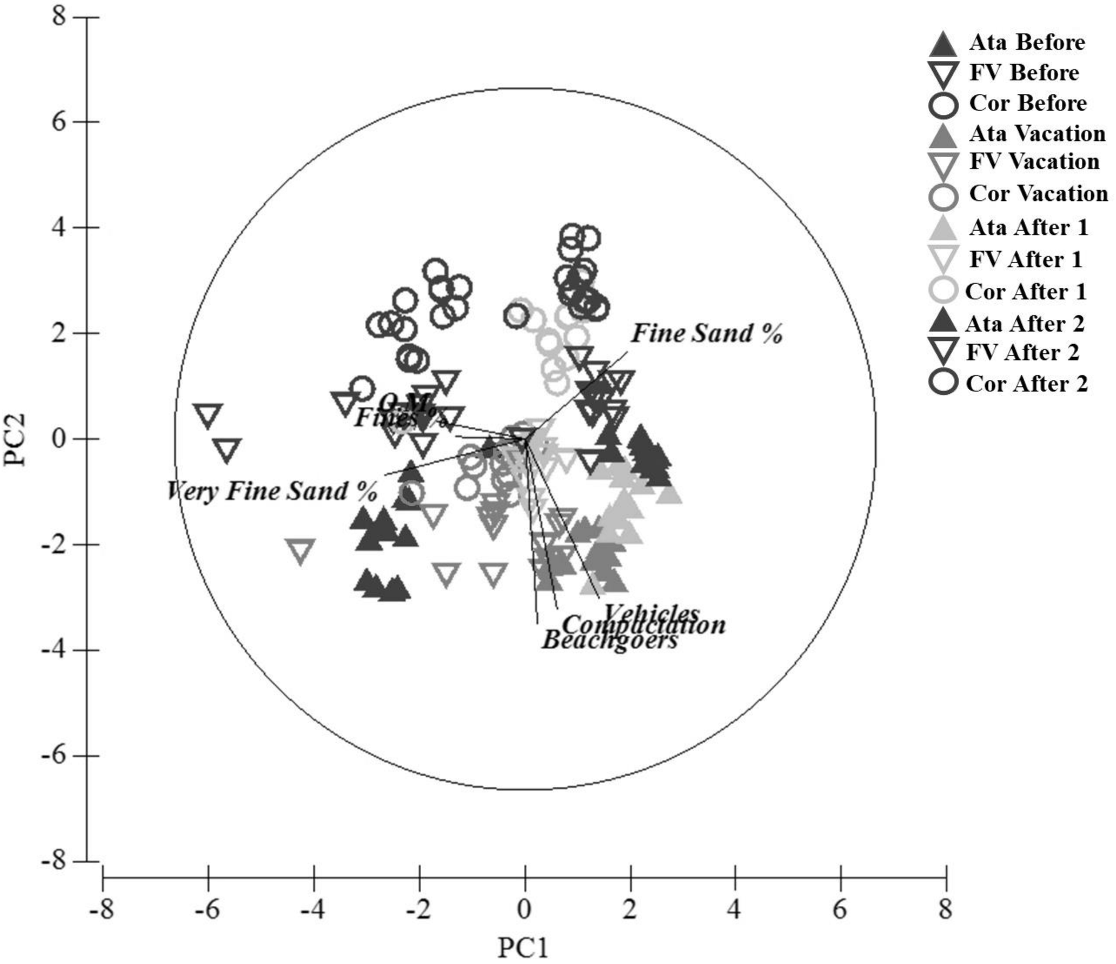

Fig. 4. Plots of the Principal Coordinate Analysis (PCA) based on environmental variables collected from the study areas (Atalaia – Urban area; Farol-Velho – Intermediary area; and Corvinas – Control area) in the different periods (Before vacation, during Vacation, After vacation 1 and 2).

Table 2. Summary of results of Multiple Linear Regression Analysis between regression results showing the correlations and levels of significance for each significant predictor environmental variable used for modelling sandy beach community attributes.

	Model results			
	R	**R^2**	**$F_{(3.80)}$**	***p***
Organic matter	0.44	0.14	3.90	0.00*
Mean grain size	0.41	0.13	5.46	0.00*
Sorting	0.36	0.10	4.09	0.00
Compaction	0.78	0.61	66.68	0.00*

	Dependent variables											
	Mean grain size			**Sorting**			**Compaction**			**Organic matter**		
Independent Variables	**B**	**T**	***P***	**β**	**t**	***p***	**β**	**T**	***p***	**β**	**t**	***p***
Vehicles	0.30	2.69	0.01*	-0.19	-1.49	0.14	0.33	3.13	0.00*	-0.05	-0.47	0.63
Beachgoers	0.11	0.94	0.35	0.24	1.91	0.05	0.50	4.68	0.00*	-0.14	-1.14	0.25
Mean grain size	-	-	-	0.10	1.05	0.29	-0.05	-0.72	0.47	-0.12	-1.51	0.13
Sorting	0.09	1.12	0.26	-	-	-	0.14	1.50	0.13	0.34	3.18	0.00*
Compaction	-0.10	-0.90	0.36	0.34	1.99	0.04	-	-	-	0.04	0.35	0.72
Organic matter	-0.11	-1.51	0.13	0.24	2.21	0.03	0.01	0.16	0.87	-	-	-

*$p<0.05$, β – standardized coefficients

3.2.Macrobenthic community

A total of 46 taxa were recorded (Supplementary material 2). Annelida (mainly Polychaeta) was the most diverse phylum (18 species), followed by crustaceans (16 species), mollusks (5 species), insect larvae (3 species), Nemertea, Acari, and Echinodermata (1 species each). Relative abundance major taxa at each area in different periods are shown in Fig. 5. In the Before Vacation campaign polychaetes and bivalves were dominant in all areas, except in Control, where bivalves were not very abundant. During Vacation polychaetes dominated in all areas, followed by bivalves and crustaceans in the Urban area and insects in the Intermediary area. After vacation, the abundance of crustaceans and insects increased in the Urban and Intermediary areas.

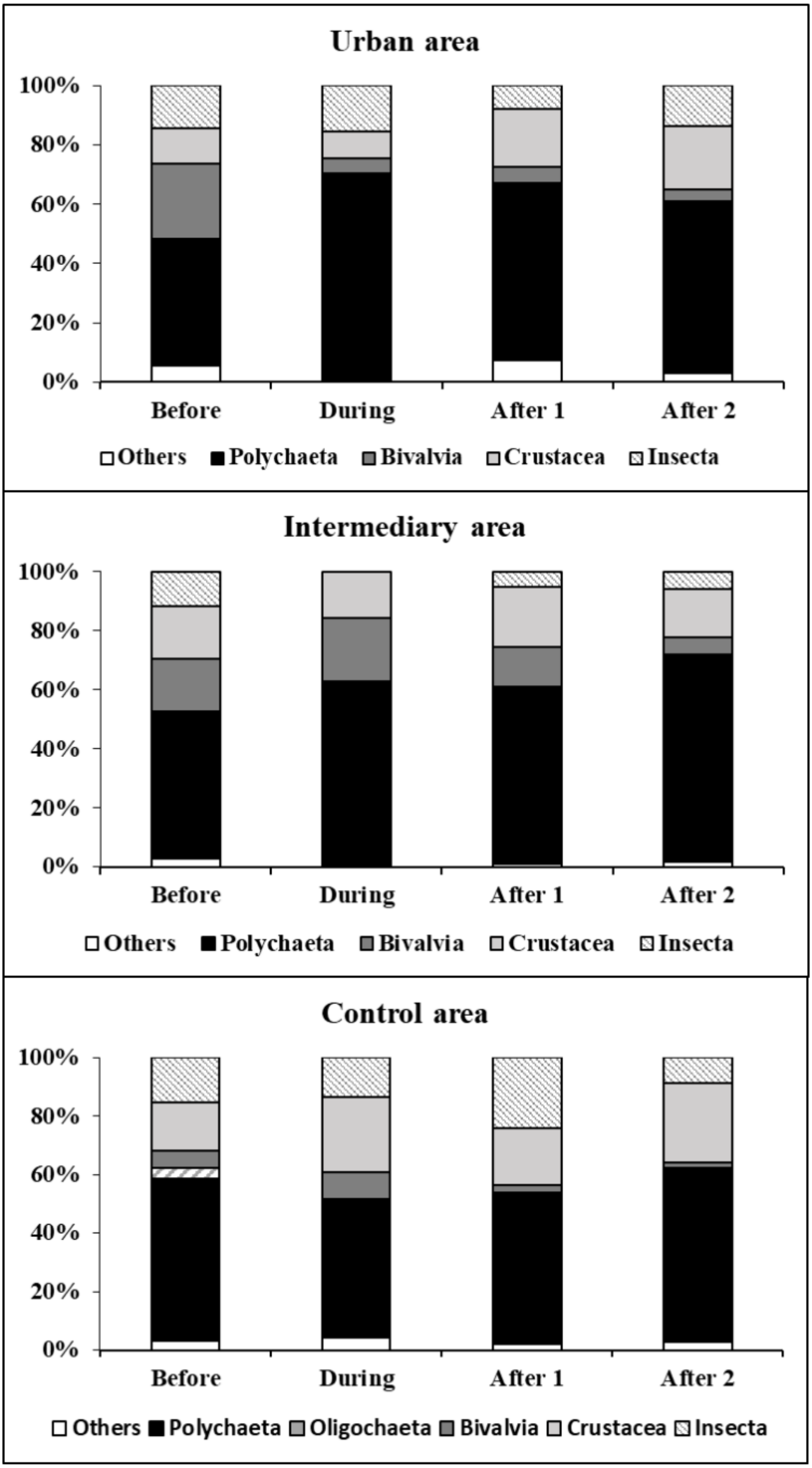

Fig. 5. Relative abundance (%) of major macrobenthic taxa at each area in Amazonian sandy beaches.

Mean macrobenthic densities significantly varied among periods, areas and sampling stations (Table 3). Higher densities were generally recorded in Control, in all periods. Significant differences were mainly found when Vacation was compared with other periods (Before, and After 1 and After 2) in the Urban and Intermediary areas. Overall, the lowest densities were recorded during Vacation on all areas. Comparing sampling levels, significant differences were observed during Vacation, particularly in the Urban and Intermediary areas. Densities markedly increased seaward in all areas. In the After-1 period, density increased at all sampling stations on all beaches. No significant differences were found between the periods After 2 and Before in all areas (Fig. 6).

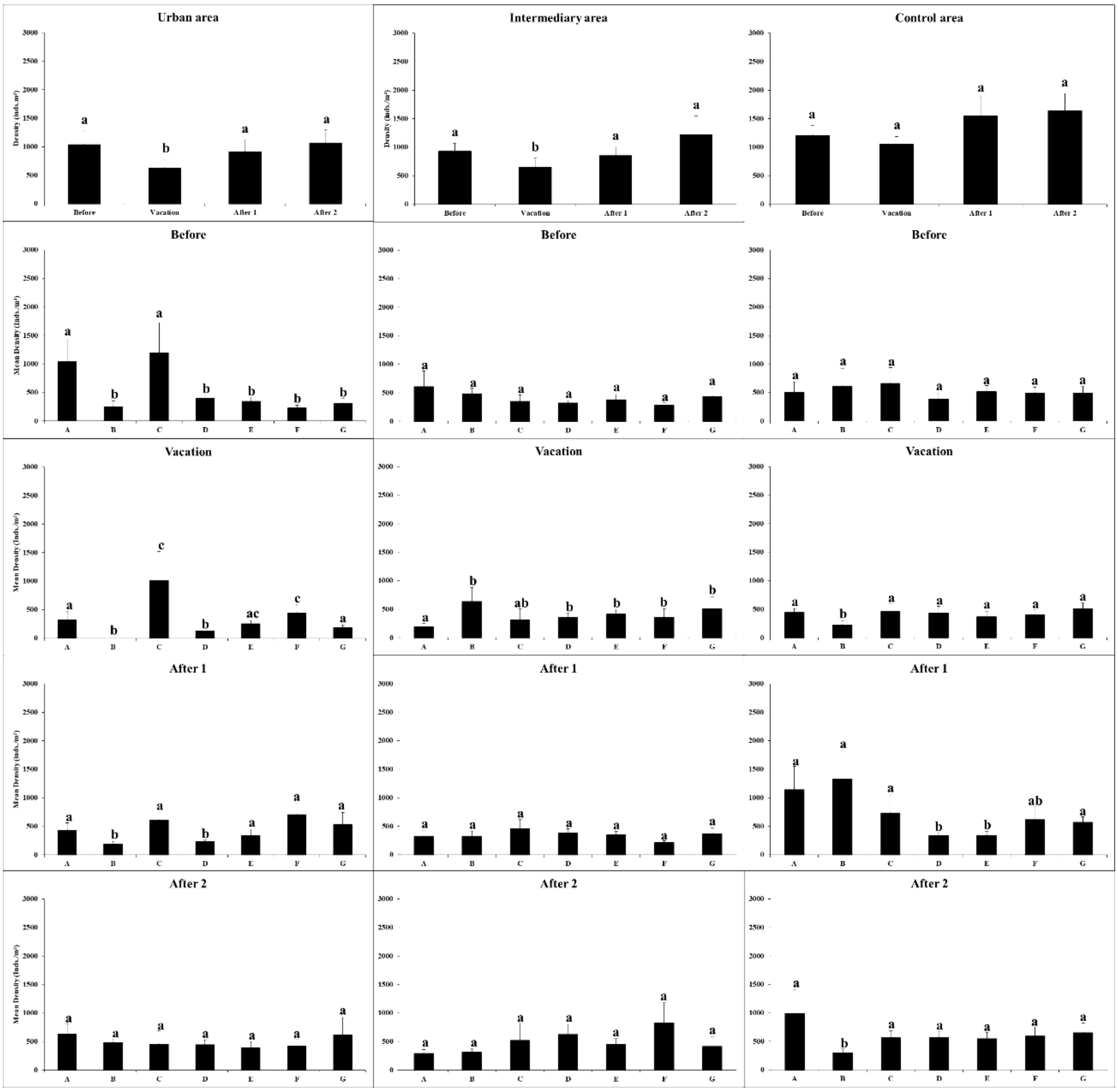

Fig. 6. Macrobenthos density (*mean* ± SE) along the intertidal zone of Amazonian sandy beaches in different sampling campaigns. Different letters indicate significant differences.

Richness also significantly changed among areas, periods and sampling sites (Table 3). Strongest differences were generally observed among Vacation and other periods (Fig.

7). Higher richness was generally found in the Control area in all periods, and lower richness was found during Vacation in the Urban area. Richness only significantly changed among periods in the Urban and Intermediary areas. Among sampling stations, lower richness was observed at the upper stations in the Urban area, whereas higher values were recorded at mid-stations in all periods. The number of taxa in the Control area decreased at all sampling stations during Vacation, although not significantly.

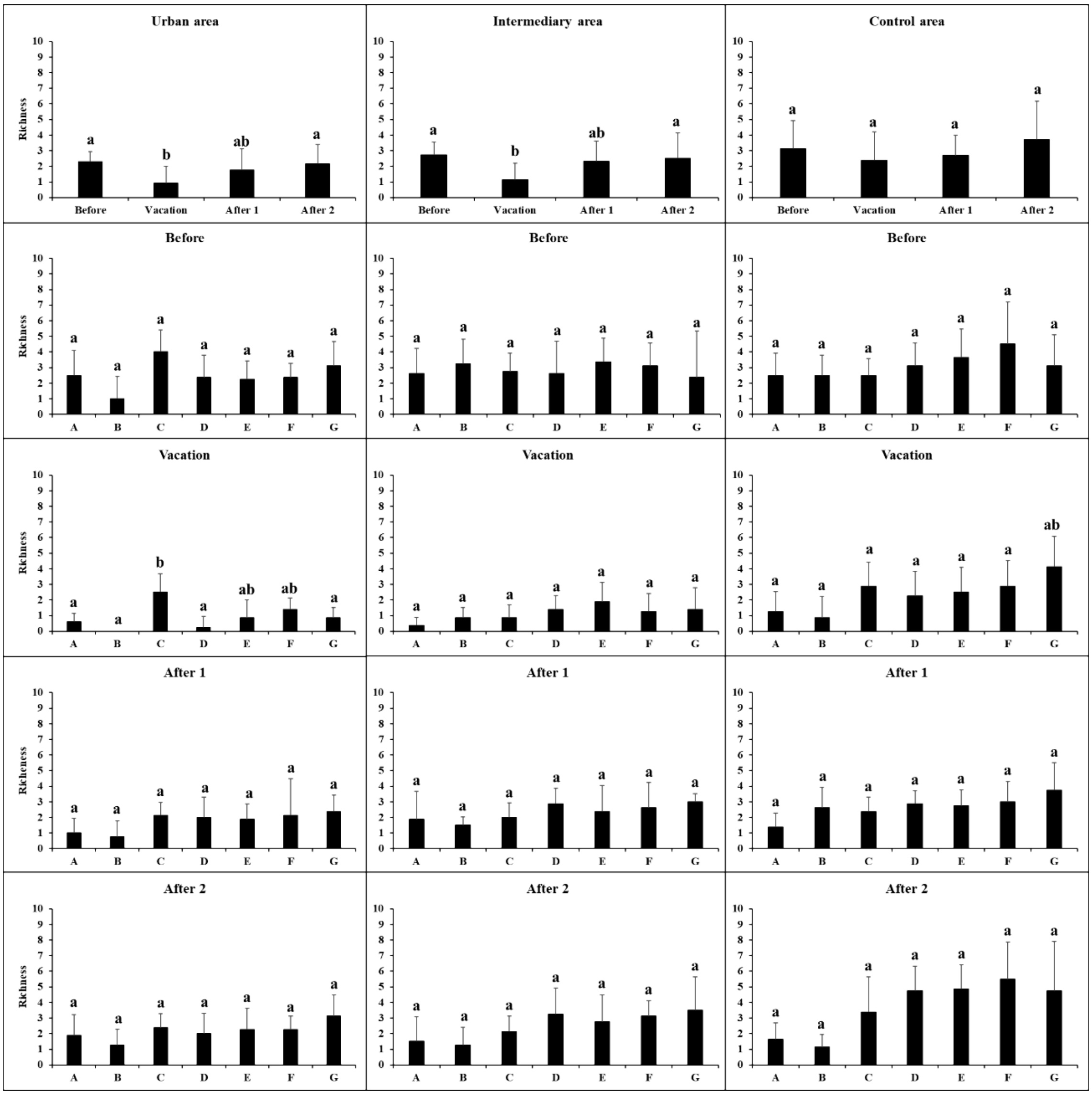

Fig. 7. Macrobenthos richness (mean ± SE) along the intertidal zone of Amazonian sandy beaches in different sampling campaigns. Different letters indicate significant differences.

Table 3. Results of the ANOVA analysis evaluating the significance of differences in descriptors of macrofaunal community of the study areas.

		Density (inds./m²)		**Richness (total taxa)**	
Factors	**Df**	**F**	***p***	**F**	***P***
Period (Pe)	3	23.04	0.00*	28.91	0.00*
Area (Ar)	2	33.08	0.00*	41.05	0.00*
Sampling stations (S)	6	8.94	0.00*	16.12	0.00*
Pe x Ar	6	1.02	0.04*	1.96	0.05*
Pe x S	18	2.58	0.00*	1.77	0.02*
Ar x S	12	3.00	0.00*	3.99	0.00*
Pe x Ar x S	36	2.12	0.00*	1.34	0.09
Error	588				

*p<0.05; df = degrees of freedom

PERMANOVA showed significant differences among periods, beaches, and sampling stations and these differences occurred mainly in the Urban and Intermediary areas during Vacation (Table 4). The SIMPER test showed a high level of dissimilarity in the communities among all study periods in all areas. A complete list of species that contributed to the differences between periods in each area is shown in Supplementary Material 4. Comparing areas, most species indicated by SIMPER were more abundant in the periods Before and After vacation in all areas, particularly polychaetes (*Thoracophellia papillata*, *Nephtys simoni* and *Paraonis* sp.), the mollusk – *Donax striatus,* and the insect – Ceratopogonidae larvae. The multiple regression analysis showed that macrobenthic density and richness had a significant negative correlation with sediment compaction and human beach use (beachgoers and vehicles) (Table 5).

Table 4. Results of the PERMANOVA tests for benthic macrofaunal structure between study areas and periods.

Source	**Df**	**MS**	**Pseudo-*F***	***p*(*perm*)**
Period (Pe)	3	11589	80.68	0.001*
Area (Ar)	2	13328	92.78	0.001*
Sampling stations (S)	6	34969	24.34	0.001*
Pe x Ar	6	2511.5	17.48	0.002*
Pe x S	18	3765.2	26.21	0.001*
Ar x S	12	5524.3	3.84	0.001*
Pe x Ar x	36	2767.5	19.26	0.001*
Res	588	1436.4		
Total	671			

**p*<0.05; df = degrees of freedom; MS = mean squares

Table 5. Multiple regression results showing correlations and levels of significance of each significant predictor environmental variable used for modelling sandy beach community attributes**.**

	Model results			
	R	**R^2**	**$F_{(3.80)}$**	***P***
Density (inds./m^2)	0.58	0.32	14.04	0.00*
Richness (total taxa)	0.60	0.34	15.57	0.00*

	Dependent variables					
	Density (inds./m^2)			**Richness (total taxa)**		
Independent variables	**B**	**t**	***p***	**B**	**T**	***P***
Compaction	-0.23	0.22	0.02*	0.40	2.79	0.00
Vehicles	-0.23	-1.70	0.04*	-0.50	-3.76	0.00*
Beachgoers	-0.42	-2.72	0.00*	-0.42	-2.78	0.00*
Organic matter	0.15	1.51	0.13	0.31	3.40	0.00*
Mean grain size	-0.08	-0.83	0.40	-0.08	-0.87	0.38
Sorting	-0.11	-1.10	0.27	-0.12	-1.34	0.18

*$p<0.05$; β – standardized coefficients

4.Discussion

Macrofaunal density and community composition in the present study showed different patterns in different periods. The Urban and Intermediary areas followed the same temporal pattern. This pattern was characterized by a sharp reduction in density and a significant change in community structure Before and during Vacation, followed by density increase and community composition restoration in the After-vacation periods. Alternatively, the Control area showed higher stability throughout the periods with no significant changes in community structure.

The results obtained here showed that with exception for the sediment compaction, the key habitat characteristics (*e.g.* sediment size, sorting, and organic matter) did not markedly differ among areas and remained constant over the periods. Moreover, all beaches have similar morphodynamic properties (Ranieri and El-Robrini, 2016). Thus, it is unlikely that habitat attributes drove faunal differences among areas and periods. Additionally, environmental variables were not significantly correlated with differences in community structure among areas, but the number of beachgoers and vehicles were.

It is well known that seasonal changes in environmental characteristics affect macrofaunal communities (Harris et al., 2011; McLachlan and Defeo, 2018). However, in the present study, few temporal variations in environmental or biological changes were observed. Consequently, we consider that recreational activities were the major source of variability of macrofaunal community. This observation is supported by the negative correlation between the number of beach users and community descriptors. The seasonal patterns of changes on the benthic communities in Amazonian sandy beaches are well documented (Rosa-Filho et al., 2009; Santos and Aviz, 2018; Baia and Venekey, 2019; Venekey et al., 2019), and most studies reports significant seasonal variations, especially when the peak of rainy season (March) is compared with the peak of dry (September) season

Within the study area, ecological changes were consistent with sampling stations particularly in the Urban and Intermediary areas: higher differences were recorded particularly at the upper sampling stations (upper 100 m) compared to other stations on both beaches. In fact, the upper stations were found the lower values of density and richness, especially in the Urban and Intermediary areas, and in the present study, these stations are those where most of the vehicle traffic and beachgoer activities occur (Santos, T. personal observation). In fact, this is a common pattern on Amazonian beaches, since most recreational activities are concentrated in the upper 100 m, between the lower limit of the backshore and the intertidal zone, during ebb and low tides (Silva et al., 2016). On the beaches studied here, as well as on other Amazonian beaches, the intertidal zone during ebb and low tides is formed by channels and sandbanks, which hamper bathing due to the long distances from the backshore to the water edge (Silva et al., 2016). Consequently, fewer vehicles and beachgoers go to the lower part of the beach, and thus, macrobenthic assemblages in this zone had higher species density and richness than the upper zone.

Based on our results, we can attribute faunal differences to the distribution of physical impacts caused by recreational activities along with sampling stations, as no great differences were found in the Control area along the intertidal region even during Vacation period. Overall, the severity of these direct impacts in the study areas appears to be dependent principally on the compactness of the sand. It is known that recreational activity has a negative effect on beach communities once may enhance the sediment compaction (Ugolini et al., 2008). The degree of sediment compaction can be influenced by the intensity of the recreational activities (Schlacher et al., 2007), and it correlates well with several sedimentary physical properties (Hsu et al., 2009). Thus, sites with high compaction, reflecting firmer substrates, may be unfavorable to a wide range of organisms. Moreover, several invertebrates can be killed through direct crushing by a high presence of vehicle traffic and trampling (Wolcott and Wolcott 1984; van der Merwe and van der Merwe 1991; Schlacher et al., 2007).

In general, the macrobenthic community composition was similar among study areas and periods. However, only the Control area had all taxa occurring throughout the study period. Beaches with less recreational activities in general are more complex, organized, mature, and active environments than urbanized beaches (Reyes-Martínez et al., 2014). It is well known that crustaceans, in particular Talitridae amphipods (*e.g.* Ugolini et al., 2008; Veloso et al., 2008, 2009), Cirolanidae isopods (*e.g.* Veloso et al., 2010), and Ocypodidae crabs (*e.g.* Neves and Bemvenuti, 2006; Lucrezi et al., 2009) are good bioindicators of recreational activities on sandy beaches. However, the macrobenthic fauna of the present study was dominated particularly by polychaete worms and comprised by typical marine and estuarine taxa. This composition is a pattern usually recorded in other intertidal habitats of the Amazonian coast (*e.g.* Rosa-Filho et al., 2006, 2009, 2011; Beasley et al. 2010; Braga et al., 2011, 2013; Morais and Lee 2014; Santos and Aviz, 2018, 2020). Thus, the impact of recreational activities in this study was verified by changes in density and composition of these soft body organisms.

Some taxa, particularly the polychaetes *Scolelepis squamata* and *Paraonis* sp., seemed to be rather sensitive to recreational impacts, as indicated by the relatively higher abundance of these organisms in the Control area. Furthermore, they also had changes in density throughout the study periods, which may be due to changes in impact intensity. *S. squamata* and *Paraonis* sp. are more vulnerable to trampling probably because they have no hard structures such as shells and carapaces (MacCord and Amaral, 2005). The decline in these taxa was more pronounced in the Urban and Intermediary areas, where density reached minimum values, and these taxa were even absent in some cases. Similar results were found in the highly urbanized sectors of sandy beaches of Rio de Janeiro (Brazil) by Machado et al. (2017), who observed that the impact occurred especially on soft body organisms, such as Nemertea and the polychaete *Hemipodia californiensis* (Hartman, 1938), a species that is usually abundant in that region.

In fact, during the present study, sharp reductions in polychaete density were observed in sites with high compaction (>20 kg.f/cm^2), mainly in the Urban and Intermediary areas during vacation period. It is well known that recreational activity has a negative effect on beach communities probably due to sediment compaction, which might hamper burrowing and thus reduce the probability of survival of organisms (Ugolini et al., 2008). Therefore, sites with high compaction, reflecting firmer substrates, may be unfavorable to a wide range of small-sized burrowers and sessile and semi-sessile infaunal polychaetes, because compaction increases the energy cost of burrowing activities (Brown and Trueman, 1991; Hsu et al., 2009). Thus, the presence of high abundance of polychaetes may be an indicative of less-compacted sediments.

Disturbances, depending of their duration and/or intensity, are commonly classified as either pulse or press disturbances (Glasby and Underwood, 1996; Lake, 2000). Overall, the recreational activities observed on Amazonian beaches can be classified as pulse disturbances as they are strongly concentrated in short periods (*i.e.* school vacation period and long bank holidays), which occur mostly during the second half of the year (Pessoa et al., 2013; Sousa et al., 2011, 2014). In addition, pulse disturbances can produce either a pulse or a press response in the community (Glasby and Underwood, 1996; Bravo et al. 2015). In this regard, recreational activities on Amazonian sandy beaches would be causing a pulse disturbance affecting principally the upper intertidal benthic community of the Urban and Intermediary areas during the vacation period, but organisms recover to their initial condition (Before period) soon after vacation (*i.e.* After 2 period).

Recovery depends not only on the cessation of disturbance at the end of vacation but also on having enough time for recruitment and growth of the species that have been affected (Schiel and Taylor, 1999). As previously mentioned, although recreational activities caused a significant decrease in species density and richness in the study areas, their natural characteristics might enable potentially rapid community recovery (Carr, 2000). Furthermore, the stability of the macrofaunal communities found in the Control area highlights the importance of these areas in the conservation and maintenance of local biodiversity. In spite of that, the consequence of intensive use the beaches by tourists could lead to a long-term loss of biodiversity, which might become irreversible (Reyes-Martinez et al., 2015).

5.Conclusion

Although there are obvious difficulties in comparing locations, habitats, systems, and methodological approaches, the macrobenthic densities reported in this study showed patterns similar to those found by previous studies assessing the effect of recreational activities on sandy beaches. Thus, the hypothesis that recreational activities trigger changes in benthic macrofaunal structure and composition, reducing species diversity, richness, and abundance in the community was confirmed.

Areas such as the studied beaches along the Amazonian coast are attractive recreational sites that are intensively visited during vacation time and holydays. This study shows that in these beaches recreational activities may have adverse effects in intertidal benthic assemblages. Long-term studies are required to determine the status of communities under the influence of tourism disturbances. Furthermore, the vulnerability of some taxa, particularly the polychaetes *S. squamata* and *Paraonis* sp., indicates that they might be potential indicators of recreational activity impacts, and can be used as fast and economically feasible tools to investigate environmental impacts.

This study also highlights the importance of establishing and implementing effective management actions to mitigate the consequences of recreational activities on sandy beaches. Management plans and conservation strategies should include (1) the development of protected areas with restricted access and use; (2) control of number of visitors and their decentralization (Machado et al., 2017); and (3) implementation of educational activities for visitors and installation of informative signs. The above-mentioned actions, together with the prohibition of vehicles in the intertidal zone, should be implemented in the short term on Amazonian sandy beaches.

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Conflict of interest

The authors declare that they have no conflict of interest.

Author contribution

All authors designed the study; TMT performed fieldwork; V and MP contributed with infrastructure/material/technical support; TMT analyzed the data; and all authors contributed with the manuscript.

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Supplementary material

Supplementary material 1. Environmental characteristics of the study areas. Different letters indicate significative differences ($p<0.05$).

Supplementary material 2. Multiple regression results showing the correlations and levels of significance for each significant predictor environmental variable used for modelling sandy beach community attributes.

Supplementary material 3. Mean density (ind.m^{-2}±SE) of the benthic macrofauna at the study area.

Supplementary material 4. PERMANOVA pairwise tests for the structure of the macrobenthic community collected at different areas and periods.

Supplementary material 5. The results of the SIMPER analysis, showing the mean abundances (ind.m^{-2}±SE) and similarity of the species that most contributed to the samples between study areas and periods.

Supplementary material 6. Multiple regression results showing correlations and levels of significance of each significant predictor environmental variable used for modelling sandy beach community attributes

Supplementary material 1. Environmental characteristics of the study areas. Different letters indicate significative differences ($p<0.05$).

		Urban area							Intermediary area							Control area						
		A	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Organic Matter %	**B**	0.009±0.010 **a**	0.024±0.011 **a**	0.039±0.015 **a**	0.030±0.005 **a**	0.053±0.043 **a**	0.132±0.07 **a**	0.118±0.05 **a**	0.037±0.011 **a**	0.042±0.007 **a**	0.050±0.003 **a**	0.052±0.003 **a**	0.085±0.001 **a**	0.259±0.241 **b**	0.260±0.218 **b**	0.033±0.005 **a**	0.039±0.001 **a**	0.052±0.009 **a**	0.053±0.005 **a**	0.062±0.016 **a**	0.081±0.019 **a**	0.189±0.125 **b**
	V	0.01±0.01 **a**	0.009±0.004 **a**	0.043±0.007 **a**	0.0313±0.003 **a**	0.016±0.001 **a**	0.040±0.016 **a**	0.051±0.029 **a**	0.003±0.001 **a**	0.016±0.007 **a**	0.033±0.002 **a**	0.036±0.004 **a**	0.040±0.008 **a**	0.052±0.006 **a**	0.279±0.052 **b**	0.025±0.016 **a**	0.029±0.004 **a**	0.040±0.001 **a**	0.044±0.001 **a**	0.049±0.007 **a**	0.053±0.003 **a**	0.073±0.016 **a**
	A1	0.041±0.005 **a**	0.029±0.003 **a**	0.040±0.010 **a**	0.054±0.001 **a**	0.066±0.009 **a**	0.076±0.007 **a**	0.071±0.012 **a**	0.045±0.001 **a**	0.046±0.004 **a**	0.052±0.006 **a**	0.053±0.016 **a**	0.068±0.002 **a**	0.062±0.001 **a**	0.136±0.064 **a**	0.026±0.003 **a**	0.046±0.007 **a**	0.046±0.003 **a**	0.069±0.01 **a**	0.062±0.012 **a**	0.076±0.021 **a**	0.119±0.035 **a**
	A2	0.024±0.006 **a**	0.031±0.005 **a**	0.046±0.001 **a**	0.036±0.003 **a**	0.035±0.005 **a**	0.049±0.017 **a**	0.067±0.032 **a**	0.019±0.001 **a**	0.042±0.018 **a**	0.040±0.011 **a**	0.055±0.010 **a**	0.067±0.002 **a**	0.072±0.011 **a**	0.060±0.008 **b**	0.042±0.004 **a**	0.049±0.014 **a**	0.043±0.018 **a**	0.062±0.004 **a**	0.056±0.007 **a**	0.084±0.004 **a**	0.092±0.008 **a**
Grain Size	**B**	2.25 **a**	2.42 **a**	2.54 **a**	1.26 **a**	1.45 **a**	2.95 **a**	1.48 **a**	2.63 **a**	2.72 **a**	2.9 **a**	2.79 **a**	2.87 **a**	2.77 **a**	3.88 **a**	2.75 **a**	1.35 **a**	2.54 **a**	2.97 **a**	2.95 **a**	1.47 **a**	1.3 **a**
	V	2.22 **a**	1.98 **a**	2.17 **a**	1.03 **a**	2.01 **a**	2.53 **a**	2.58 **a**	1.29 **a**	2.58 **a**	2.79 **a**	2.71 **a**	3.05 **a**	3.28 **a**	3.09 **a**	2.69 **a**	2.68 **a**	2.79 **a**	2.54 **a**	2.52 **a**	2.53 **a**	1.3 **a**
	A1	2.15 **a**	2.29 **a**	2.28 **a**	2.22 **a**	2.38 **a**	2.44 **a**	1.25 **a**	3.15 **a**	3.15 **a**	3.02 **a**	3.02 **a**	3 **a**	1.5 **a**	3.09 **a**	2.6 **a**	2.46 **a**	2.77 **a**	2.47 **a**	3.05 **a**	1.22 **a**	1.25 **a**
	A2	2.26 **a**	2.26 **a**	2.25 **a**	2.22 **a**	2.52 **a**	2.25 **a**	1.12 **a**	2.42 **a**	2.71 **a**	2.91 **a**	2.73 **a**	1.27 **a**	1.28 **a**	2.59 **a**	2.76 **a**	2.75 **a**	2.77 **a**	2.77 **a**	2.77 **a**	2.76 **a**	2.77 **a**
Medium Sand %	**B**	6.92 **a**	11.27 **a**	4.43 **a**	0.01 **b**	2.85 **a**	0.00 **b**	5.24 **a**	1.71 **a**	1.07 **a**	1.09 **a**	1.93 **a**	1.66 **a**	0.24 **a**	0.0 **a** 0	3.90 **a**	0.83 **a**	4.43 **a**	0.00 **a**	2.82 **a**	0.00 **a**	5.09 **a**
	V	13.15 **a**	11.64 **a**	7.53 **a**	32.58 **a**	46.98 **a**	12.89 **a**	7.88 **a**	7.72 **a**	7.92 **a**	8.27 **a**	15.09 **a**	3.14 **a**	0.00 **b**	0.00 **b**	11.16 **a**	4.41 **a**	0.00 **a**	6.10 **a**	0.00 **a**	12.86 **a**	5.09 **a**
	A1	9.39 **a**	3.20 **a**	2.30 **a**	9.92 **a**	2.03 **a**	10.44 **a**	3.16 **a**	4.71 **b**	0.78 **a**	0.00 **a**	0.07 **a**	0.00 **a**	0.00 **a**	0.00 **a**	1.13 **a**	1.55 **a**	0.00 **a**	0.00 **a**	0.00 **a**	1.33 **a**	2.46 **a**
	A2	1.70 **a**	0.52 **a**	0.39 **a**	1.24 **a**	6.46 **a**	1.17 **a**	2.87 **a**	3.04 **a**	1.77 **a**	1.47 **a**	1.25 **a**	2.45 **a**	1.88 **a**	2.76 **a**	2.13 **a**	0.36 **a**	0.25 **a**	1.23 **a**	2.37 **a**	1.15 **a**	2.85 **a**
Fine Sand %	**B**	93.08 **a**	88.73 **a**	95.10 **a**	99.99 **a**	62.82 **a**	59.70 **b**	84.18 **a**	89.61 **a**	87.81 **a**	83.84 **a**	72.46 **a**	71.77 **a**	62.86 **a**	40.72 **b**	89.11 **a**	93.45 **a**	95.10 **a**	61.32 **a**	62.15 **a**	59.04 **a**	81.83 **a**
	V	86.85 **a**	86.00 **a**	92.47 **a**	64.01 **a**	53.02 **a**	76.87 **a**	81.83 **a**	92.28 **a**	87.72 **a**	35.53 **b**	82.57 **a**	23.29 **b**	39.26 **b**	60.83 **a**	86.34 **a**	93.23 **a**	72.53 **a**	91.37 **a**	97.10 **a**	76.90 **a**	81.83 **a**
	A1	90.61 **a**	95.58 **a**	79.70 **a**	0.08 **b**	99.69 **a**	88.53 **a**	94.54 **a**	12.22 **a**	17.71 **a**	19.61 **a**	44.10 **a**	48.76 **a**	48.75 **a**	33.51 **a**	85.87 **a**	90.54 **a**	72.53 **a**	100.00 **a**	0.00 **b**	88.67 **a**	94.17 **a**
	A2	93.58 **a**	99.48 **a**	99.61 **a**	98.76 **a**	93.54 **a**	88.75 **a**	96.27 **a**	94.16 **a**	93.62 **a**	91.88 **a**	21.40 **b**	93.05 **a**	87.44 **a**	93.25 **a**	95.13 **a**	98.54 **a**	98.07 **a**	97.97 **a**	96.95 **a**	96.89 **a**	95.51 **a**
Very Fine Sand %	**B**	0.00 **a**	0.00 **a**	0.47 **a**	0.00 **a**	34.33 **b**	40.30 **b**	10.59 **a**	8.55 **a**	11.04 **a**	14.97 **a**	25.00 **a**	25.36 **a**	36.73 **a**	25.91 **a**	6.99 **a**	5.72 **a**	0.47 **a**	38.68 **a**	33.97 **a**	39.85 **a**	10.29 **a**
	V	0.00 **a**	0.00 **a**	0.00 **a**	0.52 **a**	0.00 **a**	10.24 **a**	10.29 **a**	0.00 **a**	4.36 **a**	56.20 **b**	2.34 **a**	73.57 **b**	59.77**b**	38.49 **a**b	2.50 **a**	2.37 **a**	27.47 **a**	2.53 **a**	2.90 **a**	10.25 **a**	10.29 **a**
	A1	0.00 **a**	0.00 **a**	0.00 **a**	0.00 **a**	0.28 **a**	1.03 **a**	2.31 **a**	83.07 **a**	81.51 **a**	80.39 **a**	55.84 **a**	51.24 **a**	51.25 **a**	66.4 **a** 9	0.00 **a**	7.91 **a**	27.47 **a**	0.00 **a**	8.81 **a**	1.00 **a**	3.37 **a**
	A2	4.72 **a**	0.00 **a**	0.00 **a**	0.00 **a**	0.00 **a**	10.09 **a**	0.86 **a**	2.72 **a**	4.42 **a**	6.48 **a**	7.25 **a**	4.33 **a**	10.49 **a**	3.94 **a**	0.29 **a**	0.67 **a**	1.24 **a**	0.44 **a**	0.23 **a**	1.11 **a**	0.70 **a**
Fines %	**B**	0	0	0	0	0	0	0	0.01 **a**	0.03 **a**	0.02 **a**	0.03 **a**	0.04 **a**	0.10 **a**	33.35 **b**	0 **a**	0 **a**	0 **a**	0 **a**	1.06 **b**	1.11 **b**	2.79 **b**
	V	0	0	0	0	0	0	0	0 **a**	0 **a**	0 **a**	0.67 **b**	0 **a**	0 **a**	0.28 **b**	0 **a**	0 **a**	0 **a**	0 **a**	0 **a**	0 **a**	2.79 **b**
	A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 **a**	0 **a**	0 **a**	0 **a**	1.19 **a**	0 **a**	0 **a**
	A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02 **a**	0.07 **a**	0.26 **a**	0.22 **a**	0.18 **a**	0.39 **a**	0.51 **a**

Granulometry classification	**B**	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	V.F.S	F.S	F.S	F.S	F.S/V.F.S	F.S	F.S	F.S
	V	F.S	M.S/F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	V.F.S	V.F.S	V.F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S
	A1	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S/V.F.S	F.S	F.S
	A2	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S
Sorting Classification	**B**	V.W.S	W.S / V.W. S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	W.S / V.W. S	W.S / V.W. S	W.S / V.W. S	M.S	V.W.S	V.W.S	W.S / V.W. S	M.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	W.S / V.W. S
	V	V.W.S	W.S/M.S	V.W.S	V.W.S	W.S/M.S	V.W.S	W.S	W.S	W.S	W.S / V.W. S	W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	V.W.S	V.W.S	W.S	V.W.S	W.S / V.W. S	W.S
	A1	W.S / V.W. S	W.S / V.W. S	V.W.S	V.W.S	W.S / V.W. S	W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	V.W.S	V.W.S	V.W.S	W.S	V.W.S
	A2	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	W.S / V.W. S	M.S	V.W.S	V.W.S	W.S / V.W. S	M.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S
Compactation (Kg.F/cm²)	**B**	13.5±0.70 **a**	15.5±0.70 **a**	14 **a**	16.5±2.12 **a**	17±1.41 **a**	15.5±0.70 **a**	15±1.41 **a**	11.5±2.12 **a**	10.5±0.70 **a**	10.5±0.70 **a**	13.5±2.12 **a**	12±1.41 **a**	13.5±0.70 **a**	12.5±2.12 **a**	4.5±0.70 **a**	5.5±0.70 **a**	5 **a**	6±1.41 **a**	9±1.41 **a**	10.5±0.70 **a**	11±1.41 **a**
	V	19±1.41 **a**	20 **a**	15.5±0.70 **a**	15.5±0.70 **a**	18.5±2.12 **a**	16.5±0.70 **a**	16 **a**	20 **a**	20 **a**	17±1.41 **a**	14.5±0.70 **a**	11.5±2.12 **b**	16±1.41 **a**	14±1.41 **a**	12.5±0.70 **a**	12.5±2.12 **a**	16±1.41 **a**	16±2.82 **a**	16±2.82 **a**	12 **a**	13±1.41 **a**
	A1	16±1.41 **a**	16.5±0.70 **a**	14 **a**	16.5±0.70 **a**	15 **a**	15.5±0.70 **a**	17 **a**	15.5±4.94 **a**	16±2.82 **a**	15±4.24 **a**	14±1.41 **a**	14.5±0.70 **a**	14±4.24 **a**	14.5±2.12 **a**	7.5±0.70 **a**	6±1.41 **a**	7 **a**	10.5±2.12 **a**	12±4.24 **a**	12±1.41 **a**	12.5±2.12 **a**
	A2	14.5±0.70 **a**	16±1.41 **a**	14 **a**	14±1.41 **a**	14±2.82 **a**	13±1.41 **a**	12±2.82 **a**	13.5±3.53 **a**	14.5±0.70 **a**	13±1.41 **a**	13.5±0.70 **a**	13 **a**	13±2.82 **a**	12±2.82 **a**	7.5±3.53 **a**	6.5±2.12 **a**	8±2.82 **a**	9±1.41 **a**	10 **a**	9±1.41 **a**	11.5±0.70 **a**

***B: Before, V: Vacation, A1: After 1, A2: After 2; FS: Fine sand, V.F.S: Very fine sand, W.S: Well sorted, V.W.S: Very well sorted.**

Supplementary material 2: Mean density (inds./m²± SD) of the benthic macrofauna at the study area.

Taxa		**Urban area**							**Intermediary area**							**Control area**						
		A	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Nemertea (N)	**B**					47.46±134.26				15.82±44.75		15.82±44.75	31.64.58.59	15.82±44.75							47.46±134.26	63.29±135.32
	Vac																				63.29±135.32	63.29±95.68
	A1							47.46±94.18													15.82±44.75	63.29±135.32
	A2						15.82±44.75	31.64±89.5						15.82±44.75	47.16±94.18						15.82±44.75	47.46±94.18
Acari (AC)	**B**	110.75±105.63																				
	Vac																					
	A1	31.64±89.50	15.82±44.75																			
	A2	47.46±94.18																				
Eunicidae (P)	**B**		15.82±44.75		15.82±44.75	15.82±44.75																
	Vac																					
	A1																					
	A2																					
***Capitella capitata* (P)**	**B**														47.46±94.18		15.82±44.75			15.82±44.75	63.29±95.68	
	Vac									15.82±44.75												47.46±94.18
	A1													15.82±44.75	15.82±44.75				47.46±134.26			
	A2																					
***Armandia* sp. (P)**	**B**		31.64±58.59	94.93±175.78							63.29±179.01	31.64±89.50	63.29±95.68					158.22±200.14	94.93±122.20	31.64±89.50		
	Vac																	94.93±147.46				
	A1		15.82±44.75	79.11±115.96					15.82±44.75	15.82±44.75	15.82±44.75	47.46±94.18					15.82±44.75	31.64±89.50				
	A2			15.82±44.75	15.82±44.75					31.64±89.50	15.82±44.75	63.29±179.01						94.93±147.46	47.46±65.51	47.46±94.18		
***Thoracophelia papillata* (P)**	**B**		15.82±44.75	395.56±385.35	31.64±58.59					158.22±175.78	142.40±196.53	63.29±117.19	15.82±44.75				15.82±44.75	322.27±233.77	142.40±142.53			
	Vac			395.56±347.89	15.82±44.75						110.75±142.53	79.11±94.18						158.22±131.02	189.97±213.96	15.82±44.75		

	A1			158.22±200.14	31.64±58.59	15.82±44.75		63.29±179.01		79.11±115.96	158.22±200.14	110.75±171.67						221.51±221.84	79.11±115.96	15.82±44.75		
	A2			316.45±165.73	110.75±142.53	31.64±89.50	63.29±179.01		15.82±44.75		363.72±320.49	300.63±233.77	110.75±125.44	31.64±58.59				205.69±190.62	126.58±179.01	15.82±44.75		
Scolelepis squamata(P)	**B**			126.58±135.32	63.29±67.66			15.82±44.75		47.46±134.26	47.46±134.26	15.82±44.75	31.64±89.50					47.46±94.18	63.29±135.32	158.22±147.46	94.93±188.36	
	Vac			237.34±196.53						47.46±94.18	15.82±44.75		79.11±115.96	31.64±89.50					110.75±210.85	79.11±150.34		
	A1	15.82±44.75	15.82±44.75	47.46±94.18	47.46±94.18	142.40±157.77	79.11±115.96	300.29±178.21		47.46±94.18	189.87±234.38		47.46±65.51	15.82±44.75	142.40±157.77			47.46±94.18	31.64±58.59	94.93±147.46	205.69±178.21	15.82±44.75
	A2			15.82±44.75	63.29±117.19	94.93±175.78	63.29±135.32	31.64±89.5			15.82±44.75	110.75±157.77	79.11±150.34	142.40±265.84	15.82±44.75			79.11±150.34	126.58±179.01	126.58±191.37	94.93±147.46	63.29±179.01
Dispio remanei (P)	**B**			31.64±58.59	47.46±94.18				15.82±44.75	31.64±89.50		63.29±95.68	15.82±44.75						15.82±44.75	94.93±147.46	79.11±150.36	
	Vac					31.64±89.50	15.82±44.75											63.29±179.01	47.46±134.26			
	A1						110.75±157.77	15.82±44.75			31.64±89.50	15.82±44.75	94.93±268.52	15.82±44.75				31.64±58.59	31.64±89.50	31.64±58.59		
	A2			31.64±89.50	47.46±134.26	126.58±151.29	15.82±44.75					15.82±44.75	94.93±174.46		15.82±44.75		31.64±58.59	47.46±94.18	63.29±95.68	15.82±44.75		
Paraonis sp. (P)	**B**			47.46±94.18	47.46±94.18	94.93±147.46		15.82±44.75			31.64±58.59	47.46±65.51	189.87±191.37	63.29±95.68						47.46±65.51	79.11±65.51	142.40±142.53
	Vac					47.46±94.18	79.11±115.96	15.82±44.75				63.29±179.01	47.46±134.26	31.64±89.50						47.46±94.18	94.93±89.50	110.75±184.52
	A1				31.64±58.59	79.11±178.21	189.87±234.38				63.29±179.01	63.29±117.19							31.64±89.50	63.29±135.32	142.40±142.53	110.75±184.52
	A2				31.64±89.50	15.82±44.75	31.64±89.50	490.50±367.1	15.82±44.75			189.87±358.02		552.15±456.08	332.27±164.86				31.64±89.50	110.75±125.44	174.05±150.34	273.34±184.52
Nephtys simoni (P)	**B**					79.11±94.18	47.46±94.18	94.93±112.20	15.82±44.75		15.82±44.75	47.46±65.51	63.29±135.32	79.11±94.18						158.22±175.78	221.51±211.27	15.82±44.75
	Vac					15.82±44.75	94.93±58.59	47.46±94.18				31.64±58.59	94.93±112.20	79.11±150.34	79.11±150.34				31.64±58.59		47.46±94.18	47.46±65.51
	A1				31.64±89.50	31.64±58.59	63.29±95.68	63.29±117.19				110.75±171.67	31.64±58.59	63.29±95.68	110.75±142.43				15.82±44.75	79.11±150.34		94.93±221.84
	A2					63.29±135.32	189.87±213.96	142.50±105.63			15.82±44.75	31.64±58.59	94.93±175.78	142.40±196.53	63.29±117.19			31.64±58.59	94.93±147.46	205.69±178.21	110.75±184.52	79.11±150.34
_Orbinia_sp. (P)	**B**																			79.11±134.26	79.11±94.18	31.64±89.50
	Vac												31.64±89.50	31.64±58.59	63.29±135.32							174.05±190.62
	A1											47.46±94.18	79.11±150.34	15.82±44.75	15.82±44.75				31.64±58.59	31.64±58.59	31.64±58.59	47.46±94.18
	A2													31.64±89.50	15.82±44.75						31.64±89.50	
Sigambra grubii (P)	**B**												31.64±89.50							31.64±89.50		
	Vac											15.82±44.75			79.11±115.96							
	A1													15.82±44.75	15.82±44.75							

	A2													31.64±89.50					15.82±44.75	47.46±134.26	47.46±94.18	
***Magelona*sp. (P)**	**B**							15.82±44.75														
	Vac																					
	A1																					
	A2																					
Hesionidae (P)	**B**																					
	Vac																		15.82±44.75			
	A1																					
	A2																					
***Laeonereis culveri* (P)**	**B**					15.82±44.75		15.82±44.75	31.64±5.59			63.29±179.01	94.93±188.36									
	Vac								126.58±135.32					63.29±117.19	31.64±89.50		47.46±65.51	205.69±302.11	63.29±179.01	15.82±44.75	15.82±44.75	
	A1													15.82±44.75	31.64±89.50		221.51±308.21	363.92±880.73	63.29±179.01	110.75±228.82	205.69±394.16	94.93±268.52
	A2			15.82±44.75								31.64±89.50	15.82±44.75	79.11±150.34			15.82±44.75	47.46±94.18	174.05±178.21	189.67±179.01	205.69±178.21	205.69±213.29
***Eteone* sp. (P)**	**B**					15.82±44.75	31.64±89.50						47.46±94.18	31.64±89.50								
	Vac														31.64±89.50				31.64±89.50	31.64±58.59		
	A1												31.64±89.50	47.46±134.26					15.82±44.75	31.64±58.59		31.64±58.56
	A2							15.82±44.75				31.64±89.50								79.11±150.34	63.29±179.01	31.64±84.50
***Glycera* sp. (P)**	**B**					63.29±117.19						15.82±44.75	31.64±89.50						31.64±58.59	31.64±89.50	15.82±44.75	
	Vac			15.82±44.75									47.46±94.18					15.82±44.75	15.82±44.75			
	A1				47.46±94.18						15.82±44.75		31.64±89.50					15.82±44.75	31.64±89.50	15.82±44.75		
	A2			63.29±95.68								47.46±94.18	15.82±44.75					31.64±89.50	110.75±142.53	63.29±135.32		
***Goniadides* sp. (P)**	**B**					15.82±44.75	31.64±89.50					31.64±89.50	47.46±134.26					47.46±134.26	15.82±44.75	31.64±89.50		15.82±44.75
	Vac			31.64±89.50									47.46±94.18					31.64±89.50	15.82±44.75			
	A1					31.64±89.50						47.46±94.18	15.82±44.75						63.29±135.32	31.64±89.50		
	A2			31.64±89.50	63.29±135.32							31.64±89.50	15.82±44.75					63.29±179.01	31.64±58.59	31.64±89.50	15.82±44.75	

***Diopatra cuprea* (P)**	**B**													31.64±58.59						47.46±94.18	15.82±44.75	
	Vac																					
	A1																					
	A2																					
***Lumbrinereis* sp. (P)**	**B**														31.64±58.59							
	Vac												15.82±44.75									
	A1														15.82±44.75							
	A2																					
Oligochaeta (O)	**B**																	15.82±44.75	152.22±356.42			
	Vac																					
	A1																					
	A2																					
***Donax striatus* (B)**	**B**		79.11±134.26	47.46±65.51	31.64±58.59			31.64±58.59	332.27±302.11	63.29±67.66				31.64±89.50					15.82±44.75		63.29±95.68	126.58±135.32
	Vac			15.82±44.75	15.82±44.75	15.82±44.75			15.82±44.75	110.75±105.63		31.64±89.50		15.82±44.75			15.82±44.75		31.64±89.50	63.29±95.68	31.64±58.59	110.65±171.67
	A1			47.46±65.51	31.64±58.59	15.82±44.75	15.82±44.75					15.82±44.75	63.29±95.68	31.64±58.59	31.64±89.50					15.82±44.75	47.46±65.1	63.29±95.68
	A2			47.46±65.51	31.64±58.59	15.82±44.75	47.46±65.51				31.64±89.50	47.46±94.18	63.29±117.19	63.29±95.68					15.82±44.75	31.64±58.59	31.64±58.59	15.82±44.75
***Corbula* sp. (B)**	**B**																					
	Vac																					
	A1																					
	A2					15.82±44.75																
***Petricolaria* sp. (B)**	**B**							142.40±125.44						47.46±65.51	253.16±376.72						31.64±89.50	63.29±95.68
	Vac														189.97±213.96							79.11±134.26
	A1							47.46±94.18				47.46±94.18		47.46±94.18	142.40±142.53							31.64±89.50
	A2							15.82±44.75							63.29±95.68							31.64±58.59
***Hiatella* sp. (B)**	**B**														15.82±44.75							

	Vac																					
	A1											31.64±58.59		15.82±44.75	31.64±89.50							
	A2																					
***Olivella minuta* (G)**	**B**																					
	Vac																					
	A1					15.82±44.75	15.82±44.75	31.64±89.50														15.82±44.75
	A2																					15.82±44.75
***Melita quisqueperforata* (E)**	**B**						15.82±44.75	31.64±89.50						15.82±44.75								47.46±94.18
	Vac							15.82±44.75							15.82±44.75							15.82±44.75
	A1							47.46±134.26						15.82±44.75	15.82±44.75							31.64±59.58
	A2							15.82±44.75							15.82±44.75						15.82±44.75	94.93±112.20
Cumacea (CR)	**B**			15.82±44.75	47.46±94.18									15.82±44.75				47.46±94.18	15.82±44.75			
	Vac								15.82±44.75		15.82±44.75							15.82±44.75				31.64±59.58
	A1	47.46±94.18							31.64±89.50				15.82±44.75					15.82±44.75				
	A2		79.11±150.34								31.64±89.50								15.82±44.75	15.82±44.75	15.82±44.75	
***Phoxocephalidae* (CR)**	**B**				47.46±94.18	31.64±89.50		15.82±44.75	15.82±44.75						15.82±44.75				15.82±44.75	79.11±150.34	15.82±44.75	
	Vac							31.60±89.50		63.29±95.68	15.82±44.75		31.64±89.50	79.11±150.34	31.64±89.50			15.82±44.75	31.64±89.50	110.75±142.53		
	A1		31.64±89.50		15.82±44.75	15.82±44.75				79.11±178.21	15.82±44.75				15.82±44.75				31.64±58.59		63.29±135.32	110.75±125.44
	A2	15.82±44.75		15.82±44.75			31.64±89.50				31.64±89.50	79.11±134.26			15.82±44.75					79.11±115.96	332.27±252.59	284.81±259.85
***Mysida* sp. (CR)**	**B**						15.82±44.75	63.29±67.66		15.82±44.75			31.64±58.59		15.82±44.75			15.82±44.75			31.64±89.50	15.82±44.75
	Vac							15.82±44.75				31.64±58.59			15.82±44.75							47.46±94.18
	A1				31.64±89.50	31.64±89.50	142.40±282.54													47.46±134.26		
	A2					15.82±44.75	15.82±44.75							31.64±89.50	15.82±44.75					15.82±44.75	31.64±58.59	
***Ogyrides alphaerostris* (CR)**	**B**							15.82±44.75							31.64±89.50							47.46±65.51
	Vac							15.82±44.75													94.93±131.02	

	A1							31.64±89.50				15.82±44.75	15.82±44.75								15.82±44.75	
	A2							31.64±89.50						15.82±44.75	47.46±94.18							31.64±58.59
Kalliapseudes schubartii (CR)	**B**							15.82±44.75					15.82±44.75	79.11±223.76								
	Vac													15.82±44.75								
	A1																					
	A2							15.82±44.75					15.82±44.75								31.64±58.59	
***Excirolana armata* (CR)**	**B**	63.69±95.68							15.82±44.75	15.82±44.75						31.64±89.50	15.82±44.75					
	Vac																	15.82±44.75				
	A1		15.82±44.75						15.82±44.75								15.82±44.75	63.29±135.32				
	A2	63.69±95.68	63.29±135.32																			
***Excirolana brasiliensis* (CR)**	**B**			31.64±89.50					15.82±44.75	94.93±147.46	15.82±44.75						15.82±44.75	63.29±117.19	15.82±44.75			
	Vac										15.82±44.75	31.64±89.50						15.82±44.75	31.64±58.59	15.82±44.75	15.82±44.75	31.64±59.58
	A1	15.82±44.75	94.93±147.46	15.82±44.75					15.82±44.75	15.82±44.75	31.64±89.50							15.82±44.75	94.93±112.20	15.82±44.75		158.22±356.42
	A2	63.69±95.68	63.29±135.32	47.46±94.18						63.29±135.32	63.29±117.19	31.64±89.50						47.46±65.51	63.29±67.66	63.29±67.66		
***Sphaeromopsis mourei* (CR)**	**B**																					
	Vac																					
	A1																					
	A2																			15.82±44.75		15.82±44.75
***Clibanarius simmetricus* (CR)**	**B**													15.82±44.75	31.64±89.50							
	Vac																					
	A1														31.64±89.50							
	A2								15.82±44.75						15.82±44.75							
***Lepidophtalmus siriboia* (CR)**	**B**							31.64±58.59						15.82±44.75							47.46±65.51	
	Vac					47.46±94.18															15.82±44.75	31.64±59.58
	A1											15.82±44.75		15.82±44.75	31.64±89.50						15.82±44.75	

	A2													31.64±58.59	31.64±58.59						79.11±115.96	15.82±44.75
Pinnixa (CR)	**B**													47.46±134.26								
	Vac						31.64±89.50														47.46±94.18	
	A1				15.82±44.75			15.82±44.75					47.46±94.18						15.82±44.75		15.82±44.75	126.58±234.38
	A2						31.64±89.50	15.82±44.75						47.46±134.26	63.29±179.01						15.82±44.75	15.82±44.75
***Lepidopa richmondi* (CR)**	**B**											47.46±94.18	15.82±44.75	15.82±44.75					31.64±89.50		15.82±44.75	
	Vac																			47.46±65.51	15.82±44.75	31.64±89.50
	A1			31.64±89.50	15.82±44.75								47.46±134.26	31.64±89.50							15.82±44.75	
	A2							94.93±188.36					63.29±135.32		15.82±44.75						15.82±44.75	110.75±171.67
Harparticoida (CR)	**B**											63.29±179.01										
	Vac																					
	A1																					
	A2																					
Axiidea (Megalopa) (CR)	**B**										15.82±44.75											
	Vac																					
	A1																					
	A2																					
Brachiura (Megalopa) (CR)	**B**													15.82±44.75			15.82±44.75					110.75±313.27
	Vac																					
	A1																					
	A2																					
***Cyprideis* sp. (CR)**	**B**					47.46±65.51										15.82±44.75	63.29±95.68					
	Vac															63.29±135.32	63.29±177.19	15.82±44.75	47.46±134.26			
	A1				15.82±44.75				15.82±44.75	31.64±59.58	31.64±89.50			47.46±134.26		94.93±147.46	205.69±351.17			15.82±44.75		
	A2		63.29±135.32	31.64±89.50	79.11±115.96	47.46±65.51	31.64±58.59		47.46±94.18	47.46±94.18						316.45±532.76			79.11±178.21			15.82±44.75

Dolichopodidae (larvae) (IN)	**B**	110.75±184.52							126.58±224.40	47.46±94.18						142.40±105.63						
	Vac															63.29±95.68	15.82±44.75	47.46±134.26				
	A1	63.29±179.01							47.46±94.18							174.05±134.26	15.82±44.75	31.64±58.59				
	A2	63.69±95.68	47.46±134.26						79.11±150.34	47.46±94.18						142.40±207.85	63.29±135.32	15.82±44.75				
Ceratopogonidae (larvae) (IN)	**B**								63.29±95.68	47.46±94.18						47.46±65.51	300.63±223.76					
	Vac	273.34±265.84	15.82±44.75	31.64±58.59												31.64±58.59	15.82±44.75	47.46±94.18				
	A1		47.46±134.26						31.64±89.50	15.82±44.75	15.82±44.75					268.98±760.81	490.50±751.37					
	A2	174.05±278.46	31.64±89.50						31.64±58.59	15.82±44.75						94.93±147.46	31.64±58.59					
Dysticidae (Larvae) (IN)	**B**	47.47±94.18							79.11±94.18	79.11±94.18	47.46±94.18					158.22±131.02	79.11±115.96	15.82±44.75				
	Vac															63.29±95.68	31.64±89.50	15.82±44.75				
	A1	110.75±184.52							63.29±135.32							31.64±89.50	348.10±527.36					
	A2	110.75±184.52	79.11±223.76						47.46±65.51	31.64±59.58	15.82±44.75					47.46±94.18	47.46±94.18	110.75±171.67				

B: Before, V: Vacation, A1: After 1, A2: After 2;

Supplementary material 3. PERMANOVA pairwise tests for the structure of the macrobenthic community collected at different areas and periods.

	Before vacation							**During vacation**					
	Urban		**Intermediary**		**Control**			**Urban**		**Intermediary**		**Control**	
Groups	**t**	**P(*perm*)**	**t**	**P(perm)**	**t**	**P(*perm*)**	**Groups**	**t**	**P(*perm*)**	**t**	**P(*perm*)**	**t**	**P(*perm*)**
A x B	27.402	0.003	11.722	0.263	25.303	0.004	**A x B**	33.437	0.022	21.434	0.019	0.8548	0.543
A x C	4.128	0.001	21.465	0.003	31.804	0.001	**A x C**	52.662	0.001	19.764	0.014	21.697	0.002
A x D	27.284	0.001	21.748	0.001	29.133	0.001	**A x D**	25.791	0.029	18.677	0.014	16.413	0.023
A x E	26.482	0.001	2.412	0.001	31.187	0.001	**A x E**	21.721	0.005	21.142	0.002	20.373	0.003
A x F	28.727	0.006	20.813	0.002	30.832	0.003	**A x F**	34.355	0.002	11.494	0.293	22.637	0.001
A x G	31.389	0.001	23.873	0.001	31.534	0.001	**A x G**	20.687	0.004	2.167	0.023	25.542	0.002
B x C	33.803	0.001	12.757	0.154	29.447	0.001	**B x C**	6.671	0.001	24.387	0.006	22.366	0.001
B x D	14.963	0.1	18.206	0.002	26.565	0.001	**B x D**	1	1	21.212	0.009	15.501	0.022
B x E	19.897	0.003	2.064	0.001	29.833	0.001	**B x E**	15.067	0.076	21.629	0.001	17.879	0.012
B x F	14.299	0.121	20.121	0.002	29.693	0.001	**B x F**	34.333	0.001	16.536	0.032	21.725	0.003
B x G	25.413	0.001	21.147	0.001	30.316	0.001	**B x G**	10.738	0.459	26.176	0.002	24.176	0.001
C x D	1.819	0.011	11.273	0.299	0.71645	0.794	**C x D**	48.052	0.003	0.98321	0.409	0.94541	0.562
C x E	34.109	0.001	15.478	0.019	23.666	0.001	**C x E**	36.878	0.001	19.937	0.001	19.228	0.002
C x F	43.375	0.001	15.937	0.012	2.617	0.001	**C x F**	46.249	0.001	16.595	0.008	22.343	0.001
C x G	35.265	0.001	17.557	0.004	27.117	0.001	**C x G**	37.273	0.001	22.793	0.005	2.424	0.001
D x E	18.107	0.004	0.97703	0.483	17.336	0.012	**D x E**	12.116	0.258	16.358	0.028	13.931	0.077
D x F	20.487	0.002	11.626	0.225	20.078	0.003	**D x F**	28.777	0.001	13.683	0.104	19.035	0.003
D x G	21.576	0.001	17.128	0.005	22.857	0.002	**D x G**	10.216	0.471	18.309	0.017	20.763	0.001
E x F	15.225	0.047	11.778	0.194	11.046	0.34	**E x F**	16.985	0.063	11.172	0.276	13.819	0.107
E x G	19.577	0.001	19.166	0.001	21.803	0.001	**E x G**	0.8946	0.637	17.699	0.017	18.895	0.001
F x G	22.652	0.003	14.068	0.075	16.191	0.01	**F x G**	1.574	0.049	14.141	0.101	1.621	0.02
	After 1							**After 2**					
Groups	**t**	**P(*perm*)**	**t**	**P(*perm*)**	**t**	**P(*perm*)**	**Groups**	**t**	**P(*perm*)**	**t**	**P(*perm*)**	**t**	**P(*perm*)**
A x B	12.398	0.149	16.122	0.026	21.988	0.008	**A x B**	10.494	0.325	0.5858	0.839	13.581	0.169

A x C	20.545	0.001	20.263	0.001	23.356	0.002	**A x C**	25.377	0.001	2.234	0.001	20.971	0.004
A x D	14.778	0.022	20.465	0.001	22.646	0.001	**A x D**	19.895	0.001	22.655	0.002	25.463	0.001
A x E	17.589	0.012	17.792	0.005	22.105	0.001	**A x E**	19.382	0.001	19.999	0.006	2.901	0.001
A x F	17.617	0.039	14.512	0.039	32.813	0.001	**A x F**	20.357	0.001	25.787	0.001	32.854	0.001
A x G	24.824	0.001	22.507	0.001	26.651	0.001	**A x G**	31.588	0.001	26.609	0.001	29.358	0.001
B x C	18.009	0.02	0.71029	0.817	22.008	0.002	**B x C**	2.402	0.001	23.876	0.002	17.725	0.022
B x D	1.169	0.232	15.947	0.013	20.208	0.002	**B x D**	15.626	0.026	23.837	0.001	24.848	0.001
B x E	15.502	0.032	14.325	0.039	19.716	0.004	**B x E**	15.784	0.033	21.282	0.002	27.979	0.001
B x F	16.583	0.057	13.869	0.019	2.807	0.001	**B x F**	18.058	0.003	27.862	0.001	32.453	0.001
B x G	24.612	0.001	19.543	0.004	23.576	0.001	**B x G**	31.427	0.001	28.695	0.001	2.904	0.001
C x D	12.064	0.222	15.547	0.021	0.95413	0.505	**C x D**	13.584	0.119	11.275	0.303	11.135	0.315
C x E	16.446	0.02	1.443	0.054	13.251	0.091	**C x E**	22.455	0.002	14.344	0.047	1.799	0.004
C x F	18.335	0.025	15.637	0.009	22.251	0.001	**C x F**	23.384	0.006	27.599	0.001	26.227	0.001
C x G	21.736	0.004	18.592	0.006	20.312	0.001	**C x G**	39.609	0.001	33.436	0.002	25.376	0.001
D x E	0.81213	0.698	13.138	0.104	0.60229	0.888	**D x E**	10.829	0.377	10.563	0.385	11.087	0.318
D x F	0.84074	0.59	0.93855	0.578	16.528	0.008	**D x F**	14.591	0.081	18.101	0.008	22.119	0.001
D x G	17.338	0.028	1.407	0.049	1.092	0.355	**D x G**	30.068	0.001	24.775	0.001	22.884	0.001
E x F	0.53526	0.889	0.85242	0.661	11.232	0.287	**E x F**	11.831	0.247	19.373	0.003	1.266	0.154
E x G	11.146	0.283	14.579	0.04	11.917	0.242	**E x G**	26.049	0.001	25.965	0.001	16.138	0.011
F x G	1.711	0.033	0.87303	0.643	1.721	0.009	**F x G**	21.292	0.002	1.271	0.126	0.74597	0.756

Supplementary material 4. The results of the SIMPER analysis, showing the mean abundances (inds./m² ± SE) and similarity of the species that most contributed to the samples between study areas and periods

Urban area					**Intermediary area**					**Control area**				
Groups: Before x Vacation	**Average dissimilarity = 94.19**				**Groups: Before x Vacation**	**Average dissimilarity = 94.24**				**Groups: Before x Vacation**	**Average dissimilarity = 91.41**			
Before	**Before**	**Vacation**				**Before**	**Vacation**				**Before**	**Vacation**		
Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Donax striatus	0.37	0.09	11.91	11.91	*Donax striatus*	0.23	0.15	9.79	9.79	*Thoracophelia papillata*	0.26	0.23	8.2	8.2
Nephtys simoni	0.19	0.16	11.61	23.51	*Thoracophelia papillata*	0.23	0.16	9.5	19.29	*Paraonis* sp.	0.24	0.2	6.92	15.12
Thoracophelia papillata	0.22	0.18	9.44	32.96	*Nephtys simoni*	0.21	0.2	8.96	28.26	Dysticidae (Larvae)	0.2	0.14	6.51	21.63
Ceratopogonidae (larvae)	0.19	0.11	9	41.96	*Paraonis* sp.	0.26	0.07	7.37	35.63	Ceratopogonidae (larvae)	0.21	0.16	6.47	28.1
Paraonis sp.	0.16	0.14	8.33	50.29	*Petricolaria* sp.	0.15	0.11	6.11	41.74	*Donax striatus*	0.17	0.2	5.52	33.63
					Dysticidae (Larvae)	0.19	0	5.63	47.36	*Scolelepis squamata*	0.23	0.09	5.02	38.65
					Phoxocephalidae sp.	0.11	0.09	5.31	52.67	*Nephtys simoni*	0.26	0.09	4.88	43.53
										Armandia sp.	0.19	0.06	4.67	48.2
										Phoxocephalidae sp.	0.08	0.16	4.5	52.7
Groups: Before x After 1	**Average dissimilarity = 92.74**				**Groups: Before x After 1**	**Average dissimilarity = 92.59**				**Groups: Before x After 1**	**Average dissimilarity = 90.23**			
	Before	**After 1**				**Before**	**After 1**				**Before**	**After 1**		

Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Scolelepis squamata	0.19	0.43	12.85	12.85	*Nephtys simoni*	0.21	0.25	8.18	8.18	*Scolelepis squamata*	0.23	0.28	7.34	7.34
Donax striatus	0.37	0.13	10.42	23.28	*Thoracophelia papillata*	0.23	0.21	8.12	16.3	*Thoracophelia papillata*	0.26	0.19	7.11	14.45
Thoracophelia papillata	0.22	0.18	8.07	31.34	*Scolelepis squamata*	0.09	0.29	6.66	22.96	*Paraonis* sp.	0.24	0.23	6.46	20.9
Nephtys simoni	0.19	0.16	7.4	38.74	*Donax striatus*	0.23	0.13	5.91	28.86	Ceratopogonidae (larvae)	0.21	0.18	6.4	27.3
Paraonis sp.	0.16	0.17	6.98	45.72	*Paraonis* sp.	0.26	0.07	5.72	34.58	Dolichopodidae (larvae)	0.12	0.18	5.79	33.09
Ceratopogonidae (larvae)	0.19	0.02	4.51	50.23	*Petricolaria* sp.	0.15	0.18	5.7	40.28	*Laeonereis cuvieri*	0.05	0.31	5.68	38.77
					Dysticidae (Larvae)	0.19	0.04	4.66	44.94	*Excirolana armata*	0.1	0.21	5.36	44.13
					Armandia sp.	0.1	0.09	4.19	49.13	Dysticidae (Larvae)	0.2	0.13	5.18	49.31
					Orbiniia sp.	0.1	0.12	4.08	53.2	*Nephtys simoni*	0.26	0.11	4.86	54.17
Groups: Before x After 2	**Average dissimilarity = 91.75**				**Groups: Before x After 2**	**Average dissimilarity = 90.04**				**Groups: Before x After 2**	**Average dissimilarity = 89.97**			
	Before	**After 2**				**Before**	**After 2**				**Before**	**After 2**		
Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Thoracophelia papillata	0.22	0.29	10.25	10.25	*Thoracophelia papillata*	0.23	0.45	11.67	11.67	*Laeonereis cuvieri*	0.05	0.51	6.93	6.93
Donax striatus	0.37	0.13	9.09	19.35	*Paraonis* sp.	0.26	0.43	10.54	22.22	*Paraonis* sp.	0.24	0.36	6.56	13.48
Nephtys simoni	0.19	0.27	8.76	28.11	*Nephtys simoni*	0.21	0.23	7.35	29.57	*Nephtys simoni*	0.26	0.33	6.27	19.76
Cyprideis sp.	0.05	0.21	7.58	35.69	*Donax striatus*	0.23	0.16	6.57	36.14	*Thoracophelia papillata*	0.26	0.21	6.27	26.03

Paraonis sp.	0.16	0.25	7.07	42.76	Dysticidae (Larvae)	0.19	0.11	6.28	42.42	Phoxocephalidae sp.	0.08	0.36	5.54	31.56
Scolelepis squamata	0.19	0.18	6.31	49.07	*Thoracophelia papillata*	0.09	0.2	4.69	47.11	*Scolelepis squamata*	0.23	0.27	5.53	37.09
Ceratopogonidae (larvae)	0.19	0.09	5.72	54.78	*Petricolaria* sp.	0.15	0.06	3.69	50.8	Dysticidae (Larvae)	0.2	0.16	5.39	42.48
										Ceratopogonidae (larvae)	0.21	0.1	5.1	47.59
										Dolichopodidae (larvae)	0.12	0.13	4.69	52.27
Groups: Vacation x After 1	**Average dissimilarity = 94.25**				**Groups: Vacation x After 1**	**Average dissimilarity = 93.32**				**Groups: Vacation x After 1**	**Average dissimilarity = 91.80**			
	Vacation	**After 1**				**Vacation**	**After 1**				**Vacation**	**After 1**		
Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Scolelepis squamata	0.15	0.43	18.4	18.4	*Nephtys simoni*	0.2	0.25	10.82	10.82	*Thoracophelia papillata*	0.23	0.19	7.44	7.44
Paraonis sp.	0.14	0.17	10.71	29.11	*Thoracophelia papillata*	0.16	0.21	10.32	21.14	*Laeonereis cuvieri*	0.14	0.31	7.17	14.61
Nephtys simoni	0.16	0.16	9.81	38.92	*Scolelepis squamata*	0.14	0.29	10.31	31.45	*Scolelepis squamata*	0.09	0.28	7.03	21.64
Thoracophelia papillata	0.18	0.18	9.73	48.65	*Donax striatus*	0.15	0.13	7.04	38.49	*Paraonis* sp.	0.2	0.23	6.8	28.45
Donax striatus	0.09	0.13	6.32	54.97	*Petricolaria* sp.	0.11	0.18	6.79	45.28	Dolichopodidae (larvae)	0.1	0.18	6.24	34.69
					Laeonereis cuvieri	0.1	0.14	6.25	51.53	*Excirolana armata*	0.13	0.21	6.11	40.8
										Ceratopogonidae (larvae)	0.16	0.18	6.03	46.83
										Donax striatus	0.2	0.13	5.3	52.13

Groups: Vacation x After 2	**Average dissimilarity = 93.96**				**Groups: Vacation x After 2**	**Average dissimilarity = 93.11**				**Groups: Vacation x After 2**	**Average dissimilarity = 91.05**			
	Vacation	**After 2**				**Vacation**	**After 2**				**Vacation**	**After 2**		
Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Thoracophelia papillata	0.18	0.29	13.07	13.07	*Thoracophelia papillata*	0.16	0.45	15.35	15.35	*Laeonereis cuvieri*	0.14	0.51	8.23	8.23
Nephtys simoni	0.16	0.27	11.16	24.23	*Paraonis* sp.	0.07	0.43	11.37	26.72	Phoxocephalidae sp.	0.16	0.36	7.29	15.52
Cyprideis sp.	0	0.21	9.73	33.97	*Nephtys simoni*	0.2	0.23	8.99	35.71	*Paraonis* sp.	0.2	0.36	6.83	22.35
Paraonis sp.	0.14	0.25	9.5	43.47	*Donax striatus*	0.15	0.16	7.93	43.64	*Thoracophelia papillata*	0.23	0.21	6.43	28.79
Scolelepis squamata	0.15	0.18	7.97	51.44	*Scolelepis squamata*	0.14	0.2	7.77	51.41	*Nephtys simoni*	0.09	0.33	5.79	34.58
										Cyprideis sp.	0.13	0.16	5.24	39.82
										Dysticidae (Larvae)	0.14	0.16	5.22	45.04
										Dolichopodidae (larvae)	0.1	0.13	4.75	49.8
										Ceratopogonidae (larvae)	0.16	0.1	4.61	54.41
Groups: After 1 x After 2	**Average dissimilarity = 91.89**				**Groups: After 1 x After 2**	**Average dissimilarity = 91.24**				**Groups: After 1 x After 2**	**Average dissimilarity = 88.62**			
	After 1	**After 2**				**After 1**	**After 2**				**After 1**	**After 2**		
Species	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**	**Species**	**Av.Abund**	**Av.Abund**	**Contrib %**	**Cum. %**
Scolelepis squamata	0.43	0.18	12.57	12.57	*Thoracophelia papillata*	0.21	0.45	11.93	11.93	*Laeonereis cuvieri*	0.31	0.51	9.33	9.33
Thoracophelia papillata	0.18	0.29	10.87	23.45	*Paraonis* sp.	0.07	0.43	8.73	20.67	*Scolelepis squamata*	0.28	0.27	6.99	16.31

Paraonis sp.	0.17	0.25	8.28	31.72	*Nephtys simoni*	0.25	0.23	8.42	29.09	*Paraonis sp.*	0.23	0.36	6.71	23.02
Nephtys simoni	0.16	0.27	8.04	39.77	*Scolelepis squamata*	0.29	0.2	8.24	37.33	*Phoxocephalidae sp.*	0.12	0.36	6.19	29.21
Cyprideis sp.	0.02	0.21	7.57	47.34	*Donax striatus*	0.13	0.16	4.63	41.96	*Dolichopodidae (larvae)*	0.18	0.13	6.02	35.23
					Petricolaria sp.	0.18	0.06	4.37	46.33	*Excirolana armata*	0.21	0.2	5.86	41.09
					Laeonereis cuvieri	0.14	0.08	3.79	50.12	*Thoracophelia papillata*	0.19	0.21	5.68	46.77
										Nephtys simoni	0.11	0.33	5.63	52.4

Capítulo 2 - Recreational activities trigger changes in meiofauna and free-living nematodes on Amazonian macrotidal sandy beaches.

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Resumo

As praias arenosas são recursos econômicos importantes em todo o mundo, no entanto, as atividades recreativas são uma fonte importante de perturbação nesses ecossistemas. O uso intensivo das praias pelo homem tem um efeito negativo nas comunidades bentônicas, pois altera a abundância, diversidade e/ou distribuição das espécies. Aqui, relatamos os impactos de atividades recreativas (pisoteio e tráfego de veículos) em comunidades meiobentônicas e assembleias de Nematoda nas praias arenosas da Amazônia pela primeira vez. Para tanto, foram realizadas coletas em quatro meses consecutivos abrangendo um período de pico de visitação elevado (um mês antes das férias, durante as férias e dois meses após as férias) em três praias contrastantes quanto aos distúrbios (Urbana, Intermediária e Controle). No geral, as variáveis físicas do sedimento (tamanho do grão, classificação) foram constantes ao longo do tempo em todas as praias, enquanto diferenças na intensidade das atividades recreativas e compactação do sedimento foram encontradas entre as praias e os meses. A compactação do sedimento foi considerada o fator mais importante para as diferenças observadas na estrutura da comunidade da meiofauna nas áreas de estudo, estando relacionada à intensidade das atividades recreativas. Variações na densidade e mudanças na riqueza entre os períodos foram observadas nas praias Urbana e Intermediária, principalmente na parte alta da praia, onde as atividades recreativas estão concentradas. Por outro lado, a área Controle permaneceu sem alterações ao longo do estudo. No primeiro mês após as férias, a densidade e a riqueza foram semelhantes às do período anterior às férias, indicando que a área de estudo havia se recuperado em um mês. Além disso, vulnerabilidades de Tardigrada e Copepoda, bem como dos gêneros de Nematoda, *Daptonema* e *Chromadorita*, indicam que esses taxa podem ser indicadores potenciais de atividades recreativas.

Palavras-chave: Costa amazônica; fauna bentônica; impactos antrópicos; praia arenosas.

Abstract

Sandy beaches are key economic assets worldwide, however, recreational activities are an important source of disturbance in these ecosystems. Intensive human use of beaches has a negative effect on benthic communities as it alters species abundance, diversity, and/or distribution. Here, we report the impacts of recreational activities (trampling and vehicles) on meiobenthic communities and nematode assemblages on Amazonian sandy beaches for the first time. For this purpose, samples were carried out in four consecutive months encompassing a period of high visitation peak (one month Before Vacation, During Vacation, and two months After Vacation) on three contrasting beaches regarding disturbances (Urban, Intermediary and Control). Overall, physical sediment variables (grain size, sorting) were constant over time in all beaches, whereas differences in intensity of recreational activities and sediment compaction were found between beaches and months. Sediment compaction was considered the most important factor for the differences observed in meiofauna community structure in the study areas, and it was related to intensity of recreational activities. Variations in density and changes in richness between periods were observed in the Urban and Intermediary beaches mostly at the upper beach where recreactional activities are concentrated. On the other hand, the Control area remained the same throughout the study. In the first month after vacation, density and richness were similar to those in the period before vacation, thus indicating that the beaches had recovered in one month. Furthermore, vulnerabilities of Tardigrada and Copepoda, as well as of the Nematoda genera *Daptonema*, and *Chromadorita*, indicate that they might be potential indicators of recreational activities.

Key words: Amazon coast; Benthic fauna; Human-induced impacts; Sandy beach.

1. Introduction

Sandy beaches occur in nearly all coastal zones in temperate and tropical areas (McLachlan and Turner, 1994), and historically these environments play an important role as locations for recreation upon which tourism development has been based (Orams, 2003). Beach recreation includes a wide array of activities, such as camping (Hockings and Twyford, 1997), use of vehicles (Schlacher and Thompson, 2008), and other recreational pursuits (Fanini et al., 2014). Overall, these activities can dramatically alter the natural physical characteristics of beaches through compaction, rutting, and displacement of the sand matrix (Anders and Leatherman, 1987; Priskin, 2003), which influence benthic communities either directly (*e.g.* by removing individuals, crushing) or indirectly (*e.g.* affecting biological interactions, distribution patterns) (Brosnan and Crumrine, 1994; Brown and Taylor, 1999).

Meiofauna, and particularly free-living marine nematodes, comprise an important component of the benthic biota in both abundance and biomass. They are also closely related to other organisms, playing a key role in trophic food webs (see Giere, 2009 for a review). The meiobenthic fauna that inhabits sandy beaches is generally dominated by harpacticoid copepods and nematodes, with the dominance of one group over the other depending on sediment grain size (see Giere, 2009 for review). Although the presence of nematodes is independent of sediment composition (Vanaverbeke et al., 2000), they are generally more abundant in fine sands, while harpacticoid copepods are more important in coarse sediments (McLachlan and Brown, 2006).

Benthic organisms on sandy beaches are the most effective tools for assessing environmental variations in the habitat (Coull and Chandler, 1992; Giere, 2009). Meiofauna can particularly be used as a biological indicator of anthropogenic impacts due to their small size, high abundance, species richness, ubiquitous distribution, rapid generation time, and direct benthic development (Kennedy and Jacoby, 1999; Zeppilli et al., 2015). Meiofauna abundance is more sensitive to disturbances than that of macrofauna; therefore, it can be used as a sensitive indicator of several impacts (Coull and Chandler, 1992). However, most studies on the effects of recreational activities in sandy beaches refer to macrofauna (both at the community and population levels) (Schlacher et al., 2007; Schlacher and Thompson, 2012), and little is known about the effects of these activities on meiofauna community in these environments (Johnson et al., 2007). The results of the few studies available showed a general negative effect of recreational activities on abundance, diversity, and composition of the meiobenthic community (*e.g.* Moellmann and Corbisier, 2003; Gheskiere et al., 2005; Pereira et al., 2017).

Recreational activities are known to have a negative effect on beach communities as they may increase sediment compactness (Ugolini et al., 2008). The degree of sediment compaction can be affected by the intensity of recreational activities (Schlacher et al., 2007), and it correlates with several sediment physical properties (Hsu et al., 2009). Thus, sites with high compaction, reflecting harder substrates, might be unfavorable to a wide range of organisms and meiofauna is particularly susceptible, as these organisms inhabit the sediment interstitial space (Giere, 2009).

Macrotidal sandy beaches of the Brazilian Amazonian coast, with their natural environments distributed along a coastline of 3900 km, have considerable potential for tourism (Pereira et al., 2016a,b). In general, these beaches are overcrowded during vacation (July) and some bank holidays, especially in the second half of the year (Sousa-Felix et al., 2017). Information available on the biodiversity of Brazilian sandy beaches, particularly in northern Brazil (Amazonian coast), is insufficient to ensure their preservation (Amaral et al., 2016). Furthermore, although meiofauna is a powerful tool to assess human-induced impacts (Schratzberger et al., 2009; Netto and Valgas 2010; Veiga et al. 2010), studies that aim to evaluate the effect of recreational activities on meiofauna community in macrotidal tropical sandy beaches are nonexistent.

In this context, the present study assessed the impact of recreational activities on the structure and composition of meiofauna community and nematode assemblages in three Amazonian macrotidal sandy beaches with different levels of tourism (high, intermediary and low) before, during, and after an episode of high tourist occupancy (vacation in July). The following hypothesis were tested: high intensity of recreational activities (human trampling and vehicle traffic) (1) causes changes in the structure and composition of meiobenthic community and nematode assemblages by decreasing species richness and density, particularly in the urban beach during vacation and, (2) causes changes in the distribution pattern of the meiobenthic community and nematode assemblages.

2.Material and Methods

2.1.Study area

The study area is located in the Atlantic Coastal Sector of North Brazil, one of the most densely populated areas of the Amazonian region (Sousa et al., 2011) with about

40.000 residents, where economy is based on fishing and tourism, which may receive > 280,000 beachgoers during July (IBGE, 2018). Local climate is equatorial humid with annual mean temperature and rainfall of 26-27°C and 2500-3000 mm, respectively, and approximately 75-85% of rainfall during rainy season (January - May) (Martorano et al., 1993; INMET, 2009).

This study was conducted on three beaches located in Salinópolis (0°36’49”S and 47°21’22”W), 220 km far from the city of Belém (Fig. 1A) with a variable anthropogenic pressure gradient. The Atalaia beach has a high level of urban development (*e.g.* restaurants, housing, and hotels) and high human occupancy during the summer season. The backshore is occupied by constructions and tourism infrastructure (*e.g.,* parking spaces, streets), which have destroyed the vegetation cover and the dunes system. In contrast, Corvinas beach is a pristine sector with low level of disturbance with a well-preserved dune system and mangrove vegetation in the backshore area (Silva et al., 2010). This beach can only be reached on foot (Martinelli Filho and Monteiro, 2019).

The Farol-Velho beach is an intermediate sector located in the transitional area between the Atalaia and Corvinas. This beach is urbanized with low level of tourism occupancy and the backshore includes constructions and low tourism infrastructure. Vehicles are only allowed on Atalaia and Farol-Velho beaches; however, the highest influx occurs on Atalaia beach. The main hydrodynamic features of the studied beaches are: macrotides (4 - 6 m), strong coastal currents (up to 1.5 m/s), and wave energy modulated by wave attenuation on sand banks during low tide (Monteiro et al., 2009; Pereira et al., 2009). The beaches have similar sedimentological and morphodynamic characteristics: dissipative exposed state, gentle slope, spilling waves, and sediment comprised mainly of fine to very-fine sand (Ranieri and El-Robrini, 2015).

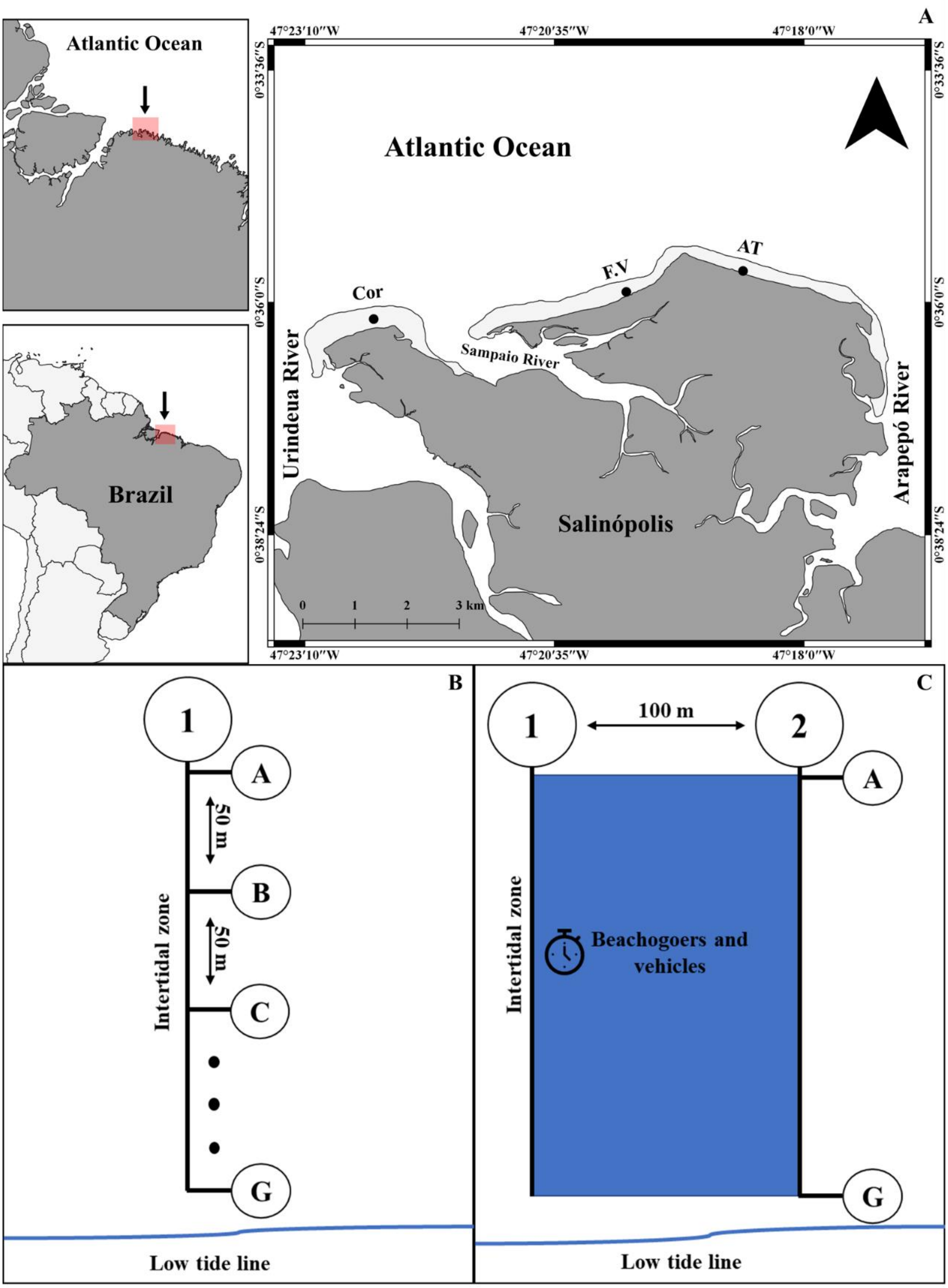

Figure 1. Map showing the location of Salinópolis and the three sandy beaches studied (Ata: Atalaia ; F.V: Farol-Velho; Cor: Corvinas) and schematic representation of sampling on the three sandy beaches: B – Macrobenthos; C – Recreational activities

2.2.Sampling and laboratory procedures

The largest tourist influx on Amazonian beaches occurs during vacation (July), and in general are concentrated in the upper 100 m, between the lower limit of the backshore and the intertidal zone, during ebb and low tides (Silva et al., 2016). Thus, in order to evaluate its effects on meiobenthos, four sampling campaigns were conducted on each beach (Atalaia, Farol-Velho, and Corvinas) during spring tides: one before vacation (June 2017; called 'Before Vacation'), one during vacation (July 2017, considered as high visitation season and called 'Vacation'), and two after vacation (August and September, 2017; called as 'After 1 and 2', respectively) (Fig. 2). Meiofauna sampling was carried out in the intertidal zone of each beach along one across-shore transect. Seven equidistant (A - G) sampling stations (SS), were established 50 m apart from each other, from the high tide mark to the swash zone (Fig. 1B). Three samples were collected at each sampling station with a 3-cm diameter corer down to a depth of 10 cm. After collection, samples were preserved in 4 % formaldehyde. Simultaneously to biological sampling, one sediment sample was collected from each sampling station for granulometric analyses and analysis of organic matter content using the same corer used for biological samples. Sediment compaction was determined at each station using a manual penetrometer.

Intensity of recreational activities was estimated based on disturbance levels of beach surface. Surface disturbance was estimated using the number of vehicles and beachgoers observed on each beach. For this purpose, four census campaigns were conducted (1 campaign per month on each beach) along with biological sampling procedures. In each campaign, vehicles and beachgoers were counted in an area between two across-shore transects (100 m distant from each other) along the intertidal zone for 10 minutes every 30 min within a 4-h period (a total of 8 counts/beach/sampling campaign; Fig. 1C).

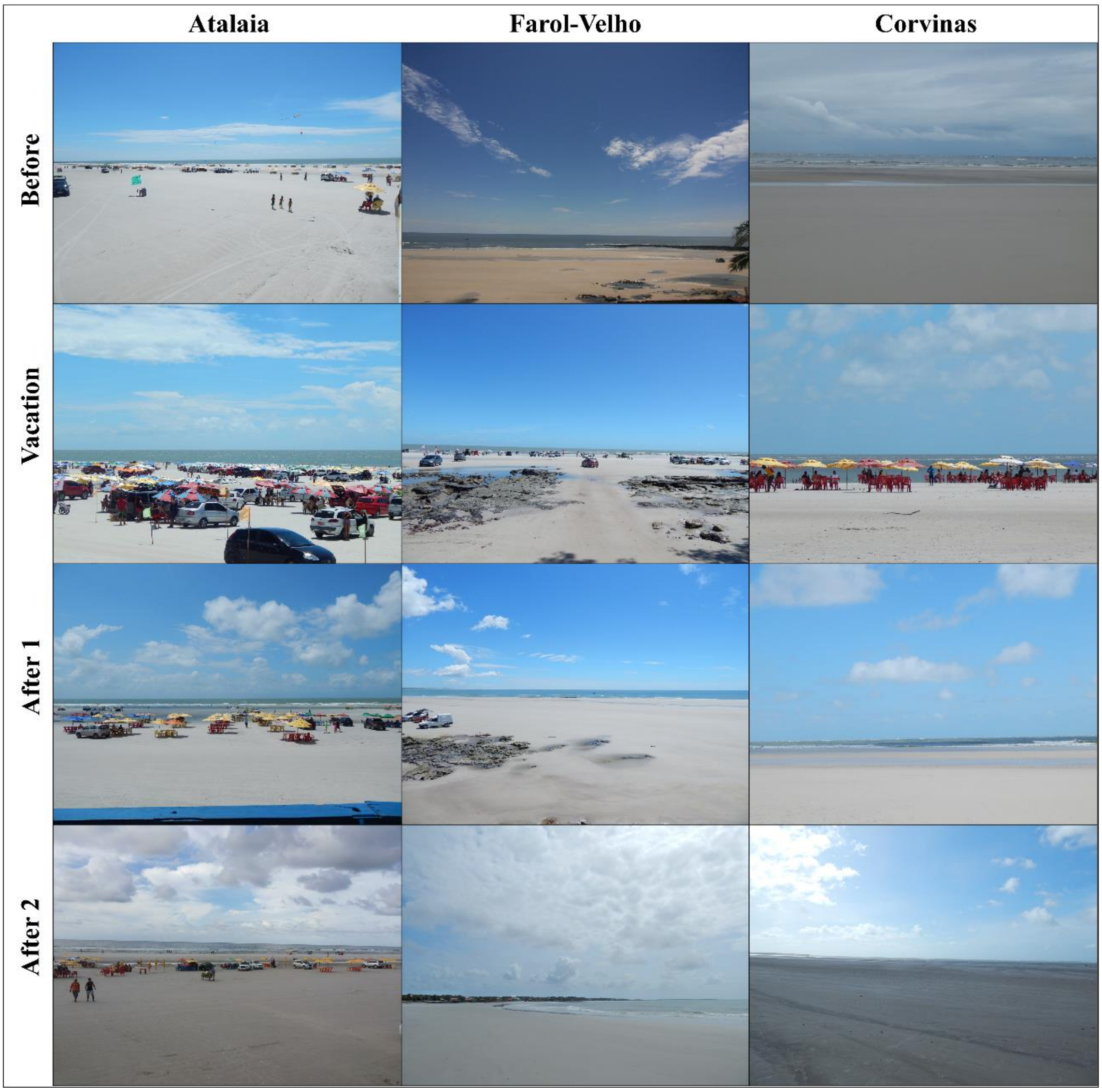

Figure 2. Visitors on the three studied sandy beaches in the different periods (Before Vacation, Vacation, After Vacation 1 and 2).

In the laboratory, meiofauna was extracted from the sediment using colloidal silica at a specific density of 1.18 g/cm^3 (Somerfield et al., 2015). The supernatant was washed through 0.3- and 0.045-mm meshes, and the organisms retained in the 0.045-mm mesh were placed on Dollfus plates and identified to the major taxonomic groups following Giere (2009). The first 50 nematodes were chosen, mounted on permanent slides using the methodology by de Grisse (1969) and Cobb (1917), and identified to the genus level, where possible, following Warwick et al. (1998) and specialized literature provided at Nemys (Bezerra et al., 2020). Nematode genera were also classified into trophic groups according to Wieser (1953), namely: selective deposit feeders (1A), non-selective deposit feeders (1B), epigrowth feeders (2A), and omnivores/predators (2B). The granulometric analysis was conducted by sieving out coarse sediments and pipetting fine sediments, as proposed by Suguio (1973). Textural parameters (mean grain size, sorting, %sand, and gravel) were calculated using the equations of Folk and Ward (1957). Grain sizes were determined by sieving the sediment in an automatic shaker and classifying the grains according to the Wentworth scale (Buchanan, 1984). Water content was initially estimated as water loss after sediment drying for 24 h at 60 °C. Dried samples were combusted at 550 °C for 4 h in order to determine organic content (Dean, 1974).

2.3.Statistical analysis

The potential impact of recreational activities on the composition and structure of meiofauna community and Nematoda assemblages were evaluated on the three beaches using taxonomic composition, genus richness and density (inds. /10cm^2). Variations in genus richness and density were analyzed using a three-way analysis of variance (ANOVA) (months: Before Vacation, During Vacation, After 1 and 2; Beaches: Atalaia, Farol-Velho and Corvinas; and sampling stations: A - G) after checking normality and homogeneity of variance assumptions, using the Kolmogorov–Smirnov and Levene tests, respectively. When necessary, data were $\log_{(x+1)}$ transformed. When ANOVA detected a significant difference, *a posteriori* Tukey's tests were applied to identify significant pairwise differences.

Canonical analysis of principal coordinates (CAP) was applied to visualize multivariate patterns of meiofauna community and Nematoda assemblages across beach x month combinations. CAP resemblance matrices were calculated using Bray Curtis similarity based on $\log_{(x+1)}$ transformed meiofauna and nematode abundances. Simultaneously, the same abundance matrices used for the CAPs were analyzed using a three-way permutational ANOVA (PERMANOVA), designed using the same layout as ANOVA. The contribution of each taxon to the dissimilarity (>50%) found among the groups was evaluated using the SIMPER (similarity percentage) routine.

The mean number of beachgoers and vehicles obtained on each beach were utilized to estimate the recreational activities in each month. Abiotic variables (grain size, sorting, % sand and % fines, % OM, and sand compaction) and recreational activities (mean number of beachgoers and vehicles) had the same configuration as ANOVA in order to detect changes in abiotic variables and recreational activities between beaches and months. Abiotic variables were also analyzed using multivariate methods (Clarke and Gorley 2006). Environmental parameters were log (x+1) transformed, normalized, and analyzed using Principal Components Analysis (PCA).

A distance-based linear model (DistLM; Anderson, 2001) was performed to link richness and density of both meiofauna and nematodes, and density of the dominant Nematoda genera (>50% of total abundance) with environmental variables. This technique analyzes and models the relationship among a multivariate data cloud, as described by a resemblance matrix and by predictor variables. Resemblance matrices were calculated using Euclidean distance ($\log_{(x+1)}$ transformed data). The best models in DistLM were chosen using a forward routine with 9999 permutations based on AIC selection criterion (Anderson et al., 2008). A 5% significance level was considered in all analyses.

3.Results

3.1.Environmental parameters and human beach use

A list of all environmental parameters is shown in supplementary material 1. In general, the number of beach users (vehicles and beachgoers) was higher during Vacation in all beaches compared to the other periods (beach x month interaction). Both Atalaia and Farol-Velho showed significant differences compared to Corvinas during Vacation ($F_{(1.84)} = 6.38$; $p<0.05$); however, differences were not detected between Corvinas and Farol-Velho in the other months. All beaches showed the same pattern monthly, with significant differences found only between Vacation and other months (Fig. 3).

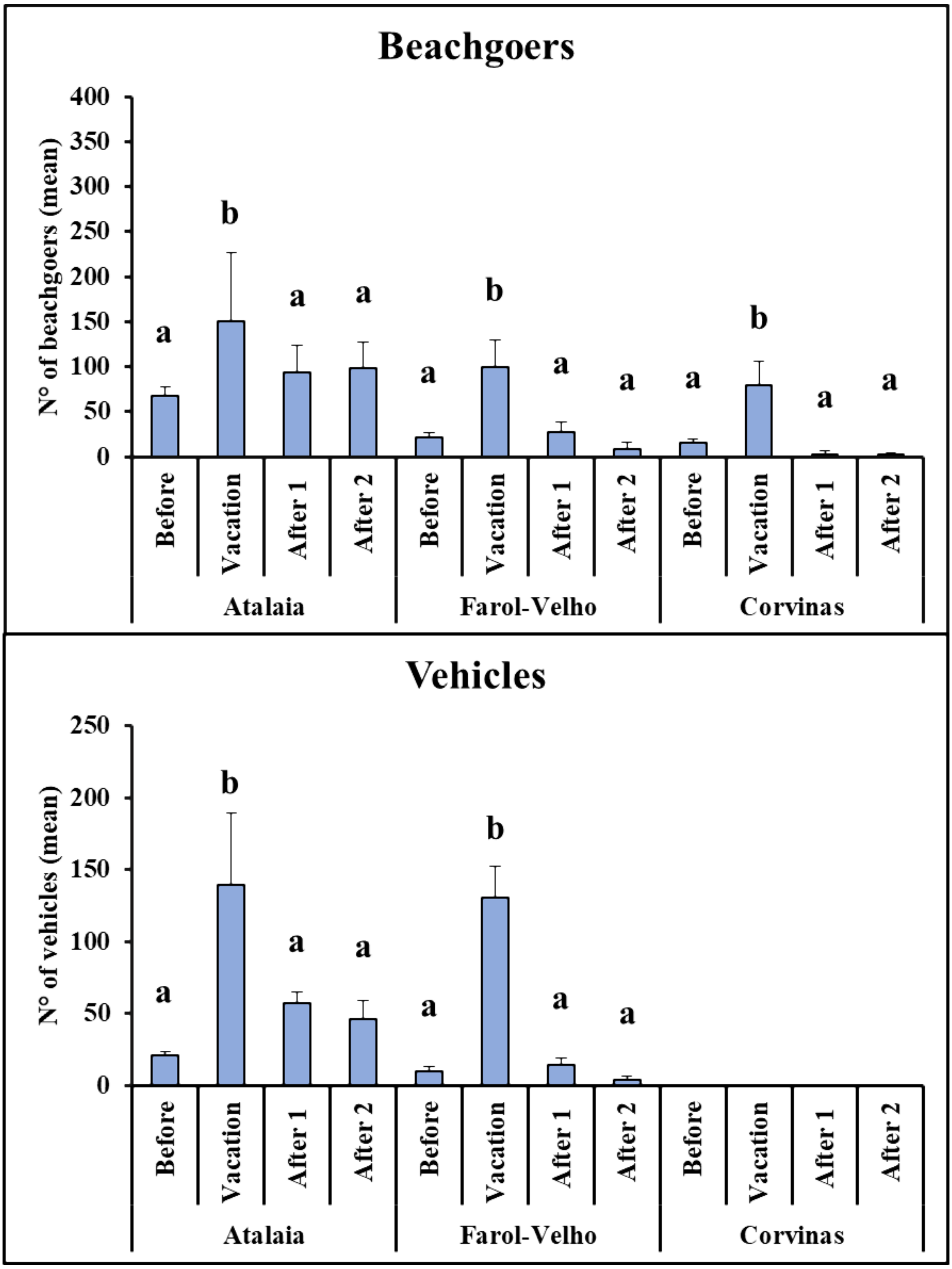

Figure 3. Number of beach visitors (beachgoers and vehicles) counted (mean ± SD) in each area in the different study periods (Before Vacation, Vacation, After Vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

All beaches were characterized by well-sorted fine to very-fine sand at all SS (Supplementary material 1). Sediment characteristics (mean grain size, sorting, and organic matter) did not differ among beaches over the months (Table 1). However, some differences were found in sediment sorting between months and beaches, with higher values in Atalaia during Vacation (Supplementary material 1). Organic matter (OM) varied between beaches ($F_{(2.84)}$=7.03, $p<0.05$), with higher values in Corvinas. Significant differences between SS ($F_{(6.86)}$=19.72, $p<0.05$) were detected in Atalaia and Farol-Velho only during Vacation, when the lowest values of organic matter were found at the higher SS (A and B) in both beaches (Supplementary material 1). Overall, higher sand compaction was found during Vacation in all beaches (Table 1), however, significant differences were found mainly between the months Before and during Vacation (Supplementary material 1). Regarding beaches, higher values of sand compaction were found in Atalaia in all months (Table 1). Concerning SS, Atalaia and Farol-Velho had the same pattern, with higher sand compaction at the higher SS (A – B), whereas in Corvinas higher values occurred at the lowest SS (F – G).

Table. 1. ANOVA analysis results regarding the significance of differences in the environmental parameters of the study areas.

		O.M		**Grain size**		**Sorting**		**Compaction**	
Factors	**df**	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***P***
Month (M)	3	6.38	0.00*	18.65	0.00*	36.67	0.00*	45.89	0.00*
Beach (Be)	2	7.03	0.00*	6.87	0.00*	18.57	0.00*	167.19	0.00*
Sampling stations (SS)	6	19.72	0.00*	1.48	0.19	6.45	0.00*	2.66	0.02*
M x Be	6	1.26	0.28	17.89	0.00*	8.16	0.00*	8.93	0.00*
M x SS	18	2.16	0.00*	0.56	0.91	3.51	0.00*	2.51	0.00*
Be x SS	12	1.80	0.05	1.37	0.19	1.94	0.04*	6.91	0.00*
M x Be x SS	36	1.02	0.44	0.66	0.91	1.34	0.13	1.13	0.30
Error	84								

*p<0.05; df = degrees of freedom; O.M: organic matter

Based on environmental variables, the first two principal components (PC) explained 37.6% of the variance between treatments (Fig. 4). The axis 1 explained 19.2% of data variance, with a clear separation of samples of Before Vacation from those from other months. All beaches had finer (very-fine sand, % fine) sediments with higher OM content Before Vacation. On the other hand, the other months had a more compacted sediment with larger grain size and a higher number of vehicles and beachgoers. The lower part of Axis 2, which explained 18.4% of data variance, was better associated with the Vacation and After 1 months. The samples from Vacation had the maximum values of compaction and recreational activities (vehicles and beachgoers).

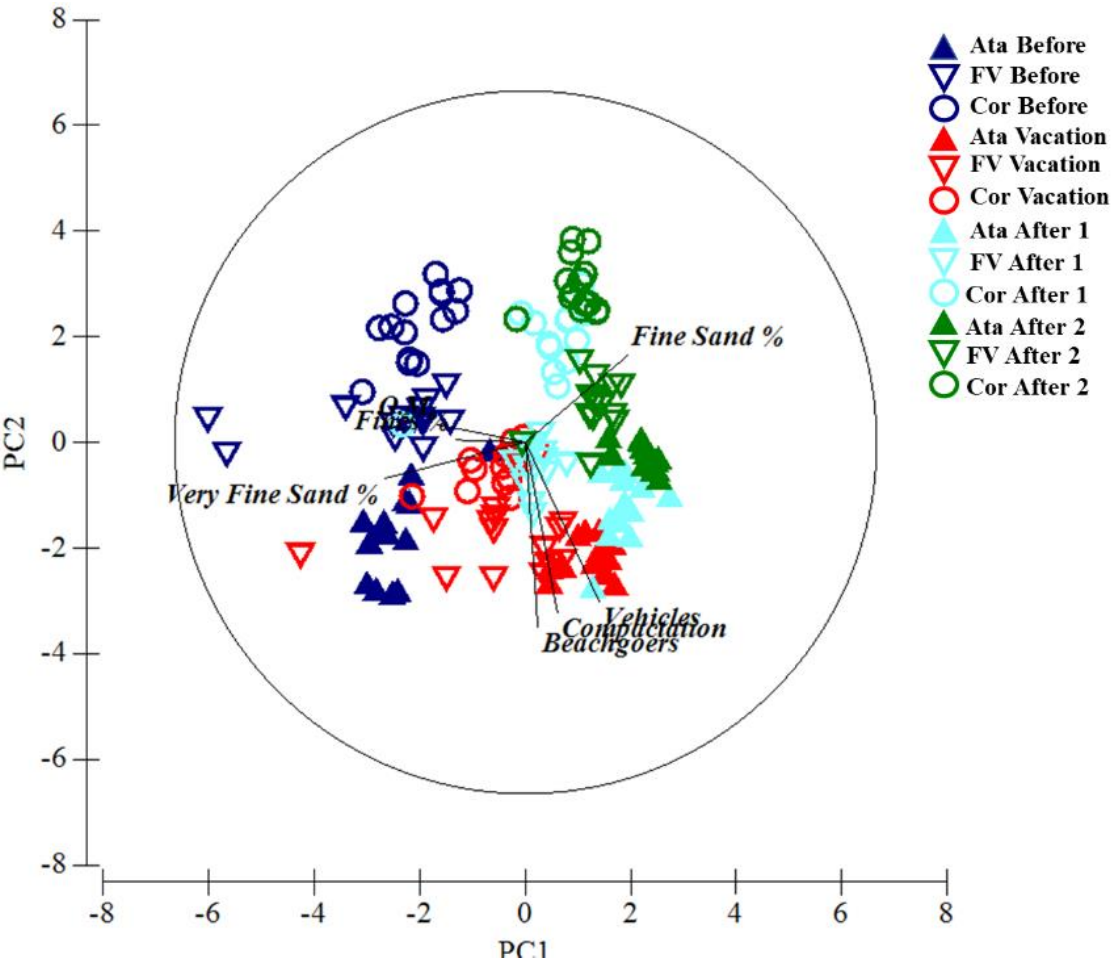

Figure 4. Plots of the Principal Coordinate Analysis (PCA) based on environmental variables collected from the study areas (Ata: Atalaia; FV: Farol-Velho; and Cor: Corvinas) in the different periods (Before Vacation, Vacation, After Vacation 1 and 2).

3.2.Meiofauna community

Meiofauna was comprised of 14 major groups (Supplementary material 2) and composition was similar among beaches. Overall, Nematoda (64%), Tardigrada (20%), and Copepoda (6%) were the dominant groups; however, their contribution varied between months, areas, and SS. Before vacation, Nematoda was the dominant group on all beaches and SS except for a few stations where Tardigrada was the most abundant group (Fig. 5). During Vacation, a marked decrease of diverse groups occurred at the highest SS (A – B) in the Atalaia and Farol-Velho, with proportional increase in nematode dominance. After vacation (1 and 2), Tardigrada contribution increased at the highest SS (A – B) in the Atalaia and Farol-Velho. Concerning the Corvinas beach, the major groups were constant over the months, with little variations in their contributions (Fig. 5).

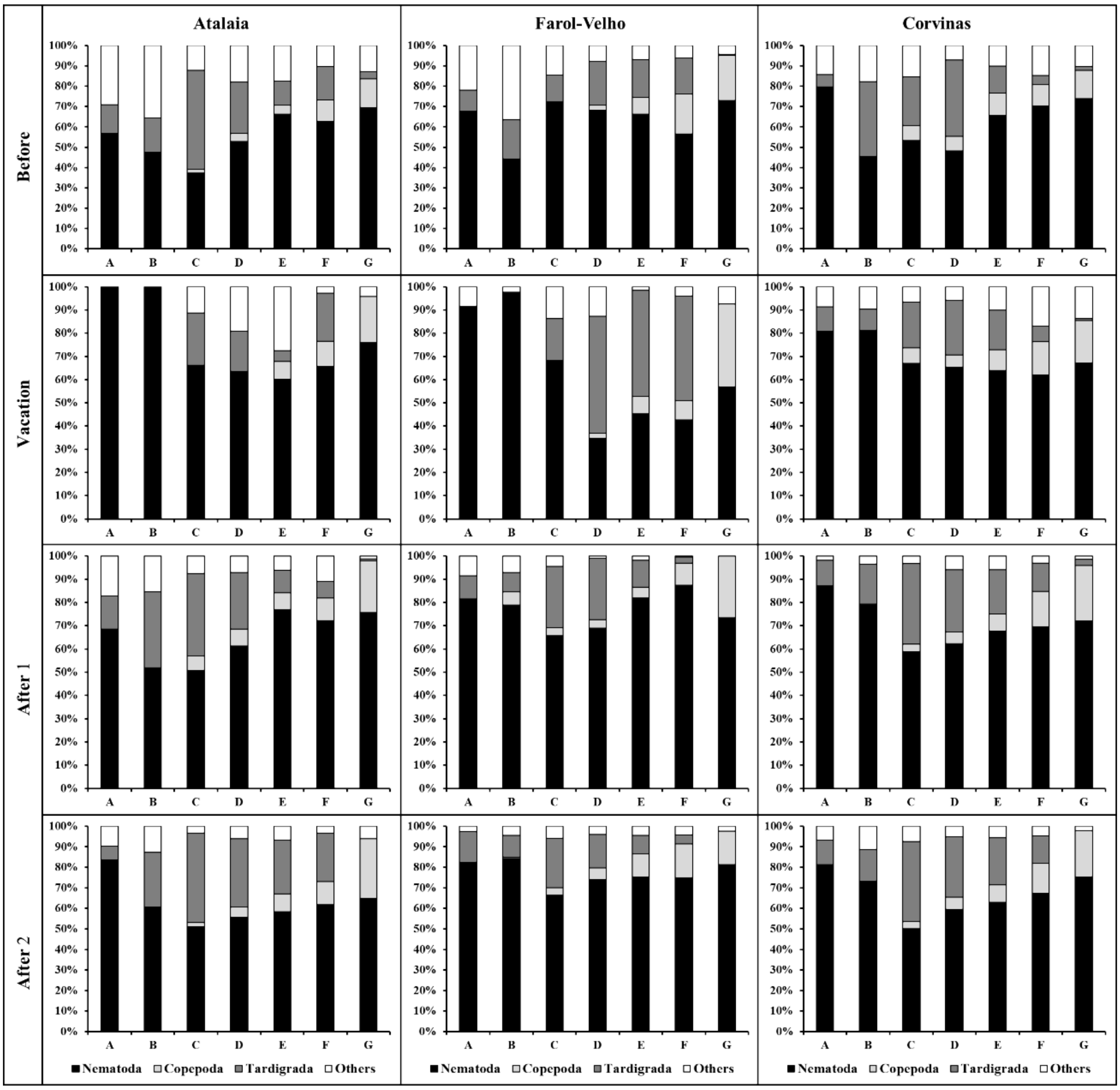

Figure 5. Relative abundance (%) of the major meiobenthic major groups in each beach in the different periods (Before Vacation, Vacation, After Vacation 1 and 2).

Density varied significantly between treatments (Table 2), with differences found mostly between ‘Vacation’ and the other months (Before Vacation and After 1 and 2) in the Atalaia and Farol-Velho (Table 2). Overall, regarding SS, higher densities were found at the mid-SS (C – E) on all beaches (Fig. 6). However, a marked decrease in density occurred at the highest SS (A – B) during Vacation in the Atalaia and Farol-Velho, while densities increased towards the low SS. In the After-vacation months (1 and 2), density increased in all beaches and at all SS (Fig. 6).

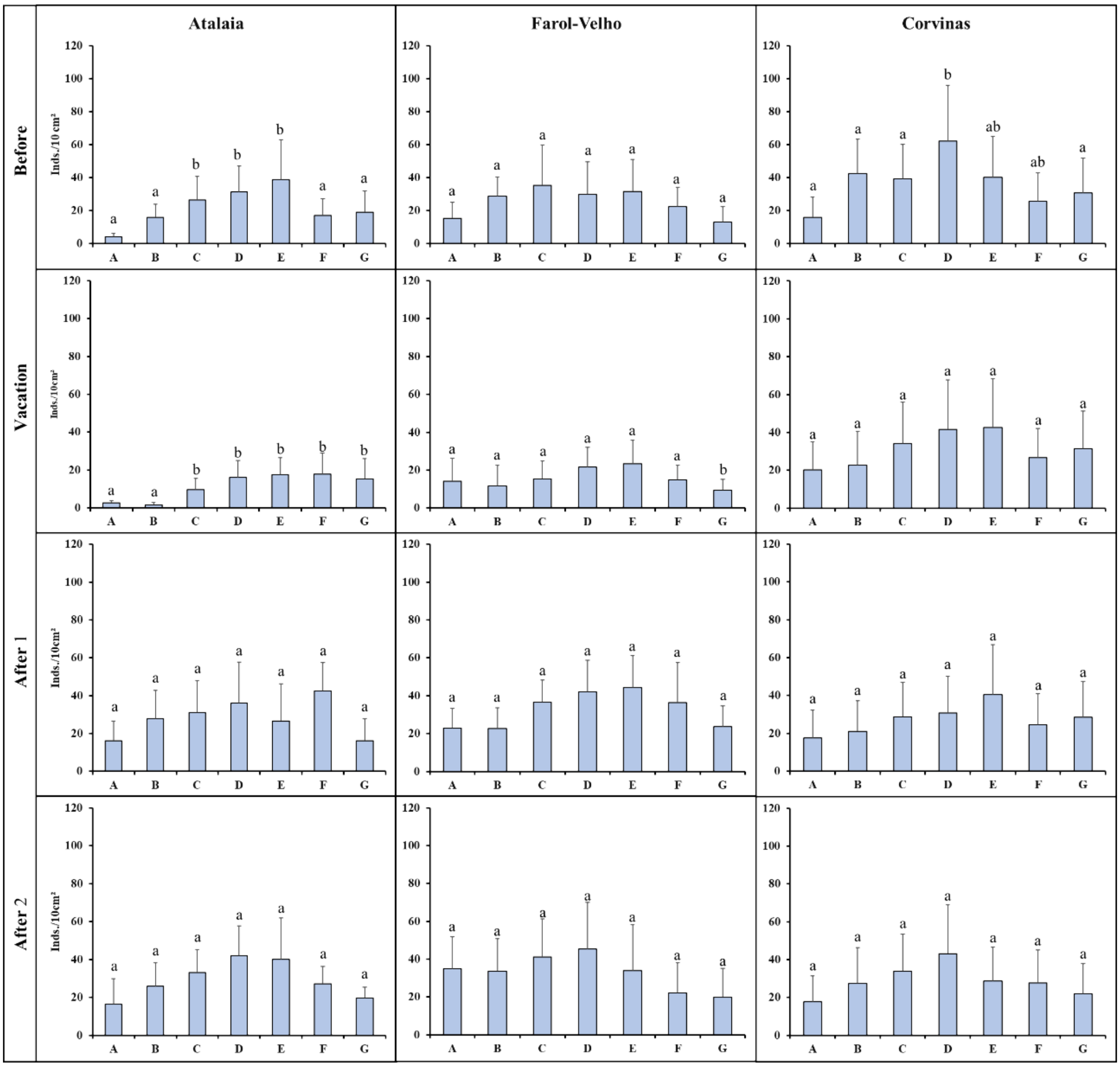

Figure 6. Mean density (inds. /10cm² ± SE) of meiobenthic community at the sampling stations (A – G) in the study beaches in the different periods (Before Vacation, Vacation, After Vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

Richness followed the same pattern as density, with significant differences between treatments (Table 2). Overall, a similar composition was found among beaches, although higher richness occurred in Corvinas in all months and lower richness was found during Vacation in Atalaia. Concerning SS, higher richness was generally found at mid-SS. A significant decrease in richness occurred at the highest SS (A – B) during Vacation in Atalaia and Farol-Velho, where the lowest richness was found. In the After-vacation months (1 and 2) richness increased in all beaches and at all SS (Fig. 7).

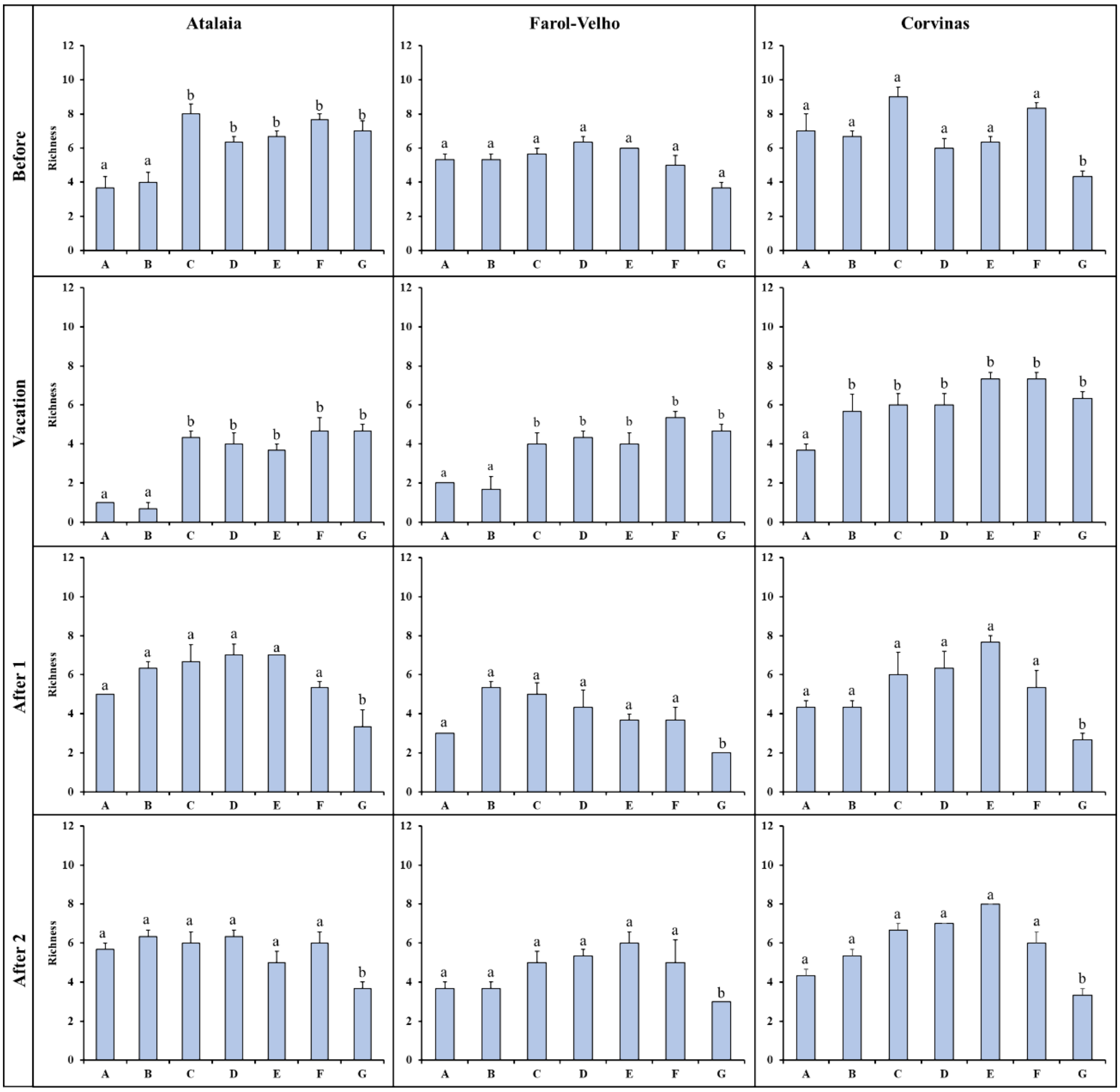

Figure 7. Richness (total major groups ± SE) of meiobenthic community at the sampling stations (A – G) in the study beaches and in the different periods (Before Vacation, Vacation, After Vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

Table. 2. Results of ANOVA analysis and pairwise test regarding the significance of differences in meiofauna community and Nematoda assemblage descriptors in the study areas.

Factors	Meiofauna					Nematoda				
		Density		Richness			Density		Richness	
	df	F	p	F	p	df	F	p	F	p
Month (M)	3	124.63	**	45.85	**	3	92.294	**	1.77	>0.05
Beach (Be)	2	165.58	**	72.00	**	2	113.434	**	35.18	**
Sampling station (SS)	6	191.14	**	38.53	**	6	99.007	**	17.21	**
M x Be	6	50.02	**	14.97	**	6	39.091	**	5.70	**
M x SS	18	14.57	**	8.52	<0.05	18	10.796	**	3.21	**
Be x SS	12	8.48	**	2.64	**	12	4.019	**	10.45	**
P x Ar x SS	36	9.22	**	3.59	**	36	6.489	**	4.08	**
Error	168					168				

Pair-wise comparation					Pair-wise comparation				
		AT x FV	**AT x CO**	**FV x CO**			**AT x FV**	**AT x CO**	**FV x CO**
Before	**Density**	>0.05	>0.05	>0.05	**Before**	**Density**	>0.05	>0.05	>0.05
	Richness	>0.05	>0.05	>0.05		**Richness**	>0.05	>0.05	>0.05
Vacation	**Density**	>0.05	>0.05	**	**Vacation**	**Density**	>0.05	>0.05	**
	Richness	>0.05	>0.05	**		**Richness**	>0.05	>0.05	**
After 1	**Density**	>0.05	>0.05	**	**After 1**	**Density**	>0.05	>0.05	>0.05
	Richness	>0.05	>0.05	**		**Richness**	>0.05	**	>0.05
After 2	**Density**	>0.05	>0.05	**	**After 2**	**Density**	>0.05	>0.05	>0.05
	Richness	>0.05	>0.05	**		**Richness**	>0.05	>0.05	>0.05

** = $p<0.001$; df = degrees of freedom; AT= Atalaia. FV = Farol-Velho. CO = Corvinas

PERMANOVA showed significant differences in meiofauna community structure between periods, beaches, and SS (Table 3). Pairwise comparisons indicate that these differences occurred mostly in Atalaia and Farol-Velho comparing Before and After Vacation 1 months (Supplementary material 3). It is possible to identify in CAP plots that Atalaia and Farol-Velho, on one side, and the Corvinas, on the other side, were different over time (Fig. 8). In Atalaia and Farol-Velho, it is possible to identify a group of samples from Before Vacation and After 2 months, and a second group of samples from Vacation and After 1 months (Figure 8). Values of leave-one-out allocation success for area x period combinations (Atalaia: 38.09% misclassified samples; Farol-Velho: 29.76% misclassified samples; Corvinas: 36.9 misclassified samples) were low.

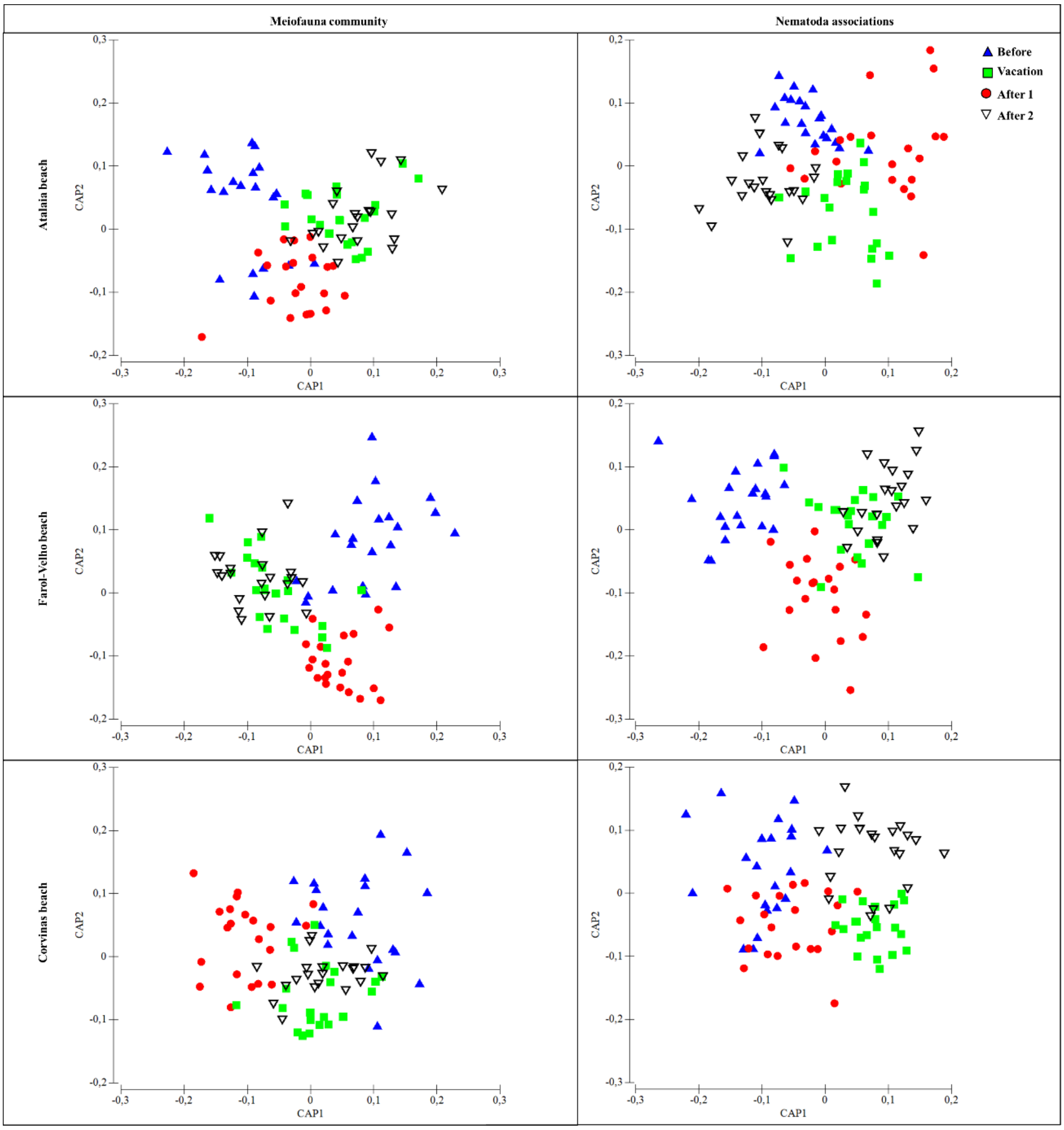

Figure 8. Canonical analysis of principal coordinates (CAP) for month x beach combinations for meiofauna community and Nematoda assemblage in the study areas.

Table. 3. Results of PERMANOVA tests regarding meiobenthic community and Nematoda assemblage structures between study areas and periods.

		Meiofauna		Nematoda	
Source	**df**	**Pseudo-F**	**P(*perm*)**	**Pseudo-F**	**P(*perm*)**
Month (M)	3	42.008	0.001	10.417	0.001
Beach (Be)	2	39.463	0.001	52.163	0.001
Sampling station (SS)	6	75.395	0.001	15.483	0.001
M x Be	6	18.488	0.001	11.372	0.001
M x SS	18	6.405	0.001	34.822	0.001
Be x SS	12	4.778	0.001	79.043	0.001
M x Be x SS	36	42.837	0.001	28.404	0.001
Res	168				

*$p<0.05$; df = degrees of freedom; MS = mean squares

SIMPER showed a high level of dissimilarity in the communities among all months and beaches (supplementary material 4). Most of the taxa were more abundant in the Before and After Vacation months. Concerning beaches, higher dissimilarities occurred mostly during Vacation in Atalaia and Farol-Velho, caused particularly due to low Tardigrada and Copepoda abundances. No high dissimilarities occurred in the Corvinas among months. The best distance-based linear model (DistLM) explained 16.6% of density and 19.6% of variation in meiofauna richness. Concerning the major groups, the analysis explained 23.1% of variation in Nematoda, 13.3% of variation in Copepoda, and 10.9% of variation in Tardigrada. Sediment compaction was the main environmental variable correlated with meiofauna and its major groups (Table 4).

3.3.Nematoda assemblage

A total of 65 genera belonging to 19 families were identified (Appendix 1). Xyalidae (13 genera) and Cyatholaimidae (7 genera) were the richest families, whereas Xyalidae (38.2%) and Chromadoridae (14.6%) were the most abundant. Overall, *Daptonema* (22%), *Chromadorita* (11.1 %) and *Paracyatholaimus* (7.5 %) were the most abundant genera. However, their contributions varied among months especially in the Atalaia and Farol-Velho (Fig. 9). Before Vacation, Atalaia and Farol-Velho were dominated by the same genus, with *Daptonema* present at all SS in Atalaia (Fig. 9). During Vacation, changes were observed mainly at the upper SS of the Atalaia and Farol-Velho, where a remarkable decrease in *Daptonema* was observed. An increase in other genera was observed in Atalaia in the After-vacation months, especially *Paracyatholaimus* in the After 1 month. On the other hand, Corvinas showed similar pattern among months, with little variation (Fig. 9).

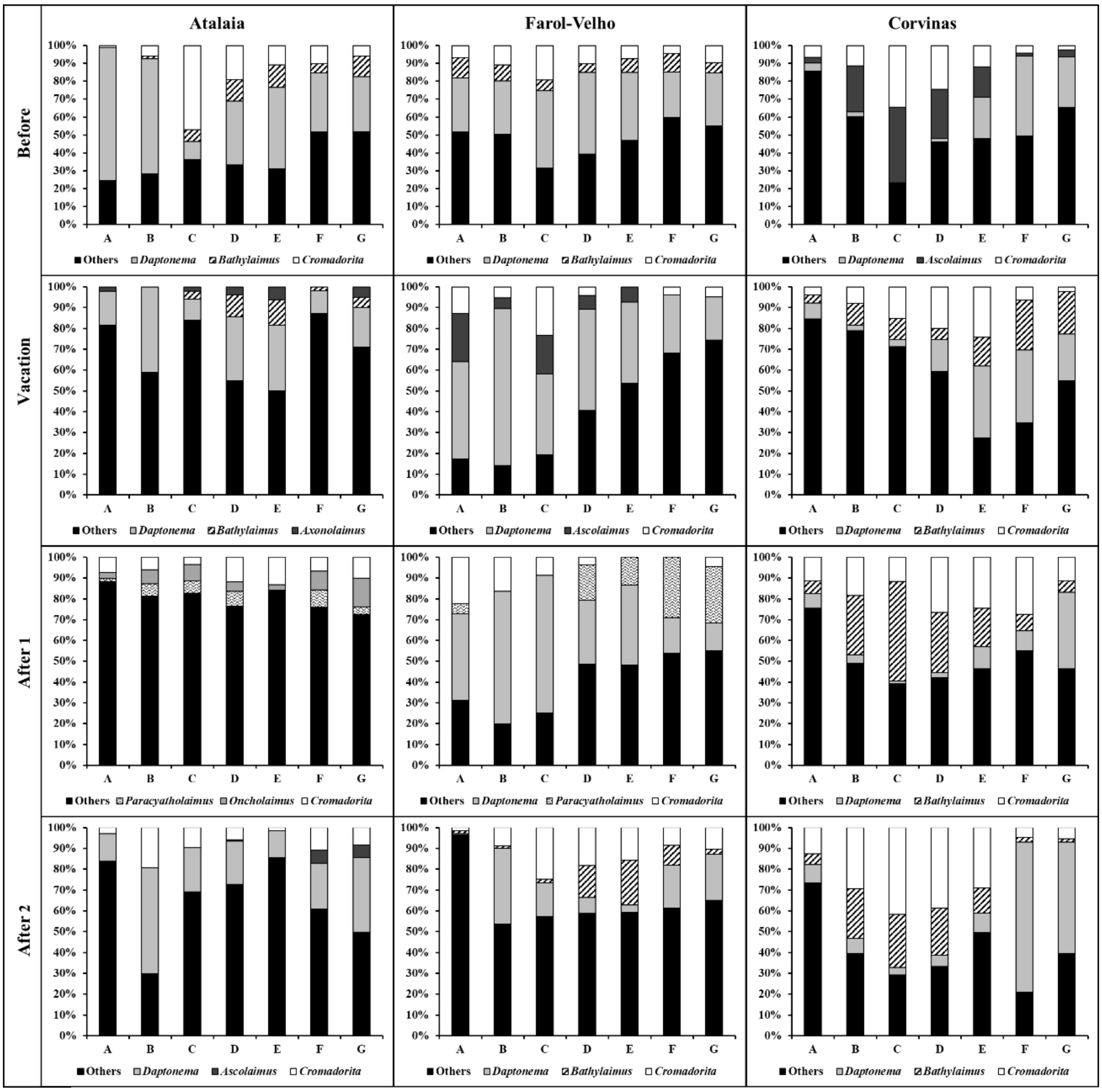

Figure 9. Relative abundance (%) of the dominant Nematoda genera (>50%) in each beach in the different periods (Before Vacation, Vacation, After Vacation 1 and 2).

Density varied significantly between treatments (Table 2), with higher density values in Corvinas in all months and the lowest densities recorded in Atalaia during Vacation. Significant differences were found mainly between Vacation and the other months (Before Vacation and After 1 and 2) in Atalaia and Farol-Velho. Comparing SS, higher densities were found generally at the mid-SS (C – E) on all beaches, with decrease at the lowest SS (F – G). During Vacation, a marked decrease in density was observed at the highest SS (A – B) in the Atalaia and Farol-Velho, with higher values found mostly at the lowest SS (F – G). In the After-vacation months (1 and 2), density increased at all SS. Indeed, except for the Corvinas, densities found in Atalaia and Farol-Velho were similar between these months (Fig. 10). Nematode density was constant in Corvinas over the months, with little variation during Vacation (Fig. 10).

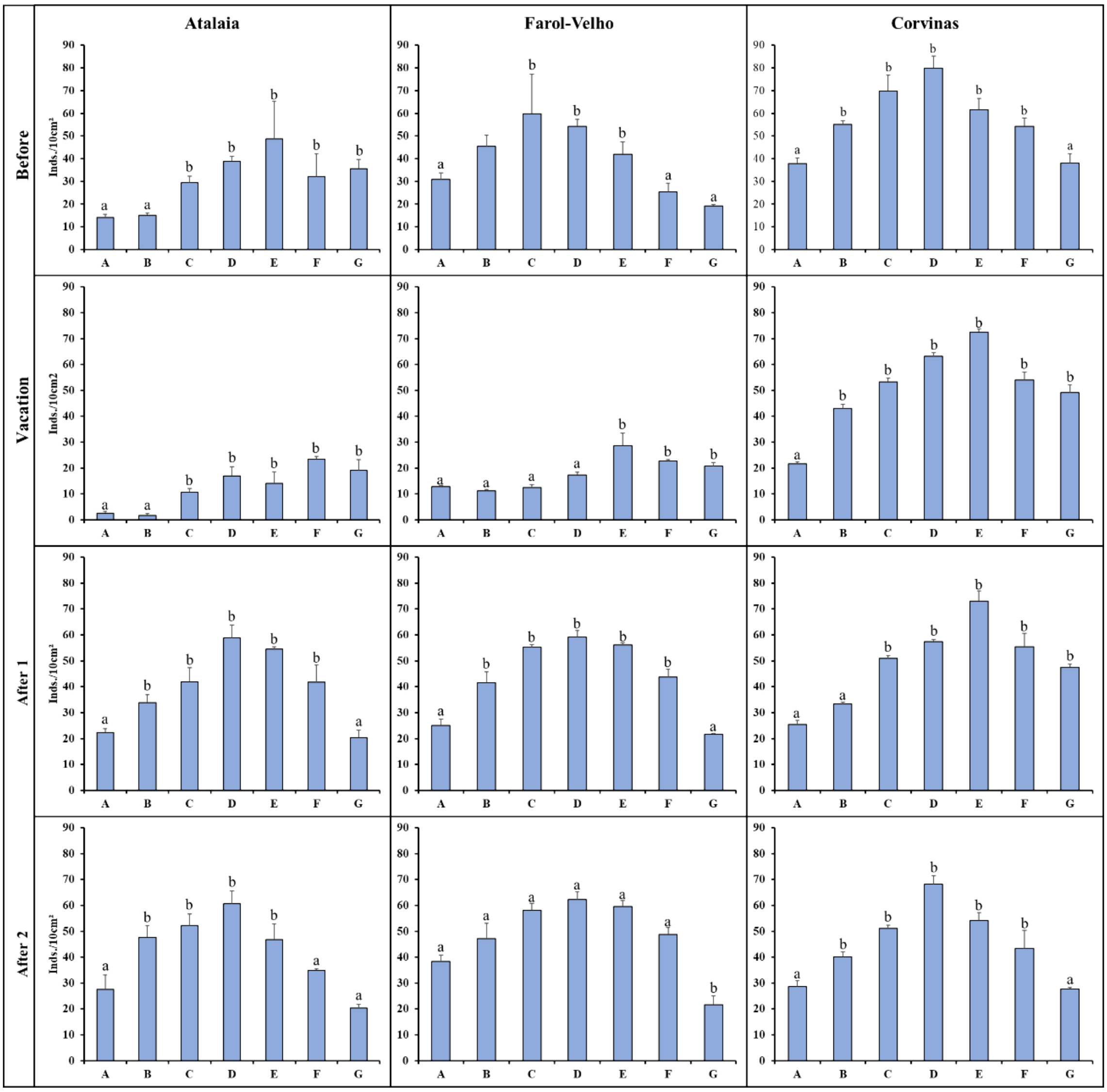

Figure 10. Mean density (inds. /10cm²±SE) of Nematoda assemblage at the sampling stations (A – G) in the study beaches and in the different periods (Before Vacation, Vacation, After Vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

Richness followed the same pattern as density, with significant differences between treatments. The pairwise test showed that these differences were found mainly between Vacation and the other months (Table 2). Overall, composition found was similar among beaches; however, higher richness was found in Corvinas in all months, with some genera recorded exclusively in this beach. On the other hand, lower richness was found during Vacation in Atalaia (Fig. 11). Concerning SS, higher richness was generally found at mid-SS. A significant marked decrease in richness occurred at the highest SS (A – B) during Vacation in Atalaia, where the lowest values of richness were found throughout the study (Fig. 11). In the After-vacation periods (1 and 2), richness increased in all beaches and at all SS. There was no great variation in richness in the Corvinas, as occurred also with density (Fig. 11).

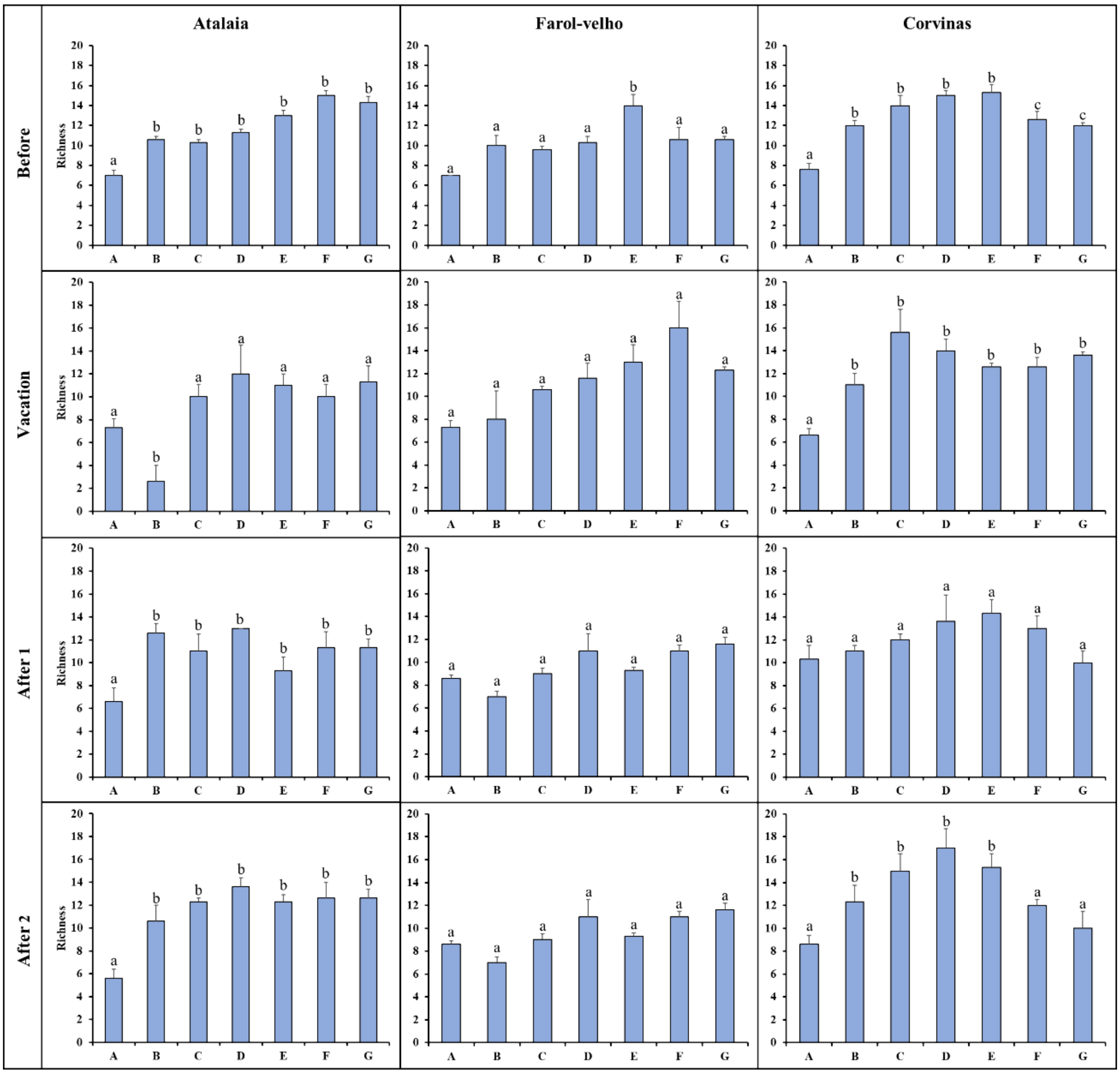

Figure 11. Nematoda assemblage richness (total genera±SE) at the sampling stations (A – G) in the study beaches and in the different periods (Before Vacation, Vacation, After Vacation 1 and 2). Different letters indicate significant differences ($p<0.05$).

Considering trophic groups, non-selective deposit-feeders (1B) were dominant (46.1 %), followed by epistrate feeders (2A), with 31.8 %, and omnivores/predators (type 2B, 19.9%). Selective deposit feeders (type 1A) comprised only 2.2% of the total Nematoda assemblage. Major differences in trophic groups were observed mostly in Atalaia in the After 1 period, when a sharp decrease in non-selective deposit-feeders occurred, followed by an increase in epistrate feeders (Figure 12).

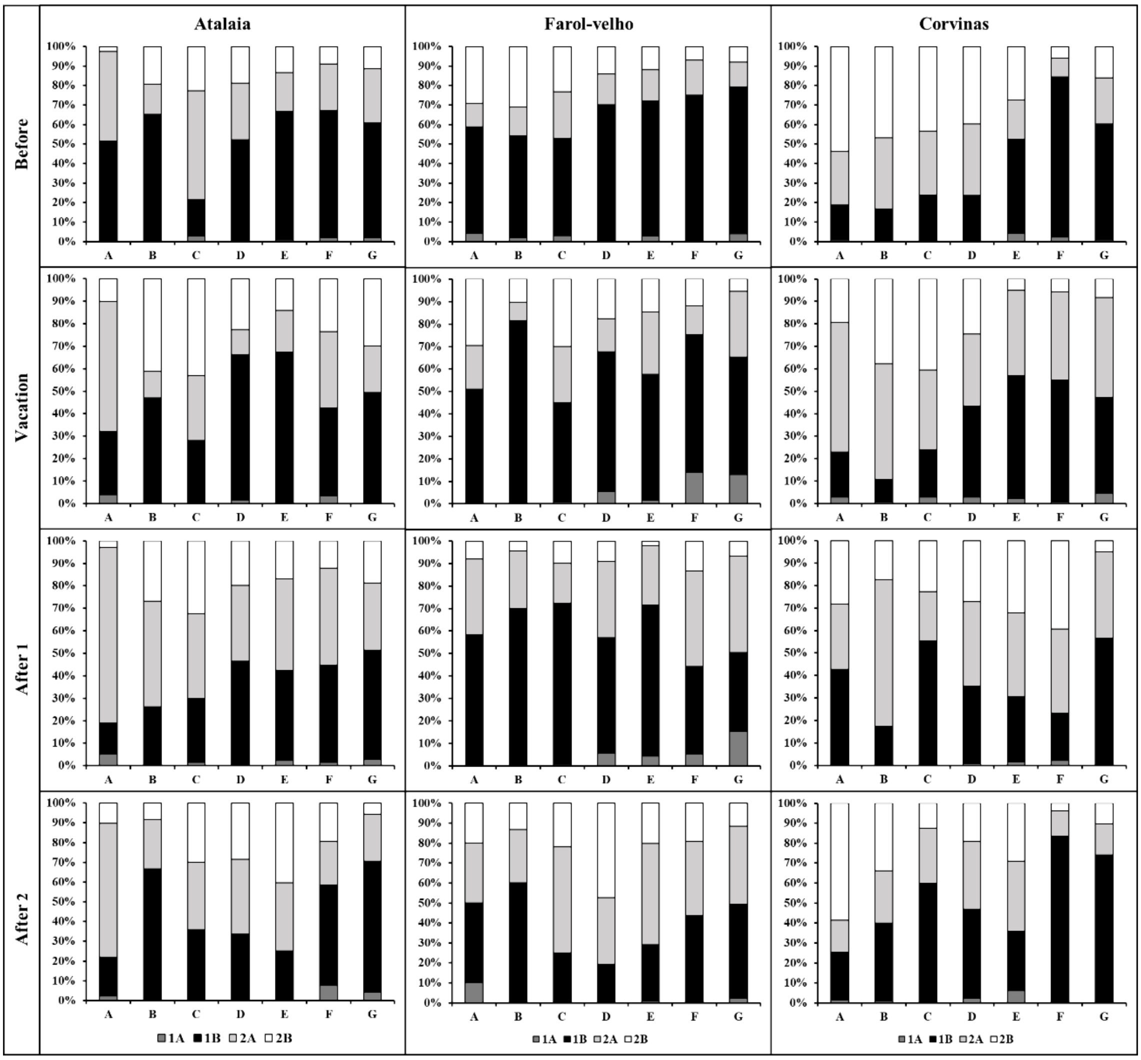

Figure 12. Relative abundance (%) of trophic groups of Nematoda assemblage at the sampling stations (A – G) in the study beaches and in the different periods (Before Vacation, Vacation, After Vacation 1 and 2).

PERMANOVA showed significant differences in meiofauna community structure among months, beaches, and SS (Table 3). Pairwise comparisons indicated that these differences occurred especially between Before Vacation and Vacation in Atalaia and Farol-Velho beaches (Supplementary material 3). CAP plots indicate that change over time was different between Atalaia and Farol-Velho compared with Corvinas (Fig. 9). In Atalaia and Farol-Velho, it is possible to identify one group of samples from Before Vacation and After 2 months, and a second group comprised of Vacation and After 1 months (Figure 8). Values of leave-one-out allocation success for beach x month combinations (Atalaia: 23.81% misclassified samples; Farol-Velho: 20.2% misclassified samples; Corvinas: 22.6% misclassified samples) were low.

SIMPER analysis showed a high level of dissimilarity in assemblages among all months in all beaches (Supplementary Material 5). Comparing months, most genera were more abundant in the Before and After Vacation. Concerning beaches, higher dissimilarities occurred mostly between Vacation and the other months in Atalaia and Farol-Velho, caused especially by the low abundance of *Daptonema* and *Paracyatholaimus*. There were no high dissimilarities among periods in the Corvinas. The best distance-based linear model (DistLM) explained 18% of richness variation. Concerning the main genera, the analysis explained 35% of variation in *Daptonema* and 34% of variation in *Cromadorita*. Sediment compaction was the environmental variable that was most correlated with Nematoda genera (Table 4).

Table. 4. Best distance-based linear models (DistLM) fitted for meiofauna and Nematoda descriptors and abundance of the major dominant meiofauna groups and Nematoda genera against environmental variables in the study areas * Values in brackets: proportion of variability explained by each variable.

Meiofauna community				
	AIC	**r^2**	**Variable included**	**p**
Richness	89.69	0.16	Compaction (16.05%)	>0.001
Density	331.99	0.17	Compaction (12.7%), N° vehicles (16.6%)	>0.001 (both)
Nematoda	-65.2	0.20	Compaction (11.8%), N° vehicles (20.4%)	>0.001 (both)
Copepoda	127.52	0.13	% Medium sand (33.9%), Compaction (8.5%)	>0.05 (both)
Tardigrada	114.38	0.10	Compaction (16,05%)	>0.01
Nematoda assemblage				
	AIC	**r^2**	**Variable included**	**p**
Richness	91.12	0.17	Compaction (18%)	>0.01
Daptonema	0.92	0.57	Compaction (35%)	>0.001
Cromadorita	17.3	0.51	Compaction (34%)	>0.05 (all)

*$p<0.05$

4.Discussion

Meiofauna composition was similar among beaches and months; with Nematoda, Tardigrada, and Copepoda as the dominant groups. Nematoda dominance in meiofauna community has been widely reported in literature. This taxon is usually the most abundant meiofauna group in sandy beach habitats (Gheskiere et al., 2005; Harriague et al., 2013; Kotwicki et al., 2014; Félix et al., 2016), as well as in Amazonian sandy beaches (Gomes and Rosa Filho, 2009; Rosa Filho et al., 2011; Baia and Venekey, 2019). Since these areas are mostly comprised of fine to very-fine sand (Ranieri and El-Robrini, 2015) this result was already expected.

Overall, all meiofauna groups were affected by recreational activities, however, their responses varied according to SS and month. These differences were found mainly in Atalaia and Farol-Velho, where sharp decreases in (and even absence of) Tardigrada and Copepoda abundance occurred at the highest and mid-SS, respectively. In fact, anthropogenic activities are likely to have a higher impact on copepods than on other meiofaunal groups (Raffaelli and Mason 1981; Levin et al., 2009). Previous studies showed that copepods are sensitive to recreational activities on sandy beaches (*e.g.* Gheskiere et al., 2005; Pereira et al., 2017) and these impacts may be related to changes in substrate characteristics. Similarly, a previous study on Tardigrada community showed high sensitivity to recreational activities, resulting in reduced abundance and diversity (Gomes Junior, 2015). In fact, the same study also showed that the immediate effect of experimental trampling on Tardigrada community was a tendency to reduce population density proportionally to stress level. The same pattern was observed in our study beaches, especially at the upper SS of Atalaia and Farol-Velho. In addition, the community recovery to original levels was already observed in the month before the Vacation in the first month after the end stress. This rapid recovery is probably a result of the short life cycle of Tardigrada (Giere, 2009).

Meiofauna density and richness had different patterns among periods. Overall, the Atalaia and Farol-Velho followed the same temporal pattern: sharp reduction in density and richness, with significant changes in community structure between Before Vacation and Vacation months, followed by an increase and restoration of community composition (density and richness) in the After-vacation months. Conversely, the Corvinas area showed more stability throughout the months, with no significant changes in community structure even during Vacation. Consequently, recreational activity can be considered the major cause of the variability in meiobenthic community found in our study. The pattern found here is similar to the results found in previous studies evaluating the effect of recreational activities on meio- and macrofauna of sandy beaches (*e.g.* Moellmann and Corbisier, 2003; Gheskiere et al., 2005; Pereira et al, 2017; Schlacher et al., 2007; Schlacher and Thompson, 2012).

It is well known that meiobenthic fauna varies alongshore within a beach depending on the susceptibility of each species to environmental factors and that community attributes are strongly linked to the physical conditions of the corresponding sandy beach habitat. Therefore, meiofauna is typically more abundant and diverse in the mid-tidal level (see Giere, 2009 for review). Overall, this pattern was found in all beaches, except for Atalaia and Farol-Velho during Vacation. Decline in density and richness was sharper at the upper SS of Atalaia and Farol-Velho, where they reached the minimum values whereas, the highest values were found increasing toward the lowest SS. Similar results were found in other studies where the impact of recreational activities was also checked, particularly in the upper zone of sandy beaches (Moellmann and Corbisier, 2003; Gheskiere et al., 2005; Pereira et al., 2017). On Amazonian beaches, including the study area, most recreational activities as vehicle traffic and beachgoer activities occurred at the upper stations (100 m), during ebb and low tides (Santos et al., non-published data). Overall, the intertidal zone on Amazonian sand beaches is formed by channels and sandbanks during ebb and low tides that hamper bathing due to the long distances from the backshore to the water line (Silva et al., 2013).

In our study, Nematoda assemblage was comprised of 65 genera, with Cyatholaimidae and Xyalidae being the richest Nematoda families. In addition, Xyalidae was the most abundant Nematoda family. Along the Brazilian coast, the diversity of Xyalidae and Cyatholaimidae richness is well documented in literature, and these families occur in several environments (Venekey et al., 2010; Venekey, 2017). Concerning the studied beaches, the Nematoda composition was similar. In fact, tourist and non-tourist beaches were expected to have similar compositions, as they are located close to each other, have similar exposure, and granulometry. However, only Corvinas presented all genera recorded throughout the study. In addition, the most dominant genera recorded in this study (*Chromadorita* and *Daptonema*) seem to be rather sensitive to recreational impacts, as indicated by the higher abundances of these organisms in Corvinas. Additionally, they also showed changes in density throughout the study periods, with lower abundance found during Vacation in the Atalaia and Farol-Velho.

Similar to meiofauna community, Nematoda density and richness showed different patterns among months, and clear changes were found in Atalaia and Farol-Velho, whereas Corvinas remained more stable. Overall, a sharp reduction in density and richness was detected during Vacation, followed by an increase in and restoration of assemblage composition (density and richness) in the After-vacation months. Concerning beaches, we found clear differences in density and richness comparing Atalaia and Farol-Velho areas with Corvinas, especially at the upper SS, while mid- and lower SS were more similar. Overall, higher values were found at the mid-SS in all beaches, however, the Atalaia and Farol-Velho had increasing density and richness values towards the lowest sampling stations during Vacation.

Nematoda are known to vary alongshore within a beach in response to environmental modifications and in tropical areas, temperature is one of the main factors structuring Nematoda assemblages (see Giere, 2009 for review). In tropical areas, lower values found in the upper beach zones can be considered a response to desiccation, since these organisms are under the influence of high temperatures throughout the year (Baia and Venekey, 2009), therefore, only more tolerant genera remain in this part of the beaches. However, we can also attribute the low values found in this zone (corresponding to the upper SS) in Atalaia and Farol-Velho to the intensity of recreational activities, since there were no high differences between this and the other SS in the Corvinas, even during Vacation. Our results corroborate those found by Gheskiere et al. (2005), who observed that the more tourist upper zones had lower density and diversity values than the non-tourist lower zones.

Overall, the severity of these direct impacts in the study beaches appears to be mainly dependent on sand compactness, since the lowest densities were found at high compaction sites (>20 kg.f/cm²), observed mostly in the upper SS of Atalaia and Farol-Velho during Vacation. Several studies have shown that a high number of vehicles (*e.g.* Schlacher and Thompson, 2007, 2008) and beachgoers (*e.g.* Schlacher and Thompson, 2012; Reyes-Martines, et al., 2015; Machado et al., 2017) can affect a wide array of physical habitat properties, including the sand compactness (Bonte and Maes, 2008; Schlacher et al., 2011; Thompson and Schlacher, 2008). Higher compaction reduces the space among sediment grains, and by increasing resistance to fluid (gases and liquid) displacement, creating a physical barrier that affects air exchange and water/hydraulic conductivity between sediment interstices and substances resulting from biological processes (Leatherman, 1988; Van der Merwe, 1988). For example, a previous study by Weslawski et al. (2000) on a Baltic tourist beach showed that one square meter receives more than 100 human steps daily during high summer season and this activity reduces soil macro-porosity, air/water permeability, it changes sediment topography, and disturbs the sand almost continuously.

Overall, no great differences in the trophic structure were detected considering periods among beaches and SS, except in the After 1 period in the Atalaia and Farol-Velho, where epigrowth feeders (2A) were the most abundant group related to the high abundance of *Paracyatholaimus*. Non-selective deposit feeders (1B) were the dominant group in the study and this dominance is related to the high abundance of *Daptonema* (Xyalidae) and sediment grain size (fine sand). Several studies have shown the dominance of Xyalidae in environments with fine to medium sand (Nicholas and Hodda, 1999; Gheskiere et al., 2004; Hourston et al., 2005; Moreno et al., 2006; Santos and Venekey, 2017), which are sediment characteristics also found in our study beaches. On the other hand, higher abundance of others trophic guilds (*i.e.* predator: 2B) were found in Corvinas, especially at the high-SS. These results suggest that beaches with lower recreational activities are more complex (with higher trophic levels), than urbanized beaches (Reyes-Martínez et al., 2014). These differences in study areas might be related to the %OM. In general, great amount of %OM (*i.e.* wreck debris) on pristine beaches is found in upper beach near the dune system (Wall et al., 2002). However, a considerably lower amount of marine and terrestrial debris was found in the Atalaia and Farol-Velho in our study (personal observation), and this is probably due the intensive use of the upper zones by higher number of houses and commercial establishments (*e.g.* bars, restaurants; Sousa et al., 2013). Therefore, low %OM and a lack of suitable niches to support rich Nematoda assemblages are indicative of a stressed or resource-limited environment (Wall et al., 2002).

Disturbances differ mostly in length and intensity of impacts and are commonly classified as either pulse or press disturbance (Glasby and Underwood, 1996; Lake, 2000). The recreational activities observed on Amazonian beaches can be classified as pulse disturbances since they are strongly concentrated in short periods of time (Pessoa et al., 2013; Sousa et al., 2011, 2014). Pulse disturbances can produce either a pulse or a press response in the community (Glasby and Underwood, 1996; Bravo et al., 2015). In this regard, recreational activities on Amazonian sandy beaches seemed to be causing a discrete pulse disturbance affecting the high intertidal community during Vacation, but organisms recovered to their initial condition (before period) soon after Vacation (*i.e.* After 1 period). Thus, although meiofauna community and Nematoda assemblage showed high susceptibility to recreational activities, they also showed high resilience. Probably the natural characteristics of the beaches (Carr, 2000) and the biological characteristics of meiofauna (Giere, 2009) contributed to maintaining community resilience and allowed for a rapid recovery.

Recovery depends not only on cessation of the disturbance at the end of vacation, but also on enough time for recruitment and growth of the species that were affected (Schiel and Taylor, 1999). Clarke and Warwick (2001) suggested that benthic communities that have been disturbed might switch to an early successional stage community (colonizers) with low species diversity, consequently resulting in an assemblage of opportunistic species with close taxonomic affinities. Looking at Nematoda trophic groups, it seems that this stage started with high abundance of epigrowth feeders in the After 1 period (increased *Paracyatholaimus*), a process which occurred at the same time as the decrease in non-selective deposit feeders, particularly *Daptonema*. Non-selective deposit feeders ingest a variety of different sized particles (Moens and Vincx, 1997). This variety may range from individual bacteria to larger inorganic particles with bacteria attached, which renders them good competitors for resources. Initially with higher abundances, deposit feeders gave way to *Cromadorita* and *Paracyatholaimus* after the disturbance, indicating the recover ability of these genera.

5.Conclusion

Although there are obvious difficulties in comparing locations, habitats, systems and methodological approaches, the results reported in this study showed a similar pattern to those found in previous studies evaluating the effect of recreational activities on sandy beaches as well as in other coastal environments. Thus, the initial hypothesis that recreational activities trigger changes in the structure and composition of meiofauna and Nematoda, thus reducing richness and abundance of the community, was confirmed. Furthermore, the vulnerability of some taxa studied here, particularly Copepoda and Tardigrada, and the Nematoda genera *Chromadorita* and *Daptonema* indicates that they might be potential indicators of recreational activities.

This study shows that the development of several recreational activities causes adverse changes in meiobenthic community and nematode assemblages. In addition, the negative impacts of recreational activities on major meiofauna groups and Nematoda genera should draw attention to the potential effects of this type of human disturbance on other taxonomic or ecological groups and to its consequences on ecological and economic services provided by sandy beaches.

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Conflict of interest

The authors declare that they have no conflicts of interest.

CRediT authorship contribution statement

Thuareag Monteiro Trindade dos Santos: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Marcelo Petracco:** Conceptualization, Methodology, Resources, Writing - review & editing. **Virág Venekey:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition.

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Appendix 1

PHYLUM NEMATODA

CLASS ENOPLEA

SUBCLASS ENOPLIA

ORDER ENOPLIDA

Suborder Enoplina

Superfamily Enoploidea

Family Thoracostomopsidae

Enoplolaimus de Man, 1893

Mesacanthion Filipjev, 1927

Paramesacanthion Filipjev, 1927

Family Anoplostomatidae

Anoplostoma Bütschli, 1874

Family Anticomidae

Cephalanticoma Platonova, 1976

Suborder Oncholaimina

Superfamily Oncholaimoidea

Family Oncholaimidae

Filoncholaimus Hopper, 1967

Oncholaimus Dujardin, 1845

Oncholaimellus de Man, 1890

Marilynnia

Metoncholaimus Filipjev, 1918

Viscosia De Man, 1890

Suborder Irinina

Superfamily Ironoidea

Family Ironidae

Dolicholaimus

Syringolaimus de Man, 1888

Thalassironus De Man, 1889

Trissonchulus Cobb, 1920

Family Oxystominidae

Halalaimus De Man, 1888

Nemanema

Oxystomina Filipjev, 1921

Thalassoalaimus

Suborder Tripyloidina

Superfamily Tripyloidoidea

Family Tripyloididae

Bathylaimus Cobb, 1894

Tripyloides

ORDER TRIPLONCHIDA

Suborder Tobrilina

Superfamily Tobriloidea

ORDER MONONCHIDA

Suborder Mononchina

Superfamily Mononchoidea

CLASS CHROMADOREA

SUBCLASS CHROMADORIA

ORDER CHROMADORIDA

Suborder Chromadorina

Superfamily Chromadoroidea

Family Chromadoridae

Chromadora Bastian, 1865

Chromadorita Filipjev, 1922

Innocuonema Inglis, 1969

Spilophorella Filipjev, 1917

Family Cyatholaimidae

Cyatholaimus Bastian, 1865

Longicyatholaimus Micoletzky, 1924

Marylynnia Hopper, 1977

Metacyatholaimus Stekhoven, 1942

Paracyatholaimus Micoletzky, 1942

Paralongicyatholaimus Stekhoven, 1942

Pomponema Cobb, 1917

Family Selachinematidae

Gammanema Cobb, 1920

Latronema Wieser, 1954

ORDER DESMODORIDA

Suborder Desmodorina

Superfamily Desmodoroidea

Family Desmodoridae

Chromaspirina Filipjev, 1918

Metachromadora Filipjev, 1918

Molgolaimus Ditlevsen, 1921

Spirinia Gerlach, 1963

Zalonema Cobb, 1920

Family Microlaimidae

Microlaimus de Man, 1880

Family Monoposthidae

Nudora Cobb, 1920

ORDER DESMOSCOLECIDA

Superfamily Desmoscolecoidea

ORDER MONHYSTERIDA

Suborder Monhsyterina

Superfamily Monhysteroidea, 1947

Family Xyalidae

Amphimonhystera Allgén, 1929

Cobbia De Man, 1907

Daptonema Cobb, 1920

Gonionchus Cobb, 1920

Ormicronema Cobb, 1920

Paramonohystera Steiner, 1916

Prorhynchonema Gourbault, 1982

Retrotheristus

Rhynchonema Cobb, 1920

Scaptrella Cobb, 1917

Stylotheristus Lorenzen, 1977

Theristus Bastian, 1865

Xyala Cobb, 1920

ORDER ARAEOLAIMIDA

Superfamily Axonolaimoidea

Family Axonolaimidae

Ascolaimus Ditlevsen, 1919

Axonolaimus de Man, 1889

Odontophora Bütschli, 1874

Synodontium

Family Comesomatidae

Dorylaimopsis Ditlevsen, 1918

Vasostoma

Family Diplopeltidae

Araeolaimus Timm, 1961

Family Aegialoalaimidae

Cyartonema

ORDER PLECTIDA

Superfamily Leptolaimoidea

Superfamily Ceramonematoidea

Family Ceramonematidae

Ceramonema Cobb, 1920

Metadasynemoides Haspeslagh, 1973

Pselionema Cobb, 1933

Supplementary material

Supplementary material 1. Environmental characteristics of the study areas. Different letters indicate significant differences (*p*<0.05).

Supplementary material 2. Mean meiofauna community density (inds. /m² ± SE) in the study area.

Supplementary material 3. Results of the PERMANOVA pairwise tests for meiofauna community and Nematoda assemblage structure among study areas and periods.

Supplementary material 4. SIMPER analysis results showing the dissimilarity of the major meiofauna groups that most contributed with samples between study areas and periods.

Supplementary material 5. SIMPER analysis results showing the dissimilarity of the Nematoda genera that most contributed to the samples between study areas and periods

Supplementary material 1. Environmental characteristics of the study areas. Different letters indicate significative differences (*p*<0.05).

		Atalaia							**Farol-Velho**							**Corvinas**						
		A	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Organic Matter %	**B**	0.009±0.010 **a**	0.024±0.011 **a**	0.039±0.015 **a**	0.030±0.005 **a**	0.053±0.043 **a**	0.132±0.07 **a**	0.118±0.05 **a**	0.037±0.011 **a**	0.042±0.007 **a**	0.050±0.003 **a**	0.052±0.003 **a**	0.085±0.001 **a**	0.259±0.241 **b**	0.260±0.218 **b**	0.033±0.005 **a**	0.039±0.001 **a**	0.052±0.009 **a**	0.053±0.005 **a**	0.062±0.016 **a**	0.081±0.019 **a**	0.189±0.125 **b**
	V	0.01±0.01 **a**	0.009±0.004 **a**	0.043±0.007 **a**	0.0313±0.003 **a**	0.016±0.001 **a**	0.040±0.016 **a**	0.051±0.029 **a**	0.003±0.001 **a**	0.016±0.007 **a**	0.033±0.002 **a**	0.036±0.004 **a**	0.040±0.008 **a**	0.052±0.006 **a**	0.279±0.052 **b**	0.025±0.016 **a**	0.029±0.004 **a**	0.040±0.001 **a**	0.044±0.001 **a**	0.049±0.007 **a**	0.053±0.003 **a**	0.073±0.016 **a**
	A1	0.041±0.005 **a**	0.029±0.003 **a**	0.040±0.010 **a**	0.054±0.001 **a**	0.066±0.009 **a**	0.076±0.007 **a**	0.071±0.012 **a**	0.045±0.001 **a**	0.046±0.004 **a**	0.052±0.006 **a**	0.053±0.016 **a**	0.068±0.002 **a**	0.062±0.001 **a**	0.136±0.064 **a**	0.026±0.003 **a**	0.046±0.007 **a**	0.046±0.003 **a**	0.069±0.01 **a**	0.062±0.012 **a**	0.076±0.021 **a**	0.119±0.035 **a**
	A2	0.024±0.006 **a**	0.031±0.005 **a**	0.046±0.001 **a**	0.036±0.003 **a**	0.035±0.005 **a**	0.049±0.017 **a**	0.067±0.032 **a**	0.019±0.001 **a**	0.042±0.018 **a**	0.040±0.011 **a**	0.055±0.010 **a**	0.067±0.002 **a**	0.072±0.011 **a**	0.060±0.008 **b**	0.042±0.004 **a**	0.049±0.014 **a**	0.043±0.018 **a**	0.062±0.004 **a**	0.056±0.007 **a**	0.084±0.004 **a**	0.092±0.008 **a**
Grain Size	**B**	2.25 **a**	2.42 **a**	2.54 **a**	1.26 **a**	1.45 **a**	2.95 **a**	1.48 **a**	2.63 **a**	2.72 **a**	2.9 **a**	2.79 **a**	2.87 **a**	2.77 **a**	3.88 **a**	2.75 **a**	1.35 **a**	2.54 **a**	2.97 **a**	2.95 **a**	1.47 **a**	1.3 **a**
	V	2.22 **a**	1.98 **a**	2.17 **a**	1.03 **a**	2.01 **a**	2.53 **a**	2.58 **a**	1.29 **a**	2.58 **a**	2.79 **a**	2.71 **a**	3.05 **a**	3.28 **a**	3.09 **a**	2.69 **a**	2.68 **a**	2.79 **a**	2.54 **a**	2.52 **a**	2.53 **a**	1.3 **a**
	A1	2.15 **a**	2.29 **a**	2.28 **a**	2.22 **a**	2.38 **a**	2.44 **a**	1.25 **a**	3.15 **a**	3.15 **a**	3.02 **a**	3.02 **a**	3 **a**	1.5 **a**	3.09 **a**	2.6 **a**	2.46 **a**	2.77 **a**	2.47 **a**	3.05 **a**	1.22 **a**	1.25 **a**
	A2	2.26 **a**	2.26 **a**	2.25 **a**	2.22 **a**	2.52 **a**	2.25 **a**	1.12 **a**	2.42 **a**	2.71 **a**	2.91 **a**	2.73 **a**	1.27 **a**	1.28 **a**	2.59 **a**	2.76 **a**	2.75 **a**	2.77 **a**	2.77 **a**	2.77 **a**	2.76 **a**	2.77 **a**
Medium Sand %	**B**	6.92 **a**	11.27 **a**	4.43 **a**	0.01 **b**	2.85 **a**	0.00 **b**	5.24 **a**	1.71 **a**	1.07 **a**	1.09 **a**	1.93 **a**	1.66 **a**	0.24 **a**	0.0 **a** 0	3.90 **a**	0.83 **a**	4.43 **a**	0.00 **a**	2.82 **a**	0.00 **a**	5.09 **a**
	V	13.15 **a**	11.64 **a**	7.53 **a**	32.58 **a**	46.98 **a**	12.89 **a**	7.88 **a**	7.72 **a**	7.92 **a**	8.27 **a**	15.09 **a**	3.14 **a**	0.00 **b**	0.00 **b**	11.16 **a**	4.41 **a**	0.00 **a**	6.10 **a**	0.00 **a**	12.86 **a**	5.09 **a**
	A1	9.39 **a**	3.20 **a**	2.30 **a**	9.92 **a**	2.03 **a**	10.44 **a**	3.16 **a**	4.71 **b**	0.78 **a**	0.00 **a**	0.07 **a**	0.00 **a**	0.00 **a**	0.00 **a**	1.13 **a**	1.55 **a**	0.00 **a**	0.00 **a**	0.00 **a**	1.33 **a**	2.46 **a**
	A2	1.70 **a**	0.52 **a**	0.39 **a**	1.24 **a**	6.46 **a**	1.17 **a**	2.87 **a**	3.04 **a**	1.77 **a**	1.47 **a**	1.25 **a**	2.45 **a**	1.88 **a**	2.76 **a**	2.13 **a**	0.36 **a**	0.25 **a**	1.23 **a**	2.37 **a**	1.15 **a**	2.85 **a**
Fine Sand %	**B**	93.08 **a**	88.73 **a**	95.10 **a**	99.99 **a**	62.82 **a**	59.70 **b**	84.18 **a**	89.61 **a**	87.81 **a**	83.84 **a**	72.46 **a**	71.77 **a**	62.86 **a**	40.72 **b**	89.11 **a**	93.45 **a**	95.10 **a**	61.32 **a**	62.15 **a**	59.04 **a**	81.83 **a**
	V	86.85 **a**	86.00 **a**	92.47 **a**	64.01 **a**	53.02 **a**	76.87 **a**	81.83 **a**	92.28 **a**	87.72 **a**	35.53 **b**	82.57 **a**	23.29 **b**	39.26 **b**	60.83 **a**	86.34 **a**	93.23 **a**	72.53 **a**	91.37 **a**	97.10 **a**	76.90 **a**	81.83 **a**
	A1	90.61 **a**	95.58 **a**	79.70 **a**	0.08 **b**	99.69 **a**	88.53 **a**	94.54 **a**	12.22 **a**	17.71 **a**	19.61 **a**	44.10 **a**	48.76 **a**	48.75 **a**	33.51 **a**	85.87 **a**	90.54 **a**	72.53 **a**	100.00 **a**	0.00 **b**	88.67 **a**	94.17 **a**
	A2	93.58 **a**	99.48 **a**	99.61 **a**	98.76 **a**	93.54 **a**	88.75 **a**	96.27 **a**	94.16 **a**	93.62 **a**	91.88 **a**	21.40 **b**	93.05 **a**	87.44 **a**	93.25 **a**	95.13 **a**	98.54 **a**	98.07 **a**	97.97 **a**	96.95 **a**	96.89 **a**	95.51 **a**
Very Fine Sand %	**B**	0.00 **a**	0.00 **a**	0.47 **a**	0.00 **a**	34.33 **b**	40.30 **b**	10.59 **a**	8.55 **a**	11.04 **a**	14.97 **a**	25.00 **a**	25.36 **a**	36.73 **a**	25.91 **a**	6.99 **a**	5.72 **a**	0.47 **a**	38.68 **a**	33.97 **a**	39.85 **a**	10.29 **a**
	V	0.00 **a**	0.00 **a**	0.00 **a**	0.52 **a**	0.00 **a**	10.24 **a**	10.29 **a**	0.00 **a**	4.36 **a**	56.20 **b**	2.34 **a**	73.57 **b**	59.77**b**	38.49 **a**b	2.50 **a**	2.37 **a**	27.47 **a**	2.53 **a**	2.90 **a**	10.25 **a**	10.29 **a**
	A1	0.00 **a**	0.00 **a**	0.00 **a**	0.00 **a**	0.28 **a**	1.03 **a**	2.31 **a**	83.07 **a**	81.51 **a**	80.39 **a**	55.84 **a**	51.24 **a**	51.25 **a**	66.4 **a** 9	0.00 **a**	7.91 **a**	27.47 **a**	0.00 **a**	8.81 **a**	1.00 **a**	3.37 **a**
	A2	4.72 **a**	0.00 **a**	0.00 **a**	0.00 **a**	0.00 **a**	10.09 **a**	0.86 **a**	2.72 **a**	4.42 **a**	6.48 **a**	7.25 **a**	4.33 **a**	10.49 **a**	3.94 **a**	0.29 **a**	0.67 **a**	1.24 **a**	0.44 **a**	0.23 **a**	1.11 **a**	0.70 **a**
Fines %	**B**	0	0	0	0	0	0	0	0.01 **a**	0.03 **a**	0.02 **a**	0.03 **a**	0.04 **a**	0.10 **a**	33.35 **b**	0 **a**	0 **a**	0 **a**	0 **a**	1.06 **b**	1.11 **b**	2.79 **b**

	V	0	0	0	0	0	0	0	0 **a**	0 **a**	0 **a**	0.67 **b**	0 **a**	0 **a**	0.28 **b**	0 **a**	0 **a**	0 **a**	0 **a**	0 **a**	0 **a**	2.79 **b**
	A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 **a**	0 **a**	0 **a**	0 **a**	1.19 **a**	0 **a**	0 **a**
	A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02 **a**	0.07 **a**	0.26 **a**	0.22 **a**	0.18 **a**	0.39 **a**	0.51 **a**
Granulometry classification	**B**	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	V.F.S	F.S	F.S	F.S	F.S/V.F.S	F.S	F.S	F.S
	V	F.S	M.S/F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	V.F.S	V.F.S	V.F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S
	A1	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S/V.F.S	F.S	F.S
	A2	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S	F.S
Sorting Classification	**B**	V.W.S	W.S / V.W. S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	W.S / V.W. S	W.S / V.W. S	W.S / V.W. S	M.S	V.W.S	V.W.S	W.S / V.W. S	M.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	W.S / V.W. S
	V	V.W.S	W.S/M.S	V.W.S	V.W.S	W.S/M.S	V.W.S	W.S	W.S	W.S	W.S / V.W. S	W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	V.W.S	V.W.S	W.S	V.W.S	W.S / V.W. S	W.S
	A1	W.S / V.W. S	W.S / V.W. S	V.W.S	V.W.S	W.S / V.W. S	W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	V.W.S	V.W.S	V.W.S	V.W.S	W.S	V.W.S
	A2	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	W.S / V.W. S	W.S / V.W. S	M.S	V.W.S	V.W.S	W.S / V.W. S	M.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S	V.W.S
Compactation (Kg.F/cm²)	**B**	13.5±0.70 **a**	15.5±0.70 **a**	14 **a**	16.5±2.12 **a**	17±1.41 **a**	15.5±0.70 **a**	15±1.41 **a**	11.5±2.12 **a**	10.5±0.70 **a**	10.5±0.70 **a**	13.5±2.12 **a**	12±1.41 **a**	13.5±0.70 **a**	12.5±2.12 **a**	4.5±0.70 **a**	5.5±0.70 **a**	5 **a**	6±1.41 **a**	9±1.41 **a**	10.5±0.70 **a**	11±1.41 **a**
	V	19±1.41 **a**	20 **a**	15.5±0.70 **a**	15.5±0.70 **a**	18.5±2.12 **a**	16.5±0.70 **a**	16 **a**	20 **a**	20 **a**	17±1.41 **a**	14.5±0.70 **a**	11.5±2.12 **b**	16±1.41 **a**	14±1.41 **a**	12.5±0.70 **a**	12.5±2.12 **a**	16±1.41 **a**	16±2.82 **a**	16±2.82 **a**	12 **a**	13±1.41 **a**
	A1	16±1.41 **a**	16.5±0.70 **a**	14 **a**	16.5±0.70 **a**	15 **a**	15.5±0.70 **a**	17 **a**	15.5±4.94 **a**	16±2.82 **a**	15±4.24 **a**	14±1.41 **a**	14.5±0.70 **a**	14±4.2 **a** 4	14.5±2.12 **a**	7.5±0.70 **a**	6±1.41 **a**	7 **a**	10.5±2.12 **a**	12±4.24 **a**	12±1.41 **a**	12.5±2.12 **a**
	A2	14.5±0.70 **a**	16±1.41 **a**	14 **a**	14±1.41 **a**	14±2.82 **a**	13±1.41 **a**	12±2.82 **a**	13.5±3.53 **a**	14.5±0.70 **a**	13±1.41 **a**	13.5±0.70 **a**	13 **a**	13±2.82 **a**	12±2.82 **a**	7.5±3.53 **a**	6.5±2.12 **a**	8±2.82 **a**	9±1.41 **a**	10 **a**	9±1.41 **a**	11.5±0.70 **a**

***B: Before, V: Vacation, A1: After 1, A2: After 2; FS: Fine sand, V.F.S: Very fine sand, W.S: Well sorted, V.W.S: Very well sorted.**

Supplementary material 2. Mean meiofauna community density (inds. /m² ± SE) in the study area.

		Atalaia							**Farol-velho**							**Corvinas**						
		A	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Nematoda	**Before**	3.91±1.43	15.01±1.06	29.41±2.88	38.81±2.28	98.74±16.6	32.10±10.11	35.59±4.13	20.91±2.87	25.35±5.08	59.82±17.47	54.24±3.13	41.97±5.49	25.4±3.88	19.21±0.54	37.77±2.57	45.02±0.63	69.87±6.96	79.93±5.33	61.66±4.84	54.24±3.63	38.05±4.08
	Vacation	2.59±0.74	1.60±0.8	10.71±1.42	16.94±3.58	14.11±4.42	23.46±1.02	19.02±4.11	12.84±0.53	11.28±0.47	17.37±1.05	12.46±1.1	17.65±4.86	12.74±0.53	10.76±1.34	21.71±0.29	43.01±1.72	53.3±1.44	63.17±1.45	72.52±1.23	43.95±3.15	49.24±2.52
	After 1	2.28±1.46	33.8±3.15	41.87±5.39	58.92±4.99	54.57±0.85	41.73±6.66	20.39±0.81	24.97±2.61	41.54±4.09	55.33±0.94	49.15±2.63	56.09±0.94	63.73±3.03	11.59±0.49	25.35±1.68	33.28±2.76	50.84±1.22	57.36±1.02	73.04±4	45.37±5.29	27.43±1.43
	After 2	27.57±5.55	77.71±4.37	72.02±4.53	80.59±5.03	46.69±6.11	24.88±0.58	10.33±1.45	38.29±2.46	47.21±5.85	48.12±2.59	52.17±3.2	59.53±2.38	38.81±2.69	21.67±3.39	28.7±2.22	40.17±1.92	51.13±1.22	68.22±3.26	54.1±3.1	43.34±6.94	27.66±0.58
Ostracoda	**Before**	0.37±0.17	0.18±0.04	2.36±0.09	6.42±1	5.76±1.27	1.32±0.12	3.39±0.64	2.92±0.82	15.53±4.54	5.94±3.61	1.74±0.12	1.51±0.53	1.55±1.41	0.04±0.04	1.41±0.42	6.18±0.69	3.35±0.74	0.47±0.47		1.55±0.69	
	Vacation			0.33±0.26	0.37±0.37		0.09±0.09	0.14±0.08			0.56±0.32				0.09±0.09	1.69±0.49	2.54±0.49	2.88±0.57	4.43±0.2	4.62±0.53	3.11±0.43	2.45±1.04
	After 1	3.87±0.81	3.16±1.51	0.04±0.04	0.09±0.04	0.28±0.08	0.14±0.14	0.09±0.09	0.37±0.37							0.18±0.04	0.28±0.08	1.03±0.46	0.6±0.6	0.94±0.49	0.33±0.33	
	After 2	1.22±0.52	5.47±0.57	0.14±0.08	0.04±0.04		0.09±0.04	0.09±0.09			0.89±0.89					1.03±0.28	0.75±0.12	1.18±0.45	1.18±0.2	0.37±0.17	0.51±0.51	
Oligochaeta	**Before**			2.88±0.2	2.07±0.69	2.69±0.63	1.08±0.37	1.08±0.17	2.31±1.11	4.1±2.5	3.58±1.93	2.73±0.4	0.84±0.24	0.8±0.66	0.18±0.18	0.33±0.17	5±0.41	6.32±0.63	2.26±1.15	3.16±1.08	2.36±0.6	1.55±0.78
	Vacation			0.42±0.29	0.33±0.26		0.04±0.04	0.28±0.08	0.42±0.42	0.18±0.18	0.75±0.61	0.75±0.75	0.18±0.18	0.28±0.08	0.7±0.08		0.84±0.43	0.42±0.42	0.47±0.24	2.83±0.29	2.59±0.41	3.11±0.29
	After 1		0.8±0.6	0.75±0.45	1.74±0.95	1.65±0.33	0.51±0.51	0.28±0.28		0.75±0.49	0.8±0.54	0.04±0.04	0.18±0.18	0.09±0.09			0.61±0.61	0.14±0.08	1.69±0.29	1.51±0.18	0.04±0.04	
	After 2	0.28±0.14	1.88±0.37	2.78±0.75	3.39±1.51	1.41±0.86	0.70±0.21	0.8±0.23			0.09±0.09	0.42±0.14	1.32±0.33	0.66±0.46	0.18±0.18	0.23±0.23		1.08±0.54	1.03±0.49	0.61±0.12	1.13±0.72	0.18±0.18
Polychaeta	**Before**		0.04±0.04	0.09±0.09		0.23±0.23		0.23±0.12			0.09±0.09	0.04±0.04				0.09±0.04	0.18±0.12	0.28±0.16	0.23±0.23	0.51±0.17	0.37±0.18	
	Vacation														0.28±0.14					1.79±0.33	2.26±0.35	1.88±0.79
	After 1	0.09±0.09	0.09±0.04	0.14±0.08	0.14±0.14	0.09±0.09	0.04±0.04			0.04±0.04	0.23±0.04	0.04±0.04		0.04±0.04				0.09±0.09	0.04±0.04	0.51±0.17	0.33±0.33	
	After 2		0.04±0.04	0.42±0.21		0.42±0.21	0.14±0.08	0.09±0.09					0.47±0.12	0.04±0.04			0.04±0.04	0.09±0.09	0.04±0.04	0.18±0.12	0.14±0.08	0.09±0.09
Turbellaria	**Before**	1.51±0.23	11.09±1.11	3.91±0.45	4.72±0.83	7.93±2.16	2.59±1.03	1.74±0.69	0.94±0.8	0.75±0.45	2.07±1.11	1.65±0.66	1.93±1.78	0.42±0.24	0.89±0.69	4.81±0.57	5.52±0.24	7.83±0.86	4.86±0.47	5.76±1.86	3.72±0.45	3.72±0.47
	Vacation			1.08±0.2	4.43±1.81	6.46±0.97	0.84±0.21	1.08±0.41	0.75±0.49	0.09±0.09	2.17±1.19	3.87±0.69	0.42±0.24	0.42±0.42	0.33±0.2		1.41±0.78	1.51±0.85	0.42±0.42	2.07±0.33	4.01±0.33	2.64±0.36
	After 1	1.41±0.29	5.57±0.2	3.82±0.86	4.48±0.33	1.93±1.24	5.42±0.68		2.26±1.13	2.83±0.78	2.69±1.41	0.23±0.23	0.99±0.99	0.23±0.23				0.9±0.9	2.73±0.62	2.97±0.35	1.13±0.8	0.56±0.56
	After 2	1.27±0.29	5.57±0.87	1.32±1.32	5.14±0.93	3.58±1.56	0.37±0.37		0.84±0.35	1.93±1.93	0.75±0.49	1.88±0.94	1.41±0.78	1.51±0.34	0.47±0.24	0.18±0.18	3.82±0.53	2.26±1.13	3.3±0.12	3.11±0.29	0.18±0.2	0.56±0.29
Copep	**Before**		0.09±0.09	1.51±0.26	2.88±0.68	4.53±0.89	5.28±0.69	7.27±0.49				2.12±1.06	5.38±0.53	8.87±0.74	5.9±1.46	0.23±0.12		9.86±1.03	11.75±0.43	10.48±2.51	8.3±2.09	7.17±1.49
	Vacation					1.84±0.94	3.87±0.85	4.95±0.86				0.8±0.46	2.97±0.28	2.45±0.34	6.75±0.77		0.09±0.09	5.38±0.51	5.28±0.96	10±0.53	10.15±1.32	13.36±0.69

	After 1			5.24±2.04	7.03±2.13	5.24±1.08	5.57±0.49	5.99±1.42		2.97±0.57	2.92±1.49	2.59±1.51	3.11±1.84	7.03±0.66	4.2±1.53			2.88±0.61	4.81±1.06	7.93±0.61	10±0.53	9.11±0.61
	After 2			3.02±0.7	7.31±1.74	7.03±1.97	4.48±1.11	4.62±1.72		0.37±0.37	2.5931.4	4.0±0.34	8.82±1.32	8.49±1.51	4.29±1.48			3.35±1.67	6.79±1.68	7.27±1.25	9.44±1.63	8.21±0.49
Acari	**Before**	0.14±0.14		0.23±0.09			0.04±0.04		0.61±0.2	0.56±0.21	0.23±0.17	0.04±0.04		0.47±0.12		0.14±0.08	0.56±0.21	1.03±0.46	3.72±1.87		2.36±0.53	
	Vacation															0.61±0.54	0.37±0.17	0.47±0.12	0.28±0.14	0.04±0.04		
	After 1	0.23±0.12	0.37±0.17	1.36±1.02	0.28±0.14	0.37±0.04	0.18±0.18	0.04±0.04		0.09±0.09		0.42±0.42	0.04±0.04			0.28±0.08	0.51±0.28	0.51±0.51	0.28±0.28	0.47±0.26	0.18±0.12	
	After 2	0.42±0.21	3.39±0.99	0.04±0.04	0.28±0.08		0.04±0.04		0.7±0.2	0.51±0.17	2.45±0.4	0.56±0.37	0.28±0.28	0.04±0.04		0.94±0.74	1.55±0.57	2.97±1.41	0.33±0.17	0.47±0.2		
Tardigrada	**Before**	0.99±0.99	5.42±5.42	38.52±4.28	18.5±2.5	12.32±2.54	8.40±3.82	1.79±0.2	3.16±0.81	11.09±5.52	11.04±2.3	17.13±1.13	11.8±4.16	7.88±2.36	0.09±0.09	2.88±1.19	36.59±0.9	31.11±1.18	62.65±6.21	12.41±4.55	3.3±1.15	0.94±0.94
	Vacation			3.63±1.60	4.62±1.65	1.08±0.66	7.41±3.41				4.62±2.22	18.08±0.41	17.84±3.98	13.45±5.58		2.83±0.61	4.86±0.6	15.67±2.64	22.75±0.81	19.4±1.1	4.86±0.99	0.51±0.51
	After 1	4.57±0.74	21.29±1.89	29.46±2.58	23.46±5.8	6.89±1.23	4.10±0.57	0.23±0.12	3.02±0.7	4.43±0.98	22.19±0.91	18.69±0.53	7.97±2.25	1.79±0.95		3.21±0.74	7.27±0.94	29.88±5.27	24.59±2.9	20.39±3.07	7.88±2.46	0.99±0.99
	After 2	2.21±0.24	33.99±2.37	61.42±6.91	48.11±3.5	20.86±2.07	9.49±3.97		6.94±1.23	5.94±0.71	17.51±4.52	11.42±2.33	7.08±0.51	2.21±1.35		4.24±0.66	8.45±1.44	39.84±2.67	33.71±3.85	17.73±1.67	8.59±2.3	
Kinorhynca	**Before**			0.23±0.12																		
	Vacation																					
	After 1																		0.04±0.04			
	After 2																			0.04±0.04		
Gastrotrica	**Before**				0.04±0.04															0.04±0.04		
	Vacation																					
	After 1																					
	After 2																					
Rotifera	**Before**					1.41±1.41	0.51±0.38	0.09±0.09										1.46±0.53		0.0430.04	1.08±0.58	
	Vacation																					
	After 1																					
	After 2																					
Mollusca	**Before**						0.04±0.04															
	Vacation																				0.04±0.04	
	After 1										0.04±0.04											

	After 2																				
Isopoda	**Before**																0.04±0.04				
	Vacation																				
	After 1														0.04±0.04		0.04±0.04				
	After 2																0.04±0.04				
Insecta	**Before**														0.04±0.04						
	Vacation																				
	After 1															0.04±0.04					
	After 2																				

Supplementary material 3. Results of the PERMANOVA pairwise tests for meiofauna community and Nematoda assemblage structure among study areas and periods.

Meiofauna community					
Within level 'Before' of factor 'Month'			**Within level 'After 1' of factor 'Month'**		
Groups	**t**	**P(perm)**	**Groups**	**t**	**P(perm)**
Atalaia x Farol-Velho	13.182	0.215	**Atalaia x Farol-Velho**	16.257	0.089
Atalaia x Corvinas	10.972	0.284	**Atalaia x Corvinas**	10.754	0.391
Farol-Velho X Corvinas	1.727	0.083	**Farol-Velho X Corvinas**	21.661	0.021
Within level 'Vacation' of factor 'Month'			**Within level 'After 2' of factor 'Month'**		
Groups	**t**	**P(perm)**	**Groups**	**t**	**P(perm)**
Atalaia x Farol-Velho	13.029	0.159	**Atalaia x Farol-Velho**	0.83671	0.56
Atalaia x Corvinas	18.423	0.009	**Atalaia x Corvinas**	13.182	0.215
Farol-Velho X Corvinas	22.496	0.003	**Farol-Velho X Corvinas**	10.873	0.32
Nematoda assemblage					
Within level 'Before' of factor 'Month'			**Within level 'After 1' of factor 'Month'**		
Groups	**t**	**P(perm)**	**Groups**	**t**	**P(perm)**
Atalaia x Farol-Velho	40.829	0.001	**Atalaia x Farol-Velho**	33.379	0.001
Atalaia x Corvinas	60.439	0.001	**Atalaia x Corvinas**	58.987	0.001
Farol-Velho X Corvinas	40.219	0.001	**Farol-Velho X Corvinas**	66.034	0.001
Within level 'Vacation' of factor 'Month'			**Within level 'After 2' of factor 'Month'**		
Groups	**t**	**P(perm)**	**Groups**	**t**	**P(perm)**
Atalaia x Farol-Velho	38.515	0.001	**Atalaia x Farol-Velho**	26.597	0.001
Atalaia x Corvinas	41.147	0.001	**Atalaia x Corvinas**	4.675	0.001
Farol-Velho X Corvinas	44.085	0.001	**Farol-Velho X Corvinas**	49.529	0.001

Supplementary material 4. SIMPER analysis results showing the dissimilarity of the major meiofauna groups that most contributed with samples between study areas and periods.

Atalaia					**Farol-Velho**					**Corvinas**				
Comparison (Month)					**Comparison (Month)**					**Comparison (Month)**				
Before x Vacation					**Before x Vacation**					**Before x Vacation**				
Average dissimilarity = 45.92					**Average dissimilarity = 39.36**					**Average dissimilarity = 28.17**				
Species	**Before**	**vacation**	**Contrib%**	**Cum.%**	**Species**	**Before**	**vacation**	**Contrib%**	**Cum.%**	**Species**	**Before**	**vacation**	**Contrib%**	**Cum.%**
Tardigrada	3.43	1.66	19.99	19.99	Tardigrada	3.54	2.46	21.26	21.26	Copepoda	3.1	2.96	15.59	15.59
Ostracoda	2.56	0.37	16.91	36.91	Ostracoda	2.52	0.23	20.15	41.41	Tardigrada	4.03	3.66	15.59	31.18
Turbellaria	3.27	1.88	16.02	52.93	Copepoda	1.94	1.64	17.37	58.78	Turbellaria	3.58	1.93	14.61	45.79
										Ostracoda	1.77	3.04	13.56	59.35
Before x After 1					**Before x After 1**					**Before x After 1**				
Average dissimilarity = 30.89					**Average dissimilarity = 35.73**					**Average dissimilarity = 32.85**				
Species	**Before**	**After 1**	**Contrib%**	**Cum.%**	**Species**	**Before**	**After 1**	**Contrib%**	**Cum.%**	**Species**	**Before**	**After 1**	**Contrib%**	**Cum.%**
Tardigrada	3.43	3.85	18.48	18.48	Ostracoda	2.52	0.1	21.22	21.22	Turbellaria	3.58	1.36	18.41	18.41
Copepoda	2.39	2.61	16.41	34.89	Copepoda	1.94	2.44	17.38	38.6	Oligochaeta	2.67	0.96	15.56	33.97
Ostracoda	2.56	1.16	16.09	50.98	Tardigrada	3.54	3.2	16.91	55.51	Tardigrada	4.03	3.92	14.99	48.96
Before x After 2					**Before x After 2**					**Before x After 2**				
Average dissimilarity = 33.52					**Average dissimilarity = 33.39**					**Average dissimilarity = 28.51**				
Species	**Before**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**Before**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**Before**	**After 2**	**Contrib%**	**Cum.%**
Tardigrada	3.43	4.18	19.57	19.57	Ostracoda	2.52	0.14	21.6	21.6	Tardigrada	4.03	3.94	17.48	17.48
Turbellaria	3.27	1.97	15.4	34.97	Copepoda	1.94	2.55	18.24	39.84	Copepoda	3.1	2.63	16.44	33.92
Ostracoda	2.56	1.07	14.91	49.88	Tardigrada	3.54	3.25	15.98	55.83	Oligochaeta	2.67	1.17	15.21	49.13
Vacation x After 1					**Vacation x After 1**					**Vacation x After 1**				
Average dissimilarity = 45.05					**Average dissimilarity = 36.46**					**Average dissimilarity = 31.01**				
Species	**Vacation**	**After 1**	**Contrib%**	**Cum.%**	**Species**	**Vacation**	**After 1**	**Contrib%**	**Cum.%**	**Species**	**Vacation**	**After 1**	**Contrib%**	**Cum.%**
Tardigrada	1.66	3.85	22.26	22.26	Tardigrada	2.46	3.2	26.85	26.85	Ostracoda	3.04	0.99	18.69	18.69

Copepoda	1.27	2.61	18.57	40.83	Copepoda	1.64	2.44	21.91	48.75	Copepoda	2.96	2.71	17.45	36.13
Turbellaria	1.88	2.63	14.89	55.72	Turbellaria	1.43	1.37	17.21	65.97	Tardigrada	3.66	3.92	14.11	50.24
Vacation x After 2					**Vacation x After 2**					**Vacation x After 2**				
Average dissimilarity = 47.65					**Average dissimilarity = 36.99**					**Average dissimilarity = 28.76**				
Species	**Vacation**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**Vacation**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**Vacation**	**After 2**	**Contrib%**	**Cum.%**
Tardigrada	1.66	4.18	23.76	23.76	Tardigrada	2.46	3.25	24.62	24.62	Copepoda	2.96	2.63	17.84	17.84
Copepoda	1.27	2.52	17.05	40.81	Copepoda	1.64	2.55	20.91	45.53	Tardigrada	3.66	3.94	16.19	34.03
Nematoda	4.05	5.62	14.28	55.08	Turbellaria	1.43	1.7	14.95	60.48	Ostracoda	3.04	1.46	14.66	48.7
After 1 x After 2					**After 1 x After 2**					**After 1 x After 2**				
Average dissimilarity = 29.71					**Average dissimilarity = 29.47**					**Average dissimilarity = 29.43**				
Species	**After 1**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**After 1**	**After 2**	**Contrib%**	**Cum.%**	**Species**	**After 1**	**After 2**	**Contrib%**	**Cum.%**
Tardigrada	3.85	4.18	19.6	19.6	Tardigrada	3.2	3.25	22.84	22.84	Copepoda	2.71	2.63	19.32	19.32
Turbellaria	2.63	1.97	16.53	36.13	Copepoda	2.44	2.55	21.31	44.15	Tardigrada	3.92	3.94	18.07	37.39
Copepoda	2.61	2.52	16.28	52.41	Turbellaria	1.37	1.7	18.8	62.95	Turbellaria	1.36	2.26	16.79	54.18

Supplementary material 5. SIMPER analysis results showing the dissimilarity of the Nematoda genera that most contributed to the samples between study areas and periods

Atalaia					**Farol-Velho**					**Corvinas**				
Comparison (period)					**Comparison (period)**					**Comparison (period)**				
Before x Vacation					**Before x Vacation**					**Before x Vacation**				
Average dissimilarity = 58.9					**Average dissimilarity = 52.4**					**Average dissimilarity = 59.4;**				
Species	**Before**	**Vacation**	**Contrib %**	**Cum. %**	**Species**	**Before**	**Vacation**	**Contrib %**	**Cum. %**	**Species**	**Before**	**Vacation**	**Contrib %**	**Cum. %**
Daptonema	1.15	0.59	13.9	13.9	*Ascolaimus*	0.36	0.36	7.4	7.4	*Daptonema*	0.49	0.56	8.9	8.9
Cromadorita	0.54	0.31	8.4	22.4	*Prorhynchonema*	0.38	0.09	6.9	14.4	*Ascolaimus*	0.56	0.29	7.5	16.4
Paracyatholaimus	0.38	0.22	7.7	30.1	*Rhynchonema*	0.23	0.43	6.8	21.2	*Nudora*	0.11	0.41	6.7	23.2
Rhynchonema	0.22	0.35	6.6	36.7	*Daptonema*	1.12	1.21	6.5	27.7	*Cromadora*	0.17	0.45	6.7	29.9
Theristus	1.16	0.34	6.4	43.1	*Cromadorita*	0.45	0.33	6.3	34.08	*Cromadorita*	0.48	0.44	5.9	35.9
Axonolaimus	0.32	0.39	6.4	49.5	*Bathylaimus*	0.39	0.12	6.2	40.3	*Prorhynchonema*	0.35	0.21	5.4	41.3
Nudora	0.24	0.29	6.06	55.6	*Omicronema*	0.29	0.24	5.6	45.9	*Bathylaimus*	0.31	0.43	5.4	46.7
					Nudora	0.26	0.22	4.7	50.6	*Metoncholaimus*	0.26	0.19	4.6	51.3
Before x After 1					**Before x After 1**					**Before x After 1**				
Average dissimilarity = 50.5					**Average dissimilarity = 54.2**					**Average dissimilarity = 60.7**				
Species	**Before**	**After 1**	**Contrib %**	**Cum. %**	**Species**	**Before**	**After 1**	**Contrib %**	**Cum. %**	**Species**	**Before**	**After 1**	**Contrib %**	**Cum. %**
Daptonema	1.15	0.46	13.8	13.8	*Paracyatholaimus*	0.08	0.46	8.1	8.1	*Daptonema*	0.49	0.39	8.7	8.7
Paracyatholaimus	0.38	0.66	9.9	23.7	*Theristus*	0.20	0.47	7.07	15.2	*Ascolaimus*	0.56	0.18	7.7	16.4
Nudora	0.24	0.49	7.2	31	*Prorhynchonema*	0.38	0.03	6.9	22.2	*Bathylaimus*	0.31	0.63	7.5	24
Cromadorita	0.54	0.58	6.9	37.9	*Ascolaimus*	0.36	0.07	6.5	28.7	*Enoplolaimus*	0.24	0.39	6.3	30.3

Theristus	0.33	0.38	5.5	43.4	*Daptonema*	1.12	1.04	6.5	35.3	*Cromadorita*	0.48	0.65	6.1	36.4
Axonolaimus	0.16	0.31	5.5	49	*Cromadorita*	0.45	0.3	6.1	41.4	*Cromadora*	0.17	0.26	5.6	42
Rhynchonema	0.22	0.32	5.3	54.3	*Omicronema*	0.29	0.27	5.6	47	*Prorhynchonema*	0.35	0.23	5.4	47.4
					Nudora	0.26	0.47	1.3	52.5	*Thalassironus*	0.04	0.3	4.6	52.1
Before x After 2					**Before x After 2**					**Before x After 2**				
Average dissimilarity = 53.3					**Average dissimilarity = 57.2**					**Average dissimilarity = 62.8**				
Species	**Before**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**Before**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**Before**	**After 2**	**Contrib %**	**Cum. %**
Daptonema	1.15	0.94	9.2	9.2	*Daptonema*	1.12	0.6	11.1	11.1	*Daptonema*	0.49	0.63	10.9	10.9
Paracyatholaimus	0.38	0.52	9.06	18.3	*Paracyatholaimus*	0.08	0.44	8.8	20.03	*Ascolaimus*	0.56	0.12	8.4	19.3
Cromadorita	0.54	0.57	8.2	26.5	*Nudora*	0.26	0.5	7.2	27.3	*Prorhynchonema*	0.35	0.48	7.5	26.9
Bathylaimus	0.16	0.38	5.9	32.5	*Prorhynchonema*	0.38	0	6.7	34.04	*Enoplolaimus*	0.24	0.46	7.2	34.1
Ascolaimus	0.03	0.3	5.5	44.03	*Omicronema*	0.23	0.48	5.9	40.02	*Cromadorita*	0.48	0.63	7.1	41.3
Axonolaimus	0.32	0.12	5.4	49.4	*Ascolaimus*	0.36	0.22	5.6	45.7	*Bathylaimus*	0.31	0.41	5.7	47.06
Theristus	0.33	0.24	5.3	54.7	*Bathylaimus*	0.39	0.32	5.5	51.2	*Theristus*	0.18	0.2	4.3	51.4
Vacation x After 1					**Vacation x After 1**					**Vacation x After 1**				
Average dissimilarity = 58.8					**Average dissimilarity = 53.4**					**Average dissimilarity = 57.8**				
Species	**Vacation**	**After 1**	**Contrib %**	**Cum. %**	**Species**	**Vacation**	**After 1**	**Contrib %**	**Cum. %**	**Species**	**Vacation**	**After 1**	**Contrib %**	**Cum. %**
Paracyatholaimus	0.22	0.66	10.9	10.9	*Daptonema*	1.21	1.04	8.1	8.1	*Cromadora*	0.45	0.26	8.7	8.7
Nudora	0.29	0.49	7.1	18.1	*Paracyatholaimus*	0.2	0.46	8.16	16.3	*Daptonema*	0.56	0.39	8.6	17.4
Cromadorita	0.31	0.58	6.9	25.1	*Theristus*	0.2	0.47	7.3	23.7	*Bathylaimus*	0.43	0.63	6.8	24.2
Rhynchonema	0.35	0.32	6.8	31.9	*Ascolaimus*	0.36	0.07	6.7	30.4	*Nudora*	0.41	0.21	6.5	30.08
Daptonema	0.59	0.46	6.4	38.3	*Chromadorita*	0.33	0.3	6.4	36.9	*Cromadorita*	0.44	0.65	6.4	37.2
Theristus	0.12	0.38	6.3	44.7	*Nudora*	0.22	0.47	6.3	43.3	*Enoplolaimus*	0.17	0.39	5.2	42.5

Axonolaimus	0.34	0.31	6.1	50.9	*Bathylaimus*	0.43	0.32	6.3	49.6	*Ascolaimus*	0.29	0.18	4.6	47.2
					Omicronema	0.24	0.27	5.1	54.7	*Theristus*	0.45	0.45	4.5	51.7
Vacation x After 2					**Vacation x After 2**					**Vacation x After 2**				
Average dissimilarity = 61.5					**Average dissimilarity = 60.5**					**Average dissimilarity = 60.3**				
Species	**Vacation**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**Vacation**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**Vacation**	**After 2**	**Contrib %**	**Cum. %**
Daptonema	0.59	0.94	10.08	10.08	*Daptonema*	1.21	0.61	12.9	12.9	*Daptonema*	0.56	0.63	10.2	10.2
Paracyatholaimus	0.22	0.52	9.3	19.4	*Paracyatholaimus*	0.2	0.44	9.3	22.3	*Cromadora*	0.45	0.02	7.4	17.7
Cromadorita	0.31	0.57	7.6	27.02	*Nudora*	0.22	0.5	7.6	29.9	*Cromadorita*	0.44	0.63	7.2	25.02
Nudora	0.29	0.30	6.01	33.03	*Cromadorita*	0.33	0.56	7.04	36.9	*Prorhynchonema*	0.21	0.48	7.2	32.3
Axonolaimus	0.39	0.12	5.9	39	*Ascolaimus*	0.36	0.22	5.9	42.9	*Nudora*	0.41	0.14	6.4	38.7
Rhynchonema	0.35	0.1	5.9	44.9	*Theristus*	0.43	0.48	5.4	48.3	*Enoplolaimus*	0.17	0.46	6.1	44.8
Theristus	0.34	0.38	5.8	50.7	*Bathylaimus*	0.12	0.32	5.2	53.6	*Bathylaimus*	0.43	0.41	5.4	50.2
After 1 x After 2					**After 1 x After 2**					**After 1 x After 2**				
Average dissimilarity = 61.8					**Average dissimilarity = 58.7**					**Average dissimilarity = 56.2**				
Species	**After 1**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**After 1**	**After 2**	**Contrib %**	**Cum. %**	**Species**	**After 1**	**After 2**	**Contrib %**	**Cum. %**
Daptonema	0.46	0.94	10.3	10.3	*Daptonema*	0.39	0.61	9.2	9.2	*Daptonema*	0.39	0.63	11.1	11.1
Paracyatholaimus	0.66	0.52	10.2	20.6	*Paracyatholaimus*	0.08	0.44	8.3	17.6	*Bathylaimus*	0.63	0.41	7.9	19.09
Nudora	0.49	0.3	7.07	27.7	*Bathylaimus*	0.63	0.32	8.1	25.7	*Prorhynchonema*	0.23	0.48	7.7	26.8
Rhynchonema	0.32	0.1	5.6	33.3	*Nudora*	0.21	0.5	7.1	32.8	*Cromadorita*	0.65	0.63	6.8	33.6
Cromadorita	0.58	0.57	5.6	39.04	*Enoplolaimus*	0.39	0.05	6.09	38.9	*Enoplolaimus*	0.39	0.46	6.7	40.3
Theristus	0.38	0.24	5.5	44.5	*Cromadorita*	0.65	0.56	5.6	44.6	*Cromadora*	0.26	0.02	4.9	45.3
Ascolaimus	0.31	0.38	5.3	49.9	*Thalassironus*	0.3	0	5.1	49.7	*Thalassironus*	0.3	0.1	4.8	50.2
Oncholaimus	0.31	0.21	5.3	55.2	*Metoncholaimus*	0.26	0.28	4.7	54.5					

Conclusões gerais

O presente estudo buscou preencher algumas das lacunas de conhecimento na ecologia de praias arenosas, de modo a incentivar a elaboração de políticas direcionadas para o manejo e conservação desse ecossistema. Em síntese, populações de praias arenosas têm sido negativamente afetadas pelos impactos oriundos das atividades recreativas, evidenciando a vulnerabilidade da macrofauna (capítulo 1) assim como da meiofauna e nematofauna (capítulo 2).

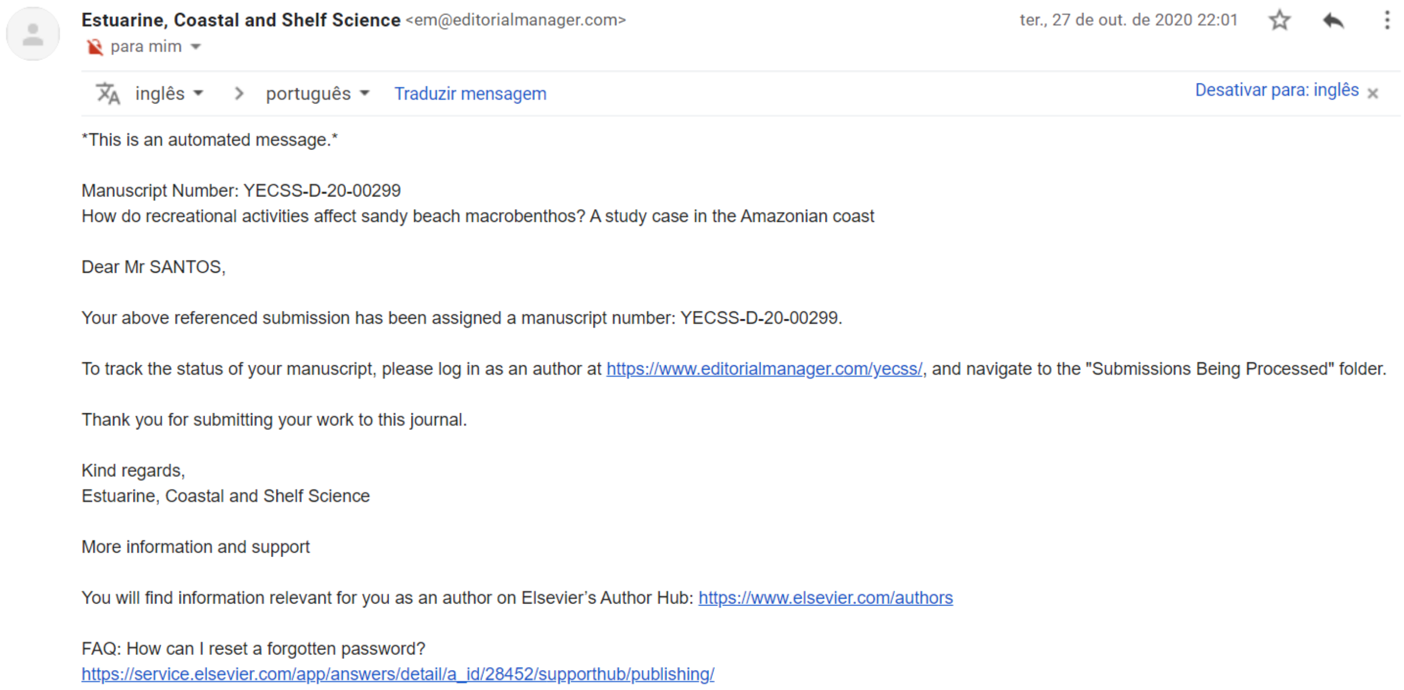
A macrofauna apresentou uma drástica redução na densidade e na riqueza, principalmente nos setores que recebem grande fluxo de turistas durante a alta temporada em julho (praias do Atalaia e Farol-Velho). Essa redução foi ainda maior nas áreas superiores da região de entremarés dessas praias, onde ocorre a maior concentração de carros e banhistas, assim como os maiores valores de compactação do sedimento. Por outro lado, a praia das Corvinas (setor com menor fluxo de turistas) permaneceu sem grandes alterações durante todo o estudo. Nesse estudo também foi possível observar uma possível recuperação da fauna 2 meses após a alta temporada. Além disso, a vulnerabilidade dos poliquetas *Scolelepis squamata* e *Paraonis* sp. às atividades recreativas encontradas no estudo, indica que eles possam ser potenciais indicadores de impactos recreativos nesse ambiente.

Assim como a macrofauna, tanto meiofauna quando a nematofauna apresentaram uma drástica redução na densidade e na riqueza principalmente nas praias do Atalaia e Farol-Velho durante o período de alta temporada, principalmente nas regiões mais superiores da região do entremarés. Entretanto, diferentemente da macrofauna, foi possível verificar uma recuperação da fauna apenas 1 mês após o período de alta temporada. Além disso, Copepoda, Tardigrada e os gêneros de Nematoda, *Daptonema* e *Chromadorita* apresentaram vulnerabilidade às atividades recreativas e podem ser usados como potenciais indicadores de impactos ambientais.

Os resultados desse estudo reforçam a importância de estabelecer e implementar ações efetivas de manejo para mitigar as consequências das atividades recreativas em praias arenosas da região amazônica. Investimentos em estratégias de manejo e conservação são essenciais, em particular no que se refere à: (1) desenvolvimento de áreas protegidas com uso e acesso restritos; (2) o controle do número de visitantes e de veículos nessas áreas, assim como a sua descentralização; (3) implementação de atividades educacionais sobre preservação e uso do meio ambiente para os visitantes e para a os habitantes dessas áreas.

O incremento do conhecimento acerca desta temática contribui diretamente para o avanço da ciência e gestão das praias. Para conservar a biodiversidade e as características ecossistêmicas das praias, a gestão costeira deve incorporar de maneira progressiva todos os aspectos ecológicos desse ambiente (que são ignorados) e não só se concentrar em manter as características físicas desse ambiente em condição para uso pelo ser humano (Reyes-Martinez, 2014). Além disso, é essencial que a sociedade se conscientize que a degradação das praias não acarreta apenas na perda de um habitat e/ou das espécies que habitam, mas sim também na perda dos bens e serviços que todos os elementos desse ambiente, assim como as suas relações e funcionamento, fornecem para o bem estar humano (Millenium Ecosystem Assesment, 2005).

Anexo 1 – Comprovante de Submissão do Capítulo 1



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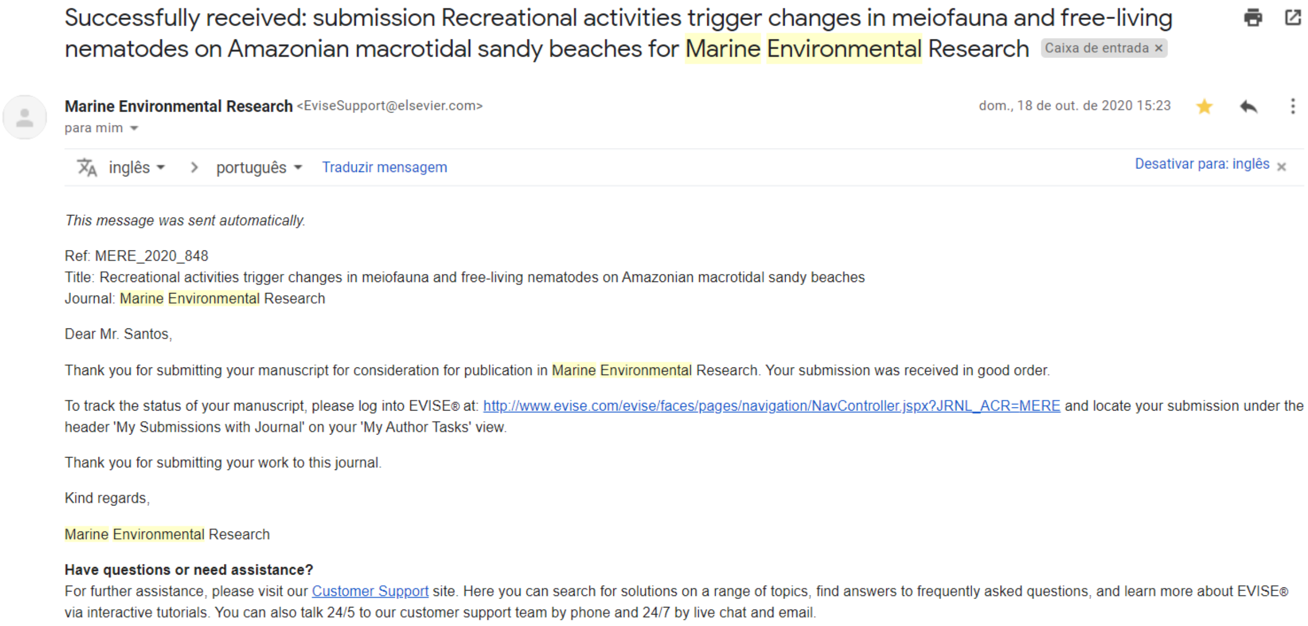

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