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PRISCILLA DE OLIVEIRA GOMES DOS SANTOS

Estudo dos caranguejos chama-maré (Decapoda: Gelasiminae) em um manguezal altamente impactado por resíduos sólidos macroscópicos

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Resumo

Os manguezais prestam uma infinidade de serviços ecossistêmicos, inclusive servindo de habitat para uma grande variedade de organismos. Neste ecossistema, os caranguejos chama-maré (Decapoda: Gelasiminae) desempenham um papel fundamental. A poluição dos ecossistemas de manguezais por detritos marinhos tem causado sérios impactos, que vão desde a mortalidade da fauna devido ao emaranhamento e ingestão de lixo, até a obstrução do substrato e o soterramento de tocas. Como há escassez de pesquisas sobre o efeito do lixo marinho macroscópico nos caranguejos de manguezais, o objetivo deste estudo foi avaliar como o lixo marinho afeta os caranguejos chama-maré. O estudo foi realizado em três etapas, considerando (a) o ambiente sem intervenção, (b) o efeito da remoção do lixo marinho macroscópico e (c) o efeito do retorno do lixo marinho. Além dos parâmetros relacionados aos caranguejos-violinistas, foi avaliada a flutuação na cobertura do substrato pelo lixo marinho. O presente estudo empregou quadrados medindo 3,0 x 3,0 m dentro da zona entremarés, considerando áreas controle (sem intervenções), áreas que passaram por limpeza e depois cercadas por barreiras para resíduos flutuante e áreas após retiradas das barreiras, com retorno progressivo dos resíduos. Os caranguejos foram analisados pelo método de captura e soltura ao longo de seis campanhas entre 2023 e 2025. A avaliação da cobertura do substrato pelo lixo marinho foi realizada através da utilização de fotos e de tratamento pelo software CPCe. A porcentagem de cobertura do substrato pelo lixo marinho variou de 1,18 ± 0,52% a 41,7 ± 6,16%. A densidade do lixo marinho variou de 2,78 a 7,56 itens por m², com predominância de materiais plásticos. A eliminação do lixo marinho levou a um aumento significativo na densidade populacional de caranguejos do gênero *Minuca*. Mesmo após a remoção das barreiras e retorno dos resíduos, esse aumento manteve-se perceptível.

Palavras-chave: *Minuca*, *Minuca rapax*, plástico, Sudeste do Brasil, Baía de Guanabara

Abstract

Mangroves provide a multitude of ecosystem services, including serving as a habitat for a diverse array of organisms. In this ecosystem, fiddler crabs (Decapoda: Gelasiminae) play a pivotal role. The pollution of mangrove ecosystems by marine debris has had serious impacts, ranging from the mortality of fauna due to entanglement and ingestion of litter, to the obstruction of the substrate and the burying of burrows. Since there is a paucity of research on the effect of macroscopic marine litter on mangrove crabs, the aim of this study was to evaluate how macroscopic marine litter affects fiddler crabs. The study was conducted in three treatments, considering (a) the environment without intervention, (b) the effect of removing marine macro litter, and (c) the effect of returning marine litter. This study used 3.0 m x 3.0 m squares within the intertidal zone, considering control areas (without interventions), areas that underwent cleaning and were then surrounded by barriers for floating litter, and areas post barriers were removed, with progressive return of litter. The crabs were analyzed using the capture and release method over six campaigns between 2023 and 2025. In addition to parameters related to fiddler crabs, fluctuations in substrate coverage by marine litter were evaluated. The present study employed quadrats measuring 3.0 m x 3.0 m within the intertidal zone. The crabs were analyzed by the catch and release method. The evaluation of substrate coverage by marine litter was conducted through the utilization of photos and treatment by the software CPCe. The percentage of substrate coverage by marine litter ranged from 1.18 ± 0.52% to 41.7 ± 6.16%. The abundance of marine litter ranged from 2.78 to 7.56 items per m², with a predominance of plastic materials. The removal of marine litter led to a significant increase in the population abundance of crabs of the genus *Minuca*. even post barriers were removed and the waste returned, this increase remained noticeable.

Keywords: *Minuca*, *Minuca rapax,* plastic, Southeast Brazil, Guanabara Bay

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1. Introdução

Características dos Manguezais

O termo manguezal refere-se à agregação de árvores de mangue localizadas nas zonas de marés ao longo da costa (Lee e Yeh, 2009). Este ecossistema é determinado por sistemas ecológicos costeiros tropicais e subtropicais que ocorre entre a transição dos ambientes terrestres e marinhos, abrigado por rios que compreendem um sistema estuarino de menor ou maior complexidade (Souza et al., 2018). Os manguezais ocorrem no litoral de mais de 120 países, e estão distribuídos pelos continentes das Américas, Oceania, África e Ásia, acredita-se que este ecossistema ocupa uma área de aproximadamente 145 mil km^2 hectares nas regiões tropicais e subtropicais do planeta (Wilkie et al., 2003; Jia et al., 2023). Neste sentido, cerca de dois terços dos manguezais estão concentrados em 8 países: na Austrália, Bangladesh, Brasil, Índia, Indonésia, Malásia, México e Papua Nova Guiné (Souza et al., 2018). Dando um foco no Brasil, as florestas de manguezais cobrem uma extensão em território brasileiro do Estado do Amapá (04° N50° W) até o Estado de Santa Catarina (28° S 48° W) possuindo uma área de 1.141.478,85 hectares (Schaeffer-Novelli et al., 1990; Amaral et al., 2025). Esses estados apresentam condições ideais para o desenvolvimento dos manguezais, já que possuem alta umidade, a presença de diversos rios que transportam e depositam matéria orgânica, um regime de marés alta e apresentam temperatura média acima de 20°C (Diniz et al., 2019). Outro fator importante é a alta intensidade de precipitações sobre a evapotranspiração potencial favorecendo a maior cobertura de florestas de mangue no Brasil (Schaeffer-Novelli et al., 1990; Souza et al., 2018). Também são caracterizados por sua vegetação lenhosa típica, adaptada às condições limitantes de salinidade,

substrato inconsolidado e com pouco oxigênio e com frequente ação das marés (Adame et al., 2020; Ahmed et al., 2022).

As características estruturais e funcionais dos ecossistemas de manguezal são determinadas pela interação de diversos fatores que atuam em escalas globais, regionais e locais, como a radiação solar, o aporte de água doce e de nutrientes, além da energia das marés (Soares et al., 2003). Um fator que favorece a existência desses ecossistemas é a baixa intensidade das correntes, resultantes da ação dos ventos e das marés, o que permite que as árvores de mangue se fixem no solo e alcancem grandes alturas (Vannucci, 1999). Outro aspecto relevante é a temperatura dos oceanos, uma vez que os manguezais se desenvolvem em regiões onde a temperatura da água se mantém acima de 20° C (Vannucci, 1999; Correia e Sovierzoski, 2005).

As feições dos manguezais são compostas por três zonas: continuum, mangue e apicum. O continuum é caracterizado por possuir bancos de sedimentos lamosos ou arenosos-lamosos desprovidos de vegetação e é constantemente inundado pela maré. Na zona dos mangues, são encontrados os bosques de mangue que possuem vegetação lenhosa do tipo arbórea típica desse ecossistema. Por fim, o apicum corresponde a uma planície hipersalina, raramente inundada, sendo atingida durante as preamares de sizígia (Bullock et al., 2017).

O substrato dos manguezais é hidromórfico composto por lama, silte, com concentrações variáveis de areia, baixo teor de oxigênio, rico em matéria orgânica em decomposição e sob variações de salinidade (Daris et al., 2023). A predominância destes componentes no solo está atrelada à origem do ecossistema e da interação da água dos rios e do mar (Correia e Sovierzoski, 2005; Souza et al., 2018). Neste contexto, a taxa de salinidade do solo é determinada pelas inundações, ou seja, pelo aporte de água salgada que avança em direção ao continente e da direção de água doce dos rios que escoa para o mar (Correia e Sovierzoski, 2005; Souza et al., 2018).

Desta forma, certas características do solo dos manguezais tornam a sobrevivência dos indivíduos, tanto a fauna quanto a flora, dependente de adaptações específicas paras as condições ambientais consideradas inóspitas (Farnsworth, 2000). O solo dos manguezais é bem característico por possuir baixa oxigenação, alta salinidade, associado às elevadas temperaturas, deficiência de nutrientes e alta concentração de Sulfeto de hidrogênio (H_2S), resultando em um odor de putrefação (McKee et al., 1988; Lyimo e Mushi, 2007). Assim, para se adaptar a este ambiente, árvores de mangue preto desenvolveram raízes especializadas que se projetam para fora do sedimento, em direção a atmosfera, para conseguir uma maior captação de oxigênio (Souza et al., 2018).

Importância dos manguezais

O manguezal é um ecossistema costeiro de grande importância devido às suas funções eco-essenciais. Possuem alta capacidade de sequestro e estocagem de carbono tanto em sua biomassa, como nas árvores, folhas, raízes, quanto, principalmente, no solo, podendo chegar a 70% de carbono estocado (Alongi, 2014). Desta forma, o aumento da quantidade de árvores de mangue é de extrema importância já que podem acumular cerca de 2.000 de toneladas por hectare em áreas maduras considerando a biomassa aérea quanto a cobertura do solo (Kauffman et al., 2020). Assim, consequentemente as florestas de mangue desempenham um papel fundamental na mitigação das mudanças climáticas e principalmente do aquecimento global (Mattos-Fonseca, 2005).

Eles funcionam como filtro biológico natural, contribuindo na manutenção da qualidade da água, já que conseguem reter partículas e poluentes presentes na água (Cui et al., 2023). Esse processo ocorre, em grande parte, pela ação de sulfobactérias que decompõem a matéria orgânica, gerando um ambiente anóxico, ocorrendo a

redução do sulfato, consequentemente se tem a produção de sulfetos que conseguem precipitar metais pesados, permitindo a purificação (Muyzer e Stams, 2008).

Os ecossistemas manguezais são altamente produtivos, eles são responsáveis pela geração de matéria orgânica primária que é essencial para a manutenção da biodiversidade, já que ela é decomposta por bactérias e fungos presentes no sedimento, que os transformam em nutrientes essenciais para a base da cadeia alimentar contribuindo para o funcionamento do ecossistema (Komiyama et al., 2008).

Desempenham um papel crucial na proteção da linha de costa através do seu sistema radicular denso que atua como barreira contra as ondas, marés, o vento, radiação solar UV-B e processos erosivos. As raízes das árvores de mangue promovem a compactação do sedimento nas margens inibindo o fluxo das marés, consequentemente, diminuindo a força das ondas que atingem a costa (Mori et al., 2022; Weaver e Stenho, 2024). Um exemplo da função protetiva por este ecossistema ocorreu em 2004 quando um terremoto de magnitude de 9,1 resultou na morte de 226 mil pessoas nos países Indonésia, Sri Lanka e Tailândia. Estudos apontaram que nas regiões com florestas de manguezais os danos foram significativamente minimizados já que as florestas absorvem o impacto das ondas (Inoue et al., 2007).

São considerados como áreas de proteção para diversas espécies que buscam alimento, abrigo e local para repouso e berçários naturais porque diversos organismos utilizam esse ambiente para a reprodução e desenvolvimento inicial de suas proles (Kathiresan e Bingham, 2001). E é importante citar que as espécies podem ser classificadas em dois tipos: os residentes que passam todo o seu ciclo de vida no manguezal ou transitória, que utilizam esse ecossistema apenas para determinada fase do seu desenvolvimento, como em sua reprodução ou para o crescimento de juvenis (MacFarlane e Burchett, 1999; Souza et al., 2018).

Segundo Kathiresan e Bingham (2001), os manguezais são essenciais para o desenvolvimento socioeconômico em razão dos diversos serviços ecossistêmicos avaliados entre USD 2.000 a USD 9.000 por hectare ao ano. Isto ocorre porque este

ecossistema fornece recursos de alto valor econômico como lenha, carvão vegetal, madeira e mel. Além disso, é importante explicitar que são fonte de alimentos, remédios, materiais de construção e combustível (Pedrosa, 1963; Corrêa, 1984; Citroen, 1987; Vanucci, 1999). Por fim, também desempenham um papel essencial na subsistência de comunidades pesqueiras fornecendo peixes, crustáceos e moluscos, importantes para o consumo local e para a geração da própria renda (Carrasquilla-Henao e Juanes, 2016).

Fauna e Flora dos manguezais

A fauna e a flora dos manguezais variam de acordo com a estrutura e composição do ecossistema, ou seja, de acordo com a variação dos fatores hidrográficos, geológico, geográficos, físicos, climáticos e da influência antrópica (Wang et al., 2020; Yudha et al., 2021). Em relação a sua flora, as plantas presentes neste ambiente são classificadas como heliófilas, ou seja, preferem ambientes com alta incidência solar e são capazes de sobreviver a climas quentes e secos. Além disso, essas espécies possuem adaptações específicas para lidar com condições inóspitas como: suportar baixas concentrações de oxigênio no sedimento, salinidade elevada na água, sendo classificadas como plantas halófitas, e substrato lodoso característico dos manguezais (ICMBIO, 2018).

Apesar da sua vegetação ser um dos fatores mais marcantes dessas florestas, eles apresentam baixa riqueza florística, com poucas espécies típicas ocorrendo. No Brasil são registradas entre três e sete espécies típicas de mangue (Mori et al., 2010; Souza, 2018). No Estado do Rio de Janeiro, especialmente na Baía de Guanabara são encontradas árvores de *Rhizophora* (mangue vermelho), *Avicennia* (mangue preto) e *Laguncularia* (mangue branco) (Santos et al., 2024).

Rhizophora é um gênero que possui três espécies*: R. mangle*, *R. racemosa* e *R. harrisonii* (Tsuji e Fernandes, 2008). O mangue vermelho, também conhecido como mangue sapateiro ou *Rhizophora mangle L.* possui este nome devido a sua casca lisa

e clara, que, por dentro, apresenta uma cor avermelhada. Essa espécie é caracterizada por raízes-escora, conhecidas como rizóforos, que desempenham um papel de estabilização das árvores, cujas suas raízes penetram o solo brotando a partir de troncos e galhos formando estruturas semelhantes a arcos. O mangue vermelho pode atingir de 10 a 20 metros de altura. Historicamente seu propágulo possuiu um valor comercial importante, já foi utilizado para tingir os tecidos de vermelho, além de ser usado também para funcionalidades antimicrobianas (ICMBIO, 2018; Souza et al., 2018).

O mangue preto, é caracterizado por possuir um tronco de cor castanho claro, apresentando no seu interior uma cor de tonalidade amarelada. Contrapondo o mangue vermelho, o mangue preto possui um sistema de raízes radial, no qual as raízes tendem a crescer na horizontal, assim, proporcionam sustentação à árvore. Estas raízes apresentam estruturas conhecidas como pneumatóforos, que se desenvolvem verticalmente e emergem do sedimento ficando expostas ao ar (ICMBIO, 2018). Esta modificação é importante porque facilita nas trocas gasosas da planta, já que o solo dos manguezais é caracterizado por conter pouco oxigenado (Allaway et al., 2001). Também é importante pontuar que essa espécie possui glândulas especializadas que secretam o excesso de sal permitindo que sobrevivam a ambientes salinos (Esteban et al., 2013).

O gênero *Laguncularia* apresenta apenas uma espécie, *Laguncularia racemosa (L.) Gaertn*, também conhecido como mangue verdadeiro ou manto. Possuem este nome devido a coloração acinzentada no seu tronco (ICMBIO, 2018). O mangue branco (*Laguncularia racemosa*) também possui pneumatóforos, uma adaptação importante devido ao alagamento constante do solo e a falta de oxigênio e adaptação para locais com alta salinidade: são glândulas chamadas de nectários extraflorais que excretam o excesso de sal nas folhas (Souza et al., 2018). Também é importante pontuar que suas folhas são características por possuírem um pecíolo vermelho (Correia e Sovierzoski, 2005). As árvores desta espécie podem atingir mais

de dez metros de altura e seu tronco é amplamente utilizado comercialmente para a construção de casas e para a produção de carvão (Silvestre, 2012).

A fauna encontrada nos manguezais não é exclusiva deste ecossistema, mas é considerada diversificada. Isso em razão de serem encontrados animais de vida livre, séssil, arborícolas, rastejantes e escavadores (Zakaria e Rajpar, 2015). Por se tratar de um ecossistema de transição entre o ambiente marinho e terrestre, o manguezal abriga uma a fauna diversificada, composta por espécies características de ambos os ambientes (Lacerda, 2002). Os macros invertebrados, principalmente moluscos e crustáceos, são os organismos mais abundantes nesse ecossistema (Souza et al., 2018). Segundo o ICMBIO (2018), estão entre os animais mais encontrados: peixes (baiacus, robalos e tainhas), crustáceos (caranguejos, siris e cracas), moluscos (ostras, sururus e ostra do mangue - *Crassostrea* spp.), aves (garça branca, colhereiros, guarás, biguás e papagaios), mamíferos (macaco prego - *Sapajus* spp., mão-pelada - *Procyon cancrivorus*, capivaras - *Hydrochoerus hydrochaeris*) e outros invertebrados.

As árvores de mangue são extremamente importantes para a fauna local, pois suas raízes oferecem abrigo e alimentação e local para reprodução para diversos animais como: moluscos, peixes e caranguejos habitarem este local. Os seres microscópicos também são abundantes no solo, como bactérias, fungos e algas que desempenham funções ecológicas importantes como a decomposição da matéria orgânica e o equilíbrio dos ciclos de nutrientes. Nos troncos e nas copas, é comum observar a presença de abelhas, pássaros, vespas, formigas, moluscos e aratus (caranguejo arborícola). Além disso, os manguezais abrigam animais predadores como guaxinins, macaco-prego, raposa, gavião, serpentes e algumas espécies de caranguejos (Husain, 2020; Oliveira et al., 2025).

Caranguejos

Os caranguejos são organismos extremamente importantes e presentes nos manguezais, eles apresentam alta diversidade contabilizando mais de 68.000 espécies descritas (Martins e Davis, 2001). Podem ser classificados de acordo com o seu habitat: terrestres, semiterrestres, marinhos e dulcícolas. Essa classificação baseada em seu habitat reflete em sua adaptação evolutiva que permitiram a colonização de ambientes marinhos, estuarinos, entremarés e terrestres. Esses organismos são considerados animais bioturbadores, já que possuem contato com o sedimento e modificam fisicamente e biologicamente as propriedades do solo mudando sua estrutura e textura através de atividades como na construção de tocas, na sua alimentação, defecação e ventilação (Capparelli et al., 2022). O processo de bioturbação tem atuação direta com o ciclo do carbono e a ciclagem de nutrientes, contribuindo com a oxigenação, riqueza e estruturação do solo. Por exemplo, os caranguejos violinistas conseguem remexer cerca de até 48% do sedimento entre 0 à 15 cm de profundidade (Crane, 1975). No Brasil há uma grande diversidade de espécies de caranguejos, com destaque em dois gêneros como: *Minuca spp.*, *Leptuca spp.* que terão uma abordagem mais profunda.

Os caranguejos chama-maré também conhecidos como caranguejos violinistas são crustáceos decápodes semiterrestres, que estão distribuídos amplamente pelas regiões tropicais e subtropicais. Eles são encontrados nas regiões entremarés e conseguem se adaptar a ambientes completamente doce e até hipersalino (Crane, 1975). De acordo com Rosenberg (2020) existem cerca de 105 espécies de caranguejos distribuídos em regiões tropicais e subtropicais. No Brasil, 11 espécies já foram identificadas, sendo *Leptuca cumulanta* (Crane, 1943), *Leptuca leptodactyla* (Rathbun in Ranlin, 1898), *Leptuca uruguayensis* (Nobili, 1901), *Minuca burgersi* (Holthuis, 1967), *Minuca mordax* (Smith, 1870), *Minuca rapax* (Smith, 1870), *Minuca thayeri* (Rathbun, 1900), *Minuca vocator* (Herbst, 1804), *Minuca victoriana* (von Hagen, 1987), *Minuca panema (Coelho, 1972)*e *Uca maracoani* (Latreille, 1803) (Masunari et al., 2020; Thurman et al., 2023).

Caranguejos chama-maré possuem dimorfismo sexual. Enquanto as fêmeas possuem 2 quelas semelhantes, os machos possuem heteroquelia, condição em que somente eles possuem quelas de tamanho diferentes, sendo uma maior e outra menor. Essa quela permite que capturem seu alimento, no cortejo reprodutivo e como defesa territorial (Spani et al., 2019). Ecologicamente estes organismos são importantes por manter o habitat saudável por meio da bioturbação, ciclagem de nutrientes e aeração do solo (Fernandes, 2022). São animais detritívoros, ou seja, se alimentam de matéria orgânica em decomposição quando a maré está baixa então quando estão construindo tocas ou se alimentando, acabam remexendo o solo e permitindo que nutrientes e matéria orgânica sejam redistribuídos evitando que permaneçam acumulados em apenas uma camada do solo além de influenciar a biogeoquímica do sedimento alterando a distribuição de carbono, nitrogênio e outros processos metabólicos microbianos (Qin et al., 2024). A construção de tocas por esses indivíduos (galerias) no solo é de extrema importância já que os protegem da variação de temperatura, predadores, salinidade, dessecação, conflitos, também os abrigam, ajudam na reprodução e muda da carapaça (Crane, 1975). Neste contexto, as tocas dos caranguejos são extremamente importantes para estes organismos e para a ecologia dos manguezais.

Ameaças aos manguezais

O aumento do uso e consumo dos recursos naturais pela população humana tem ocasionado enormes impactos negativos nos ecossistemas do mundo, como atividades antropogênicas (desmatamento, expansão da aquicultura, desenvolvimento urbano, exploração de petróleo e agricultura) tem acentuado as mudanças climáticas e a grande produção de resíduos sólidos (Defeo *et al.* 2009; Lincoln et al., 2022). Por consequência, essas ações resultam na perda de florestas de mangue, reduzindo a biodiversidade, acentuamento da poluição por metais pesados e contaminantes e compromete os serviços ecossistêmicos (proteção da costa, sequestro de carbono

entre outros) (Onyena e Sam, 2020). Infelizmente, os manguezais estão sujeitos à diversas ameaças. Em relação às mudanças climáticas, o aumento do nível do mar, a acidificação dos oceanos e a mudança nas precipitações prejudicam a ecologia do manguezal (Alongi, 2015). Além disso, segundo Lincoln et al. (2022), o plástico à base de combustível fóssil provoca emissões de gases do efeito estufa contribuindo nas alterações climáticas, e o plástico impacta diretamente nas espécies e nos habitats costeiros e marinhos.

No Brasil, os ecossistemas próximos às grandes metrópoles das regiões sudeste e nordeste são os mais impactados pela urbanização e atividades humanas (Souza et al., 2018). No Brasil, 14 das 25 maiores regiões metropolitanas estão localizadas próximas a regiões litorâneas, tornando manguezais, deltas, restingas, praias e costões rochosos significativamente vulneráveis (Lamparelli et al., 2001; Souza et al., 2018). Atividades como: desmatamento, construções, aterros urbanos, esgoto e a exploração dos recursos como madeira, crescimento urbano e populacional que muitas vezes se mostram benéficos para a estrutura urbana, também acabam demonstrando um cenário inviável para a saúde dos manguezais (Bernardino e Ferreira, 2021). No Brasil entre 1999 e 2018 houve a perda de 2% de áreas totais dos ecossistemas manguezais (Diniz et al., 2019). A região Sudeste possui 1,8 milhões de habitantes, com densidade demográfica de 145 a 2.245 habitantes/km^2, o que contribui com a intensificação do impacto negativo neste ecossistema costeiro (Souza et al., 2018). Na região sudeste cerca de 10,6 km^2 deste ecossistema foram perdidos em 20 anos sendo o maior impacto entre 1999 e 2011 (Moschetto et al., 2020).

Problemática dos resíduos sólidos

Atualmente, outro problema evidente é a enorme produção de resíduos sólidos pelos centros urbanos, que devido à falta de logística, preparo, baixa reciclagem e interesse de órgãos públicos, além do tempo mínimo necessário da decomposição dos resíduos sólidos no ambiente, se torna um problema agravante para os

ecossistemas (Li et al., 2016). Apesar das florestas de mangues reterem os sedimentos em suas raízes aéreas trazidos pelo continente, esse mesmo mecanismo de retenção favorece o acúmulo de resíduos sólidos, representando uma ameaça à integridade do ecossistema e à sua produtividade econômica (Calado, 2003).

Lixo marinho são materiais sólidos manufaturados, processados, descartados, eliminados ou abandonados em ambientes marinhos e costeiros (UNEP, 2009). Eles podem ser classificados devido a sua fonte, ou seja, como resíduo terrestre ou marinho e sua distribuição é dependente do regime de marés, da topografia e das atividades antropogênicas (Prevenios et. al., 2018). Como já citado anteriormente, os manguezais são prejudicados pela poluição de resíduos sólidos por possuírem baixo hidrodinamismo, e consequentemente se tem o acúmulo de poluentes orgânicos e resíduos sólidos antrópicos nestes ecossistemas.

Resíduos macroscópicos não são degradados facilmente e acabam se aglomerando nas raízes dos mangues. Desta forma, o plástico é o material mais encontrado nos ecossistemas em geral, representando 69-81% do lixo marinho, especialmente em áreas urbanizadas e com alta densidade populacional (Gonçalves et al., 2020). A explicação para a alta poluição de plástico nos ecossistemas é devido às suas propriedades de baixo custo de produção, alta durabilidade, versatilidade e pela falta de políticas de logística reversa ou reciclagem (UNEP 2021; Alencar et al., 2023). O descarte inadequado de plástico provoca diversos problemas ecológicos, sociais e econômicos afetando a ecologia do ambiente, turismo, navegações, a pesca, a aquacultura e a saúde humana (Alencar et al., 2023). Em 2021, sua produção foi de 300 milhões de toneladas que foram parar nos oceanos (IUCN, 2021). E segundo Lau et al. (2020), a continuidade deste cenário mostra que mais de 1.36 bilhões de toneladas de plásticos irão acumular nos ambientes terrestres e marinhos de 2016 a 2040.

Segundo Not et al. (2020), os rios têm sido as maiores fontes de poluição de plástico nas regiões costeiras. Devido a esta exposição e a ecologia dos manguezais

diversos resíduos acabam ficando presos nas raízes das árvores de mangue *Rhizophora* spp., fazendo com que o manguezal vire uma armadilha de resíduos sólidos marinhos (Garcés-Ordóñes et al., 2019). Os macroplásticos podem ser fragilizados pelos fatores ambientais como: radiação UV, umidade e as ondas. Consequentemente, se tem a formação dos microplásticos, partículas com menos de 5 mm de tamanho (Martin et al. 2019).

A crescente produção e descarte inadequado de resíduos sólidos têm gerado impactos significativos tanto para o meio ambiente quanto para a fauna aquática. Entre esses resíduos, os plásticos representam uma das principais ameaças, sendo frequentemente encontrados no interior de organismos marinhos após serem confundidos com alimento (Yang et al., 2024). Essa ingestão pode aumentar o risco de infecções por patógenos, intoxicação e perfurações internas.

As propriedades físicas do plástico, como tamanho, densidade e posição na coluna d'água, são fatores determinantes para sua ingestão, uma vez que podem se assemelhar às presas naturais dos organismos (Roch e Brinker, 2020). De acordo com Rummel et al. (2017), organismos bentônicos tendem a entrar em maior contato com polímeros mais densos ou incrustados, como politereftalato de etileno (PET) e cloreto de polivinila (PVC), que afundam na coluna d'água. Já espécies que habitam camadas superficiais são mais suscetíveis à exposição a plásticos de menor densidade que a água do mar, como polietileno (PE) e polipropileno (PP). O poliestireno (PS), também menos denso, permanece na superfície, aumentando a probabilidade de contato com a fauna que ocupa essa região.

Como os resíduos sólidos afetam os caranguejos

Os impactos físicos diretos da ingestão incluem laceração do trato digestivo, inflamação, obstrução intestinal e até morte por inanição (Carbery et al., 2018). Além disso, o enredamento em resíduos plásticos pode levar à morte por fome ou maior vulnerabilidade à predação (Laist, 1997), sendo estimado que centenas de espécies

marinhas já tenham sido afetadas por ingestão ou emaranhamento. Para além dos danos físicos, os plásticos também representam uma ameaça química, pois podem adsorver e concentrar contaminantes orgânicos e inorgânicos presentes no ambiente (Carbery et al., 2018). A absorção dessas substâncias pode resultar em desregulação endócrina, estresse oxidativo e bioacumulação ao longo da cadeia alimentar (Gallo et al., 2018; Agamuthu et al., 2019).

Estudos demonstram que os caranguejos acumulam microplásticos principalmente no hepatopâncreas, intestino e brânquias (Yu et al., 2023). Wang et al. (2021), ao investigar a espécie *Charybdis japonica*, observou que a contaminação ocorreu principalmente por filtração da água e pelo consumo de mexilhões previamente contaminados, sendo o hepatopâncreas o órgão com maior concentração de partículas. De forma semelhante, Brennecke et al. (2015) relataram a presença de microplásticos no estômago, brânquias e hepatopâncreas de *Minuca rapax*. Além disso, resíduos plásticos podem atuar como vetores de partículas persistentes e microrganismos aderidos à sua superfície, ampliando seus efeitos ecológicos (Zetler et al., 2013). A ingestão por caranguejos está associada a danos fisiológicos significativos, incluindo alterações histológicas, estresse oxidativo e comprometimento funcional de órgãos. Consigna et al. (2025) demonstraram que microplásticos de polietileno podem causar lesões severas no hepatopâncreas e nas brânquias de *Xenograpsus testudinatus*, evidenciando o potencial tóxico dessas partículas mesmo em níveis subletais.

2. Objetivos

2.1 Objetivo geral

Caracterizar os resíduos sólidos macroscópicos no substrato do manguezal da Enseada de Bom Jesus (RJ) e como eles afetam as populações de caranguejos chama-maré do gênero *Minuca*.

2.2 Objetivos específicos

- Caracterizar a condição inicial da população de caranguejos *Minuca* spp. antes da remoção dos resíduos sólidos macroscópicos presentes na área de estudo, considerando densidade populacional e tamanho corporal (largura de carapaça, de machos e fêmeas adultos).
- Analisar os efeitos da remoção dos resíduos sólidos macroscópicos e do estabelecimento de barreiras para seu retorno sobre a população de *Minuca* spp., verificando se ocorrem mudanças na densidade populacional e tamanho corporal (LC) de machos e fêmeas adultos.
- Analisar os efeitos do retorno dos resíduos sólidos macroscópicos após retiradas de barreiras sobre a população de *Minuca* spp., verificando se ocorrem mudanças na densidade populacional e tamanho corporal (LC) de machos e fêmeas adultos.
- Comparar as áreas controle e experimentais (sem resíduos / com retorno de resíduos) para avaliar o efeito das barreiras para contenção de resíduos sobre a população de caranguejos *Minuca* spp. e verificar se a limpeza promoveu mudanças significativas nos parâmetros populacionais.
- Identificar os tipos de resíduos sólidos macroscópicos, de origem antrópica, mais frequentemente encontrados na área de estudo.

Capítulo II: Artigo científico

O presente capítulo é constituído por manuscrito científico submetido ao periódico Marine Pollution Bulletin (Elsevier, online ISSN: 1879-3363; versão impressa ISSN: 0025-326X)

An experimental study on macroscopic marine litter and its effects on fiddler crabs (Decapoda: Gelasiminae)

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Abstract

The pollution of mangrove ecosystems by marine litter has serious impacts, ranging from the mortality of fauna due to entanglement and ingestion of litter, to the obstruction of the substrate and the burying of crab burrows. Since there is a paucity of research on the effect of macroscopic marine litter on mangrove crabs, the aim of this study was to evaluate how macroscopic marine litter affects fiddler crabs of the genus *Minuca*. The study was experimental and conducted in three moments, considering 1. Pre-treatment - the environment without intervention; 2. Treatment - the effect of removing macroscopic marine litter; and 3. Post-treatment - the effect of returning marine litter. To protect specific areas from the impact of marine litter, floating barriers designed specifically for this study were deployed. In addition to parameters related to fiddler crabs, fluctuations in substrate coverage by marine litter were evaluated. The present study employed quadrats measuring 3.0 m x 3.0 m within the intertidal zone. The crabs were a catch and release method. The evaluation of marine litter coverage was conducted through the utilization of photos and treatment by the software CPCe.

The abundance of marine litter ranged from 2.78 to 7.56 items per m², with a predominance of plastic materials. The marine litter coverage ranged from 1.18 ± 0.52% to 41.7 ± 6.16%. An inverse correlation between abundance of adults of *Minuca* spp. and marine litter coverage was observed (Spearman, males ρ = -0.63, p = 0.006; females ρ = -0.57, p = 0.013). Similarly, the removal of marine litter favored *Minuca* spp. abundance. No correlations were observed between crab size and marine litter coverage. This study presents novel data on the deleterious effects of marine litter on fiddler crabs. Moreover, it emphasizes the positive impact of effective waste removal practices.

Keywords: *Minuca*, marine debris, plastic, Southeast Brazil, Guanabara Bay

Highlights

- The presence of marine litter was a notable feature in the study area.
- Plastic bags and general plastics dominated marine litter.
- Fiddler crab (*Minuca*) abundance decreased with increasing marine litter coverage.
- The removal of marine litter favored *Minuca* spp. abundance.

1. Introduction

Mangroves are defined as tropical and subtropical coastal ecosystems located at the interface between terrestrial and marine environments (Souza et al., 2018). These are distributed across five continents, including Africa, North and Central America, South America, and Oceania. Brazil possesses the second largest expanse of mangrove cover globally (Amaral, et al., 2025). In this country, mangrove extends

along the Atlantic coast, from the states of Amapá (04° N 50° W) to Santa Catarina (28° S 48° W), covering an area of 1,141,478.85 ha (Amaral, et al., 2025). Mangroves are ecosystems adapted to harsh environmental conditions, including high salinity, intense solar radiation, low oxygen availability in sediments, and high tidal variation (Meera et al., 2023). Despite these constraints, mangroves provide numerous ecosystem services, including habitat for a wide variety of organisms in Brazil such as fishes (e.g., sharks and rays), birds as scarlet ibis (*Eudocimus ruber*) and yellow crowned night heron (*Nyctanassa violacea*), reptiles (e.g., *Chelonia mydas* (Linnaeus, 1758)), mammals (e.g., *Sotalia guianensis* (Van Beneden, 1864)), and a diverse assemblage of invertebrates, particularly semiterrestrial crabs (Silva and Olmos, 2007).

Despite the importance of mangrove ecosystems, they are increasingly threatened by both natural processes, such as erosion, and anthropogenic activities, including resource overexploitation, land conversion for aquaculture and agriculture, and pollution. These pressures result in biodiversity loss, sediment contamination, and the accumulation of marine litter (Defeo et al., 2009). The presence of marine litter in mangrove ecosystems can cause severe impacts, including fauna mortality due to suffocation and ingestion of plastic, as well as damage to benthic habitats through sediment deposition, seabed accumulation, obstruction, and burial of crab burrows (Luo et al., 2021).

In Brazil, approximately 82,477,300 tons of solid waste are generated annually, corresponding to about 390 kg per habit/year (ABRELPE, 2021). The increase in marine litter, particularly plastic, is driven by several factors, notably proximity to urban centers. Consequently, mangroves located near developed regions are especially vulnerable to improperly disposed domestic and municipal marine litter (Souza et al., 2018; Luo et al., 2021). The most commonly items on the Brazilian coast such as soft and hard plastic, cigarette butts, pellets, caps, Eppendorf tubes, sticks, plastic bags, PET bottles account 80.3% of the marine litter reaches the ocean (ABRELPE 2021).

Plastics originating from upstream areas may accumulate in estuaries rather than reaching the open ocean (Willis et al., 2017). According to the literature, estuaries and bays exhibit some of the highest abundances of marine litter, although their distribution and impacts remain understudied (Smith and Edgar, 2014). Furthermore, the structural complexity of mangroves particularly their dense root systems, such as pneumatophores, facilitates the retention and fragmentation of marine litter (Luo et al., 2021). Despite awareness of these facts, there are few studies showing the effects of macroscopic marine litter on crabs in mangrove ecosystems.

Fiddler crabs (Decapoda: Ocypodidae: Gelasiminae) are a key component of mangrove fauna, comprising 3 genus (*Uca*, *Minuca* and *Leptuca*) and 10 species in Brazilian mangroves (Schmidt and Diele, 2023). These organisms are considered ecosystem engineers because their burrowing and feeding activities enhance sediment aeration, promote nutrient recycling, increase the retention of organic matter, and decrease ammonium and sulfide concentrations in mangrove soil (Cannicci et al., 2008). These processes facilitate the contribution of fiddler crabs to the health of mangrove ecosystems, as evidenced by their impact on primary productivity, faunal composition, and plant structure (Kristensen, 2008). They function as predators of propagules, thereby contributing to the dynamics and dispersion of vegetation in mangroves (Farnsworth and Ellison, 1997). Furthermore, they serve as a crucial food source for the crab-eating raccoon, gulls, and wading birds, which naturally regulate crab populations (Quintela et al., 2014).

Fiddler crabs typically occur in mixed species assemblages, sex and ages and their active space does not exceed 1m². These organisms live in large colonies with a abundance ranging from 10 to 80 individuals per square meter (Koch et al., 2005). Fiddler crab populations inhabit mudflats and sandy intertidal beaches, mangroves, and riverbanks in tropical and subtropical regions, except for the female species, which leave their submerged burrows to spawn. Their distribution is mainly influenced by the tidal regime, salinity, the amount of organic matter in the sediment, the type of

vegetation and shading (Thurman et al., 2013). Because of that, these organisms are a valuable model for studying distribution and ecology because multiple species can coexist in the same environment, sharing available resources. The presence of pollutants, including untreated sewage discharge, has been demonstrated to have a detrimental effect on the abundance and diversity of fiddler crabs (Grande et al., 2018). According to Riascos and Gomez (2023), marine litter tends to reduce the abundance and quality of fiddler crab habitats, resulting in lower survival rates, especially among females.

Despite their importance, little attention has been given to the impact of marine litter on fiddler crabs inhabiting mangrove forests. This study therefore aims to evaluate the impact of macroscopic marine litter on the population abundance and size (carapace width) of fiddler crabs of the genus *Minuca*. To this end, the study was conducted in three treatments: (a) the environment without intervention; (b) the effect of removing marine litter; and (c) the effect of returning marine litter. In addition to parameters related to the crabs themselves, the evaluation also considered fluctuations in substrate coverage by marine litter.

2. Material and methods

2.1. Study Area

The Bom Jesus cove is situated within the Technology Park of Fundão Island, in proximity to the Cunha Channel, in the western portion of Guanabara Bay (SE Brazil). The Guanabara Bay is one of the largest bays in Brazil and it is considered among the most polluted coastal environments in the country (Ribeiro et al., 2015). The western side of the bay is characterized by high levels of urbanization and substantial industrial activity, leading to the accumulation of substantial quantities of

anthropogenic marine litter and the discharge of untreated effluents, primarily domestic sewage (Soares-Gomes et al., 2016). A high presence of marine litter has been observed in the mangrove swamp of Bom Jesus Cove, which is why it is considered a highly polluted area Almeida et al. (2026).

Around the Bom Jesus Cove there is a small mangrove swamp covering approximately 2.5 hectares (Fig. 1). The formation of Fundão Island is attributable to the completion of landfill works in 1952, which resulted in the union of eight islands. It is hypothesized that the mangrove swamp in Bom Jesus Cove began to establish itself in the subsequent years, as was the case in other areas of the island (Magalhães et al., 2023). The area is subject to the influence of semidiurnal microtidal regimes, characterized by maximal tidal amplitudes of approximately ±1.4 m. The climate in the region is classified as humid, with elevated precipitation levels observed during the months of December through March and a decline in rainfall between June and September.

The sediment consists predominantly of sandy-muddy gravel, according to Almeida et al. (2026). Both zones analyzed (intertidal lower and middle zones) exhibited higher pore water (LZ 50.5 ± 13.3%; MZ 39.9 ± 9.7%) and higher percentage of organic matter (LZ 18.6 ± 7.7%; MZ 11.6 ± 2.6%) (ANOVA, $p<0.05$). Presently, the mangrove ecosystem is predominantly dominated by black mangrove (*Avicennia schaueriana*), with a limited presence of red mangrove (*Rhizophora mangle*). The canopy height ranged from 4.0 to 16.0 meters (Fig. 1), and the study area was predominantly shaded.

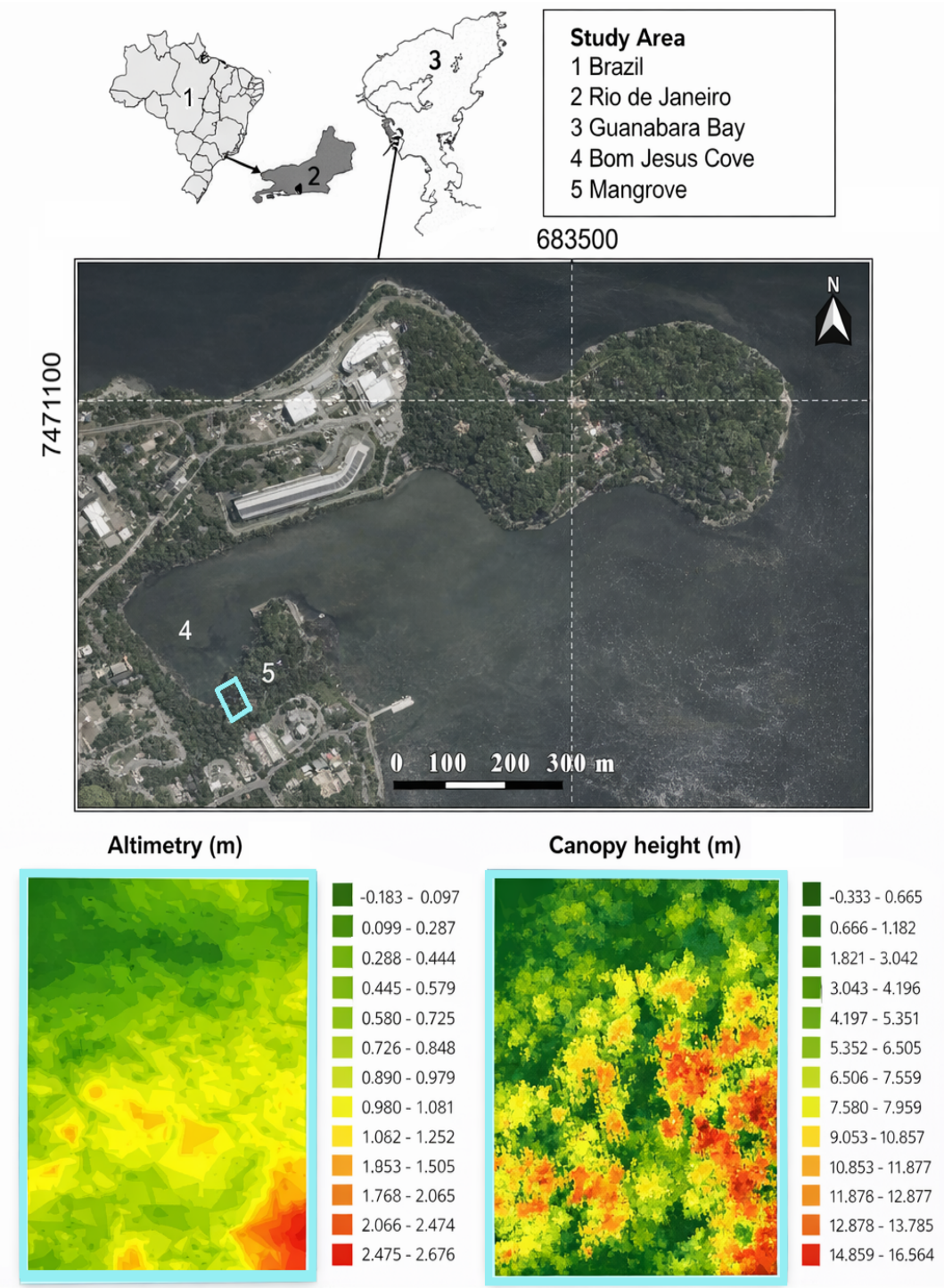

Fig. 1. Location of mangrove swamp in Bom Jesus Cove (SE Brazil), with altimetry (DEM) and canopy height (DCM) in the intertidal zone near to study area. The DEM was obtained from the Pereira Passos Institute (IPP) collection (point interpolation, LiDAR). DCM was generated from the difference between the Digital Surface Model and the interpolation of the first-return points from the LiDAR point cloud and the DTM.

2.2. Experimental and sampling design

In this study, fiddler crabs and marine litter were analyzed in the intertidal area of the mangrove swamp. The study was conducted in two zones (or subzones): LZ (low zone) - a zone that experiences daily tidal flooding inundation and MZ (middle zone) - a zone that experiences flooding mainly during spring tides.

The study was developed in three treatments, each one with two campaigns (Fig. 2). The first treatment, named “pre-treatment”, consists of campaigns without interventions in substrate (in May and August 2023). After this treatment, barriers for floating marine litter were installed (see details below). Also, the macroscopic marine litter (> 1.0 cm) was meticulously removed in the fenced areas. Following this, the second treatment involves an experiment. This stage, named “treatment”, was conducted in May and October 2024. Thus, areas fenced by barriers and external areas, referred to as control areas, were monitored. In the third treatment, named “post-treatment”, the barriers were removed. The analysis were conducted in the same areas where barriers were installed, after their removal (in April 2025). The campaigns of this treatment were conducted in June and October 2025, and control areas also were analyzed. The timeline of the study is summarized in Table 1.

Table 1. Timeline of the study, detailing the months during which each treatment was carried out and the procedures such as the installation and removal of barriers.

Treatment/ Accomplishments	Months	Situation
Pre-treatment	May and August 2023	Initial conditions of area (ia)
Barrier's installation and substrate cleanning	January 2024	-
Treatment	May and October 2024	Barrier/clean areas (b) and control areas (c)
Barriers removal	April 2025	-
Post-treatment	June and October 2025	Post barrier áreas (pb) and control areas (c)

The barriers were installed in the intertidal area, one in each zone (low and middle). The configuration of the barrier bore a striking resemblance to that of the widely utilized litter booms (e.g. river booms). However, some adaptations were made for the present study. Each barrier exhibited a rectangular configuration: 9.0 meters in length and 3.0 meters in width. The barrier's floats were composed of cylindrical polypropylene bags with a diameter of 0.4 meters, which were filled with Styrofoam fragments. A mesh strip, measuring 1.5 meters in width and located beneath the floats, displays apertures with dimensions of 2.1 cm x 2.6 cm. The mesh strip has been affixed to both the floats and the substrate. In the context of the experiment, the floats demonstrated rhythmic oscillation in response to the fluctuations in the tide, thereby causing the mesh strip to extend or retract accordingly (see Fig. 3). This was achieved to ensure that the enclosed area would be protected from marine litter, regardless of the tide.

2.3. Characterization of Marine Litter

The analysis of marine litter was conducted through two distinct methodologies. The first method entailed the implementation of a collection campaign within the areas fenced by barriers. The second method - executed across all campaigns, zones and quadrats - involves the utilization of photo analysis to the quantification of substrate coverage by marine litter (“marine litter coverage”).

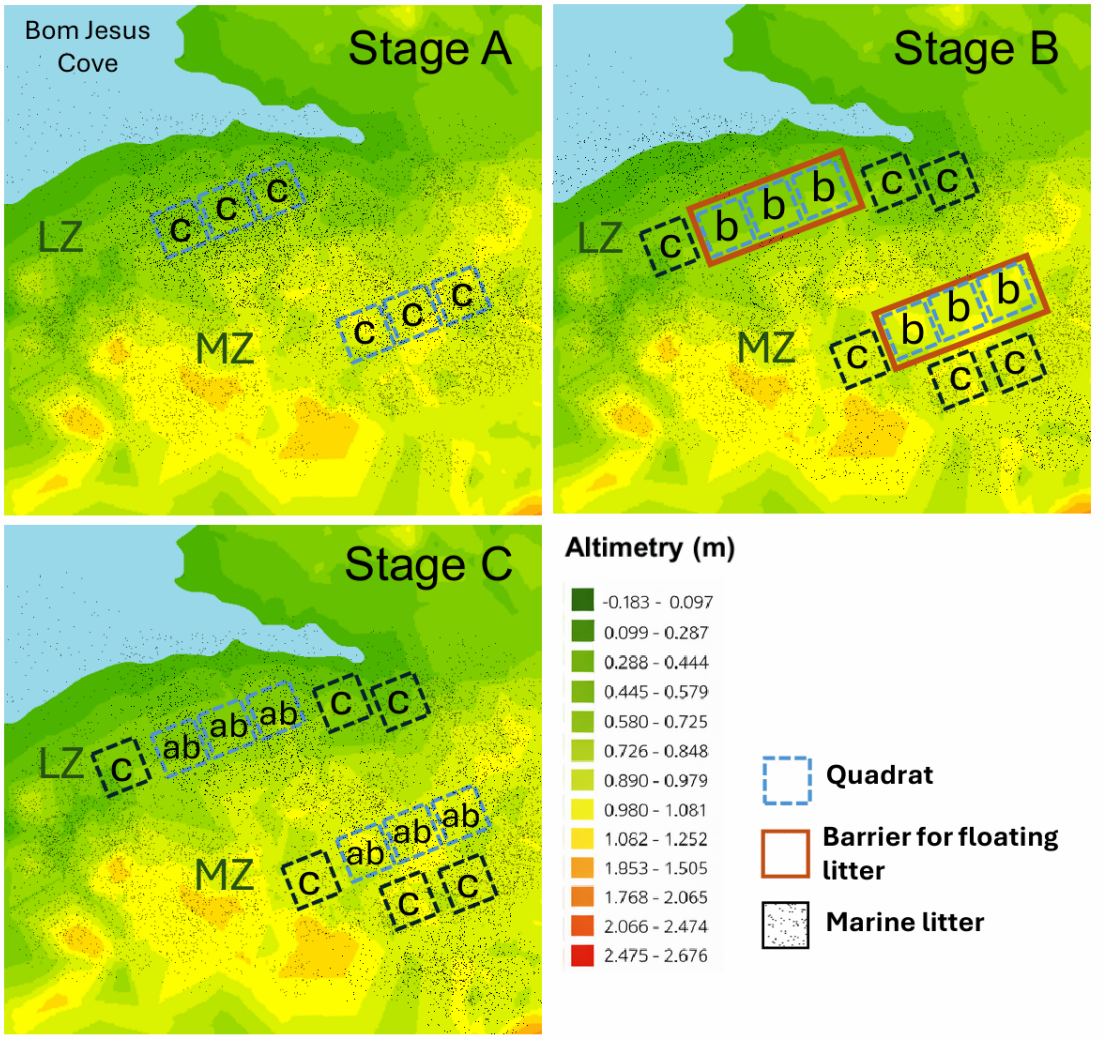

Fig. 2. Experimental design across the three study treatments. Pre-treatment includes campaigns with study of areas without interventions in the substrate (ia). Treatment includes analysis of control and barrier areas (b) (with removal of macroscopic marine litter in areas surrounded by floating barriers). Post treatment represents analysis in

control areas and areas where barriers were removed (pb, “post-barrier”). LZ and MZ were low zone and middle zone of the intertidal area, respectively.



Fig. 3. Barriers to floating marine litter in the low zone of Bom Jesus Cove's mangrove swamp (SE Brazil), in two distinct moments: (A) during an ebb tide and (B) on the flood tide.

Marine litter collection and laboratory analysis

Following the installation of the barriers, macroscopic marine litter was removed from the substrate. The remotion was made in January 2024 and items larger than 1.0 cm were carefully harvested in the surficial substrate. Two collectors were assigned to each zone with barriers. Great care was taken to avoid trampling the burrows and crabs. The items were washed to remove adhered sediments and then dried at room temperature for 48 hours. Natural items collected accidentally, such as leaves, wood, and propagules, were excluded from the count and weighing. The items were grouped

by type and weighed on a digital scale (0.001g). The plastics were classified into types according to NBR 13.230/2008 (ABNT, 2008): Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), and Other plastic types. The type of plastic was identified according to the symbols on the labels and bodies of the objects. When no label or code could be found, the item was considered in the category Other plastic types. Other no plastic marine litter was classified according to the Municipal Urban Cleaning Company of Rio de Janeiro, into the categories rubber, fabric (textiles), glass, metal, inert (construction waste), processed wood, candle/paraffin, paper/cardboard, electrical and electronic equipment (WEEE), among others (COMLURB, 2024). In instances where the item comprised multiple materials, its classification was determined by the material comprising the greater proportion.

Analysis of marine litter coverage in situ

Marine litter coverage analysis was performed on sample units measuring 3.0 m x 3.0 m, which we will refer to as quadrats. In each one, nine photos of 1.0 m x 1.0 m were taken (Olympus TG-6 camera) (as Almeida et al., 2026). To ensure a comprehensive analysis, three quadrats were examined in each experimental situation. The photographs were analyzed using the CPCe software (Coral Point Count with Excel Extensions), adapted to obtain data on marine litter coverage (percentage). In this analysis, marine litter was classified into general types that could be recognized in the photographs. Based on the photos, the items were identified and classified as: 1. Plastics - PET bottles and their caps, PVC items, plastic bags, rigid plastic; 2. Styrofoam; 3. Processed wood; 4. Metal; 5. Fabric; 6. Glass and 7. Construction material.

2.4. Analysis of Fiddler Crabs

The analysis of the fiddler crabs were performed using the capture and release technique. In the same 3.0 m x 3.0 m quadrats, fiddler crabs were sampled for 15 minutes by two experienced collectors. Collections were carried out manually using spatulas. The crabs were captured on the surface of the substrate, at the entrance to their burrows, and, when necessary, by digging down the first 10.0 cm. The genus identification of fiddler crabs was conducted in situ and is based on Stauffer (2024). It was decided to work only with the *Minuca* genus because it is the most abundant in the study area, as pointed out by Almeida et al. (2026). In accordance with the data, a total of 1,807 captures of *Minuca* were registered in the present research, while another genus registered 458. The species found were *Minuca rapax, Minuca burgersi, Minuca victoriana, Leptuca uruguayensis, Leptuca thayeri* and *Leptuca leptodactyla*. *A* small number of individuals, whose stage or sex could not be reliably determined in the field, were transported to the laboratory for detailed morphometric examination, with reference to Melo (1996) and Masunari et al. (2020). The others were released in the same places where they were captured.

The specimens were categorized into adults and juveniles, males and females, and their carapace width (CW, in mm) was measured using a digital caliper (0.01 mm). The following criteria were used to differentiate between adults and juveniles: the shape and adhesion of the abdomen, the presence or absence of pleopods, and heterochelia versus homochelia.

2.5. Data analysis

To ensure the validity of statistical analyses, data normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was verified with Levene's test. Based on these assessments, it was determined whether parametric assumptions were met, and appropriate tests were selected accordingly.

This study analyzed a high impact mangrove by marine litter. Specifically, the study examined (1) the marine litter coverage in ‘control’ and experimental areas and (2) the abundance and size of fiddler crabs in the same areas. The main objective was to investigate the effects of marine litter coverage on abundance (ind.m^{-2}) and size (CW) of fiddler crab. Thus, marine litter coverage, fiddler crab's abundance (ind.m^{-2}) and size were compared to investigating differences between areas without intervention and the experimental areas (fenced by barriers and post-barriers removal). Considering the number of quadrats in each condition and campaign (3 per treatment, 3 per control), the investigation was performed using Student’s T-test.

A correlation analysis was conducted using Spearman’s nonparametric test to examine the relationships between crab abundance and marine debris coverage, as well as between crab size and marine debris coverage. Using a scale ranging from -1 to +1, where a p-value close to 1 indicates a strong positive correlation, a p-value close to -1 indicates a strong negative correlation, and 0 indicates no correlation. To this analysis, only data from areas without intervention was used (e.g. control areas). To that end, a series of tests were conducted, encompassing a range of values for ind.m^{-2} and CW across all individuals (including juveniles) and adults limited to one sex, thereby ensuring a comprehensive evaluation. Given the outcomes of the Shapiro-Wilk and Levene's tests, it was determined that the Spearman correlation test would be utilized in this investigation.

All statistical analyses were conducted at a significant level of 5 % ($p \leq 0.05$). RStudio (R Core Team, 2024) and Jamovi software (The jamovi project, 2024) were used. Tables were prepared using Excel for Windows. Analytical figures and box plots were generated in RStudio and Jamovi and edited on the Canva platform.

3. Results

3.1. Characterization of Marine Litter

Characterization of collected marine litter

The characterization revealed differences between the low and middle zones of the mangrove (Table 2). The low zone showed less marine litter than the middle zone, both in terms of abundance and mass. Total abundance ranged from 2.78 to 7.56 items.m^{-2} and plastic were the dominant type in both zones. In the low zone, the most abundant polymer was HDPE, followed by PS and Other plastic types. In the middle zone, the highest abundance were recorded for PP, PS, and HDPE.

Table 2 Characterization of macroscopic marine litter removed from the substrate in the mangrove swamp of Bom Jesus cove (SE-Brazil). Data is presented in items.m^{-2} and grams.m^{-2} (dry weight) of items collected in the low and middle zones of the intertidal area. Classification of marine litter according to ABNT NBR 10004/2024 and Municipal Urban Cleaning Company of Rio de Janeiro, Brazil.

Main type	Specific Class	low zone		middle zone	
		items.m^{-2}	g.m^{-2}	items.m^{-2}	g.m^{-2}
Plastic	PET	0.07	2.4	0.19	9.90
	HDPE	1.41	3.44	1.07	33.25
	PVC	0.11	2.07	0.07	0.17
	LDPE	0.26	1.32	0.07	0.27
	PP	0.00	0.00	2.19	20.38
	PS	0.48	0.15	2.11	2.91
	PE	0.00	0.00	0.30	0.65
	Other plastic types	0.41	13.95	1.15	33.39
No plastic	Fabric	0.00	0.00	0.15	12.43
	Processed wood	0.00	0.00	0.04	0.02
	Glass	0.04	0.12	0.11	1.20
	Inert	0.00	0.00	0.07	3.53
	Others	0.00	0.00	0.04	0.30
Total		2.78	23.45	7.56	118.40

Marine litter coverage

During pre-treatment, the low zone presents the highest marine litter coverage, of 18.59 ± 12.92 % in May 2023 (Fig. 4). In this treatment, the others means ranged between 8.59 ± 4.50 % and 12.15 ± 5.65.

About treatment and post-treatment, a significant variation in marine litter coverage was observed between experimental conditions, in both low and middle zones. For the treatment, as expected, the values of marine litter coverage were significantly higher in control areas: 12.87 ± 3.38 % to 41.7 ± 6.16 % (both campaign and zones, T-test $p < 0.01$). Inside the areas fenced by the barrier, the values were between 1.18 ± 0.52 % and 1.67 ± 0.16 %.

In post-treatment, significant highest marine litter coverage was seen in the control areas from low zone in October 2025 ($p = 0.002$). In the middle zone, the values from control and post-barrier areas were similar (Jun 2025, $p = 0.980$; Oct 25, $p = 0.075$). At this treatment, coverage in the control areas ranged from 12.52 ± 12.09 % and 43.93 ± 3.67 %. In the areas post-barrier, it ranged from 1.56 ± 0.39 % and 17.04 ± 0.78 %. Across all treatments and zones, plastic related materials were consistently the dominant items covering the substrate (Fig. 5).

In the pre-treatment treatment, general plastic items constituted the most abundant category in both monitored zones, accounting for between 22% and 35% followed by plastic bags, which accounted for 32% to 54% of the collected marine litter. In the treatment, the most abundant items in both zones were plastic bags (24 and 57%), general plastics (23 and 62%), and Styrofoam, which appeared more frequently in the

middle zone (15 and 44%). In the post-treatment, plastic bags remained the most abundant item in both evaluated zones, with values ranging from 28 to 57%, followed by general plastic items, which ranged from 20 to 38%. A notable aspect of this treatment was the higher occurrence of processed wood in the lower zone, accounting for between 5 and 25%

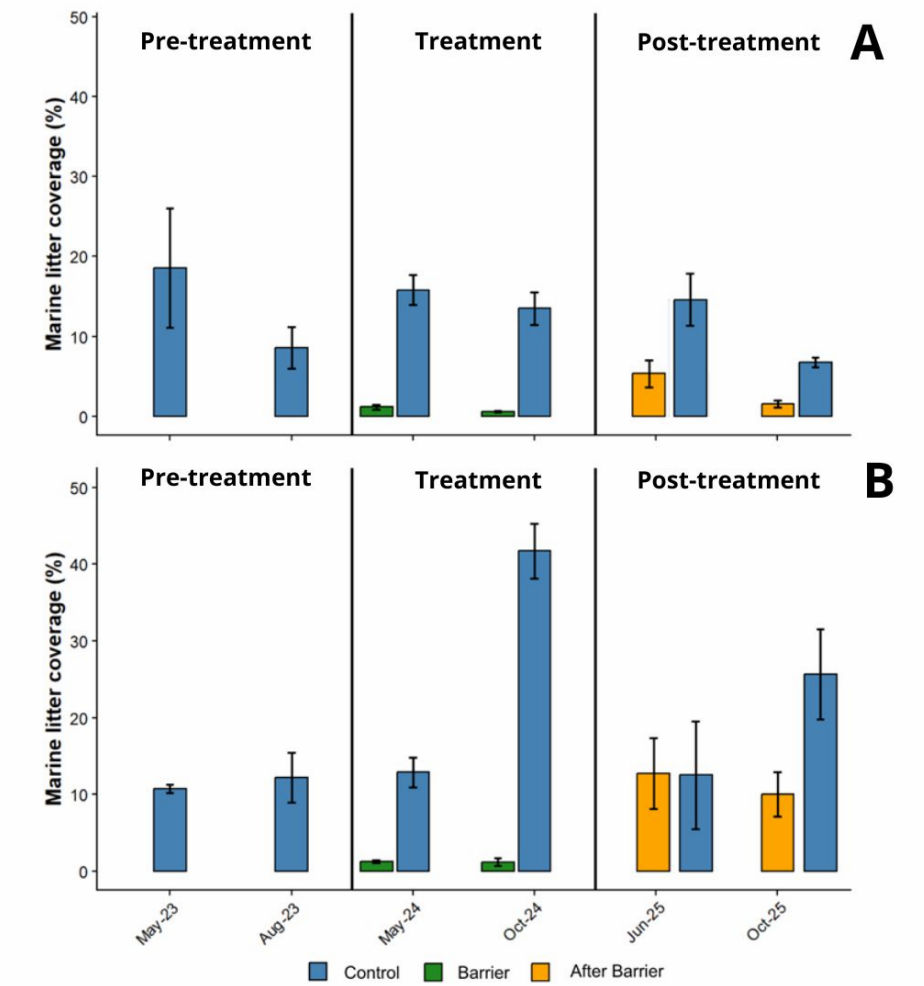

Fig. 4. Marine litter coverage (mean ± SD, %) recorded at the campaigns in the low zone (A) and middle zone (B) from intertidal areas of the mangrove swamp of Bom Jesus Cove, Guanabara Bay (SE-Brazil) (from 2023 to 2025). Pre-treatment includes campaigns with study of control areas only, without interventions in the substrate. Treatment includes analysis of control and barrier areas (with removal of macroscopic

marine litter in areas surrounded by floating barriers). Post-treatment represents analysis in control areas and areas where barriers were removed (“post-barrier”).

3.2 Fiddler Crabs

During the on-site identification procedure, the presence of two genus-level taxa was detected (*Minuca* and *Leptuca*). Among the juveniles and ovigerous females taken for laboratory analysis (see Materials and Methods section), three species of *Minuca* were identified: *Minuca rapax* (Smith, 1870), *Minuca burgersi* (Holthuis, 1967) and *Minuca victoriana* (von Hagen, 1987). Other fiddler crabs recorded were *Leptuca uruguayensis* (Nobili, 1901), *Leptuca thayeri* (Rathbun, 1900), *Leptuca leptodactyla* (Rathbun in Rankin, 1898).

In the laboratory, only ovigerous females of the species *Minuca rapax* were found. The registration was in May 2023 (n = 6), August 2023 (n = 1), October 2024 (n = 2), and October 2025 (n = 3). The smallest ovigerous female exhibited a CW of 7 mm.

Fiddler crabs’ abundance

In pre-treatment, similar abundances were recorded in both low and middle zones (T-test May 2023, p = 0.945; Aug 2023, p = 0.078). During treatment, in both zones, abundances tended to be higher in barrier areas compared to control areas, except for May 2024 (Fig. 5). Only in the middle zone of October 2024 a significant difference was detected (all population p = 0.013; only males p =0.032, only females p = 0.026).

In the low zone of post-treatment, the abundances were significantly higher in post-barrier areas. However, this was only true when considering all population (Jun 2025 p = 0.046; Oct 25 p = 0.044).

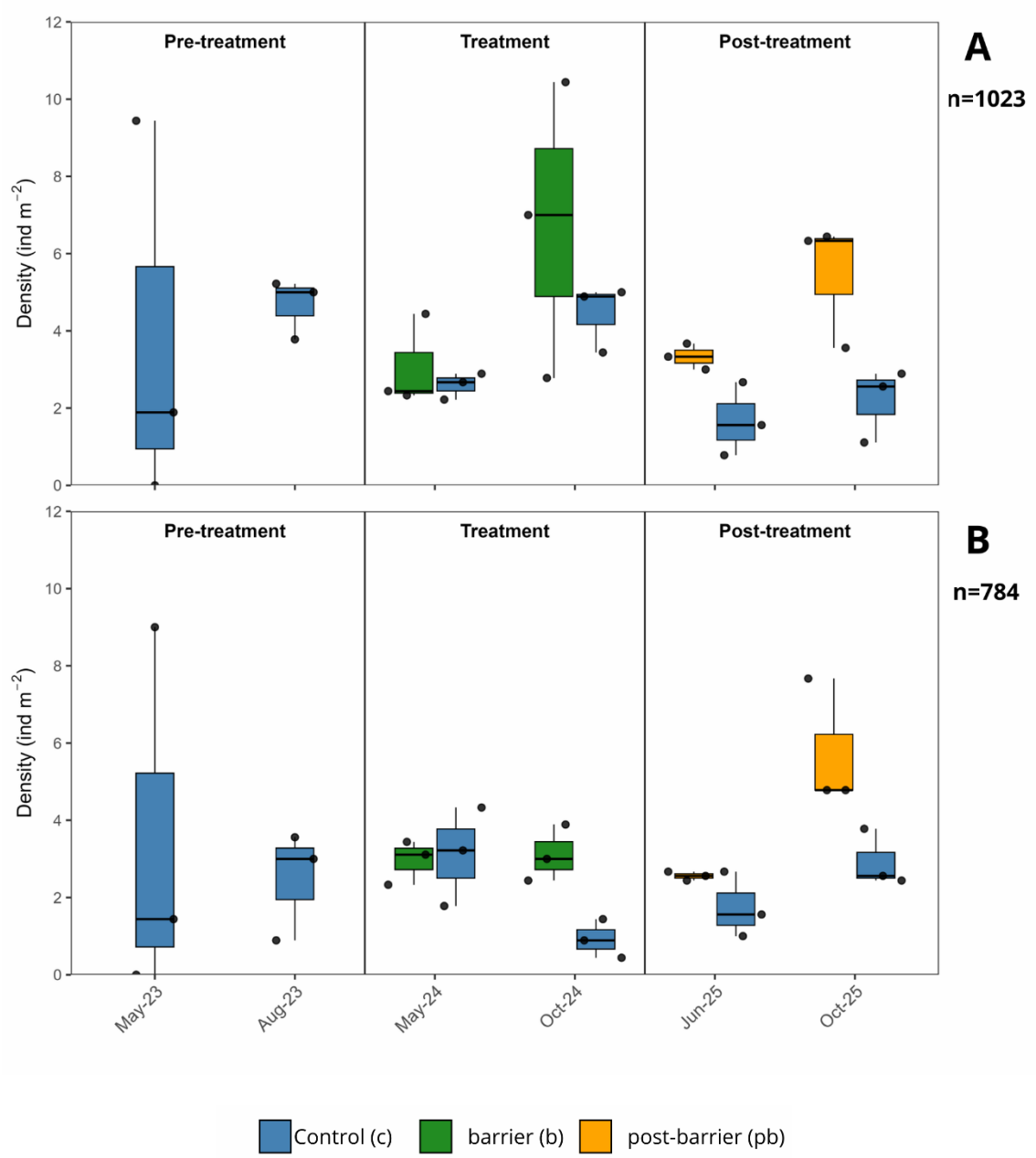

Fig. 5. Boxplots show the variation in *Minuca* spp. abundance in the low (above) and middle (below) zones of the mangrove swamp of Bom Jesus Cove, Guanabara Bay (SE-Brazil) (from 2023 to 2025). Pre-treatment includes campaigns with study of control areas only, without interventions in the substrate. Treatment includes analysis of control and barrier areas (with removal of macroscopic marine litter in areas

surrounded by floating barriers). Post-treatment represents analysis in control areas and areas where barriers were removed (“post-barrier”). LZ and MZ were low zone and middle zone of the intertidal area, respectively.

Fiddler crab size

Carapace width was significantly higher in the middle zone ($p < 0.001$). In this zone, it was 15.17 ± 1.89 mm; in the low zone, it was 11.56 ± 2.43 mm. The CW of adult males was 11.27 ± 2.73 mm in the low zone and 15.15 ± 2.28 mm in the middle zone. The respective measurements for females were 12.16 ± 1.76 mm and 14.88 ± 1.48 mm (Fig. 6)

The distribution of size classes differed significantly between zones. In the low zone a predominance of juveniles (CW 0 ⊢ 7.0 mm) and “small adults’ (7.1 ⊢ 14.0 mm) was observed ($p = 0.01$; $p = 0.04$, respectively). However, between control and barrier areas and, between control and post-barrier areas, no significant differences were observed in the abundances of each size class. Furthermore, in the low zone, higher proportions of juveniles were recorded mainly in May 2023 and June 24 (autumn), while the occurrence of young crabs was more evident in October 24-25 (spring).

There were no significant differences in CW between control and experimental areas in the treatment and post-treatment for the total population, except for October 2025, middle zone. In this campaign, males from the post-barrier area demonstrated a significant increase in size ($p = 0.046$).

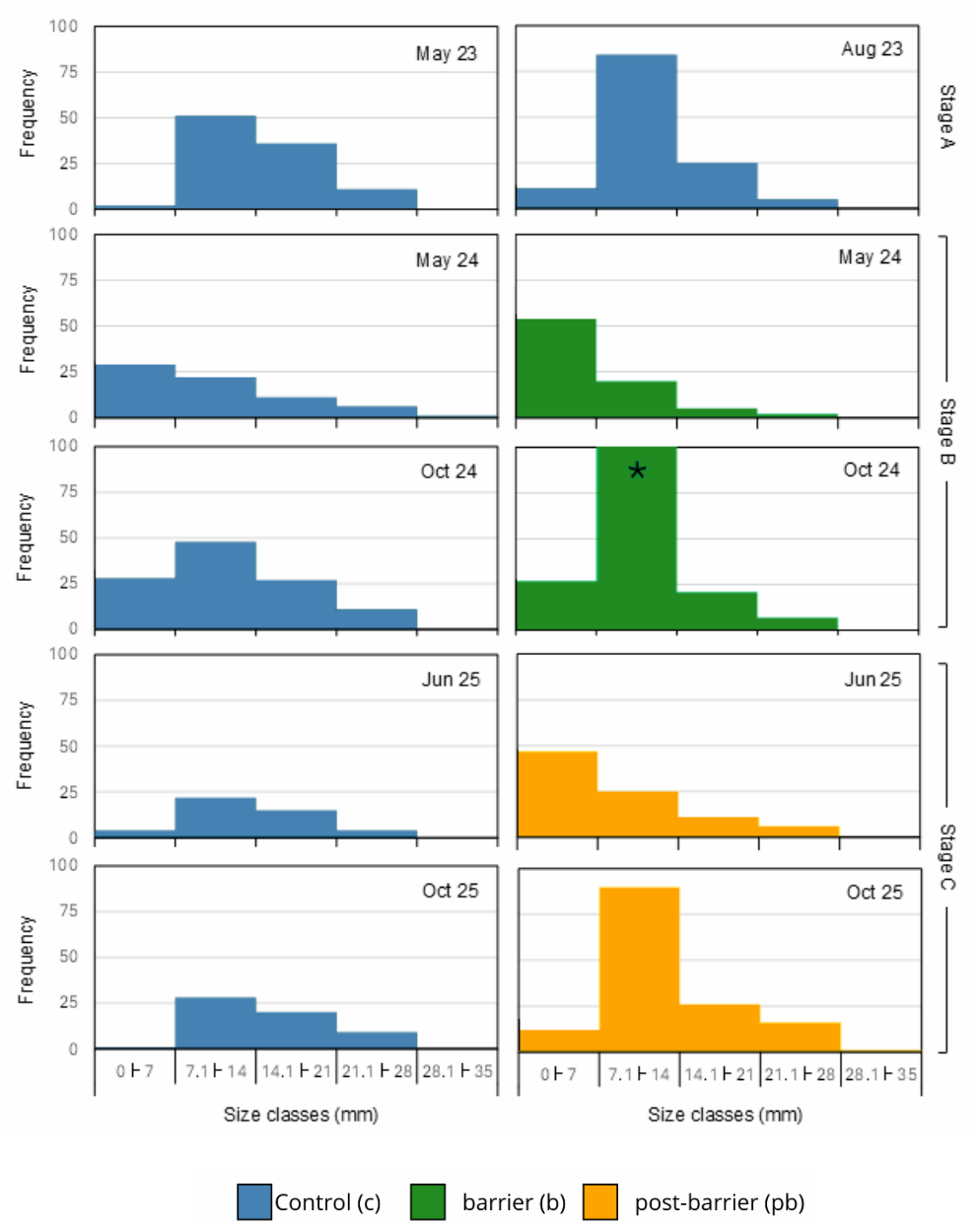

Fig. 6. Frequency distribution (number of individuals) of size classes of *Minuca spp.* in the low zone across all campaigns, illustrating temporal changes in population structure during the study (from 2023 to 2025). Pre-treatment includes campaigns with study of control areas only (c), without interventions in the substrate. The treatment includes analysis of control and barrier areas (b) (with removal of macroscopic marine litter in areas surrounded by floating barriers). Post-treatment represents analysis in control areas and areas where barriers were removed (pb, “post-barrier”). LZ and MZ were low zone and middle zone of the intertidal area, respectively.

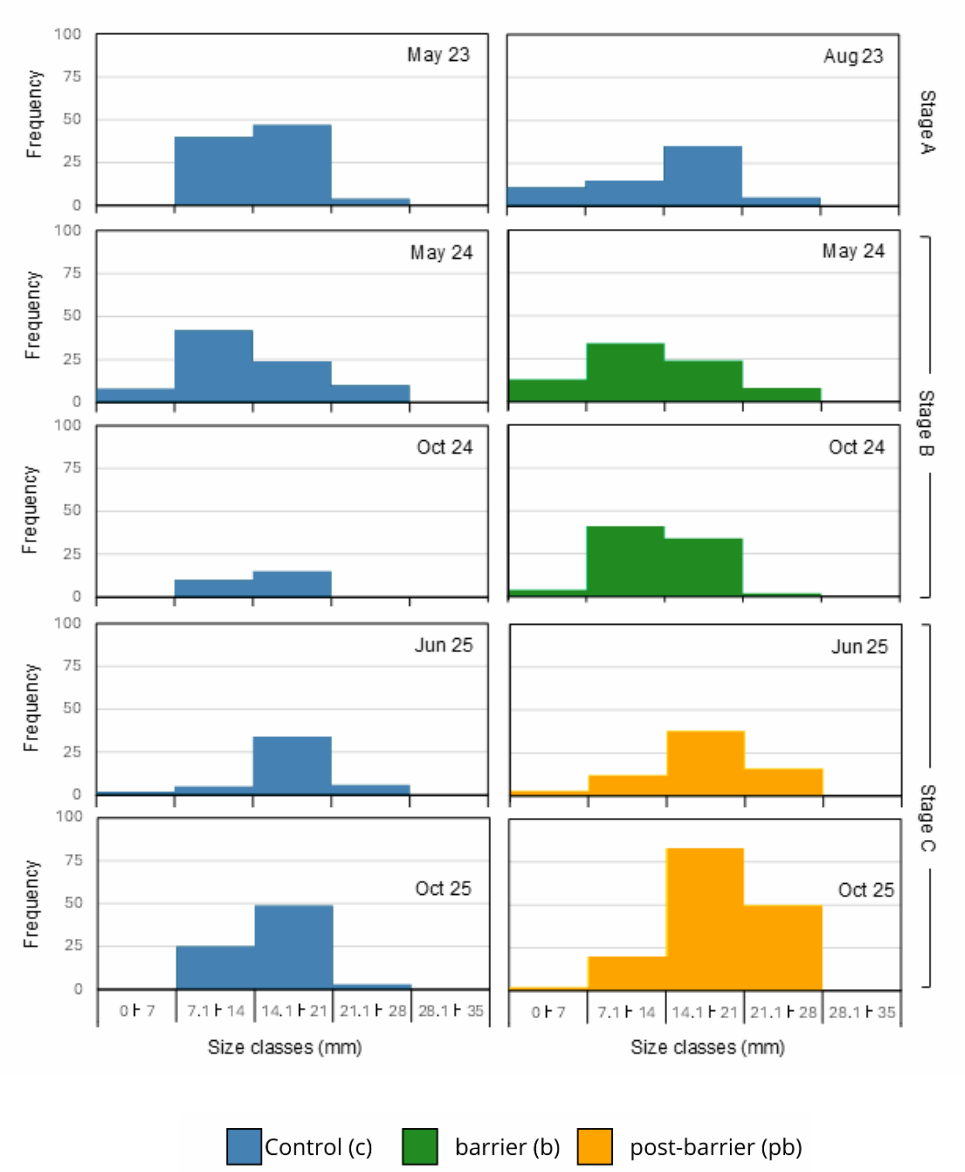

Fig. 7. Frequency distribution (number of individuals) of size classes of *Minuca spp.* in the middle zone across all campaigns, illustrating temporal changes in population structure during the study (from 2023 to 2025). Pre-treatment includes campaigns with study of control areas only, without interventions in the substrate. The treatment includes analysis of control and barrier areas (with removal of macroscopic marine litter in areas surrounded by floating barriers). Post-treatment represents analysis in control areas and areas where barriers were removed ("post-barrier"). LZ and MZ were low zone and middle zone of the intertidal area, respectively.

3.3 Correlation between marine litter coverage and crabs

In the low zone, a significant negative correlation was identified between marine litter coverage and *Minuca* spp. total population abundance (Spearman, ρ = -0.47, p = 0.043). When the adults were considered separately, the same trend was stronger, in both males (ρ = -0.63, p = 0.006) and females (ρ = -0.57, p=0.013) (Fig.8). In the middle zone, there was no significant correlation. In this zone, despite the same tendency (negative correlation), the correlation was not significative (ρ = -0.22; p = 0.31). The correlation analysis did not reveal a significant relationship in any case between marine litter and the carapace width (CW) of the individuals.

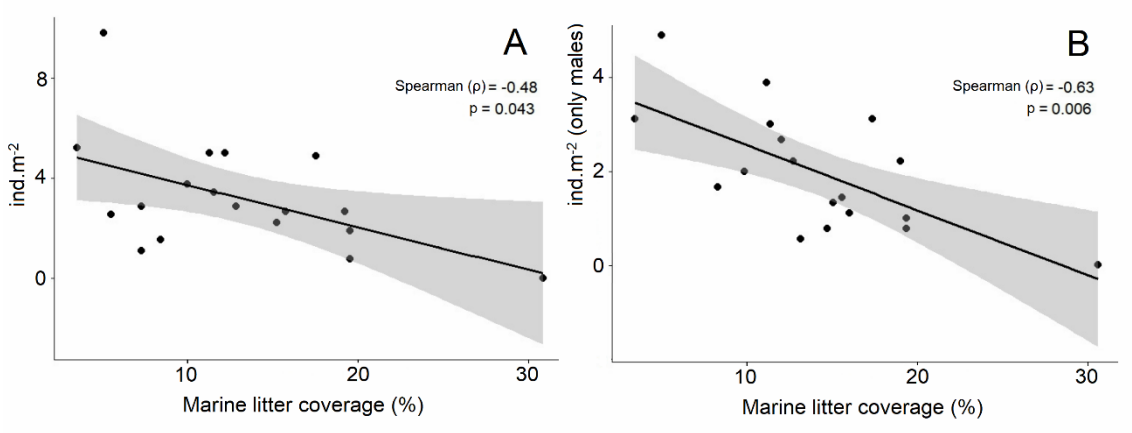

Fig. 8. Spearman´s correlation analysis between *Minuca spp.* abundance (individuals per m^2) and marine litter coverage (%) (A), and between *Minuca* spp. abundance of males and marine litter coverage (B) in the low zone of Bom Jesus cove mangrove swamp (SE-Brazil). The line represents the line regression model.

4. Discussion

Marine litter characterization

In the present study, the abundance of collected marine litter was 2.78 items.m^{-2} in the low zone, and 7.56 items.m^{-2} in the middle zone. These values were below that observed near to Port of Santos, SE Brazil (52.09 items.m^{-2}; Duarte et al., 2023). However, were similar to values reported in other mangrove from Brazil (1.33 items.m^{-2}; Cordeiro and Costa, 2010), from the Colombian Pacific coast (0.22 to 35.5 items.m^{-2}; Riascos et al., 2019), and in South China (2.04 to 3.44 5 items.m^{-2}; Sun et al., 2023). It is an established fact that the levels of marine litter vary between mangrove forests. Several factors must be given full consideration. Chief among these are natural factors such as the composition of the flora, the extent of the intertidal zone, the tidal regime itself and its range, and the direction and strength of marine currents in the region. Furthermore, several factors related to human activity must be considered, including waste management, the level of basic sanitation, public policies, and the occupation of the population in areas adjacent to mangroves.

During pre-treatment, marine litter coverage was similar between the low and middle zones; however, the greater variability observed in the low zone suggests higher spatial instability in litter deposition. In the treatment, areas fenced by barriers had significantly lower marine litter coverage compared to control areas, in both zones, demonstrating that the barriers were effective in retaining the litter brought in by the tide. Especially because they are fixed to the substrate, the barriers used in this study have a different design from most of those used for waste retention, such as river booms and similar devices. However, they proved to be efficient and fulfilled their main purpose, which was to keep the experimental areas free of marine litter. Previous studies have also demonstrated the effectiveness of barrier systems in intercepting marine debris (Schmaltz et al., 2020; Zayed and Saleh, 2025). Nevertheless, the

design utilized in this study is without precedent. The objective of its conception was to facilitate experimentation.

As reported by Zhang et al. (2020) and Zhou et al. (2025), the middle zone of mangroves has been found to accumulate more marine litter than the low zone, primarily due to its less frequent tidal flushing, which leads to marine litter retention. In the present study, the highest marine litter coverage was also recorded in the middle zone (in control areas). The findings of the present study are aligned with those documented by Bulow and Ferdinand (2013), who noted maximum sediment coverage values approaching 50% in mangroves along the Pacific coast of Panama. In a mangrove forest in eastern Sri Lanka, located in the vicinity of highly populated areas, marine litter coverage of 18.80 ± 1.74% was observed (Jayapala et al., 2024). As with the abundance of marine litter, several factors can be postulated that account for variations in litter coverage. In addition to natural and anthropogenic influences, other potentially significant factors may include the surface to volume ratio, abundance, and the capacity for attachment to the substrate. The interaction of these factors with the local abundance of marine litter may have a notable impact on the extent of marine litter coverage. Indeed, items with a high surface-to-volume ratio and low abundance, such as plastic bags and other plastic items, were predominant in campaigns with higher marine litter coverage.

Plastic materials were the dominant category of marine litter recorded in this study, corroborating global evidence that identifies plastics as the primary component of coastal and marine litter worldwide (De et al., 2023; Jayapala et al., 2024). According to Medeiros et al. (2017), plastic was the most frequently observed material, followed by Styrofoam, rubber, and metals. Likewise, Olivatto et al. (2019) reported that plastics such as cups, bags, packaging, PET bottles, and bottle caps were the predominant debris items at several sites in western portion of Guanabara Bay. Plastic bags and fragmented plastic items represented the dominant categories in other mangroves, indicating a strong contribution of lightweight and highly transportable

materials to litter accumulation (De et al., 2023). The consistent predominance of plastic materials across mangrove, estuarine, and beach environments highlights the pervasive nature of plastic pollution in highly urbanized coastal systems. This pattern is likely driven by the widespread consumption of single-use plastics, combined with their buoyancy, durability, and resistance to degradation, which facilitate their persistence and dispersion in aquatic environments. In addition, deficiencies in solid waste management and urban drainage infrastructure contribute to the continuous transport of plastic debris into coastal ecosystems. Higher plastic accumulation is generally associated with urbanized or densely populated coastal areas and with both direct and indirect anthropogenic pressures (Jayapala et al., 2024), reinforcing the strong link between human activity and debris distribution patterns.

Fiddler Crabs

The species of fiddler crabs found in the present study are consistent with previous records in the state of Rio de Janeiro (reviewed by Schmidt and Diele, 2023). In the present study, *Minuca spp.* was the most abundant genus in both zones of the intertidal area (lower and middle). According to Schmidt and Diele (op Cit.), individuals of the genus *Minuca* can occupy different ranges in the intertidal zone. For example, *M. rapax* tolerates more heat and dryness habitats and adapts well to all ranges of the mangrove, while *M. burgersi* and *M. victoriana* prefer the middle zone.

About reproduction, the reproductive period of fiddler crab's species in tropical mangroves are seasonal and generally occur during the rainy seasons (spring-summer), when the temperature is between 24 and 28° C (Ribeiro and Bezerra, 2014). In our study area, ovigerous females of *M. rapax* was recorded in May (autumn) and August/October (winter). In Itaipu Lagoon, located in proximity to Guanabara Bay, Costa and Soares-Gomes (2009) observed analogous results, with a heightened frequency of ovigerous females in April and October. Stauffer (2024) observed a higher

abundance of *M. rapax* juveniles in winter and spring (peaks in May and September) on the eastern side of Guanabara Bay. Consequently, in the bay and adjacent regions, mounting evidence suggests that *M. rapax* reproduction occurs primarily during the autumn and winter months.

The initial influence on the recruitment of meroplanktonic semi-terrestrial crabs and other species of marine invertebrates is that of settlement success (Fraschetti et al., 2003). Following the metamorphosis that transforms settlers into juveniles, several factors become relevant. In the context of estuarine crabs, salient factors encompass the interaction between adults and recently settled juveniles, predation rates, food availability, and sediment conditions, among other considerations (see Stauffer, 2024). In the present work, *Minuca* spp. juveniles and young crabs were more prevalent in the low zone, which is the area most susceptible to flooding and closest to the cove's water body. This zone has been found to have superior sediment quality conditions, with higher values of pore water (50.5 ± 13.3%) and organic matter content (18.6 ± 7.7 %). These characteristics suggest that the low zone offers greater food availability and lower risk of desiccation, creating a more favorable environment for younger fiddler crabs.

In comparison, in the region encompassing the largest mangrove forests in Guanabara Bay, Stauffer (2024) conducted an analysis of juvenile crabs within a 50-metre perpendicular transect from the waterline. Juveniles of *M. rapax were more abundant in the intermediate section, between 10 and 30m. In this section, the pore water content (≈ 37.0–39.0 %) and organic matter content (≈ 18.0–23.0 %) were found to be similar to those observed in the present study.*

The current study observed adult's CW that was comparable to those previously documented in other Brazilian mangroves. As Bezerra and Ribeiro (2014) documented, the mean CW of adult male *Minuca* spp. is typically between 10.0 and 16.0 mm. The female subject in question is between 9.0 and 15.0 mm in size. It is worth noting that *Minuca rapax* is one of the most abundant species in Brazilian

mangroves, exhibiting a high degree of adaptability to the characteristics of the environments in which it lives. Its occurrence has been documented in association with mangrove forests (as in this study), in the upper intertidal zone, and in the supralittoral zone adjacent to wetlands (Bezerra et al., 2006; Thurman et al., 2013). Furthermore, it has been observed to inhabit sediments ranging from medium sand to silty clay with humus or silty clay. Its natural habitats are those of meso- to euhaline regions, where it has been observed to construct its burrows among marsh grasses or in mangroves, in both open and shaded areas (Thurman et al., 2013). It is evident that this species exhibits a remarkable degree of adaptability, even in environments that have been subjected to significant human impact.

Marine litter versus fiddler crabs

In pre-treatment of the present study, abundances of *Minuca* spp. were similar between the low and middle zones. During the Treatment, the phase after removal of marine litter, abundances tended to be higher in areas fenced by barriers, except for middle zone in May 2024. This pattern indicates that the installation of barriers influenced crab abundance, particularly in the low zone, due to a significant increase in *Minuca* spp. abundance in October 2024. While we recognize that the presence of marine litter is not the only factor affecting the survival of these crabs, the impact of its removal is significant. As noted in this study, Bulow and Ferdinand (2013) observed lower abundances of fiddler crabs in areas with higher marine litter coverage.

During post-treatment campaigns conducted after the removal of barriers a return of marine litter to the previously fenced areas was observed. Nevertheless, positive effects in *Minuca* spp. abundance were still evident months after removal. In low zone, the abundance of fiddler crabs exhibited an increase in areas where barriers had previously been installed, especially in October 2025. This result indicates that the

habitat conditions modified during the barrier phase continued to favor the abundance of fiddler crabs.

Consequently, it is evident that if cleanup efforts in mangroves are executed in an appropriate manner, in conjunction with measures to prevent the arrival of marine litter, there is considerable potential for the conservation of fiddler crab populations. The results observed during the fieldwork of this study, in addition to those derived from the relevant literature (see Luo et al. 2021), serve to reinforce the detrimental effects of marine litter coverage, particularly regarding the reduction of substrate areas available for foraging and burrowing. Pisani et al. (2022), in a review of the literature on aquatic crustaceans, note that approximately 2.5% of studies involve the analysis of macroscopic litter, with mangroves ranking relatively low among the ecosystems examined. Given the importance of fiddler crabs and other crab species to mangroves and society, it is imperative that further studies be conducted on the impact of macroscopic marine litter on them.

Acknowledgments

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CRediT authorship contribution statement

POGS - Writing – original draft, Data curation, Field efforts, Collection and classification of marine litter, Formal analysis; LPTC - Writing – review and editing, Data curation, Field efforts, Formal analysis; VDG - Data curation, Field efforts, Taxa identification, Collection and classification of marine litter; Formal analysis; JERA - Data curation, Field efforts, Taxa identification, Collection and classification of marine litter; Formal analysis; YMG - Field efforts, Taxa identification, Collection and classification of marine litter; Formal analysis; TFL - Methodology (elaboration of barriers), Validation, Field efforts (installation and removal of barriers), Writing – review and editing; RHMM - Methodology (elaboration of barriers), Validation, Field efforts (installation and removal of barriers); DLF - Collection and classification of marine litter; Validation, Formal analysis, Writing – review and editing; SBV - Conceptualization, Methodology, Funding acquisition, Project administration; AS-G- Methodology, Project administration, Writing – review and editing; EVDA - Conceptualization, Methodology, Field efforts, Data curation, Project administration; Writing – review and editing.

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3. Comentários finais

É evidente que os resíduos sólidos macroscópicos causam diversas problemáticas ao meio ambiente, afetando especialmente os manguezais e os caranguejos, animais fundamentais para o equilíbrio e o bom funcionamento desse ecossistema. Os resíduos sólidos mais encontrados na área de estudo foram principalmente os plásticos. Na zona inferior do entremarés, o polímero mais abundante foi polietileno de alta densidade (PEAD), seguido pelo poliestireno (PS) e outros tipos de plásticos. Na zona intermediária, as maiores densidades foram registradas para o polipropileno (PP), o poliestireno (PS) e o HDPE. Considerando a caracterização dos resíduos removidos durante as campanhas de limpeza, os itens encontrados com maior frequência foram garrafas plásticas, isopor, diversos itens plásticos, sacolas plásticas, madeira processada e materiais de construção, além de outros tipos de resíduos em proporções menores. A maioria dos itens, plásticos de uso único.

No presente trabalhos, ao longo das campanhas antes e depois das intervenções no manguezal, foi possível observar a ocorrência de seis espécies dos gêneros *Minuca* (n = 3) e *Leptuca* (n = 3), sendo o primeiro o gênero com maior densidade populacional na área de estudo. *Minuca* spp. esteve distribuída nas duas subzonas do entremarés (inferior e intermediária) com densidades semelhantes em ambas, sem diferenças significativas.

De modo geral, não foram observadas diferenças significativas no tamanho corporal (largura da carapaça) entre as áreas de controle e as áreas experimentais. Com o início dos experimentos pós remoção dos resíduos sólidos, na Fase B em ambas as zonas, as densidades de caranguejos tenderam a ser maiores nas áreas limpas onde foram instaladas barreiras em comparação com as áreas de controle (poluídas). No entanto, registou-se uma diferença estatisticamente significativa em

relação à quantidade de resíduos e à densidade de caranguejos apenas na zona intermediária durante o levantamento de outubro de 2024, tanto para a população total quanto quando machos e fêmeas foram analisados separadamente.

De modo geral, não foram observadas diferenças significativas na largura da carapaça (CW) entre as áreas de controle e as experimentais, indicando que, durante esse período, a presença das barreiras não resultou em mudanças consistentes na estrutura de tamanho da população. No último estágio (C), na zona inferior, as densidades foram maiores nas áreas pós-barreira em comparação com as áreas de controle, indicando a permanência de efeitos positivos após a remoção das barreiras.

A comparação entre as áreas controle e as áreas experimentais indicou que a presença e a remoção de detritos marinhos influenciaram principalmente a densidade dos caranguejos Minuca spp., em especial na subzona inferior, mais próxima da água da enseada. Após a remoção dos detritos marinhos, observou-se um aumento na densidade nas áreas experimentais, enquanto o tamanho corporal apresentou pouca variação entre as áreas. Os resultados indicam que o acúmulo de detritos pode afetar negativamente as populações de *Minuca*.

Recomenda-se que estudos futuros investiguem os efeitos dos detritos marinhos em diferentes espécies e classes de tamanho de caranguejos chama-maré, permitindo uma avaliação mais precisa dos possíveis impactos sobre juvenis e adultos.

Além disso, sugere-se que a eficácia de estratégias de restauração ambiental, como o reflorestamento de manguezais, a instalação de barreiras para reter detritos e esforços periódicos de limpeza, seja avaliada para determinar se essas medidas contribuem para a melhoria das condições do habitat e o aumento da densidade de caranguejos nas áreas afetadas.

4. Referências complementares

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