UNIVERSIDADE FEDERAL DE PERNAMBUCO
CENTRO DE TECNOLOGIA E GEOCIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA

CARLOS EDUARDO ARAGÃO NEVES XAVIER

DIVERSIDADE E CONTAMINAÇÃO POR MICROPLÁSTICO EM CAMARÕES PELÁGICOS DE MAR PROFUNDO DAS REGIÕES NORTE E NORDESTE DO BRASIL

RECIFE
2025

CARLOS EDUARDO ARAGÃO NEVES XAVIER

Dissertação apresentada ao Programa de Pós-graduação em Oceanografia (PPGO) da Universidade Federal de Pernambuco, como um dos requisitos para a obtenção do título de Mestre em Oceanografia.

Orientador: Prof. Dr. Jesser Fidelis de Souza Filho.
Co-Orientadores: Dra. Anne Karen da Silva Justino
Dr. Guilherme Vitor Batista Ferreira

RECIFE
2025

Xavier, Carlos Eduardo Aragão Neves.
Diversidade e contaminação por microplástico em camarões pelágicos de mar profundo das regiões Norte e Nordeste do Brasil / Carlos Eduardo Aragão Neves Xavier. - Recife, 2025.
79f.: il.

Dissertação (Mestrado) - Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, Programa de Pós-Graduação em Oceanografia, 2025.
Orientação: Jesser Fidelis de Souza Filho.
Coorientação: Anne Karen da Silva Justino.
Coorientação: Guilherme Vitor Batista Ferreira.
Inclui referências.

1. Crustáceos; 2. Mar Profundo; 3. Poluição Plástica. I. Souza Filho, Jesser Fidelis de. II. Justino, Anne Karen da Silva. III. Ferreira, Guilherme Vitor Batista. IV. Título.

UFPE-Biblioteca Central

CARLOS EDUARDO ARAGÃO NEVES XAVIER

ESTRUTURA DE COMUNIDADE E PADRÕES DE CONTAMINAÇÃO POR MICROPLÁSTICO EM CAMARÕES PELÁGICOS DE MAR PROFUNDO DA ZONA ECONÔMICA EXCLUSIVA DAS REGIÕES NORTE E NORDESTE DO BRASIL

Dissertação apresentada ao Programa de Pós-graduação em Oceanografia (PPGO) da Universidade Federal de Pernambuco, como um dos requisitos para a obtenção do título de Mestre em Oceanografia.

Aprovado em: __/__/____

Nota: _____

BANCA EXAMINADORA

____

Prof. Dr. Jesser Fidelis de Souza Filho
Universidade Federal de Pernambuco - DOCEAN

____

Prof. Dr. José Souto Rosa Filho (Examinador Interno)
Universidade Federal de Pernambuco - DOCEAN

____

Dr. Leandro Nolé Eduardo (Examinador Externo)
Institut de Recherche pour le Développement - IRD

AGRADECIMENTOS

Agradeço primeiramente aos meus pais que seguem me permitindo tentar me encontrar nessa difícil vocação. Esse voto de confiança ainda é muito importante para mim. Além de tudo que eles fazem por mim em todos os âmbitos da minha existência. Essa gratidão estende-se à toda minha família, meus avós, meus tios, meus primos, meus sobrinhos, minhas cunhadas e meus irmãos. Serei pra sempre grato por toda torcida e apoio dado.

Agradeço ao CNPq e toda a estrutura fornecida pelo Departamento de Oceanografia da UFPE junto ao Museu de Oceanografia Prof. Petrônio Alves Coelho. Sem o fomento fornecido pela agência a minha pesquisa nada disso seria possível.

Agradeço também a todos os meus amigos da UFPE que me ajudaram sempre com sua amizade e companheirismo. Também aos meus amigos da vida e da minha terra querida, Pesqueira. Todo apoio dado pelos amigos ainda é muito válido, mesmo que de forma indireta.

Obrigado ao Prof. Petrônio Alves Coelho, aos meu orientador e coorientadores, Jesser, Anne e Guilherme. Também a todos do LabCarcino e Bioimpact que de alguma forma contribuíram com meu trabalho.

Por fim, e não menos importante, agradeço ao oceano, por existir e me permitir ser fascinado por ele.

RESUMO

Os camarões pelágicos desempenham papéis ecológicos cruciais em ambientes marinhos, das águas superficiais até as regiões mais profundas do oceano. São espécies que possuem grande importância na teia trófica, servindo muitas vezes como presas para espécies de elevado valor econômido e além de serem fatores determinantes no transporte de carbono para regiões de alta profundidade. Durante as expedições oceanográficas AMAZOMIX e ABRACOS, amostras representando a biodiversidade de camarões foram obtidas na região oceânica do Norte e Nordeste do Brasil, o que proporcionou uma oportunidade única para ampliar o conhecimento sobre a diversidade e ecologia desse grupo em regiões ainda pouco investigadas. Nesse contexto, a presente dissertação tem como objetivo analisar a diversidade e abundância de camarões na Zona Econômica Exclusiva (ZEE) das regiões Norte e Nordeste do Brasil, além de examinar os padrões de distribuição vertical desses organismos ao longo do dia. Discutindo também o impacto da poluição por microplásticos (MPs) nos ecossistemas marinhos, com foco na contaminação dos camarões de profundidade. Foram identificadas 66 espécies de camarões distribuídas em 34 gêneros e 10 famílias, destacando a Acanthephyridae como a mais representativa em número de espécies. Foram observados padrões de migração vertical diária, com a maior abundância sendo registrada em águas superficiais e a maior biomassa nas camadas mesopelágicas (400 - 800 m), ambos no período noturno, evidenciando o papel desses organismos na transferência de nutrientes e na bomba biológica de carbono. A pesquisa também documentou, pela primeira vez, formações de cardumes de invertebrados na região e ampliou a distribuição conhecida de várias espécies no Brasil. A contaminação por MPs foi avaliada em quatro espécies de camarões de profundidade, na região norte da ZEE brasileira. Foram identificadas 209 partículas de MPs em 70 espécimes (2.25 ± 2.19 indivíduo^{-1}), sendo as fibras o formato predominante. A espécie *Notostomus gibbosus* apresentou o maior nível de contaminação (4.55 ± 2.01 MPs Camarão^{-1}). Esses resultados destacam os riscos ecológicos associados à poluição por MPs, especialmente em áreas influenciadas pela pluma do Rio Amazonas, e ressaltam a importância desses camarões para a compreensão da dinâmica trófica e do impacto ambiental em regiões profundas.

Palavras-chave: Crustáceos; Mar Profundo; Poluição Plástica;

ABSTRACT

Pelagic shrimp play crucial ecological roles in marine environments, ranging from surface waters to the deepest ocean regions. These species are highly important in the trophic web and hold significant economic value. During the AMAZOMIX and ABRACOS oceanographic expeditions, key samples representing the biodiversity of shrimp were collected from the oceanic region of Northern and Northeastern Brazil, providing a unique opportunity to expand knowledge on the diversity and ecology of this group in areas that are still poorly studied. In this context, the present thesis aims to analyze the diversity and abundance of shrimp in the Exclusive Economic Zone (EEZ) of Northern and Northeastern Brazil and examine the vertical distribution patterns of these organisms throughout the day. The study also discusses the impact of microplastic (MP) pollution on marine ecosystems, focusing on the contamination of deep-sea shrimp. Sixty-six shrimp species were identified and distributed across 34 genera and 10 families, with Acanthephyridae being the most representative in terms of number of species. The analysis revealed daily vertical migration patterns, with higher abundance in surface waters at night and greater biomass in mesopelagic layers (400 – 800 m) during the night, highlighting the role of these organisms in nutrient transfer and in the biologic carbon bomb. The research also documented, for the first time, the formation of invertebrate schools in the region and expanded the known distribution of several species in Brazil. Regarding MP contamination evaluated in four deep-sea shrimp species in the Amazon EEZ, 209 MP particles were identified (2.25 ± 2.19 individual^{-1}), with fibers and transparent particles being the predominant forms. The species *Notostomus gibbosus* showed the highest contamination levels (4.55 ± 2.01 MPs Shrimp^{-1}. These findings underscore the ecological risks associated with MP pollution, especially in areas influenced by the Amazon River plume, and highlight the importance of these shrimp for understanding trophic dynamics and environmental impact in deep regions.

Keywords: Crustaceans; Deep sea; Plastic Pollution;

SUMÁRIO

1 INTRODUÇÃO

Os crustáceos são um dos grupos mais bem-sucedidos e diversificados do reino animal, com uma presença marcante nos oceanos. Esses organismos, predominantemente marinhos, são encontrados em uma vasta gama de profundidades e habitats, desde as zonas costeiras até as regiões mais profundas do oceano (Viana et al., 2021). Sua abundância e diversidade fazem deles componentes essenciais da fauna marinha, especialmente na plataforma continental e no oceano profundo (Nunomura, 2024). A diversidade morfológica dos crustáceos é uma das mais elevadas entre os metazoários, permitindo-lhes explorar uma grande variedade de nichos ecológicos (Bánki et al., 2023; Campli et al., 2024).

Dentro deste vasto grupo, a ordem Decapoda Latreille, 1803 se destaca, abrangendo algumas das espécies mais conhecidas e estudadas, como camarões, caranguejos, lagostas e siris. Esta ordem é dividida em duas subordens principais: Dendrobranchiata, que inclui camarões das superfamílias Penaeoidea e Sergestoidea, e Pleocyemata, subdividida em infraordens como Anomura (caranguejos eremitas), Astacidea (lagostas), Brachyura (caranguejos verdadeiros) e Caridea (camarões verdadeiros). Esses animais desempenham papéis ecológicos cruciais, atuando como predadores, herbívoros, omnívoros, saprófitos e filtradores, além de estarem adaptados a diferentes estratégias alimentares e ambientes aquáticos (De Grave et al., 2009; Aguirre-Guzmán & López-Acevedo, 2020; Medina-Contreras et al., 2022).

Entre os diversos ambientes aquáticos habitados por esses crustáceos, muitos camarões habitam o domínio pelágico, o maior habitat da Terra (Omori, 1975), estendendo-se da superfície até o oceano profundo e considerado um dos mais importante (Webb et al., 2010). O oceano profundo é parte da zona pelágica, sendo um ambiente hostil, e repleto de diversidade de vida a ser conhecida (Grassle & Maciolek, 1992; Jamieson et al., 2013). Com o aumento da profundidade, os organismos lidam com fortes gradientes de temperatura, pressão, oxigênio, nutrientes e a ausência de luz (Danovaro et al., 2014; Winnikoff et al., 2024; Zhang et al., 2024). Devido à dificuldade de acesso, o conhecimento sobre a diversidade do mar profundo é bastante limitado, principalmente por questões logísticas e financeiras (Jamieson et al., 2013; Soares, 2020).

A zona mesopelágica é a região da coluna d'água que se estende de 200 a aproximadamente 1000 metros de profundidade no oceano (Quero et al. 2020) e a batipelágica a partir de 1000 metros até meados de 4000 m (Sutton et al., 2017; Eduardo et al., 2024). As pesquisas sobre as comunidades das zonas meso- e batipelágicas estão ainda em seus estágios iniciais, o que gera grande preocupação de que os serviços ecossistêmicos fornecidos por essas espécies estejam em risco antes que possamos compreender plenamente as consequências das ações antrópicas, como a pesca, mineração e poluição (Santos et al., 2013; Groeneveld et al., 2024).

Apesar dos desafios logísticos, expedições oceanográficas multidisciplinares com ênfase no ambiente de mar profundo foram realizadas e os esforços de pesquisa vem aumentado no últimos anos (Howell et al., 2021). Dentre elas, destaca-se a expedição do REVIZZE (Programa de Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva) por ser uma das pioneiras na Zona Econômica Exclusiva (ZEE) do Brasil e possuir grande amplitude geográfica. Ela ocorreu entre os anos de 1996 e 2006, proporcionando novos conhecimentos sobre a fauna pelágica e demersal (Simões, 2007). Posteriormente, entre os anos de 2015 e 2022, foram realizadas duas outras expedições na região Norte e Nordeste com ênfase no estudo do ambiente de mar profundo e conhecimento da fauna mesopelágica, com amostragens focadas em peixes e diversos grupos de invertebrados. Expedições essas que fizeram parte os projetos ABRACOS I e II (*Acoustics along the Brazilian Coast*), com ênfase na região Nordeste da ZEE brasileira e avaliação do papel das ilhas e monte oceânicos e AMAZOMIX (*Amazon Shelf Mixing and its Impact on Ecosystems*), que possui ênfase na região Norte e influências da pluma do Rio Amazonas (BERNTRAND, 2015; BERNTRAND, 2017; BERNTRAND, 2021).

Mesmo com esse esforço amostral, e atualmente havendo a possibilidade de detecção acústica de outros grupos de organismos pelágicos, a maioria dos estudos ainda estão sendo direcionados para o estudo de comunidades de peixes (PROUD et al., 2019; PEÑA & HERNÁNDEZ-LEÓN, 2023). Esta lacuna de conhecimento é ainda maior em outros grupos como os crustáceos, cnidários e cefalópodes (Díaz-Pérez et al., 2024).

No oceano profundo, camarões são considerados importante elos na cadeia trófica, sendo a principal presa de peixes e moluscos, mas também importante consumidores de plâncton (Fanelli et al., 2011; Eduardo et al., 2023). No entanto, quantitativamente, possuem uma baixa ocorrência em amostras devido à alta seletividade equipamentos de amostragem (Christiansen et al., 2024). Atualmente, é utilizada uma combinação de redes e equipamentos acústicos para aumentar a precisão na estimativa de dados sobre a biomassa e abundância (Kang et al., 2024). Decápodes, peixes pelágicos de pequeno porte e eufasiídeos constituem a maior parte da biomassa do micronectôn, com os decápodes representando cerca de 20% da biomassa total (Díaz-pérez et al., 2024).

Apesar da relevância ecológica, econômica (Bordbar et al., 2018; Prezello et al., 2024) e da elevada biomassa dos crustáceos pelágicos, ainda há uma lacuna de informações acerca de sua diversidade, abundância, ecologia, distribuição espacial e composição taxonômica (Lizarraga, 2022). A biomassa desses crustáceos varia tanto latitudinalmente quanto verticalmente na coluna d'água (Vereshchaka et al., 2019). Uma grande parte da comunidade de camarões pelágicos realiza migrações verticais ao longo da coluna d'água (Deleo & Bracken-Grissom, 2020). Durante o dia, esses organismos permanecem nas camadas mais profundas, onde a baixa intensidade luminosa dificulta sua detecção por predadores (Suntsov & Domokos, 2013; Chipps et al., 2022).

Durante a noite, os camarões migram para as camadas superficiais para forragear, retornando as camadas mais profundas ao amanhecer (Krumme, 2009; Chipps, 2022). Esse comportamento é um fator muito importante para a diversificação desse grupo de crustáceos (Deleo, 2020). As migrações dependem de diversos fatores, desde ambientais como as condições oceanográficas ou estratégias específicas relacionadas à fatores comportamentais, como forrageamento, competição por alimento e espaço e a ontogenia (Kikuchi & Omori, 1986; Aguzzi, 2007).

O funcionamento do ciclo biogeoquímico do ecossistema pelágico tem grande relação com esses movimentos e migrações de biomassa, caracterizando a bomba de carbono. Diariamente, os organismos ingerem carbono orgânico nas camadas mais superficiais produtivas e ao amanhecer, se deslocam para as camadas mais profundas do oceano, onde excretam, respiram e também podem ser predados (Baustian et al., 2014; Folkersen et al., 2018; Thibault et al., 2024).

Os camarões possuem uma fase larval planctônica e processos hidrológicos, como frentes e vórtices, são descritos como importantes fatores para a maior abundância, dispersão e retenção de larvas de decápodes (Mcconaugha, 1992; Anger & Urzúa, 2024; Monteiro et al., 2024). Esses processos hidrológicos atuam diretamente na abundância e na distribuição das comunidades planctônicas e são fatores potenciais que podem causar distúrbios no gradiente costeiro-oceânico. Normalmente, há uma maior abundância de organismos em águas mesotróficas costeiras, em oposição às áreas oceânicas oligotróficas (Boltovskoy et al., 1999; Farias et al., 2024). As interações biológicas, incluindo relações como presa-predador e competição, assim como mudanças físicas no ambiente, exercendo um efeito simultâneo e sinergético e destacando-se pela sua importância na estruturação das populações e comunidades de organismos (Mcgill et al., 2006; Gray & Elliott, 2009; Veloso et al., 2017).

A partir da Segunda Guerra Mundial, plásticos se tornaram uma parte fundamental do estilo de vida contemporâneo, integrando-se a diversos setores da economia (Andrady, 2009; Geyer et al., 2017; Paterson, 2019). Embora a indústria do plástico tenha impulsionado avanços tecnológicos significativos, o acúmulo de resíduos plásticos em habitats naturais e aterros sanitários emergiu como uma grave ameaça para os ecossistemas e saúde dos organismos vivos (Getor et al., 2020; Pilapitiya & Ratnayake, 2024; Thushari & Senevirathna, 2020). A produção global de plásticos ultrapassou 400 milhões de toneladas em 2022 (PlasticsEurope, 2023). Esse elevado consumo, somado à ineficiente gestão de resíduos, fez da poluição plástica um dos principais desafios ambientais da atualidade (Cowger, 2024; Pilapitiya & Ratnayake, 2024).

Os detritos plásticos são divididos em três categorias quanto à dimensão: macroplásticos, com tamanho superior a 5 mm; microplásticos, que possuem até 5 mm; e nanoplásticos, com dimensões menores que 1 µm (Pelegrini et al., 2023). Nos últimos anos, os microplásticos (MPs) têm recebido crescente atenção em pesquisas ao redor do mundo, pelo seu descarte indevido, ocorrência em diversos ecossistemas e capacidade de adsorver e transportar diversos contaminantes (Rochman et al., 2019; Pilapitiya & Ratnayake, 2024; Zhu et al., 2024). Os MPs podem ser classificados como primários, quando são produzidos em pequenas dimensões para serem utilizados em processos industriais, ou como secundários, que surgem da fragmentação de plásticos maiores, como fibras têxteis sintéticas, devido à degradação mecânica, térmica ou biológica (Cao, 2024; Thavasimuthu, 2024; Yang, 2024).

Atualmente, os MPs são identificados como um dos contaminantes ambientais emergentes de maior preocupação nos ecossistemas marinhos (Martín, 2022), e já foram encontrados em ambientes terrestres, marinhos, de água doce e inclusive em regiões polares (Meng, 2020; Tirelli, 2022; Arat, 2024; Zeb, 2024). Essa ampla distribuição dos MPs aumenta significativamente o risco de ingestão acidental por diversos animais aquáticos, que acabam consumindo essas partículas durante suas atividades alimentares (Amponsah 2024; Valdez-Cibrián, 2024). Diversos estudos evidenciam a presença de MPs em camarões de profundidade, entre eles camarões de importância econômica (Curren et al., 2020; Bordbar et al., 2023; Timilsina et al., 2023). Os MPs podem ainda estar associados a outros contaminantes, como Hidrocarbonetos Policiclicos Aromáticos (HPAs) e metais pesados (Aydin et al., 2024; Narwal et al., 2024; Xie et al., 2024) devido ao processo de fabricação do plástico ou à adsorção no ambiente (Holmes et al., 2014; Kong et al., 2023; Sui et al., 2024)

Considerando essa problemática, o presente estudo fornecerá uma descrição detalhada da composição e variabilidade espacial de espécies de camarão de mar profundo em áreas oceânicas, inclusive em áreas influenciadas pela pluma do Rio Amazonas. Analisando também a distribuição vertical diária. Com isso ampliando a distribuição de diversas espécies raras, em um ambiente extremo e de alta dificuldade de amostragem. Além disso, uma das áreas de coleta é de importância mundial, a região da Pluma do Rio Amazonas, o maior rio do mundo (Mikkola, 2024). Adicionalmente, serão investigados os níveis e padrões de contaminação por MP na fauna, identificando e classificando as principais formas encontradas.

.

2 CAPÍTULO 1

2.1 Diversity and vertical distribution of deep-pelagic shrimps in the western central and south Atlantic Ocean

Abstract

This study analyzes the biodiversity and vertical distribution of deep-sea pelagic shrimps in the Exclusive Economic Zone of Brazil's North and Northeast regions. Sample were taken during the ABRACOS (2015-2017) and AMAZOMIX (2021) campaigns, covering depths from 70 to 1200 m during daytime and nighttime periods. A total of 66 species were identified, distributed in 34 genera and 10 families, with Acanthephyridae as the most representative family. The species Challengerosergia sp. stood out in abundance, while *Acanthephyra acutifrons* and *Robustosergia regalis* showed a high frequency of occurrence. The biomass was concentrated in mesopelagic layers (400-800 m), especially at night, showing vertical migration. We also observed the unprecedented formation of shoals of shrimps in the region. This work expanded the known distribution of several species in Brazil and provided the first integrated list of pelagic shrimps in the North and Northeast regions. The results highlight the importance of these organisms in trophic dynamics and biogeochemical cycles, contributing to the advancement of knowledge about deep-sea biodiversity.

Keywords: Marine biodiversity, DVM, Decapoda

2.2 Introduction

Pelagic shrimps are a vital part of deep-pelagic ecosystems. The families Sergestidae, Benthesicymidae, Acanthephyridae, and Oplophoridae are dominant groups in terms of abundance and biomass (Vereshchaka et al., 2019; Worms, 2024). With a worldwide presence, these shrimp frequently have vertical migrations and have developed several adaptations to survive the unique econditions of the deep ocean (Decele, 2010; Deleo et al., 2020; Yuan et al., 2021).

The diel vertical migration of marine fauna is the largest daily movement of animal biomass on Earth (Hays, 2003; Bianchi et al., 2013; Archibald et al., 2019; Behrenfeld et al., 2019; Hernández-León, 2013). Typically, migrating organisms feed in shallower waters and descend to deeper layers, releasing organic carbon through respiration, excretion, or egestion (Getzlaff & Kriest, 2024). This behavior drives the active carbon pump (Boyd et al., 2019) and influences biogeochemical cycles (Buesseler & Boyd, 2009).

Mesopelagic shrimp are crucial for capturing and storing carbon, cycling nutrients through the ecosystem, and functioning as important intermediaries between primary consumers and top predators in the food chain (Hûgler et al., 2011;). They also serve as an essential food source for commercially valuable fish stocks and act as a vital connection between shallow and deep-sea ecosystems (Braga et al., 2012; Drazen et al., 2017).

The deep sea is one of the most unexplored extreme environment, holding immense potential and interest for scientific study (Nagano & Nagahama, 2012; Colaço et al., 2017). Given that the deep-pelagic zone constitutes most of the habitable volume of the ocean, it is essential to accurately assess the biomass of its primary components, including shrimps (Spalding, 2012; Vereshchaka, 2019). Extreme environments encompass a variety of abiotic factors that surpass the tolerance limits of most organisms, with abiotic factors playing a major role in determining the presence and abundance of species (Convey, 1997; Rampelotto, 2016). However, biotic factors remain important contributors to ecosystem dynamics (Camacho, 2006; Hogg et al., 2006).

The mesopelagic habitat is distinguished by its unique temperature, oxygen levels and light conditions, which include low irradiance, a narrow spectral range, and a restricted angular distribution (Li et al., 2014; Kaartvedt et al., 2019; Aparecido et al., 2023; Eduardo et al., 2024). Some shrimp species are adapted to extreme environments and share their habitats with many microorganisms and other multicellular organisms (Benvenuto et al., 2015). The crustaceans' complex visual and bioluminescence systems inhabiting this zone exhibit several adaptations that allow them to maximize using these light conditions (Bracken-Grissom et al., 2020; Collins et al., 2024). Some other adaptations include low metabolic rates and morphological adaptation, such as an increase in the size of the gills (Childress, 1995; Decelle, 2010). Through these specialized biological adaptations, many of these species are endemic to their extreme habitatssuch as the deep sea (Eilertsen et al., 2024; Giraldes et al., 2024). This makes the mesopelagic zone home to one of the ocean's most diverse shrimp communities, contributing to numerous essential ecosystem functions (Basher, 2014; Therber et al., 2014; Antonio et al., 2024).

The REVIZEE program (*Programa de Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva*) conducted expeditions between 1996 and 2006, surveying waters 200 m deep off the Brazilian coast (SIMÕES et al., 2007). These explorations culminated in the identification of new species, the documentation of previously unrecorded specimens, and an expanded understanding of the distribution of pelagic shrimp species (Anker, 2014; Silva, 2020). Between 2015 and 2022, two more expeditions targeting mesopelagic fauna were conducted in the North and Northeast regions. These were part of the ABRACOS (Acoustics Along the Brazilian Coast) and AMAZOMIX (Amazon Shelf Mixing and Its Impact on Ecosystems) projects and marked the first extensive survey of the mesopelagic zone in the Southwestern Tropical Atlantic (SWTA), resulting in the collection of thousands of deep-sea invertebrates and fishes.

Several studies have been published based on these collections, exploring the taxonomy, ecology and geographical distribution of deep-sea shrimps (Alves-Júnior et al., 2019a), taxonomic descriptions (Alves-Junior et al., 2019b), new species (Rodrigues et al., 2018) and new records (Alves-Júnior et al., 2016, 2018). In addition to these studies, there exists a body of research concerning other assemblages of deep-sea crustaceans, such as Amphipoda (Alves-Júnior et al., 2021) and Isopoda (Ferreira et al., 2023), but predominantly focusing on fish (Afonso et al., 2021; Eduardo et al., 2020; Mincarone et al., 2022).

There is a noticeable lack of research on deep-water pelagic shrimp in Brazil's northern and northeastern regions, particularly in the area influenced by the plume of the Amazon River. While these regions are home to rich and diverse marine ecosystems, the specific focus on pelagic shrimp, especially those inhabiting deeper waters, has been largely overlooked in scientific studies. Also, no published work on any aspect of pelagic shrimp biology using AMAZOMIX data and much of the ABRACOS expedition's data, such as findings on shrimp, remain unpublished. In general, there is a lack of knowledge about mesopelagic species' diversity, ecology and distribution (Sutton et al., 2017; Martin et al., 2020; Lizarraga, 2022).

The present study analyzes the mesopelagic shrimp biodiversity in the SWTA, presenting a comprehensive species list gathered during the ABRACOS and AMAZOMIX expeditions. It highlights newly recorded species and potential discoveries while examining critical aspects of mesopelagic shrimp diversity, such as depth distribution.

2.3 Material and methods

2.3.1 Sampling Strategy

The study area is located in the North and Northeast of Brazil. The deep-sea shrimps were collected during three multidisciplinary oceanographic campaigns on board the R/V ANTEA (Figure 1). The Northeast region was sampled during two expeditions, ABRACOS 1 and 2 (AB1 and AB2). The study area extended from Rio Grande do Norte to Alagoas, including the Fernando de Noronha Archipelago, various seamounts, and the Atol das Rocas. The geological features of this region significantly influence current dynamics, enhancing primary productivity by driving nutrient-rich deep currents to the surface. This process fosters a unique variety of ecosystems, which play a vital role in supporting the fishing productivity of the Brazilian Exclusive Economic Zone (Tchamabi et al., 2017; Claudino-Sales, 2019; Eduardo et al., 2022).

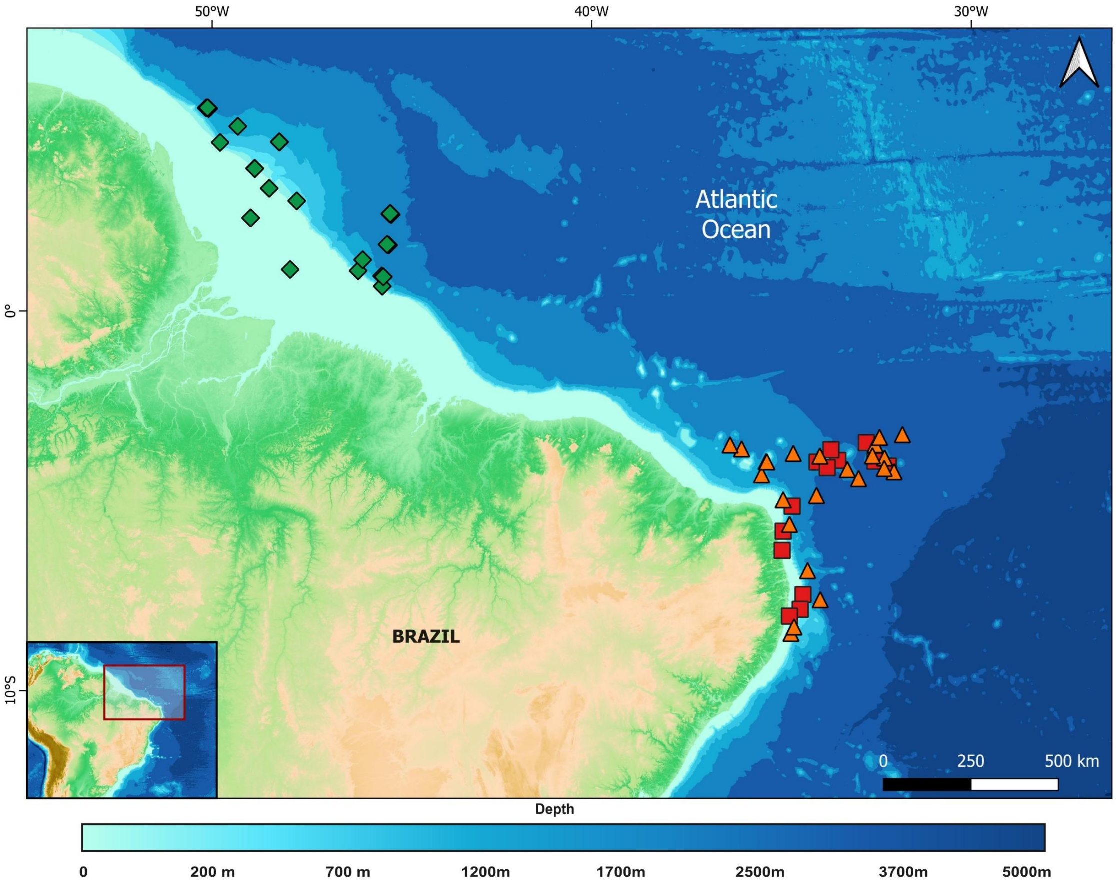

Figure 1. Map of the North and Northeast regions, including areas close to oceanic islands, sampled by the R/V ANTEA. Campaign ABRACOS 1 (AB1), ABRACOS 2 (AB2) and AMAZOMIX (AM). Red circles represent the AB1 samples: Orange for the AB2 samples and Green for the AM samples.

The campaigns were conducted from September to October 2015 (AB1) and April to May 2017 (AB2). A total of, 31 sampling stations were surveyed using a midwater net with a 30 mm mesh, a 4 mm cod end mesh, and a net mouth size of 16.6 x 8.4 meters (AB1), while 51 collection stations were sampled using a micronekton net with a 40 mm mesh, 10 mm cod end mesh, and a net mouth size of 24 x 24 meters (AB2) (Bertrand, 2021).

Sampling from the Northern region as part of the AMAZOMIX Project was carried out on board the N/Oc ANTEA, between September and October 2021, divided into two legs along the states of Pará and Amapá. There were 14 stations in the first leg and 21 in the second leg, collecting off the Amazon River to oceanic regions adjacent to the northern continental shelf during the day and night between the isobaths of 70 and 1,200 meters. A 1mm mesh micronet net was used, covering 15 meters of mouth and 18 meters in length, and trawled for 30 minutes at previously determined isobaths with the boat sailing at a speed of between 1.5 and 3 knots. This region encompasses the mouth of the Amazon River, which is characterized by being a region with a strong outflow of fresh water (210,000 m³/s) into the marine environment, with the river plume acting as a biogeographical barrier (RObertson et al., 2006; Moura et al., 2016; Tosetto et al., 2022).

A CTD (SBE911+) was simultaneously attached to the nets each trawl, totaling 71 depth profiles, in order to measure the physical/chemical parameters of the region (temperature (°C), salinity, dissolved oxygen (μM/Kg) and fluorescence (mm/m³). Once collected, the individuals were frozen in labeled 500 ml jars.

2.3.2 Data processing and analysis

The samples were taken to the Crustacean Laboratory (LabCarcino) at the Prof. Petrônio Alves Coelho Oceanography Museum (MOUFPE), where shrimps were identified to the lowest possible taxonomic level (Crosnier & Forest, 1973; Vereshchaka, 2009; Alves-Júnior, 2019b, 2019c; Lunina et al., 2019; Rodrigues & Cardoso, 2019), weighed and measured (total length, carapace length and total weight).

The index for abundance and biomass was calculated based on CPUE (catch per unit effort), considering the number of individuals and the weight of the shrimp caught per season, divided by the trawling time (ind./h and grams/h). The frequency of occurrence (number of occurrences of species (x100), divided by the total number at the station, %F) was also calculated (Vo et al., 2024).

The variables (richness, abundance and biomass) were compared according to depth (every 100 m) and daily periods (day/night), considering the entire survey. For richness, the number of individuals was used, and for abundance and biomass, average values. Statistical analyses and the calculation of diversity indices were carried out using WPS Spreadsheets 2024.

2.4 Results

A total of 2,559 specimens of deep-sea pelagic shrimp were collected, 296 of which in the ABRACOS 1 campaign (20 stations), 444 in the ABRACOS 2 campaign (25 stations) and 1,819 in the AMAZOMIX campaign (13 stations). A total of 65 species were identified, belonging to 34 genera and 10 families (Table 1).

Table 1. List of species and related data found in the ABRACOS 1 (AB 1), ABRACOS 2 (AB 2) and AMAZOMIX (AM) surveys, total length (TL). carapace length (CL) and total weight (TW) (average, minimum and maximum values), depth, temperature, oxygen and salinity (minimum and maximum values), locality (Alagoas, Amapá, Pará, Paraíba and Rio Grande do Norte Islands).), temperature (T), oxygen (minimum and maximum values) and salinity, location (Alagoas, Amapá, Pará, Paraíba, Pernambuco, Rio Grande do Norte, Fernando de Noronha and Seamounts) and daily period of the day (D) and night (N). * Data not sampled.

Species	N Individuals			FO%	TL (mm)	CL (mm)	TW (g)	Depth (m)	T (°C)	Oxygen	Salinity	Day Period	Locality
	AB1	AB2	AM										
ACANTHEPHYRIDAE													
Acanthephyra acanthitelsonis	104	81	74	9%	87.9	21.1	5	0 - 1000	4.4 - 26.7	3 - 4.7	34.4 -37.1	D - N	AL - AP - FN - PA - PE
Acanthephyra acutifrons	41	51	40	5%	79.8	19	2.1	0 - 1200	4.4 - 24.5	2.9 - 4.7	34.5 - 37.1	D - N	AL - AP - FN - PA - PE - PB - RN
Acanthephyra curtirostris	18	33	253	11%	30.8	8.5	4	400 - 1000	4.6 - 8.8	2.9 - 4.1	34.4 - 34.7	D - N	FN - PA - PB - PE - SM
Acanthephyra kingsleyi	5	31	*	1%	82.8	16.7	3.4	200 - 1000	4.4 - 13.7	3.6 - 4.5	34.4 -35.3	D - N	FN - RN
Acanthephyra quadrispinosa	9	*	*	0%	*	*	*	500 - 600	4.4	4.0	34.6	N	PE
Acanthephyra sp.1	*	29	*	1%	*	*	*	1100 - 1200	*	*	*	N	RN
Acanthephyra sp.2	*	*	1	0%	*	*	*	400 - 500	8.8	3	34.8	D	PA
Acanthephyra stylorostratis	*	*	17	1%	56.5	13.4	1.1	0 - 1100	4.4 - 5.1	3.2 - 3.8	34.5 - 34.7	D - N	AP - FN - PA
Ephyrina benedicti	3	*	*	0%	*	*	*	0 - 1100	*	*	*	D	RN
Ephyrina ombango	3	9	10	1%	84.8	20.2	4.6	0 -1000	4.4 - 8.8	3 - 3.8	34.4 -34.8	D - N	AP - FN - RN - PA - PE
Ephyrina sp.1	*	*	1	0%	35.9	13.7	0.2	800 - 900	5.1	3.1	34.6	D	AP
Ephyrina sp.2	*	*	1	0%	*	*	*	800 - 900	5.1	3.1	34.6	D	AP
Meningodora compsa	*	*	10	0%	74.6	17.7	2.9	900 - 1000	5.1	3.3	34.6	D	AP
Meningodora longisulca	1	4	3	0%	46.4	14.3	1.1	500 -1000	5 - 5.1	3.3 - 3.7	34.4 - 34.7	D - N	FN - RN
Meningodora mollis	*	1	*	0%	52.2	18.2	1	400 - 700	8.8	3	34.8	D - N	PA - RN

Meningodora sp.1	*	*	2	0%	50.7	18	1.3	900 - 1000	4.6 - 5.1	3.3 - 3.5	34.6 -34.7	N	PA
Meningodora sp.2	*	*	1	0%	66.7	25.2	2.1	900 - 1000	4.6	3.5	34.6	N	AP
Meningodora vesca	9	3	2	0%	45	12	0.7	400 - 1000	4.6 - 6	3.5 - 4.1	34.4 - 34.6	D - N	FN - RN
Notostomus elegans	4	5	0	0%	55	19	0.9	400 - 1000	4.4 - 6.9	3.7 - 4.1	34.4 - 34.5	D - N	FN - RN
Notostomus gibbosus	10	19	51	3%	91.4	39.3	6.3	400 - 1200	4.4 - 19.6	3 - 3.9	34.4 - 36.1	D - N	AP - FN - RN - PA
BENTHESICYMIDAE													
Bentheogennema intermedia	2	*	*	0%	*	*	1.2	0 - 200	15.7 - 24.5	3.4 - 4.7	35.7 - 37.1	D - N	FN - RN
Bentheogennema sp.1	*	3	*	0%	40	9	0.5	900 - 1000	4.4	3.8	34.4	D	SM
Gennadas bouvieri	10	14	5	1%	40	9	0.9	400 - 1100	8.5	3	34.8	D - N	AP - FN - RN
Gennadas capensis	3	15	9	1%	43.7	13.1	0.6	500 - 1100	4.4 - 5.1	3.3 - 3.8	34.5 - 34.7	D - N	AP - FN - RN - PA
Gennadas scutatus	*	5	*	0%	*	*	*	300 - 600	*	*	*	D	FN - RN
Gennadas talismani	*	3	*	0%	*	*	*	300 - 600	*	*	*	D	FN - RN
LUCIFERIDAE													
Belzebub faxoni	4	*	*	0%	*	*	0.2	0 - 500	6 - 26.8	4.1 - 4.7	34.5 - 36.8	N	FN
PALAEMONIDAE													
Nematopalaemon schmitti	*	*	300	11%	34.5	9.9	0.4	0 - 100	*	*	*	D	AP - MA
Palaemonidae gen. sp.1	3	*	*	0%	*	*	*	0 -100	26.6 - 26.8	4.6 - 4.7	36.8 - 36.9	N	FN - RN
PANDALIDAE													
Heterocarpus ensiver	*	*	1	0%	35.4	12.3	0.5	500 - 600	7.9	2.6	34.7	D	PA
Heterocarpus sp.1	2	*	*	0%	*	*	*	100 - 200	15.7 - 25.5	3.4 - 4.7	35.6 - 37.2	N	FN - RN
Plesionika sp.1	2	*	*	0%	*	*	*	0 - 100	26.6	4.7	37	N	FN
PASIPHAEIDAE													
Eupasiphae sp.1	*	*	1	0%	135.7	48.2	17.1	600 - 1000	5.1 - 6.3	3 - 3.3	34.7	D	AP
Parapasiphae sp.1	*	*	1	0%	55.8	7.2	2.2	800 - 900	5.1	3.1	34.6	D	AP

Parapasiphae sulcatifrons	*	3	6	0%	70.1	19.8	2.2	400 - 1000	4.4 - 8.8	3.1 - 3.8	34.5 - 34.8	D - N	AP - FN - RN- PA
Pasiphaea sp.1	*	*	1	0%	75.8	24.2	2.3	400 - 500	8.8	3	34.8	D	PA
Pasiphaea antea	1	1	*	0%	*	*	*	*	*	*	*	*	RN
Pasiphaea merriami	*	*	16	1%	47.5	14.6	0.5	100 - 1000	4.6 - 18.7	3 - 3.7	34.6 - 35.7	N	AP - PA
Pasiphaea princeps	*	*	1	0%	*	*	*	300 - 400	10.2	3.5	34.9	N	PA
Pasiphaeidae gen. sp.1	1	*	*	0%	*	*	*	0 - 100	24.5	4.7	37.1	D	RN
Pasiphaeidae gen. sp.2	*	49	*	2%	57.8	18	2.5	0 - 1000	4.4 - 13.7	3.6 - 4.5	34.4 - 35.3	D - N	FN - RN - SM
Pasiphaeidae gen. sp.3	*	*	1	0%	*	*	*	600 - 700	6.3	3	34.6	D	AP
PENAEIDAE													
Funchalia danae	*	5	5	0%	72.8	17.9	2.4	300 -1100	4.6 - 8.8	2.6 - 3.5	34.6 - 34.8	D - N	FN - RN - MA - PA
Funchalia villosa	6	2	*	0%	*	*	*	0 - 700	5.3 - 24.7	4.5	34.4 - 37.2	D - N	CE - RN
Hymenapenaeus laevis	*	*	2	0%	51.6	17.2	0.7	0- 1000	5.1	3.3	34.7	D	AP
Penaeidae gen. sp.1	1	*	*	0%	*	*	*	100 - 200	15.7	3.4	35.7	N	SM
OPLOPHORIDAE													
Janicella spinicauda	2	*	*	0%	*	*	*	100 - 200	24.5	4.7	37.1	N	FN
Oplophorus gracilirostris	18	*	45	2%	52	15.4	1.5	0 - 1000	4.4 - 25.7	2.8 - 4.7	37.1	D - N	FN - RN - PA
Systellaspis curvispina	6	7	*	0%	74	23.3	4.8	400 - 1000	4.4 - 5.7	3.6 - 4.5	34.4 - 35.5	D - N	FN - RN
Systellaspis debilis	2	*	2	0%	63	19.4	3.2	0 - 600	4.4	4	34.6	D - N	PE
Systellaspis pellucida	1	*	*	0%	*	*	*	0 - 100	25.5	4.7	37.2	D	FN
SERGESTIDAE													
Challengerosergia sp.1	*	*	842	30%	47.4	14.2	0.3	100 - 500	7 - 18.7	3 - 3.7	34.6 - 35.7	N	AP - PA
Challengerosergia sp.2	*	*	26	1%	59.1	18.1	2.5	0 - 700	6.3 - 21.5	3.1 - 4.3	34.6 - 36.2	D - N	PA
Parasergestes sp.1	*	*	1	0%	3.9	1.3	4.9	900 - 1000	5.1	3.3	34.7	D	AP
Phorcosergia burukovskii	10	13	30	2%	48.1	13.3	0.7	100 - 1200	5 - 18.7	3 - 4.5	34.4 - 35.7	D - N	AP - CE - FN - RN - PA
Phorcosergia sp.1	*	*	1	0%	118	34	5	*	*	*	*	D	AP

Robustosergia regalis	15	57	29	4%	60.9	17.6	1.9	300 - 1100	4.4 - 10.2	3 - 3.8	34.5 - 34.9	D - N	AP - FN - RN -PA
Robustosergia sp.1	*	*	1	0%	64.7	22.5	2	400 - 500	8.8	3	34.8	D	PA
Sergestidae gen sp.1	*	1	*	0%	*	19	3.4	400 - 500	*	*	*	N	FN
Sergestidae gen sp.2	*	*	3	0%	62.8	19.7	2.4	900 - 1000	4.6 - 5.1	3.3 - 3.5	34.6 - 34.7	N	AP - PA
Sergestidae gen sp.3	*	*	4	0%	41..5	10.9	0.2	400 - 500	7	3	34.6	N	AP
Sergestidae gen sp.4	*	*	8	0%	52.1	15.3	1.3	400 - 500	7	3	34.6	N	AP
Sergia laminata	*	*	11	0%	41.8	10.7	0.3	400 - 1000	5.1 - 7	2.9 - 3.1	34.6 - 34.7	D - N	AP
Sergia sp.1	*	*	1	0%	*	*	*	300 - 400	10.2	3.5	34.9	N	PA

The family Acanthephyridae represented 30% (20 species) of the species observed, followed by the family Sergestidae (19%, 13 species), and Pasiphaeidae (15%, 10 species). Other families had less than ten species (Benthesicymidae - 6 species, Oplophoridae - 5 species, Peneidae - 4 species, Pandalidae - 3 species, Palaemonidae - 2 species and Luciferidae - 1 species.

The most abundant species in the three campaigns was *Challengerosergia* sp, had 842 individuals in just one sample, a result much higher than any other species sampled in the campaigns. Two other Sergestidae were also abundant: *Robustosergia regalis* (Gordon, 1939) (101 individuals) and *Phorcosergia burukovskii* (Vereshchaka, 2000) (53 individuals).

Nematopalaemon schmitti (Holthuis, 1950) contributed 300 individuals collected in the AM campaign. The family Acanthephyridae family is represented by the species *Acanthephyra curtirostris* Wood-Mason & Alcock, 1891 (304), *Acanthephyra pelagica* RISSO, 1813 (259), *Acanthephyra acutifrons* Spence Bate, 1888 (132) and *Notostomus gibbosus* A. Milne-Edwards, 1881 (80).

The species *Oplophorus gracilirostri*s A. Milne-Edwards, 1881, also obtained less than 100 individuals in the sample. It was represented by 63 individuals. The other species had fewer than 100 individuals. Several species were represented by only one individual in the samples. They are, therefore, considered rare. These are *Heterocarpus ensifer* A. Milne-Edwards, 1881, *Meningodora mollis* Smith, 1882, *Metapenaeopsis hobbsi* Pérez Farfante, 1971, *Pasiphaea princeps* Smith, 1884 *and Systellaspis pellucida* (Filhol, 1884).

Specifically, the species with the highest frequency of occurrence were *A. acutifrons* (30%), *R. regalis* (27%), A. curtirostris (19%) *Ephyrina ombango* Crosnier & Forest, 1973 (19%), *N. gibbosus* (19%), *P. burukovskii* (19%), A. pelagica (16%) and *Acanthephyra kingsleyi* Bate, 1888 (16%). The frequency of occurrence of most the other species was considered rare.

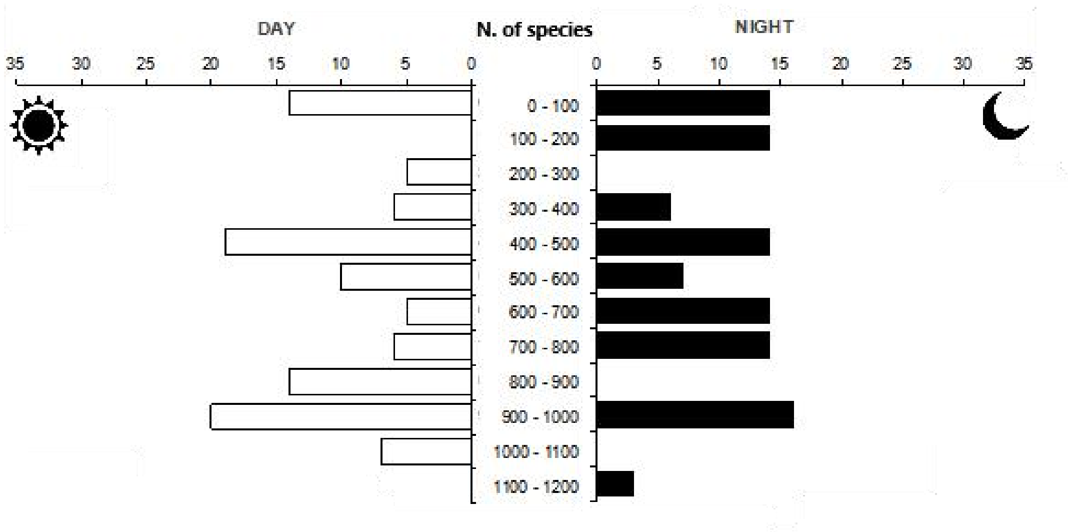

Figure 2. Total number of species by depth stratification and by day and night period of the shrimp sampled.

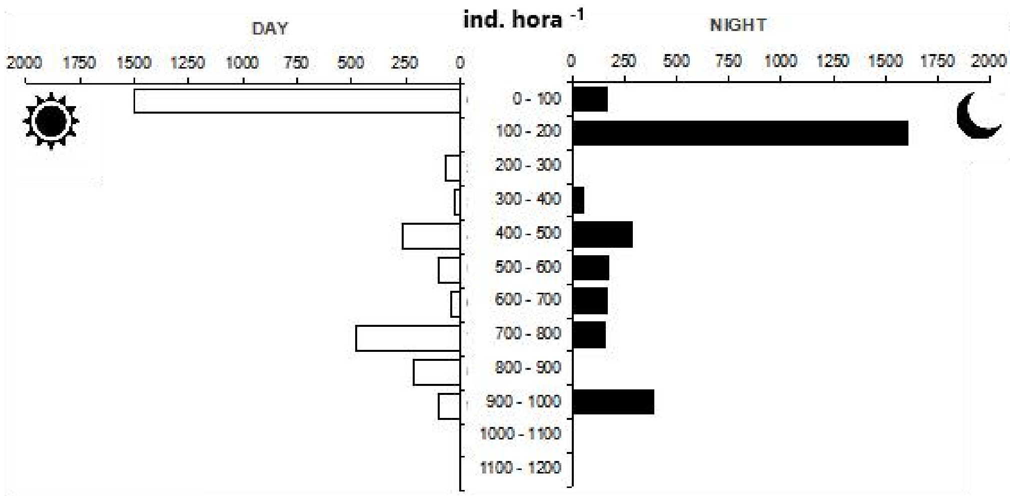

Figure 3. Average values of total abundance (ind. hour^{-1}) by depth stratification and by day and night period of the shrimp sampled.

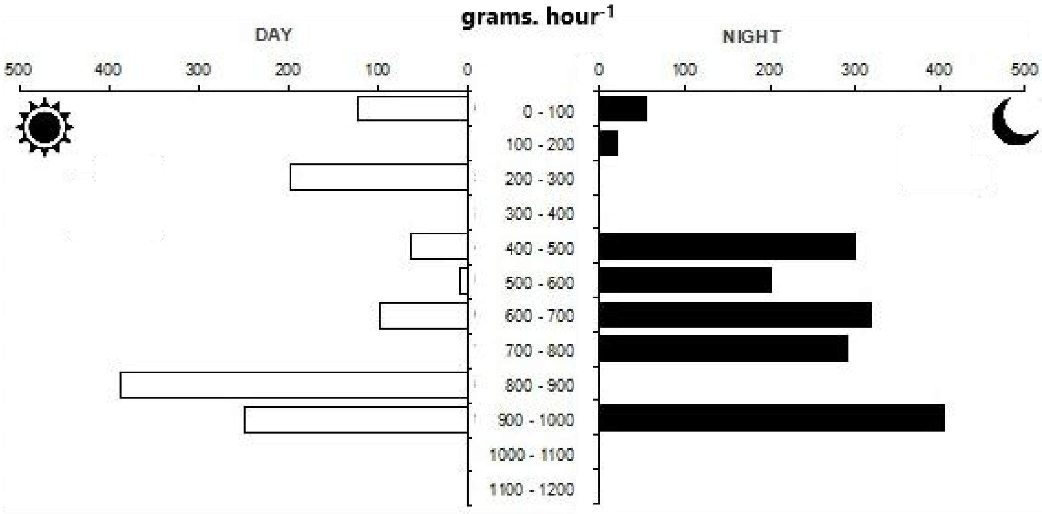

Figure 4. Average values of total biomass (grams. hour^{-1}) per depth stratification and per day and night period of the shrimp sampled.

Looking at the richness, abundance and biomass by depth and daily period (day and night) from all three campaigns (Fig. 2; Fig 3; Fig 4), it is possible to see that the shrimp show richness with peaks in the epipelagic zone (0-100m), mesopelagic zone (400-500m) and the beginning of the bathypelagic zone (900-1000m), where there is also a peak in richness at night. Species richness during the night was somewhat more similar across the depth ranges. Abundance was maximum in shallower water, with the highest values being found between 0-100m during the day and 100-200m at night. A few species were responsible for this high abundance, and there was evidence of the formation of schools. During the day, the second highest value was found in the 700-800m range, where another peak is formed. During the night, there is a greater abundance in the mesopelagic zone, with a peak at the beginning of the bathypelagic zone. Most of the biomass was distributed in the mesopelagic zone during the night, with a clear concentration of samples between 400 and 800m. There were peaks at night between 900 and 1000m and during the day, at a slightly shallower depth, between 800 and 900m. However, there was also a substantial result between 900 and 1000m during the day, the second highest biomass value found.

Species of Acanthephyridae, such as *A. pelagica* and *A. acutifrons* showed a wide distribution among the layers, both during the day and at night, ranging from the surface to more than 1000m deep, occurring in collections near the state of Amapá to Alagoas, including the oceanic islands. Also, representatives of this family, *Ephyrina benedict* and *Ephyrina ombango* had a wide distribution in the water, occurring from surface waters to depths of over 1000m. Their distribution in the Brazilian states was more restricted, occurring from Amapá to Rio Grande do Norte and on oceanic islands. *Ephyrina benedict* occurred only during the daytime, and *E. ombango* in all daily periods. The species *Hymenopenaeus laevis* was represented by only two individuals, observed at depths ranging from the surface to 1000 meters. It was recorded exclusively in the Amapá region and only during daytime. In this study, the species *O. gracilirostris* occurred from the surface to 1000m depth, day and night, in Pará, Rio Grande do Norte and the Fernando de Noronha Archipelago.

Some species were restricted to a certain depth and daily period. During the day, *Nematopalaeon schmitti*, *Systellapsis pellucida*, and some other species were restricted to the first 100m. Between 100 and 200m, during the day, there was no occurrence of any species, while at night, there was a restricted occurrence of *Janicella spinicaudata*. Several species of the family were limited to 400 and 500m. *Meningodora compsa* and two other species of the genus were restricted to high depths, occurring only between 900 and 1000m. This is also the case for a species of the genus Acanthephyra, which only occurred between 1100 and 1200m during the night.

2.5 Discussion

The deep sea is a difficult environment to access, and studying it is a major challenge (Feng et al., 2022). Investigating the diversity of pelagic species is of great importance to science and society (Martin et al., 2020), and understanding the distribution, composition and lifestyle of these animals fills a gap in understanding the oceanic trophic chain. There is important work on the distribution and diversity of shrimp in the North and Northeast of Brazil, but most studyes focused on estuarine (Coelho et al., 2006). Also, in the study of Coelho et al. (2006), the knowledge regarding the distribution of shrimp species in Northern and Northeastern Brazil is based on specific literature, such as the studies by Christoffersen (1998), D'Incao (1998), and Ramos-Porto and Coelho (1998), as well as on specimens stored in the crustacean collection at MOUFPE. However, there is still a huge lack of information, especially regarding the deep sea specimens of shrimp in the North and Northeast regions of Brazil.

To fill this knowledge gap, here we present data on the species collected in oceanographic campaigns from the North and Northeast of Brazil, where 66 species distributed in 34 genera and 10 families were identified. Considering the entire survey of the expeditions, the dominant family was Acanthephyridae, which is a family of shrimp with a global distribution and one of the most specious among the decapods (Lunina, 2021). This result indicates that members of this family play an important ecological role, contributing greatly to the structure of the trophic chain, often being predators, but also serving as a food source for predators such as fishes and rays (Modica et al., 2014; Dhurmeea, et al., 2020; Molina-Salgado et al., 2021).

The family Sergestidae, which also has a wide diversity around the globe and a high diversity of species (WORMS, 2024), are part of the marine zooplankton, representing the transmission of energy between photosynthesizing organisms, phytoplankton and bacterioplankton to consumers at higher trophic levels such as fish, molluscs and even planktivorous crustaceans, a role of paramount importance for the maintenance of the ecosystem where they live (Cavalcante-Braga, 2017). In addition, these shrimp are also economically important in fisheries production in some African and Asian countries (Costa & Simões, 2016), as well as in northern Brazil (Nunes, 2013).

The family Pasiphaeidae is an important component of the planktonic communities of meso- and bathypelagic environments, with most of its distribution documented in the Atlantic Ocean, but with a global occurrence, also occurring in other oceans, including the polar regions (Komai et al., 2012). Many pasiphaeids are pelagic and participate in diel vertical migrations, often consuming planktonic species at night (CArtes, 1993; Karuppasamy et al., 2006). Some species can reach such high abundances that they become commercially viable. (Motoh, 1999; Nanjo et al., 2016). Families that obtained fewer than ten specimens also had representative species of high environmental, ecological and commercial importance (Menon, 2002; Mantelatto et al., 2010; Wehrtmann et al., 2012; Bochini et al., 2014; Moraes et al., 2024).

The species most abundant was *Challengerosergia* sp1. Species of the family Sergestidae are among the most common in many ecosystems and important objects of fisheries in some areas, such as *Sergestes lucens* in Japan and Acetes spp. in Masalia and Thailand (Vereshchaka et al., 2014; Anandkumar et al.,2017; Phudhom et al., 2024). They also play a vital role as prey for larger, commercially harvested species, and certain species, known for forming large, shallow aggregations, support fisheries themselves (Collins et al., 2024). Although they are important, sergestids are still not well understood when it comes to their higher-level classification and phylogenetic relationships. (Vereshchaka et al., 2014). In fact, there are no in-depth studies on the genus *Challengerosergia*, and there are no records for anywhere in Brazil.

Although fish aggregation behavior is well-studied, our understanding of shoaling in marine invertebrates remains limited (Evans et al., 2007). However, this behavior has already been recorded in the literature on crustaceans (Evans et al., 2007; Ward & Webster, 2016; Hassan Othman, 2021). The sergestid shrimps were collected in an open sea region, where schooling is a good strategy to avoid predation (Brierley & Cox, 2010; Delcourt & Poncin, 2012; Schaerf et al., 2024). In addition, this aggregation may also be related to the search for food; environments where there are phytoplankton blooms due to an increase in nutrients cause a proportional response by zooplankton to consume this available food (Nair et al., 1992; Shakawi et al., 2021). The species *Robustosergia regalis*, and *Phorcosergia burukovski* have already been recorded in the tropical and subtropical Atlantic Ocean (Díaz-Pérez et al., 2024) and in other regions of Brazil, such as Northeast (Alves-Júnior et al., 2019) and Southeast (Cardoso et al., 2020), but in this work their distribution has been extended to the North.

The species *Nematopalaemon schmitti* is known as White Belly Shrimp, one of the main fishing items for seine fishers in China (Lakenarine et al., 2024). Also is one of several by-catch species in fisheries targeting large penaeid shrimps, including *Farfantepenaeus paulensis* (Perez-Farfante, 1967), *F. brasiliensis* (Latreille, 1817), *Litopenaeus schmitti* (Burkenroad, 1936), and *Xiphopenaeus kroyeri* (Heller, 1862) (Fransozo et al., 2009; Reis-Júnior & Freire, 2024). These species play an important ecological role within the trophic web of soft bottom environments to which it pertains (Fransozo et al., 2009). There is a substantial understanding of the biology of these species, such as studies on ecological distribution (Almeida et al., 2012), spatial and temporal distribution (Fransozo et al., 2009), population structure, reproductive strategy and period (Almeida et al., 2011; Pereira et al., 2017) and also about relative growth and morphological sexual maturity (Herrera et al., 2018). Coelho et al. (2006) previously recorded this species in states in the North and Northeast regions of Brazil. In this study, this species is again found in the North.

Belonging to the Acanthephyridae family, the species *A. curtirostris*, *A pelagica*, *A. acutifrons* and *Notostomus gibbosus* A. Milne-Edwards, 1881 were also quite frequent in the samples. The species of the genus *Acanthephyra* are voracious predators, feeding on small fish, decapods and euphausiids (Burukovsky, 2009). Most species within the genus are bathypelagic, featuring morphological adaptations suited to a pelagic lifestyle, such as swimming exopods and a lightly calcified carapace (Bauer, 2004; Cardoso, 2013). Alves-Júnior et al. (2016) recorded the species *A. pelagica* for the first time in Northeastern Brazil. Subsequently, Alves-Júnior et al. (2019) published the occurrence of this and the species *A. curtirostris* and *A. acutifrons* again in the Northeast region. There are also records in other regions of Brazil, such as the southwest (Cardoso & Young, 2005). In this work, we see an expansion of the documented distribution of these very important species.

Notostomus gibbosus is a common deep-sea shrimp found worldwide (Alves-Júnior et al., 2019), and it plays a key role in the bathypelagic food web and ecosystem functioning due to its wide distribution and substantial individual biomass (Burghart et al. 2010). According to Sanders and Childress (1988), this species stands out for its positive buoyancy, using ion replacement to balance its body density. The reinforced carapace and partially serrated mandibles of *N. gibbosus* are well-suited for feeding on gelatinous prey, primarily cnidarians (Lunna et al. 2021). Gelatinous animals are major contributors to pelagic biomass across various ocean depth zones (Vereshchaka et al., 2016), they are consumed by a relatively small number of predators, making them a potentially valuable food source. There are records of *N. gibbosus* in Northeast Brazil (Moreira, 1901; Coelho & Ramos, 1972; Coelho, 2006; Judkins, 2014). However, there is still no record for the northern region, so this work expands this distribution by filling the gap on the Brazilian coast.

An important species always present in deep-sea shrimp sampling, *Oplophorus gracilirostri*s, also obtained less than 100 individuals in the sample and was represented by 63 individuals. With a global presence, these shrimps are often essential members of pelagic and benthopelagic oceanic communities, contributing significantly to these ecosystems. Oplophorus is consistently recorded, but only in small numbers, indicating an absence of schooling behavior (Lunina et al., 2019). Predators in this genus exhibit insatiable feeding habits, with fish and crustaceans being their most common and abundant dietary items. These shrimps possess characteristic oplophoroid mandibles featuring a reduced molar process and a subtriangular incisor process lined with teeth along the entire inner margin. This adaptation allows them to crush crustacean carapaces, break fish bones, and further cut through tissues (Burukovsky, 2009).

The ocean plays a crucial role in climate regulation by absorbing carbon from the atmosphere through both biological activity and physical mechanisms (Wang & Ren, 2024). The biological carbon pump transfers particulate organic carbon generated mainly by photosynthetic organisms that convert carbon dioxide into organic matter. This process creates a downward flow of carbon (Legendre, 2024). This downward flow consists of marine snow, phytoplankton debris, zooplankton and nekton fecal pellets, as well as the remains of dead organisms (Christina & Passow, 2007; Burd, 2024).

About the species richness found in the results, it can be seen that there is a somewhat similar distribution of species throughout the depth ranges. Species were more abundant in shallower waters, close to the surface and up to 100 m deep, during the day and at night; there was a peak at the beginning of the mesopelagic zone and distribution of species abundance throughout this zone.

However, when we look at the biomass results, we see that the highest values are concentrated in the deep sea region, with a clear migration during the night to the mesopelagic region at depths between 400 and 800 m. There is also an increase in biomass between 900 and 1000 m. The biomass and abundance of pelagic shrimps vary with latitude and depth, and many pelagic shrimp species exhibit vertical migrations throughout the water column (Vereshchaka et al., 2019). According to Díaz-Pérez et al. (2024), these biomass movements are important for the biogeochemical functioning of the pelagic ecosystem. Daily, these micronektonic migrants consume organic carbon in the productive shallower layers and then migrate to deeper waters, where they respire, excrete, defecate, or become prey for deep-water predators (Díaz-Pérez et al., 2024). Shrimps do this strategically, seeking cover in deep dark water during daytime and only entering the risky upper layers to feed at night-time to avoid predators (Hays, 2003; Thibault et al., 2024). The relationships between predation and defense mechanisms significantly contribute to the evolutionary diversity of pelagic crustaceans (Bashevkin & Morgan, 2020; Golightly et al., 2022). The extent of this migration is influenced by preferences for specific oceanographic conditions and species-specific strategies related to ontogenetic development and foraging behaviors. (Bollens et al., 2011).

Pelagic species are reported in the literature to carry out diel vertical migration, being cited as the Earth's largest animal migration (Hans, 2003; Vestheim, Kaartvedt, 2009; CisewskI et al., 2021), these organisms are active swimmers, including fish, crustaceans and cephalopods (BRODEUR and PAKHOMOV, 2019), and although they are less abundant than zooplankton, micronekton can play a similarly important role in driving carbon flux (Pinti et al., 2022). Their greater swimming abilities allow them to go deeper, where they produce larger organic particles. Additionally, the longer gut transit time of larger migrant organisms allows organic matter to be transported into the mesopelagic zone (Kobari et al., 2008).

Thus, this active transport of organic carbon plays an important role in the biological carbon pump within the ocean (Le Moigne, 2019).

By actively transporting carbon to the deep ocean, the mesopelagic migratory pump reduces particle fragmentation and remineralization in surface layers while improving the efficiency of the biological carbon pump (Cavan et al., 2019). These migratory movements enable the transfer of energy from shallow waters to deeper zones, and they are fundamental in channeling energy from zooplankton and micronekton to top pelagic predators and deep-sea creatures. (Schukat et al., 2013; Eduardo et al., 2022).

2.6 Conclusion

The study revealed notable differences in the shrimp assemblage between the sampling campaigns, which used diverse strategies that enabled a broad representation of the individuals caught. The shrimp collected exhibited significant diversity in richness, size, shape, and life strategies, highlighting their importance in ecological and environmental contexts.

A significant aggregation of individuals forming shoals was observed, including some species whose shoaling behavior had never been documented in Brazil before. This finding is especially significant, as it provides the first record of shoaling behavior in invertebrates in the region and represents the discovery of a new species in Brazilian waters.

Among the 81 species identified, *Challengerosergia* sp. stood out in terms of abundance, while *A. acutifrons* and *R. regalis* were the most frequent in terms of occurrence. Several species were rare, represented by only a few individuals, with an occurrence frequency close to 0%.

Pelagic shrimp play a vital role in trophic relationships, contributing significantly to nutrient transport in the water column. Some species were found to be restricted to specific depths, areas, or times of day, while others had a broader distribution, likely migrating vertically. Additionally, some of these species are of economic importance.

The study also expanded the known distribution of several species in Brazilian waters, particularly in the North, where no previous surveys had been conducted. As a result, the research contributed to creating the first integrated checklist of deep-sea pelagic shrimps in the North and Northeast of Brazil.

This information is valuable in advancing our understanding of shrimp diversity, distribution, and ecology in the deep-sea environment, helping to fill a significant knowledge gap in this field.

3 CAPÍTULO 2

3.1 Microplastics in deep-pelagic shrimps in the tropical Atlantic Ocean

Abstract

This study investigates microplastic (MP) contamination in four species of deep-sea pelagic shrimp (Acanthephyra pelagica, Notostomus gibbosus, Challengerosergia sp. and Thysanopoda cristata)c ollected from the North Brazilian Exclusive Economic Zone (EEZ), an area influenced by the Amazon River plume. Samples from 70 specimens were analyzed to quantify and characterize MPs by size, shape, and color. More than 80% of shrimps had MPs. A total of 209 MP particles were found. Fibers was the prevalent MP shape, and most particles were transparent. Statistically significant differences in contamination levels were observed among species, with *Notostomus gibbosus* exhibiting the highest contamination rate (4.55 ± 2.01 MPs shrimp^{-1}). This research highlights the presence of MPs on mesopelagic organisms, shedding light on the potential ecological risks. These findings underscore the importance of addressing MP pollution, particularly in regions influenced by riverine inputs like the Amazon.

Keywords: Marine pollution; Oceanic crustaceans; Submarine habitats;

3.2 Introduction

Plastics are persistent in the oceans due to their resistance to degradation (Moore, 2008), being widely distributed from the surface waters to the seabed (Graham & Thompsom, 2009; Murray & Cowie, 2011). While the impacts of large plastic items on marine megafauna are relatively better documented, studies on smaller plastic fragments and their effects, particularly on invertebrates, have gained attention only recently (Murray, 2011; Aragaw, 2020; Ahmed, 2021; Zhang, 2021).

The small plastic fragments, known as MPs (size between 1 nm and 5 mm), similar in size to the food particles consumed by marine invertebrates, can be mistakenly ingested, leading to harmful impacts (Browne et al., 2008; Fu & Wang, 2020), reducing feeding efficiency, survival, and fecundity (Jitrapat et al., 2024). In addition to the potential physical impacts, concern has been expressed due to the possibility of MPs adsorbing and transporting persistent organic pollutants available in the water column (Teuten et al., 2007). Microplastics might pose serious threats to aquatic organisms and humans who consume them (Barboza et al., 2018). Most decapod crustaceans, such as crabs, shrimps and lobsters, are caught or farmed as a food source and, therefore, form an important part of the diet of the human population (D'Costa, 2022)

Rivers are the main pathways for plastic and MP waste into the oceans (Lebreton & Andrady, 2019). The increase in population, most of whom live along riverine and coastal areas, and the lack of proper waste management intensifies the risks of environmental contamination, as well as the development of economic activities, such as aquaculture, agriculture, mining and extraction of fossil fuels (Capparelli et al., 2020; Galarza et al., 2021, Lucas-Solis et al., 2021).

The Amazon River stands out for being the largest river in the world, considering its average flow. This river is estimated to carry about 38,900 tons of plastic yearly into the Atlantic Ocean (Lebreton et al., 2017). Considering the dual role of the Brazilian Amazon coast as both a sink and a source of MP pollution, it is imperative to undertake comprehensive research into the origins and drivers of MP contamination within estuarine systems. The Amazon Basin, with its critical significance in fisheries, traditional communities, and biodiversity, warrants prioritization as a focal region in local and global endeavors to limit the deleterious effects of plastic pollution. As highlighted by Martinelli Filho and Monteiro (2019), the ecological and socio-economic value of the Amazon underscores its importance in the global context of pollution mitigation efforts.

Crustaceans under the influence of river plumes are likely to be susceptible to greater MP exposure, as rivers are important sources of MPs to the oceans, and decapods can be used as indicator species of environmental quality, as well as model organisms to test the toxicity of various environmental pollutants (Anderson & Philips, 2016). There are some criteria for choosing good bioindicator species, such as the availability of basic information on the biology and ecology of the species, information on the habitat, trophic level and feeding behavior, spatial distribution, commercial importance, conservation status and having the ingestion of marine litter documented in the literature (Fossi, 2018).

There are no studies that evaluate the Amazon plume's MP transport capacity. Recent research has mainly documented plastic ingestion in molluscs and pelagic fish species in the Brazilian EEZ (Ferreira et al., 2022; Justino, 2023). However, studies on plastic ingestion in deep-sea crustaceans remain limited (Taylor et al., 2016; Carreras-Colom, 2018; Jamieson et al., 2019; Cau et al., 2019; Yin et al., 2022). Smaller commercial seafood, such as crustaceans, including shrimps, are more likely to be impacted by MPs rather than large fish since MPs fall in a similar size range to their prey or foods (Curren et al., 2020). Shrimps are among the most popular seafood with the highest international trade value (Gurjar et al., 2021). This evidence has raised concerns about the human ingestion of MPs through consuming contaminated crustaceans and the potential impact on human health (BARBOZA et al., 2018), highlighting the possible role of shrimp in the trophic chain.

Despite the growing research interest in MPs in seafood and other human food items, the available information is still limited to some regions worldwide. Currently, there is no regulatory framework or international standard regarding the amount of permissible plastics in food for human safety (EFSA, 2016). Despite its progress, there are significant gaps in current legislation (Osuna-Laveaga, 2023). There is no data on MP ingestion in deep-water shrimp in the Southwestern Tropical Atlantic (SWTA). Thus, expanding our understanding of plastic contamination in deep-sea crustaceans is crucial to fill this knowledge gap. Therefore, we evaluated MP contamination in deep-sea pelagic shrimps, identifying them according to size, shape and color. In addition, an analysis will be carried out among the species sampled to understand the contamination patterns in these animals. The hypotheses that microplastic contamination is associated with the species-specific were tested, and the relationships between the total amount, size, and different shapes were verified.

3.3 Material and methods

3.3.1 Study Area

The study area is located ~450 km off Northern Brazil, within the Exclusive Economic Zone (EEZ), in an ocean area influenced by the Amazon River plume (Fig. 1). The Amazon River is the largest river in average flow on the planet (Morozov et al., 2024) and has a plume of desalinated water that spreads over distances of more than 4000km from the mouth of the river, reducing the salinity of the surface and mixing to form a biogeographical barrier and strongly affecting the regime of the Tropical and Equatorial Atlantic (Varona et al., 2019). The spread of the Amazon

River plume is influenced by various processes that are regulated both by seasonal and interannual fluctuations in Amazon River discharge as well as oceanic and atmospheric factors, including heavy precipitation, ocean currents, winds and surface mixing (Grodsky et al., 2014; Coulet et al., 2025)

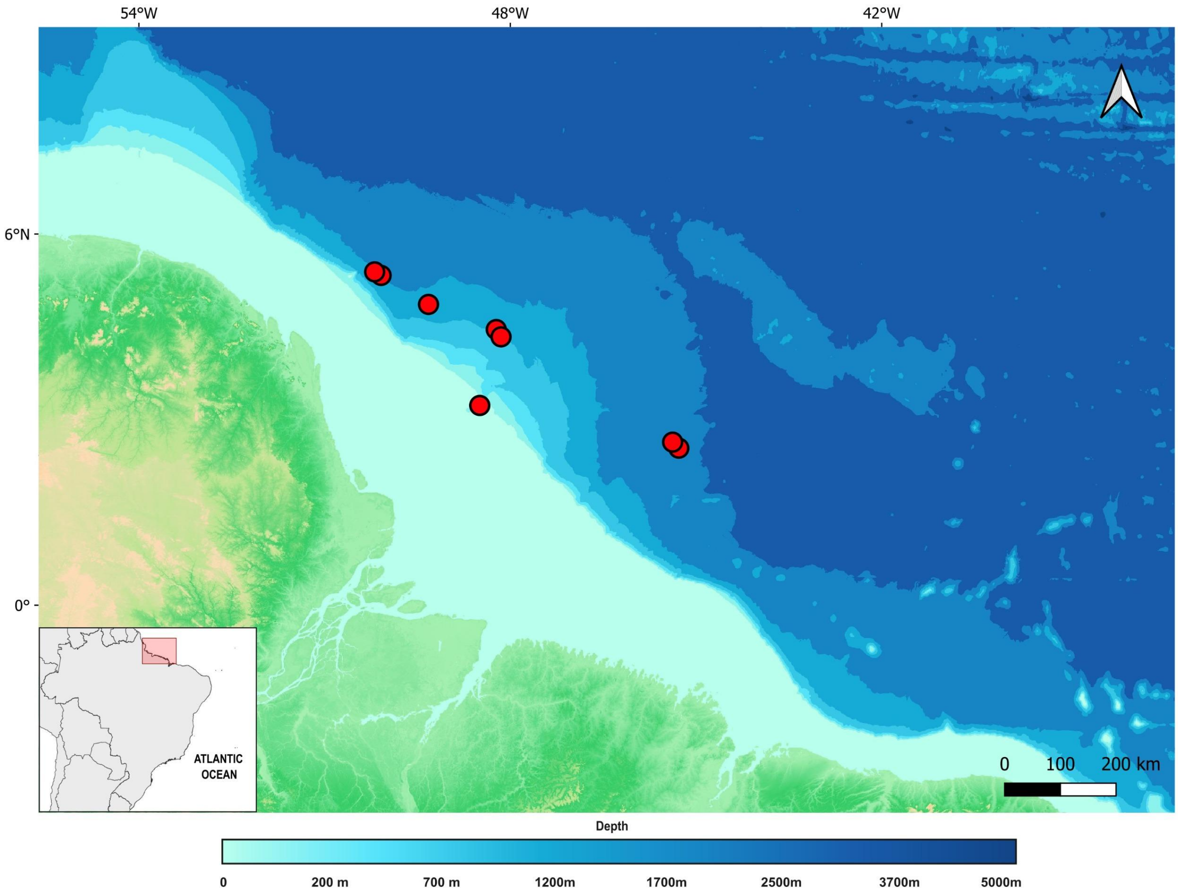

Figure. 1 Study area in the tropical Western Atlantic, sampled by the R/V ANTEA. The green circles represent the sampling stations from the AMAZOMIX campaign.

The deep-sea shrimps were collected as part of the during the AMAZOMIX project on board of the R/V ANTEA, selected according to the number of individuals, collected between September and October 2021, off the Amazon River to oceanic regions adjacent to the Northern continental shelf during the day and night, between the isobaths of 70 and 1,200 meters. Samples from five stations were used. The stations were not influenced by the river plume (Vantrepotte, *in prep)*, and the minimum sample size for each species was 15 individuals to avoid bias due to a low sample size (Markic et al., 2020). A 40 mm mesh micronekton net was used, covering 15 meters of mouth and 18 meters in length, and trawled for 30 minutes at previously determined isobaths with a speed of between 1.5 and 3 knots.

After the sampling, the specimens were labelled, and the individuals were frozen (-20 ºC). At the laboratory, individuals were identified (Crosnier & Forest, 1973; Vereshchaka, 2009; Alves-Júnior, 2019a, 2019b; Lunina et al., 2019; Rodrigues & Cardoso, 2019), measured (0.01 mm) and weighted (0.001 g). The frequency of occurrence (number of occurrences of MPs (x100), divided by the total number of individuals in the station, %F) was also calculated (Vo et al., 2024).

Four deep-sea shrimp species were selected for this study, given their ecological importance and key interactions in the trophic chain (Suh, 1990; Burukovsky & Andreeva, 2010; Vereshchak et al., 2014; Yuan et al., 2021). The species were *Acanthephyra pelagica* (RISSO, 1813), *Notostomus gibbosus* A. Milne-Edwards, 1881, *Challengerosergia* sp. and *Thysanopoda cristata* G.O. Sars, 1883.

3.3.2 Contamination Control

Before the laboratory analysis, several steps were carried out to ensure quality control (Quality Assurance and Quality Control - QA/QC) and avoid possible airborne and cross-contamination, following the protocol described by Justino et al. (2021). This protocol requires the use of cotton lab coats, disposable latex gloves, the filtration of any solution used and the control of the flow of people within the laboratory. In addition, blank procedures were implemented for each set of 5 and 10 samples, depending on the maximum number of samples of each species.

3.3.3 Plastic Extraction Protocol

The shrimp samples were washed with filtered distilled water to remove any particles adhering to the external tissue, following the protocol proposed by Justino et al. (2021). They were then placed in a 50 ml beaker and submerged in NaOH solution (1 mol L^{-1}; PA 97%). The samples were covered with a glass lid and dried in an oven at 60 °C for 24 hours. Afterward, the samples were filtered using a vacuum pump system through a glass fiber filter (47 mm GF/F, 0.7 µm, © Whatman). The filtered samples were carefully transferred to a Petri dish, covered, and dried again in the oven at 60 °C for an additional 24 hours.

The filters were then visually examined for MPs using a stereomicroscope. Particles suspected of being MPs were photographed, counted, and measured in length (mm). The MPs found were categorized according to their shape: fibers (filamentous shape), fragments (irregular shape), films (flat shape), foams (soft with an irregular shape), or pellets (spherical shape) (Justino et al., 2021).

3.4 Data Analysis

3.4.1 Microplastic contamination

Violin plots were used to assess the MP contamination patterns relative to quantity, shape and size according to species. The violin plots combined boxplots and density estimations and can reveal more information about the shape of the distribution and the clusters in the dataset (Kabacoff, 2022).

a Kruskal-Wallis test was used to check whether the MPs identified (total quantity, size and shapes) varyed among species. Whether significant differences were detected, a Dunn's test was performed to investigate the sources of variance (Dunn, 1964). Statistical analyses were carried out using R software version 4.4.2 (R Core Team, 2020), with a significance level of 5%.

3.5 Results

A total of 15 individuals of *Acanthephyra pelagica*, 20 of *Notostomus gibbosus*, 20 of *Challengerosergia* sp. and 15 of *Thysanopoda cristata* were analyzed. Microplastics were detected in most specimens (FO= 81.4%). A total of 209 MPs were detected with an average of 2.25 ± 2.19 individual^{-1}. The specimens *N. gibbosus* had the highest prevalence of MPs (FO= 100%), followed by *Challengerosergia* sp. (85%), *A. pelagica* and *T. cristata* (60%) (Table 1).

Table. 1. Morphometric measurements and MP data of the analyzed species. N (Sample size); depth of capture; mean ± standard deviation of Total Length (TL); CL (Carapace Length); TW (Total Weight); Number and size of MPs and Frequency of occurrence of MP (FO%).

Species	**N**	**Depth (m)**	**TL (mm)**	**CL (mm)**	**TW (g)**	**Number of MPs**	**FO%**	**Size of MPs (mm)**
Acanthephyra pelagica	15	900	70.79 ± 21.08	21.42 ± 6.39	3.01 ± 1.45	1.66 ± 1.53	80%	0.32 ± 0.41
Challengerosergia sp.	20	130	47.23 ± 4.44	14.39 ± 1.20	0.39 ± 0.14	1.15 ± 1.03	85%	0.78 ± 0.57
Notostomus gibbosus	20	1000	96.54 ± 19.63	41.75 ± 6.15	7.16 ± 4.23	4.55 ± 2.01	100%	1.56 ± 0.86
Thysanopoda cristata	15	450	50.82 ± 4.76	14.38 ± 1.94	1.31 ± 0.41	1.26 ± 1.66	60%	0.44 ± 0.69

Notostomus gibbosus was the most contaminated species (4.55 ± 2.01 MPs shrimp^{-1}), followed by *A. pelagica* (1.66 ± 1.53 MPs shrimp−1), *T. cristata* (1,26 ± 1,66 MPs shrimp−1) and Challengerosergia sp (1.15 ± 1.03 MPs shrimp−1) (Fig. 2). With the species N. gibbosus being the only source of variance (chi-squared = 29.283, p-value ≤ 0.05).

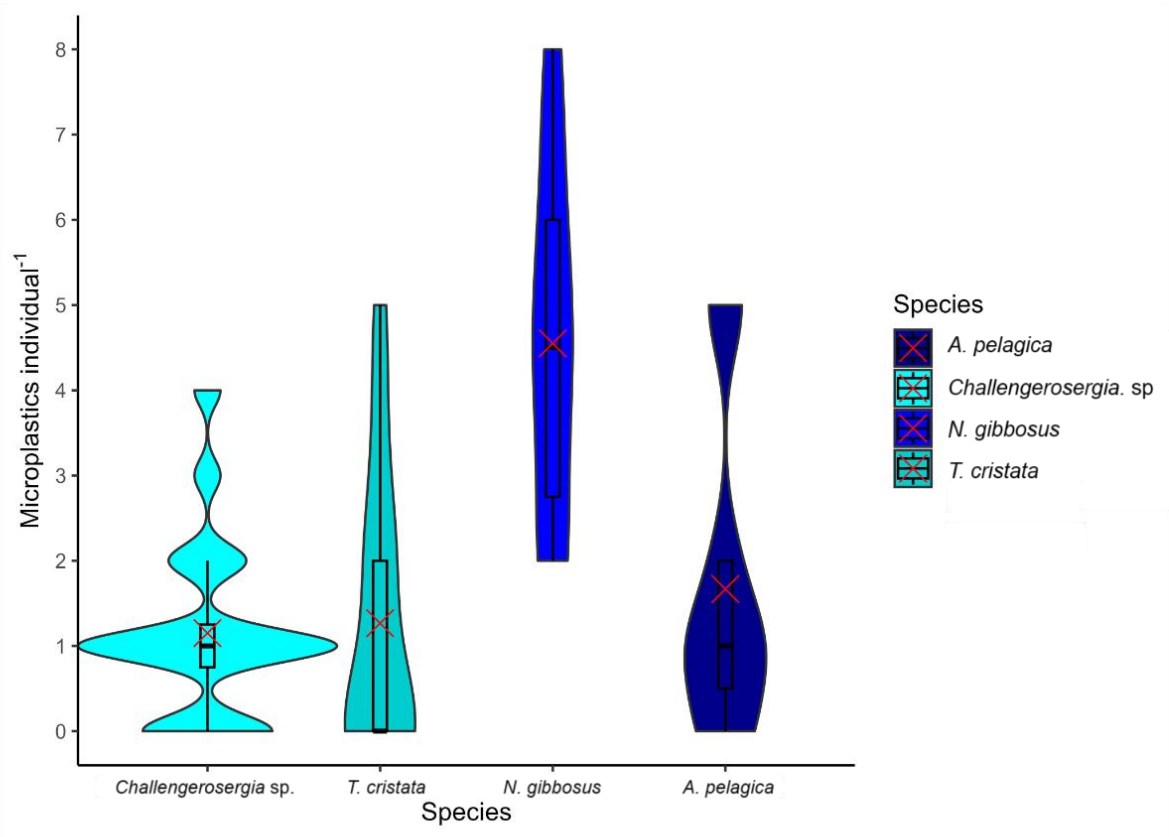

Figure 2. Total number of MPs ingested by deep-sea shrimps from the North Brazilian Exclusive Economic Zone. The violin plots show kernel density estimation as a representation of data distribution. The horizontal line within the box plots shows the inter-quartile range, the whiskers show the 1.5× interquartile range, and the red cross represents the mean values.

Fibers were the prevailing MP shape in the studied species, followed by fragments, *T. cristata* was the exception, with fragments corresponding to 70% of MPs (Fig. 3). The predominant color was transparent, accounting for 32% of particles. This was followed by blue and brown, with 28% and 15% respectively. There were also fewer black (11%), red (6%), and purple (5%) MPs. There were no significant differences in the number of fragments among species (chi-squared = 4.3339, p-value = 0.22) (Fig. 4).

The species *N. gibbosus* was notably prominent concerning the number of fibers ingested (4.25 ± 1.30 Frags shrimp−1) (Fig. 4). It was again the only source of variance, showing a statistically significant difference (chi-squared = 29.283, p-value ≤ 0.05).

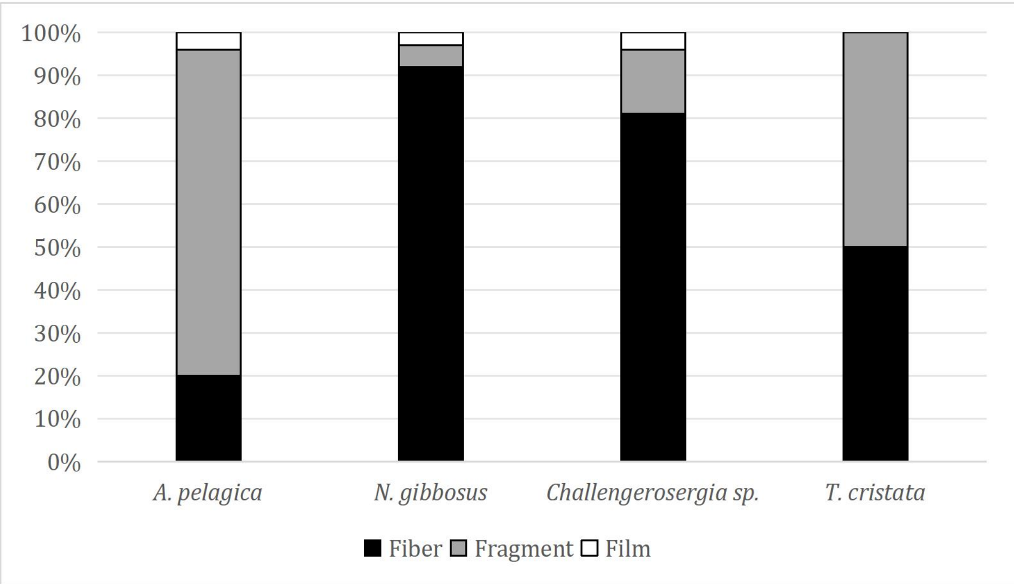

Figure 3. Different shapes of MPs (fibres, fragments, and films) ingested by deep-sea shrimp species from the North Brazilian Exclusive Economic Zone expressed as a percentage.

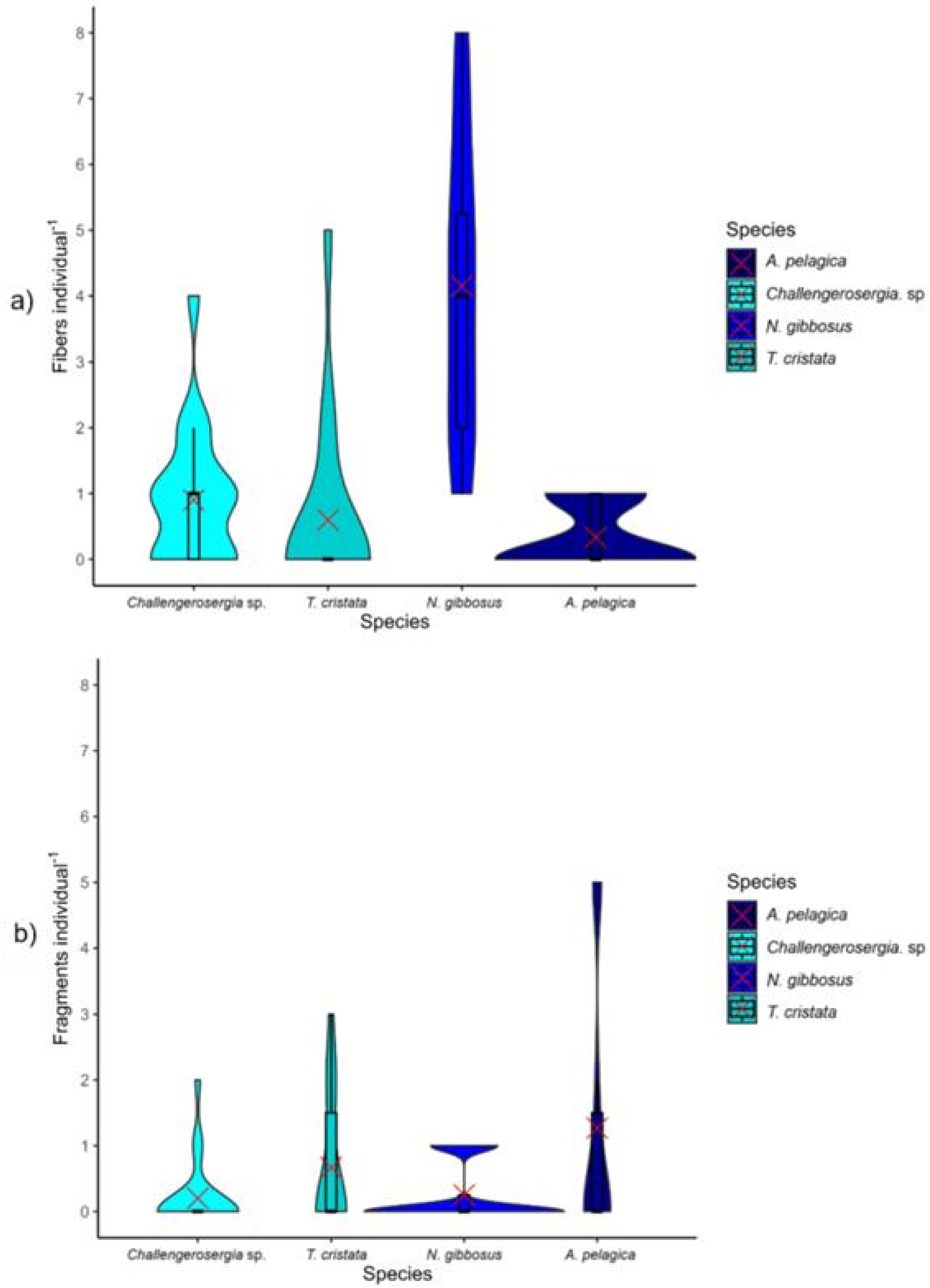

Figure 4. The number of fibers (a) and fragments (b) ingested by deep-sea shrimps from the North Brazilian Exclusive Economic Zone. The violin plots show kernel density estimation as a representation of data distribution. The horizontal line within

the box plots shows the inter-quartile range, the whiskers show the 1.5× interquartile range, and the red cross represents the mean values.

The smallest particle found measured 0.01 mm, and the largest, 2.45 mm, with an average of 0.46 ± 0.40 mm. The largest particles were found in the species *N. gibbosus* (1,56 ± 0,86 mm), followed by *Challengerosergia sp.* (0,78 ± 0,57 mm), *T. cristata* (0,44 ± 0,69 mm) and *A. pelagica* (0,32 ± 0,41 mm) (Fig. 6; Tab. 1). Statistical analysis of the size of plastic particles ingested, in relation to the species, showed a significant difference in the samples (chi-squared = 11.573, p-value ≤ 0.05), the source of variance, in this case, was the difference only between the species *N. gibbosus* and *A. pelagica* (Fig. 6).

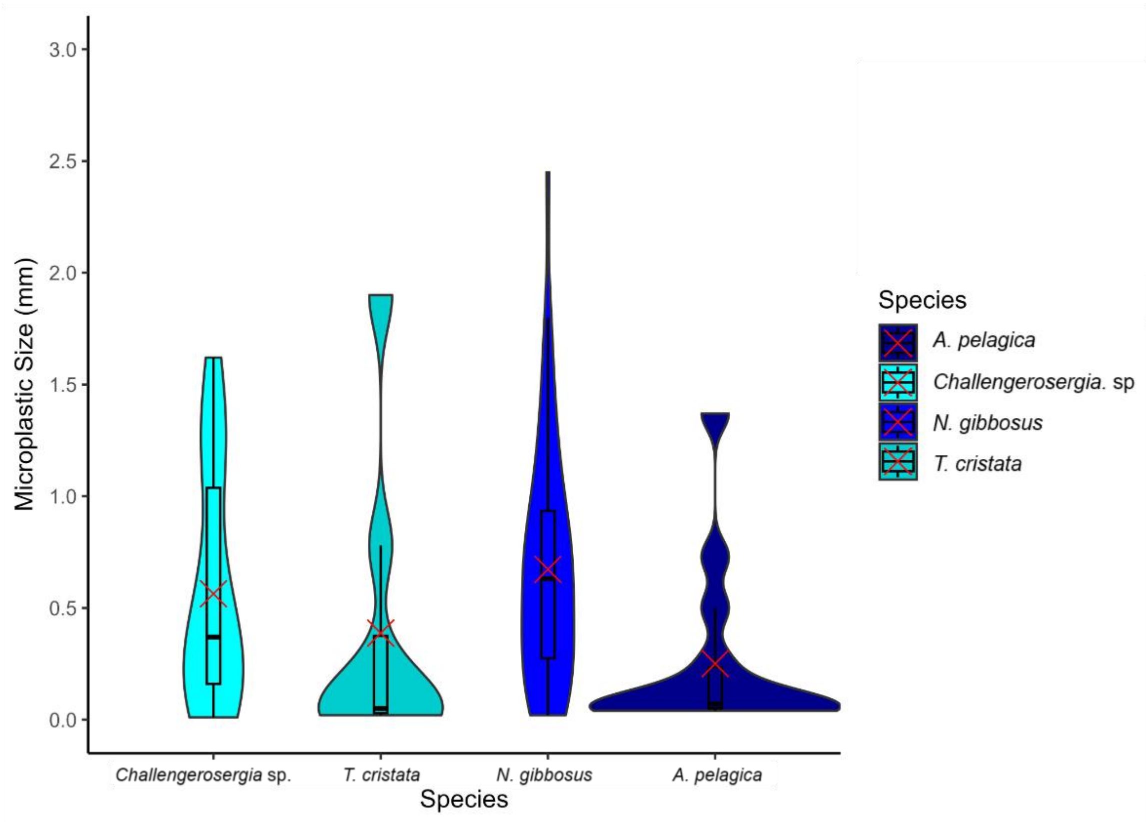

Figure 6. The size of MPs ingested by deep-sea shrimps from the North Brazilian Exclusive Economic Zone. The violin plots show kernel density estimation as a representation of data distribution. The horizontal line within the box plots shows the inter-quartile range, the whiskers show the 1.5× interquartile range, and the red cross represents the mean values.

The fibers had an average size of 0,78 ± 0,48 mm (Fig. 7). It is possible to notice a similarity in the values obtained for all species, with no significant differences (chi-squared = 1.0908, p-value = 0.77). On the other hand, fragments were found in smaller sizes, with an average of 0,08 ± 0,15 mm (Fig. 7). There was no significant difference among species (chi-squared = 4.7932, p-value = 0.18)

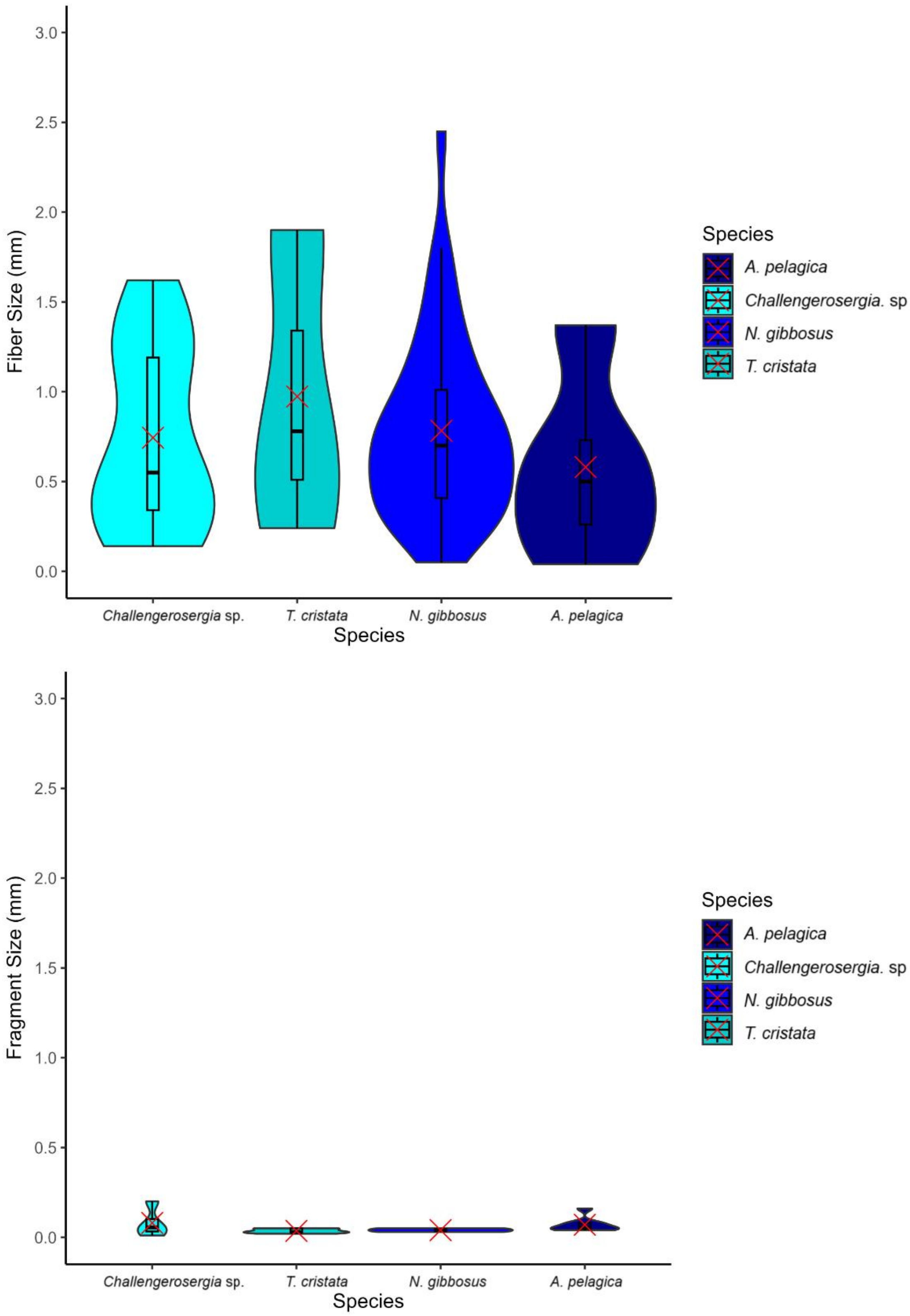

Figure 7. The size of fibers and fragments ingested by deep-sea shrimps from the North Brazilian Exclusive Economic Zone. The violin plots show kernel density estimation as a representation of data distribution. The horizontal line within the box

plots shows the inter-quartile range, the whiskers show the 1.5× interquartile range, and the red cross represents the mean values.

3.6 Discussion

Microplastics currently represent one of the most significant environmental threats (Tian et al., 2023), given their pervasive presence across all ecosystems, including remote regions such as the deep ocean (Courtene-Jones et al., 2017; Cau et al., 2019). These particles primarily enter marine environments through rivers, sewage, industrial effluents and offshore activities (e.g. fishing) (Akbari et al., 2024).

In the aquatic environment, these fragments undergo degradation due to environmental and biological forcings, being readily ingested by a wide variety of marine organisms, from small invertebrates to large marine mammals (Botterell et al., 2019; Trestrail et al., 2020; Zantis et al., 2021). This can result in problems such as intestinal obstruction, nutrient depletion and the absorption of chemical compounds that can be associated with MPs (Verla et al., 2019; Wang et al., 2020; D'Costa, 2022), which may affect the health of these organisms and consequently the entire marine food chain (Siddiqui et al., 2023; Tang et al., 2024).

Deep-sea species are thought to be less affected by MP contamination than those living in surface waters, primarily because most plastic polymers are buoyant and accumulate in the upper layers (Summers et al., 2023). Furthermore, although the deep sea is located farther away from major pollution sources, surface currents and wind-driven processes contribute to forming accumulation zones in the upper layers, which consequently allow pollution to sink and reach the deep sea (Eriksen & Lebreton, 2019).

Deep-sea organisms exhibit slower metabolic rates associated with low temperatures at these depths (Mcclain et al., 2020; Yagi et al., 2025). Pelagic shrimps also inhabit the oxygen minimum zone and display tonic immobility by adopting an inverted orientation (Burford et al., 2018). This low metabolism may limit their ability to detoxify and eliminate harmful substances efficiently (Yu et al., 2023; Xing et al., 2024); however, there is no evidence that this physiological trait contributes to the accumulation of MPs. For this reason, the impact on the deep sea becomes especially worrying because, although deeper waters are less accessible, recent studies indicate that MPs are being found up to 11,000 meters deep in areas such as the Marceau, Mariana and New Britain Trench (Peng et al., 2018; Peng et al., 2020). This waste affects fragile ecosystems that are difficult to recover, with MPs being ingested by species adapted to extreme environments (Park et al., 2024). In addition, the accumulation of toxic substances by the MPs leads to their release into the animals' bodies, causing cumulative effects over time (Mohan & Raja, 2024), which may result in altered feeding behavior and starvation, transparent carapace, impaired digestion and excretion, and further inhibit growth (Leads et al., 2019). This invisible and growing pollution has global implications, affecting biodiversity, ocean health and food security since many marine animals contaminated with MPs end up in human food (Mamun et al., 2023; Mercy & Alam, 2024).

Information on ingested plastics for deep-sea shrimps is still rather scarce (Chen et al., 2024). Terrazas-López et al. (2024) explored the presence of MPs in the marine food web in Latin America’s surrounding Atlantic and Pacific Oceans, highlighting their environmental and ecological impact. The study addresses the distribution of MP at different trophic levels, from planktonic organisms to larger species such as fish and seabirds. It is possible to notice that fish species are the most investigated group, with 61% of the studies being directed at this group, while shrimp account for less than 5%.

The number of studies specifically focusing on deep-sea shrimp is even more limited, with no research available for Tropical Western Atlantic. However, several studies involving other deep-sea groups have been published in this area, focusing on cephalopods (Ferreira et al., 2022) and fishes (Ferreira et al., 2023; Justino et al., 2023). In the Gulf of Mexico, Bos et al. (2023) found a higher contamination rate in crustaceans (29%) compared to abundant fish groups, including the Myctophidae and Sternoptychidae families. These families were also the focus of an investigation conducted by Justino et al. (2022) along the Fernando de Noronha Ridge, SWTA, where levels of 67% were observed. In comparison to the findings of the present study, these levels were notably lower.

Various environmental and biological factors, including migration patterns, feeding strategies, and ontogenetic stages, influence MP contamination in deep-sea species (Bos et al., 2019; Ferreira et al., 2022; Scacco et al., 2022). Key determinants include the concentration of MPs in the water column (Hall et al., 2015), which significantly affects the likelihood of ingestion by marine organisms. A higher concentration of MPs in the water increases the probability of deep-sea shrimp encountering and ingesting these particles. Nevertheless, data on the MP abundance in the deep layers of the study area are absent in the literature. Additionally, the size, shape, and composition of MPs influence the ingestion process (Grey & Weinstein, 2017). Smaller particles are more readily ingested (Lehtiniemi et al., 2018), whereas certain MP shapes, such as fibers, tend to have a longer residence time within biological systems (Cunningham et al., 2020).

Furthermore, the Amazon River, recognized as the largest river system globally, drains an extensive area of South America and discharges vast quantities of fresh water into the Atlantic Ocean (Gallo & Vinzon, 2015). This characteristic establishes the Amazon as a significant vector for the transport of MPs (Lebreton et al., 2017), likely originating from the improper disposal of waste from urban, industrial, and fishing activities (Boucher & Friot, 2017; Geyer et al., 2017; Xue et al., 2021) along its course. Although this study focuses on mesopelagic shrimps, it is crucial to acknowledge that the surface layers act as a substantial source of MPs, permeating deeper ocean layers (Egger et al., 2020). Thus, the input of MPs from the Amazon River, combined with the transported by long-range ocean currents, constitutes a potential source of contamination for the organisms investigated herein.

Marine biota is particularly susceptible to ingesting MP fibers (Willis et al., 2017; Rebelein et al., 2021). In addition to sewage discharge, fibers can also originate from using, maintaining and discarding of fisheries gear (Xue et al., 2021). The high number of MP fibers in the gastrointestinal tract of fish, shrimps and oysters have been previously reported (Kibria, 2022); this result corroborates that found in our study, with a high number of MP fibers being found in the four species of shrimp analyzed, especially in the *N. gibbosus* species.

In conjunction with the ecological patterns of pelagic shrimp, these environmental factors are likely to influence the contamination levels. Migration and feeding behaviors of deep-sea organisms, particularly pelagic species, can significantly influence their exposure to MPs (Ferreira et al., 2022; 2023; Justino et al., 2022). The migratory patterns, which frequently involve vertical movements, can expose them to regions with elevated plastic pollution, thereby increasing their risk of contamination (Bos, 2019). However, although this has been observed in other species groups, such as fish, studies show that shrimp species that do not migrate have the highest levels of contamination (Bos et al., 2023). When comparing migration strategies of the analyzed species, corroborating the literature, it was observed that non-migrant species, such as *N. gibbosus*, had the highest MP contamination (Bos et al., 2023).

Mesopelagic euphasiid species such as *T. cristata* show daily vertical migration and omnivorous behavior with opportunistic capacities to live in favourable water column layers (Couwelaar, 1994). Presenting a filter-hunting strategy, they often feed on marine snow, which is primarily composed of particulate organic matter, such as fecal pellets, phytoplankton, bacteria, and protists, which promote increased sinking rates through aggregation (Porter et al., 2018). This process, influenced by bottom currents, has been identified as the primary pathway for the eventual deposition of MPs in the deep sea (Kane et al., 2020; Ding et al., 2022).

During feeding, pelagic organisms may inadvertently ingest MPs when consuming prey that has accumulated plastic particles (Ryan et al., 2019; Justino et al., 2023). This dynamic interaction between migration, feeding, and the distribution of MPs can ultimately affect the extent of contamination and the health of these species (Fan et al., 2023). The four species analyzed are predators, each employing a distinct predation strategy (Couwelaar, 1994; Burukovskii and Falkenhaug, 2015; Bauer et al., 2021; Lunina et al., 2021). Consequently, contamination was observed in all species, with a likely source being their foraging activities (ROCH et al., 2020). Predator species exhibit heightened vulnerability to MP contamination due to the trophic transfer of MPs (JUSTINO et al., 2023).

The species that demonstrated the highest contamination was *N. gibbosus*. This species has a high trophic level (Eduardo et al., 2023), and the result was shown in its high contamination, with an average ingestion three times higher than the others. *Notostomus gibbosus* is a non-migrant voracious predator with specialized jaw feeding mainly on cnidarians (Lunina et al., 2021; Díaz-Peres et al., 2024). Interestingly, they also feed on prey larger than themselves (Lunina et al., 2021), but this was not evidenced in the size of MPs ingested. *Acanthephyra pelagica* is also a non-migrant typical predator that actively hunts, captures, and consumes small fish and crustaceans with specialized jaws (Burukovskii & Falkenhaug, 2015). Sergestids are migrant predators, preying upon copepods, euphasiids, small crustaceans and invertebrate larvae (Bauer et al., 2021). Additionally, stomach content studies also regularly find fish remains (Bauer et al., 2021).

Our study provides information on MP contamination in four species of deep-sea shrimps off the Amazon River mouth for the first time. Microplastic contamination was high (frequency of occurrence of 81%) for the four analyzed pelagic species, which is higher than that found in studies using other pelagic shrimps (Carreras-Colomet al., 2018; Bono et al., 2020; Saborowskl et al., 2022; Chiacchio et al., 2025). Overall, other deep-sea pelagic species are frequently reported to have a high ingestion of MPs (e.g. 1% to 100%) (Carreras-Colom et al., 2018; Cau et al., 2019; Justino et al., 2023; Ferreira et al., 2025). In our samples, the fibers were the prevailing MP shape detected, as often reported in the literature (Carreras-Colom et al., 2018; Jamal et al., 2025). Also, transparent fibers were the most abundant fibers color observed, in agreement with the findings of the other crustacean studies (Yao et al., 2021).

3.7 Conclusion

This study provides the first insights into microplastic (MP) contamination in deep-sea shrimps from the Amazon Exclusive Economic Zone (EEZ), demonstrating high contamination rates and variability among species. The non-migratory species *Notostomus gibbosus* showed significantly higher contamination, likely due to its predatory habits and diet, which includes gelatinous organisms associated with high MP levels. Fibers were the most abundant MP shape, consistent with findings in similar studies. These results emphasize the urgent need for targeted research on deep-sea ecosystems. Expanding sampling efforts and monitoring programs in the Amazon basin and adjacent marine regions is critical to understanding the full impact of MPs on biodiversity, ecosystem health, and food security.

4 CONSIDERAÇÕES FINAIS

Este trabalho fornece informações inéditas sobre a diversidade, padrões de migração vertical e contaminação por MPs dos camarões de mar profundo da região adjacente à pluma do Rio Amazonas, possibilitando uma melhor compreensão da composição e distribuição da comunidade. Dessa forma, contribui para os estudos desse grupo nas regiões norte e nordeste do Brasil. Além disso, apresenta resultados importantes sobre a presença de microplásticos em camarões pelágicos de mar profundo, correlacionando-os com seus padrões de migração na coluna d'água e estratégias de alimentação.

Foram identificadas 66 espécies distribuídas em 34 gêneros e 10 famílias, com destaque para a Acanthephyridae, a mais representativa em abundância e diversidade. A pesquisa evidencia padrões de migração vertical diária, com maior abundância durante a noite em águas mais superficiais e maior biomassa nas camadas mesopelágicas, também durante a noite. Esses resultados ressaltam o papel crucial dos camarões pelágicos na transferência de energia e nutrientes entre diferentes níveis da coluna d'água, contribuindo para o funcionamento dos ciclos biogeoquímicos e para a estruturação das cadeias tróficas em ecossistemas de mar profundo. Além disso, houve a observação inédita de formação de cardume por indivíduos do gênero *Challengerosergia* sp. e a ampliação da distribuição de várias espécies reforçam a importância ecológica dessa comunidade para a região.

Também foram evidenciados altos níveis de contaminação por MPs em quatro espécies de camarões de profundidade, com uma FO% ultrapassando 80% e a espécie *Notostomus gibbosus* apresentando as maiores taxas de contaminação. A predominância de fibras e partículas transparentes destaca a extensão da poluição marinha em regiões profundas, enquanto os padrões de migração vertical e as estratégias de alimentação específicas de algumas espécies sugere uma vulnerabilidade acentuada à ingestão de MPs. Esses resultados enfatizam a necessidade de monitoramento contínuo da poluição por plásticos e de estudos sobre seus impactos nos organismos mesopelágicos e nos ecossistemas marinhos como um todo.

Embora este trabalho tenha fornecido contribuições para o entendimento da fauna e ecologia dos crustáceos de mar profundo na região, ele também evidencia a necessidade de esforços amostrais contínuos e de projetos direcionados ao estudo dessas comunidades com objetivo de preencher lacunas de conhecimento e subsidiar ações de conservação em um dos ecossistemas mais ricos e vulneráveis do planeta.

REFERÊNCIAS

Afonso, G. V. F. et al. Taxonomy and distribution of deep-sea bigscales and whalefishes (Teleostei: Stephanoberycoidei) collected off northeastern Brazil, including seamounts and oceanic islands. **Ichthyology & Herpetology**, v. 109, n. 2, p. 467-488, 2021.

Aguirre-Guzman, G.; Lopez-Acevedo, E. A. Presence of the giant tiger shrimp Penaeus monodon (Decapoda: Penaeidae) from American Atlantic coasts. Review. **REVISTA DE BIOLOGIA MARINA Y OCEANOGRAFIA**, v. 55, n. 2, p. 90-99, 2020.

Aguzzi, J. et al. Ontogenetic changes in vertical migratory rhythms of benthopelagic shrimps
Pasiphaea multidentata and P. sivado. **Marine Ecology Progress Series**, v. 335, p. 167-174, 2007

Ahmed, A. et al. Microplastics in the environment: Occurrence, fate, risks, and analytical approaches. *Science of the Total Environment*, v. 795, p. 148829, 2021.

Akbari, A. et al. Sources of microplastics in the environment and human exposure routes: A review. **Caspian Journal of Health Research**, v. 9, n. 3, p. 163-176, 2024.

AL Mamun, A. et al. Microplastics in human food chains: Food becoming a threat to health safety. **Science of The Total Environment**, v. 858, p. 159834, 2023.

Almeida, A. C. et al. Population structure and reproductive period of whitebelly prawn Nematopalaemon schmitti (Holthuis 1950)(Decapoda: Caridea: Palaemonidae) on the southeastern coast of Brazil. **Invertebrate Reproduction & Development**, v. 55, n. 1, p. 30-39, 2011.

Alves-Junior, F.A. et al. First report of two deep-sea shrimps of the genus Acanthephyra A. Milne-Edwards, 1881 (Crustacea: Decapoda: Acanthephyridae) from southwestern Atlantic. Zootaxa, p. 193–200, 2016.

Alves-Júnior, F. A. et al. New records of deep-sea prawn of the genus Gennadas Spence Bate, 1881 (Crustacea: Decapoda: Benthesicymidae) from Southwestern Atlantic. **Zootaxa**, v. 4450, n. 3, p. 376-384, 2018.

Alves Júnior, F. A. Community ecology, taxonomy and geographic distribution of the deep-sea shrimps in northeastern Brazil. 2019a.

Alves-Junior, F. A. et al. Taxonomy of deep-sea shrimps of the superfamily Oplophoroidea Dana 1852 (Decapoda: Caridea) from Southwestern Atlantic. **Zootaxa**, v. 4613, n. 3, p. 401–442-401–442, 2019b.

Alves-Júnior, F. A. et al. Meso-and bathypelagic prawns of the superfamilies Penaeoidea Rafinesque, 1815 and Sergestoidea Dana, 1852 (Crustacea: Decapoda: Dendrobranchiata) from Southwestern Atlantic: new records and bathymetric distribution. **Thalassas: An International Journal of Marine Sciences**, v. 35, p. 465-484, 2019c.

Alves-Júnior, F. A. et al. Further records of Eurythenes obesus (Chevreux, 1905)(Crustacea: Amphipoda: Eurytheneidae) from Brazilian deep waters. **Biota Amazonia**, v. 11, n. 1, p. 94-95, 2021.

Amponsah, A. et al. Plastic in the food chain: Investigating microplastic consumption by the blue-swimming crab (de Rochebrune, 1883) and shrimp (Pérez-Farfante, 1967) from an estuarine system in Ghana. **Scientific African**, v. 25, p. e02261, 2024.

Anandkumar, A. et al. Trace metal dynamics and risk assessment in the commercially important marine shrimp species collected from the Miri coast, Sarawak, East Malaysia. **Regional Studies in Marine Science**, v. 16, p. 79-88, 2017.

Anderson, B.; Phillips, B. Saltwater toxicity tests. **Marine Ecotoxicology**, Academic Press, p. 167-197, 2016.
ANDRADY, A. L.; NEAL, M. A. Applications and societal benefits of plastics. **Philosophical Transactions of the Royal Society B: Biological Sciences**, v. 364, n. 1526, p. 1977-1984, 2009.

Anger, K.; Urzúa, A. Evolutionary transitions of decapod crustaceans to non-marine, polar, and deep-sea environments: developmental, physiological and biochemical adaptations. **Crustaceana**, v. 97, n. 5-9, p. 1115-1133, 2024.

Anker, A. et al. Two new species and two new records of deep-water caridean shrimps from Brazil (Decapoda: Pandalidae, Palaemonidae, Crangonidae). **Zootaxa**, v. 3815, n. 2, p. 263-278, 2014.

Antonio, S. et al. Distribution, abundance, and size structure of deepsea shrimps of the family Aristeidae (Crustacea: Decapoda) in the southern Gulf of Mexico. **Bulletin of Marine Science**, v. 100, n. 1, p. 59-80, 2024.

Aparecido, K. C. et al. Living in darkness: functional diversity of mesopelagic fishes in the western tropical Atlantic. **Frontiers in Marine Science**, v. 10, p. 1117806, 2023.

Aragaw, T. A. Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. *Marine Pollution Bulletin*, v. 159, p. 111517, 2020.

Arat, S. A. An overview of microplastic in marine waters: Sources, abundance, characteristics and negative effects on various marine organisms. **Desalination and Water Treatment**, p. 100138, 2024.

Archibald, K. et al. Modeling the impact of zooplankton diel vertical migration on the carbon export flux of the biological pump. **Global Biogeochemical Cycles**, v. 33, n. 2, p. 181-199, 2019.

Aydin, S. et al. Occurrence, characteristics, and risk assessment of microplastics and polycyclic aromatic hydrocarbons associated with microplastics in surface water and sediments of the Konya Closed Basin, Turkey. **Environmental Science and**

Pollution Research, p. 1-21, 2024.

Banki, O. et al. Catalogue of Life Checklist. Catalogue of Life,Leiden, Netherlands. 2023.

Barboza, L. G. A. et al. Marine microplastic debris: An emerging issue for food security, food safety and human health. **Marine pollution bulletin**, v. 133, p. 336-348, 2018.

Basher, Z. et al. Diversity and distribution of deep-sea shrimps in the Ross Sea region of Antarctica. **PLoS One**, v. 9, n. 7, p. e103195, 2014.

Bashevkin, S. M.; MORGAN, S. G. Predation and competition. **The natural history of the Crustacea**, v. 7, p. 360-382, 2020.

Bauer, R. T. **Remarkable shrimps: adaptations and natural history of the carideans**. University of Oklahoma Press, 2004.

Bauer, R. T. The families of decapod shrimps. In: **Shrimps: Their diversity, intriguing adaptations and varied lifestyles**. Cham: Springer International Publishing, p. 69-194, 2023.

Baustian, M. M. et al. Linking the bottom to the top in aquatic ecosystems: mechanisms and stressors of benthic-pelagic coupling. **Eco-DAS X Symposium Proceedings**. p. 25-47. 2014.

Behrenfeld, M. J. et al. Global satellite-observed daily vertical migrations of ocean animals. **Nature**, v. 576, n. 7786, p. 257-261, 2019.

Benvenuto, C. et al. Crustaceans of extreme environments. **The natural history of the Crustacea**, v. 2, p. 379-417, 2015.

Bertrand, A. **ABRACOS cruise**, RV Antea, 2015. DOI: 10.17600/15005600. Disponível em: https://campagnes.flotteoceanographique.fr/campagnes/15005600/. Acesso em: 19 de setembro 2024.

Bertrand, A. **ABRACOS 2 cruise**, RV Antea, 2017. DOI: 10.17600/17004100. Disponível em: https://campagnes.flotteoceanographique.fr/campagnes/17004100/. Acesso em: 19 de setembro 2024.

Bertrand, A. et al.. AMAZOMIX 2021 cruise, RV Antea, 2021. DOI: 10.17600/18001364. Disponível em: https://campagnes.flotteoceanographique.fr/campagnes/18001364/. Acesso em: 19 setembro 2024.

Bianchi, D. et al. Diel vertical migration: Ecological controls and impacts on the biological pump in a one-dimensional ocean model. **Global Biogeochemical Cycles**, v. 27, n. 2, p. 478-491, 2013.

Bollens, S. M. et al. Cascading migrations and implications for vertical fluxes in pelagic ecosystems. **Journal of Plankton Research**, v. 33, n. 3, p. 349-355, 2011.

Boltovskoy, D. et al. General biological features of the South Atlantic. **South Atlantic Zooplankton. Backhuys Publishers, Leiden**, v. 2, p. 1-41, 1999.

Bono, G. et al. Microplastics and alien black particles as contaminants of deep-water rose shrimp (Parapenaeus longistroris Lucas, 1846) in the Central Mediterranean Sea. **Journal of Advanced Biotechnology and Bioengineering**, v. 8, p. 23-28, 2020.

Bordbar, L. et al. First evidence of ingested plastics by a high commercial shrimp species (Plesionika narval) in the eastern Mediterranean. **Marine Pollution Bulletin**, v. 136, p. 472-476, 2018.

Bos, R. P. et al. Microplastic ingestion by deep-pelagic crustaceans and fishes. **Limnology and Oceanography**, v. 68, n. 7, p. 1595-1610, 2023.

Bos, R. P. The Association between Stomach Fullness and Vertical Migration Behavior in Deep-Pelagic Crustaceans and Fishes in the Gulf of Mexico, with Notes on Microplastic Ingestion, 2019.

Botterell, Z. L. R. et al. Bioavailability and effects of microplastics on marine zooplankton: A review. **Environmental Pollution**, v. 245, p. 98-110, 2019.

Boyd, P.W. *et al.* Multi-faceted particle pumps drive carbon sequestration in the ocean. *Nature* **568**, 327–335. 2019.

Boucher, J.; Friot, D. Primary Microplastics in the Oceans: A Global Evaluation of Sources. 2017.

Bochini, G. L. et al. Temporal and spatial distribution of the commercial shrimp Litopenaeus schmitti (Dendrobranchiata: Penaeidae) in the south-eastern Brazilian coast. **Journal of the Marine Biological Association of the United Kingdom**, v. 94, n. 5, p. 1001-1008, 2014.

Bracken-Grissom, H. D. et al. Light organ photosensitivity in deep-sea shrimp may suggest a novel role in counterillumination. **Scientific reports**, v. 10, n. 1, p. 4485, 2020.

Braga, R R. et al. Feeding ecology of fishes: an overview of worldwide publications. **Reviews in Fish Biology and Fisheries**, v. 22, p. 915-929, 2012.

Brierley, A, S.; Cox, M. J. Shapes of krill swarms and fish schools emerge as aggregation members avoid predators and access oxygen. **Current Biology**, v. 20, n. 19, p. 1758-1762, 2010.

Brodeur, R. et al. Encyclopedia of Ocean Sciences, v. 3, p. 582-587, 2019.
BUESSELER, K. O.; BOYD, P. W. Shedding light on processes that control particle export and flux attenuation in the twilight zone of theopen ocean. Limnology & Oceanography, 54(4), 1210–1232. 2009.

Browne, M. A. et al. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). *Environmental Science & Technology*, v. 42, n. 13, p. 5026–5031, 2008.

Burd, A. B. Modeling the Vertical Flux of Organic Carbon in the Global Ocean. **Annual review of marine science**, v. 16, n. 1, p. 135-161, 2024.

Burford, B. P. et al. Pelagic shrimp play dead in deep oxygen minima. **Plos one**, v. 13, n. 11, p. e0207249, 2018.

Burghart, S. et al. Partitioning of food resources in bathypelagic micronekton in the eastern Gulf of Mexico. **Marine Ecology Progress Series**, v. 399, p. 131-140, 2010.

Burukovsky, R. N. Feeding and trophic relations of shrimps, 2009.

Burukovsky, R. N.; Andreeva, V. M. On the biology of Acanthephyra pelagica (Decapoda: Natantia: Oplophoridae) of the North Atlantic Subtropical convergence zone. 2010.

Burukovsky, R. N.; Falkenhaug, T. Feeding of the pelagic shrimp Acanthephyra pelagica (Risso, 1816)(Crustacea: Decapoda: Oplophoridae) in the northern Mid-Atlantic Ridge area in 1984 and 2004. **Arthropoda Selecta**, v. 24, n. 3, p. 303-316, 2015.

Camacho, A. Planktonic microbial assemblages and the potential effects of metazooplankton predation on the food web of lakes from the maritime Antarctica and sub-Antarctic islands. **Reviews in Environmental Science and Bio/Technology**, v. 5, p. 167-185, 2006.

Campli, G. et al. The moulting arthropod: a complete genetic toolkit review. **Biological Reviews**, 2024.

Cao, Y. et al. Progress and Prospects of Microplastic Biodegradation Processes and Mechanisms: A Bibliometric Analysis. **Toxics**, v. 12, n. 7, p. 463, 2024.

Capparelli, G. et al. Plastic pollution in freshwater ecosystems: A review on its occurrence and impacts. *Science of the Total Environment*, v. 739, p. 139990, 2020.

Cardoso, I. A.; Young, P. Deep-sea Oplophoridae (Crustacea Caridea) from the southwestern Brazil. **Zootaxa**, v. 1031, n. 1, p. 1–76-1–76, 2005.

Cardoso, I.A. On some rare Oplophoridae (Caridea, Decapoda) from the South Mid-Atlantic Ridge. Latin American Journal of Aquatic Research, p. 209–216, 2013.

Cardoso, I. A. et al. Catalogue of Typical Deep-Sea Decapod Fauna from Brazilian Waters. **Deep-Sea Pycnogonids and Crustaceans of the Americas**, p. 499-584, 2020.

Carreras-Colom, E. et al. Spatial occurrence and effects of microplastic ingestion on the deep-water shrimp Aristeus antennatus. **Marine Pollution Bulletin**, v. 133, p. 44-52, 2018.

Cartes, J. E. Feeding habits of pasiphaeid shrimps close to the bottom on the western Mediterranean slope. **Marine Biology**, v. 117, p. 459-468, 1993.

Cau, A. al. Microplastics in the crustaceans Nephrops norvegicus and Aristeus antennatus: flagship species for deep-sea environments?. **Environmental Pollution**, v. 255, p. 113107, 2019.

Cavalcante-Braga, D. V. Distribuição Populacional da Família Luciferidae (Decapoda: Sergestoidea) na Plataforma Continental do Amazonas. 2017. Tese (Doutorado em Ecologia Aquática e Pesca), UFPA, 2017.

Cavan, E. L. et al. Exploring the ecology of the mesopelagic biological pump. **Progress in Oceanography**, v. 176, p. 102125, 2019.

Chen, B. et al. Assessment of microplastic hazards in Penaeus vannamei shrimp in a typical estuary of China: polymer composition, risk assessment, and health implications. **Journal of Oceanology and Limnology**, p. 1-17, 2024.

Chiacchio, L. et al. Comparative assessment of microplastic ingestion among deep sea decapods: distribution analysis in Sardinian and Catalan waters. **Environmental Research**, p. 120962, 2025.

Childress, J. J. et al. Metabolic rates of benthic deep-sea decapod crustaceans decline with increasing depth primarily due to the decline in temperature. **Deep Sea Research Part A. Oceanographic Research Papers**, v. 37, n. 6, p. 929-949, 1990.

Childress, J. J. Are there physiological and biochemical adaptations of metabolism in deep-sea animals?. **Trends in Ecology & Evolution**, v. 10, n. 1, p. 30-36, 1995.

Chipps, S. R. et al. The cost of avoiding predators: a bioenergetic analysis of diel vertical migration by the opossum shrimp Mysis diluviana. **Hydrobiologia**, v. 849, n. 8, p. 1871-1884, 2022.

Christiansen, S. et al. Extensive avoidance behaviour of krill from predators and nets. **ICES Journal of Marine Science**, p. fsae123, 2024.

Christina, L.; Passow, Uta. Factors influencing the sinking of POC and the efficiency of the biological carbon pump. **Deep Sea Research Part II: Topical Studies in Oceanography**, v. 54, n. 5-7, p. 639-658, 2007.

Christoffersen, M.L. Decapod Crustacea: Alpheoida. Campagne de la Calypso au large des côtes atlantiques de l'Amérique du Sud (1961–1962). I. 36, Annales de l'Institute Océanographique, Monaco, Suppl., 55, 297–377, 1979.

Cisewski, B, et al. Vertical migration of pelagic and mesopelagic scatterers from ADCP backscatter data in the southern Norwegian Sea. **Frontiers in Marine Science**, v. 7, p. 542386, 2021.

Claudino-Sales, V. Brazilian Atlantic islands: Fernando de Noronha and Atol das Rocas, Brazil. **Coastal world heritage sites**, p. 217-223, 2019.

Coelho, P. A.; Ramos, M. A. A constituição e a distribuição da fauna de decápodos do litoral leste da Amárica do Sul entre as latitudes de 5o e 39o S. Trabalhos do Instituto Oceanográfico da Universidade Federal de Pernambuco, p. 135–236, 1972.

Coelho, P. A. et al. Diversity and distribution of the marine and estuarine shrimps (Dendrobranchiata, Stenopodidea and Caridea) from North and Northeast Brazil, 2006.

Colaço, A. et al. Ecossistemas do Mar Profundo. 2017.

Collins, S. B.; Bracken‐Grissom, H. D. The language of light: a review of bioluminescence in deep‐sea decapod shrimps. **Biological Reviews**, 2024.

Convey, P. How are the life history strategies of Antarctic terrestrial invertebrates influenced by extreme environmental conditions?. **Journal of Thermal Biology**, v. 22, n. 6, p. 429-440, 1997.

Costa, R.C.; Simões, S.M. Avaliação dos Camarões Sergestídeos (Decapoda: Sergestidae), p. 390- 399, 2016.

Coulet, P. et al. Dynamics of Yearly Maximum Water Levels in the Amazon Estuary. **Estuaries and Coasts**, v. 48, n. 2, p. 54, 2025.

Courtene-Jones, W. et al. Microplastic pollution identified in deep-sea water and ingested by benthic invertebrates in the Rockall Trough, North Atlantic Ocean. **Environmental pollution**, v. 231, p. 271-280, 2017.

Couwelaar, M. Vertical distribution and feeding pattern of Euphausiacea (Crustacea) in the eastern Banda Sea (Indonesia) during the SE and NW monsoons. **Journal of plankton research**, v. 16, n. 12, p. 1717-1740, 1994.

Cowger, W. et al. Global producer responsibility for plastic pollution. **Science Advances**, v. 10, n. 17, p. eadj8275, 2024.

Crosnier, A.; Forest, J. **Les crevettes profondes de l'Atlantique oriental tropical**. IRD Editions, 1973.

Cunningham, E. M. et al. High abundances of microplastic pollution in deep-sea sediments: evidence from Antarctica and the Southern Ocean. **Environmental Science & Technology**, v. 54, n. 21, p. 13661-13671, 2020.

Curren, E. et al. Evidence of marine microplastics in commercially harvested seafood. **Frontiers in Bioengineering and Biotechnology**, v. 8, p. 562760, 2020.

Danopoulos, E. et al. Microplastic contamination of seafood intended for human consumption: a systematic review and meta-analysis. **Environmental Health Perspectives**, v. 128, n. 12, p. 126002, 2020.

Danovaro, R. et al. Challenging the paradigms of deep-sea ecology. **Trends in ecology & evolution**, v. 29, n. 8, p. 465-475, 2014.

D'Costa, A. H. Microplastics in decapod crustaceans: Accumulation, toxicity and impacts, a review. **Science of the total environment**, v. 832, p. 154963, 2022.

D’Incao, F. Malacostraca. Eucarida. Dendrobranchiata. Catalogue of Crustacea of Brazil. Museu Nacional, Rio de Janeiro, pp. 311–321, 1998.

D'Costa, Avelyno H. Microplastics in decapod crustaceans: Accumulation, toxicity and impacts, a review. **Science of the total environment**, v. 832, p. 154963, 2022.

De Grave, S. et al. A classification of living and fossil genera of decapod crustaceans. **Raffles bulletin of zoology**, 2009.

Decelle, J. et al. Morphological adaptations to chronic hypoxia in deep-sea decapod crustaceans from hydrothermal vents and cold seeps. **Marine biology**, v. 157, p. 1259-1269, 2010.

Delcourt, J.; Poncin, P. Shoals and schools: back to the heuristic definitions and quantitative references. **Reviews in Fish Biology and Fisheries**, v. 22, p. 595-619, 2012.

Deleo, D. M.; Bracken‐Grissom, H. D. Illuminating the impact of diel vertical migration on visual gene expression in deep‐sea shrimp. **Molecular Ecology**, v. 29, n. 18, p. 3494-3510, 2020

Dhurmeea, Z. et al. Diet of albacore Thunnus alalunga from the waters of Mauritius (western Indian Ocean) inferred from stomach contents and fatty acid analysis. **African Journal of Marine Science**, v. 42, n. 2, p. 131-140, 2020.

Díaz-Pérez, J. et al. Distribution patterns of micronektonic crustaceans (Decapoda, Euphausiacea, and Lophogastrida) in the tropical and subtropical Atlantic Ocean. **Progress in Oceanography**, p. 103331, 2024.

Ding, Y. et al. Distribution pattern and influencing factors for the microplastics in continental shelf, slope, and deep-sea surface sediments from the South China Sea. **Environmental Pollution**, v. 309, p. 119824, 2022.

Drazen, J. C.; Sutton, T. T. Dining in the deep: the feeding ecology of deep-sea fishes. **Annual review of marine science**, v. 9, n. 1, p. 337-366, 2017.

Eduardo, L. N. et al. Hatchetfishes (Stomiiformes: Sternoptychidae) biodiversity, trophic ecology, vertical niche partitioning and functional roles in the western Tropical Atlantic. **Progress in Oceanography**, v. 187, p. 102389, 2020.

Eduardo, L. N. et al. Rich and underreported: First integrated assessment of the diversity of mesopelagic fishes in the Southwestern Tropical Atlantic. **Frontiers in Marine Science**, v. 9, 2022.

Eduardo, L. N. et al. From the light blue sky to the dark deep sea: Trophic and resource partitioning between epipelagic and mesopelagic layers in a tropical oceanic ecosystem. **Science of the Total Environment**, v. 878, p. 163098, 2023.

Eduardo, L. N. et al. Deep‐Pelagic Fishes Are Anything But Similar: A Global Synthesis. **Ecology Letters**, v. 27, n. 9, p. e14510, 2024.

EFSA. Opinion of the Scientific Committee on the risks to human health of microplastics in food. *European Food Safety Authority*, EFSA Journal, v. 14, n. 6, p. 4176, 2016.

Egger, M. et al. First evidence of plastic fallout from the North Pacific Garbage Patch. **Scientific reports**, v. 10, n. 1, p. 7495, 2020.

Eilertsen, M. H. et al. Diversity, habitat endemicity and trophic ecology of the fauna of Loki's Castle vent field on the Arctic Mid-Ocean Ridge. **Scientific Reports**, v. 14, n. 1, p. 103, 2024.

Evans, S. R. et al. Shoaling preferences in decapod crustacea. **Animal Behaviour**, v. 74, n. 6, p. 1691-1696, 2007.

Fan, S. et al. Biological effects on the migration and transformation of microplastics in the marine environment. **Marine Environmental Research**, v. 185, p. 105875, 2023.

Fanelli, E. et al. Food web structure of deep-sea macrozooplankton and micronekton off the Catalan slope: insight from stable isotopes. **Journal of Marine Systems**, v. 87, n. 1, p. 79-89, 2011.

Farias, G. B. et al. Nutrient availability regulates the microbial biomass structure in marine oligotrophic waters. **Hydrobiologia**, v. 851, n. 8, p. 1923-1938, 2024.

Feng, J. et al. Deep-sea organisms research oriented by deep-sea technologies development. **Science Bulletin**, v. 67, n. 17, p. 1802-1816, 2022.

Ferreira, G. V. B. et al. Lanternfish as bioindicator of microplastics in the deep sea: A spatiotemporal analysis using museum specimens. **Journal of Hazardous Materials**, p. 137125, 2025.

Ferreira, R. C. P. et al. Abundance and diversity of deep-sea crustaceans (Decapoda and Isopoda) in the upper slope of state of Pernambuco–Brazil: With five new records. **Regional Studies in Marine Science**, v. 60, p. 102878, 2023.

Ferreira, G. V. B. et al. Plastic in the inferno: Microplastic contamination in deep-sea cephalopods (Vampyroteuthis infernalis and Abralia veranyi) from the southwestern Atlantic. **Marine Pollution Bulletin**, v. 174, p. 113309, 2022.

Folkersen, M. V. et al. The economic value of the deep sea: A systematic review and meta-analysis. **Marine Policy**, v. 94, p. 71-80, 2018.

Fossi, M. C. et al. Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity. **Environmental Pollution**, v. 237, p. 1023-1040, 2018.

Fransozo, V. et al. Spatial and temporal distribution of the shrimp Nematopalaemon schmitti (Decapoda: Caridea: Palaemonidae) at a subtropical enclosed bay in South America. **Journal of the Marine Biological Association of the United Kingdom**, v. 89, n. 8, p. 1581-1587, 2009.

Fu, Z; Wang, J. Current practices and future perspectives of microplastic pollution in freshwater ecosystems in China. *Science of the Total Environment*, v. 704, p. 135242, 2020.

Galarza, E. et al. Assessing the quality of amazon aquatic ecosystems with multiple lines of evidence: the case of the Northeast Andean foothills of Ecuador. **Bulletin of Environmental Contamination and Toxicology**, v. 107, p. 52-61, 2021.

Gallo, M. N.; Vinzon, S. B. Estudo numérico do escoamento em planícies de marés do canal Norte (estuário do rio Amazonas). **Ribagua**, v. 2, n. 1, p. 38-50, 2015.

Getor, R, Y. et al. The role of technological innovation in plastic production within a circular economy framework. **Resources, Conservation and Recycling**, v. 163, p. 105094, 2020.

Getzlaff, J.; Kriest, I. Impacts of vertical migrants on biogeochemistry in an Earth system model. **Global Biogeochemical Cycles**, v. 38, n. 7, 2024.

Geyer, R. et al. Production, use, and fate of all plastics ever made. **Science advances**, v. 3, n. 7, 2017.

Ghosh, S. et al. Microplastics as an emerging threat to the global environment and human health. **Sustainability**, v. 15, n. 14, 2023.

Giraldes, B. W. et al. The tale of an endemic shrimp's exceptional osmoregulation and the ancient Athalassic mangrove oasis. **Scientific Reports**, v. 14, n. 1, p. 66-77, 2024.

Golightly, C. et al. Tracing the evolution of bioluminescent light organs across the deep-sea shrimp family Sergestidae using a genomic skimming and phylogenetic approach. **Invertebrate Systematics**, v. 36, n. 1, p. 22-35, 2022.

Graham, E. R.; Thompson, J. T. Deposit-and suspension-feeding sea cucumbers (Echinodermata) ingest plastic fragments. **Journal of experimental marine biology and ecology**, v. 368, n. 1, p. 22-29, 2009.

Grassle, J. F; Maciolek, N. J. Deep-sea species richness: regional and local diversity estimates from quantitative bottom samples. **The American Naturalist**, v. 139, n. 2, p. 313-341, 1992.

Gray, J. S.; Elliott, M. **Ecology of marine sediments: from science to management**. Oxford university press, 2009.

Gray, A. D.; Weinstein, J. E. Size‐and shape‐dependent effects of microplastic particles on adult daggerblade grass shrimp (Palaemonetes pugio). **Environmental toxicology and chemistry**, v. 36, n. 11, p. 3074-3080, 2017.

Grodsky, S. A. et al. Year-to-year salinity changes in the Amazon plume: Contrasting 2011 and 2012 Aquarius/SACD and SMOS satellite data. **Remote Sensing of Environment**, v. 140, p. 14-22, 2014.

Groeneveld, R. A. et al. Climate damage from fishing the mesopelagic zone exceeds its economic benefits. **ICES Journal of Marine Science**, v. 81, n. 8, p. 1620-1631, 2024.

Hall, N. M. et al. Microplastic ingestion by scleractinian corals. **Marine Biology**, v. 162, p. 725-732, 2015.

Hassan, R.; Othman, M. N. A. Temporal and spatial variations of selected water quality parameters in sergestid shrimps'habitat along coastal water of miri, sarawak, malaysian borneo. **Malaysian Applied Biology**, v. 50, n. 3, 2021.

Hays, G. C. A review of the adaptive significance and ecosystem consequences of zooplankton diel vertical migrations. In: **Migrations and Dispersal of Marine Organisms: Proceedings of the 37 th European Marine Biology Symposium held in Reykjavík, Iceland, 5–9 August 2002**. Springer Netherlands, p. 163-170, 2003.

Hays, G. C. A review of the adaptive significance and ecosystem consequences of zooplankton diel vertical migrations. p. 163-170, 2003.

Hernández-León, S. The biological carbon pump, diel vertical migration, and carbon dioxide removal. **Iscience**, v. 26, n. 11, 2023.

Herrera, D. R, et al. Relative growth and morphological sexual maturity of the caridean shrimp Nematopalaemon schmitti (Decapoda: Caridea: Palaemonidae) in an upwelling region in the Western Atlantic. **Invertebrate Reproduction & Development**, v. 62, n. 1, p. 56-62, 2018.

Hogg, I. D. et al. Biotic interactions in Antarctic terrestrial ecosystems: are they a factor?. **Soil Biology and Biochemistry**, v. 38, n. 10, p. 3035-3040, 2006.

Holmes, L. et al. Interactions between trace metals and plastic production pellets under estuarine conditions. **Marine Chemistry**, v. 167, p. 25-32, 2014.

Howell, K. L. et al. A decade to study deep-sea life. **Nature Ecology & Evolution**, v. 5, n. 3, p. 265-267, 2021.

Hügler, M. et al. Pathways of carbon and energy metabolism of the epibiotic community associated with the deep-sea hydrothermal vent shrimp Rimicaris exoculata. **PLoS One**, v. 6, n. 1, p. e16018, 2011.

Jamal, N. T. et al. Microplastic contamination in some popular seafood fish species from the northern Bay of Bengal and possible consumer risk assessment. **Food Control**, v. 171, p. 111-114, 2025.

Jamieson, A. J. et al. Deep-Sea Benthic Sampling. **Methods for the study of marine benthos**, p. 285-347, 2013.

Jamieson, A. J. et al. Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. **Royal Society open science**, v. 6, n. 2, p. 180667, 2019.

Jitrapat, H. et al. Ingestion and adherence of microplastics by estuarine mysid shrimp. **Marine Environmental Research**, v. 197, p. 106-455, 2024.

Judkins, D. C. Geographical distribution of pelagic decapod shrimp in the Atlantic Ocean. **Zootaxa**, v. 3895, n. 3, p. 301–345-301–345, 2014.

Justino, A. K. S. et al. Microplastic contamination in tropical fishes: An assessment of different feeding habits. **Regional Studies in Marine Science**, v. 45, p. 101857, 2021.

Justino, A. K. S. et al. The role of mesopelagic fishes as microplastics vectors across the deep-sea layers from the Southwestern Tropical Atlantic. **Environmental Pollution**, v. 300, p. 118988, 2022.

Justino, A. K. S. et al. From prey to predators: Evidence of microplastic trophic transfer in tuna and large pelagic species in the southwestern Tropical Atlantic. **Environmental Pollution**, v. 327, p. 121532, 2023.

Kaartvedt, S. et al. Enlightening the ocean's twilight zone. **ICES Journal of Marine Science**, v. 76, n. 4, p. 803-812, 2019.

Kane, Ian A. et al. Seafloor microplastic hotspots controlled by deep-sea circulation. **Science**, v. 368, n. 6495, p. 1140-1145, 2020.

Kang, M. et al. Characterization of pelagic communities in the Pacific sector of the Arctic Ocean using a broadband acoustic system, net samplers, and optical instruments. **Journal of Marine Systems**, v. 244, p. 103976, 2024.

Karuppasamy, P. K. et al. Distribution and abundance of pelagic shrimps from the deep scattering layer of the eastern Arabian Sea. **Journal of Shellfish Research**, v. 25, n. 3, p. 1013-1019, 2006.

Kibria, G. et al. Microplastic pollution and contamination of seafood (including fish, sharks, mussels, oysters, shrimps and seaweeds): a global overview. **Microplastic Pollution: Environmental Occurrence and Treatment Technologies**, p. 277-322, 2022.

Kikuchi, T.; Omori, M.. Ontogenetic vertical migration patterns of pelagic shrimps in the ocean: some examples. **UNESCO Technical Paper Mar Sci**, v. 49, p. 172-176, 1986.

KOBARI, T. et al. Impacts of ontogenetically migrating copepods on downward carbon flux in the western subarctic Pacific Ocean. **Deep Sea Research Part II: Topical Studies in Oceanography**, v. 55, n. 14-15, p. 1648-1660, 2008.

Koelmans, A. A. et al. All is not lost: deriving a top-down mass budget of plastic at sea. **Environmental Research Letters**, v. 12, n. 11, p. 114028, 2017.

Komai, T. et al. Bathypelagic shrimp of the genus Pasiphaea (Decapoda: Caridea: Pasiphaeidae) from waters around Taiwan, with descriptions of four new species. **Journal of Crustacean Biology**, v. 32, n. 2, p. 295-325, 2012.

Kong, X. et al. Insights into adsorption mechanisms of nitro polycyclic aromatic hydrocarbons on common microplastic particles: Experimental studies and modeling. **Chemosphere**, v. 320, p. 138050, 2023.

Krumme, U. Diel and tidal movements by fish and decapods linking tropical coastal ecosystems. **Ecological connectivity among tropical coastal ecosystems**, p. 271-324, 2009.

Lakenarine, R. et al. Characterization of small-scale net fisheries off the coast of Guyana. **PloS one**, v. 19, n. 6, p. e0306332, 2024.
LE MOIGNE, F. A. C. Pathways of organic carbon downward transport by the oceanic biological carbon pump. **Frontiers in Marine Science**, v. 6, p. 634, 2019.

Leads, R. et al. The effect of microplastic ingestion on survival of the grass shrimp Palaemonetes pugio (Holthuis, 1949) challenged with Vibrio campbellii. **Environmental toxicology and chemistry**, v. 38, n. 10, p. 2233-2242, 2019.

Lebreton, L. CM et al. River plastic emissions to the world’s oceans. **Nature communications**, v. 8, n. 1, p. 15611, 2017.

Lebreton, L.; Andrady, A. Future scenarios of global plastic waste generation and disposal. *Environmental Science & Technology*, v. 53, n. 13, p. 7227–7234, 2019.

Legendre, L. Jigsaw puzzle of the interwoven biologically-driven ocean carbon pumps. **Progress in Oceanography**, p. 103338, 2024.

Lehtiniemi, M. et al. Size matters more than shape: Ingestion of primary and secondary microplastics by small predators. **Food webs**, v. 17, p. e00097, 2018.

Li, L. et al. Characterization of the solar light field within the ocean mesopelagic zone based on radiative transfer simulations. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 87, p. 53-69, 2014.

Lizarraga, R. G. M. Diversidade e distribuição de procariotos na zona mesopelágica da Bacia de Santos Brasil. 86 p. Dissertação (Microbiologia), **Universidade de São Paulo**, 2022.

Lucas-Solis, C. et al. Effects of human activities on plastic pollution in aquatic ecosystems. *Marine Pollution Bulletin*, v. 173, p. 113020, 2021.

Lebreton, L. et al. River plastic emissions to the world's oceans. *Nature Communications*, v. 8, p. 15611, 2017.

Lunina, A. et al. Oplophoridae (Decapoda: Crustacea): phylogeny, taxonomy and evolution studied by a combination of morphological and molecular methods. **Zoological Journal of the Linnean Society**, v. 186, n. 1, p. 213-232, 2019.

Lunina, A. et al. Phylogenetic revision of the shrimp genera Ephyrina, Meningodora and Notostomus (Acanthephyridae: Caridea). **Zoological Journal of the Linnean Society**, v. 193, n. 3, p. 1002-1019, 2021.

Mantelatto, F. L. et al. Avaliação dos camarões palemonídeos (Decapoda: Palaemonidae). **Livro Vermelho dos crustáceos do Brasil: avaliação**, v. 2014, p. 252-267, 2010.

Martinelli Filho, J. E.; Monteiro, M. Microplastics in the Amazon: Challenges and opportunities for understanding pollution in tropical estuarine systems. *Environmental Science and Pollution Research*, v. 26, n. 8, p. 7298–7310, 2019.

Markic, A. et al. Plastic ingestion by marine fish in the wild. **Critical Reviews in Environmental Science and Technology**, v. 50, n. 7, p. 657-697, 2020.

Martin, A. et al. The oceans' twilight zone must be studied now, before it is too late. Nature 580, 26–28, 2020.

Martín, J. et al. Microplastics and associated emerging contaminants in the environment: Analysis, sorption mechanisms and effects of co-exposure. **Trends in Environmental Analytical Chemistry**, v. 35, p. e00170, 2022.

Mcconaugha, J. R. Decapod larvae: dispersal, mortality, and ecology. A working hypothesis. **American Zoologist**, v. 32, n. 3, p. 512-523, 1992.

Mcgill, B. et al. Rebuilding community ecology from functional traits. **Trends in Ecology and Evolution**, v. 21, n. 4, p. 178-185, 2006.

Medina-Contreras, D, et al. Carbon sources supporting macrobenthic crustaceans in tropical eastern pacific mangroves. **Food Webs**, v. 30, p. e00219, 2022.

Meng, Y. et al. Advances and challenges of microplastic pollution in freshwater ecosystems: A UK perspective. **Environmental Pollution**, v. 256, p. 113445, 2020.

Menon, N. G. Book Review: Palaemonid Prawns-Biodiversity, Taxonomy, Biology and Management. **Marine Fisheries Information Service, Technical and Extension Series**, v. 173, p. 11-12, 2002.

Mercy, F. T.; Alam, A. K. M. Assessment of microplastic contamination in shrimps from the Bay of Bengal and associated human health risk. **Marine Pollution Bulletin**, v. 201, p. 116185, 2024.

Mikkola, H. **Amazon Ecosystem-Past Discoveries and Future Prospects**. BoD–Books on Demand, 2024.

Mincarone, M. M. et al. New records of rare deep‐sea fishes (Teleostei) collected from off north‐eastern Brazil, including seamounts and islands of the Fernando de Noronha Ridge. **Journal of Fish Biology**, v. 101, n. 4, p. 945-959, 2022.

Modica, L. et al. Food consumption of five deep‐sea fishes in the Balearic Basin (western Mediterranean Sea): are there daily feeding rhythms in fishes living below 1000 m?. **Journal of Fish Biology**, v. 85, n. 3, p. 800-820, 2014

Mohan, A. V.; Raja, S. Unveiling the Tiny Invaders: A deep dive into microplastics in shrimp–Occurrence, detection and unraveling the ripple effects. **Saudi Journal of Biological Sciences**, p. 103981, 2024.

Molina-Salgado, P. et al. Diet of the rasptail skate, Rostroraja velezi (Rajiformes: Rajidae), off Piura, Peru. **Ciencias marinas**, v. 47, n. 2, p. 127-138, 2021.

Moura, R. L. et al. An extensive reef system at the Amazon River mouth. **Science advances**, v. 2, n. 4, p. e1501252, 2016.

Monteiro, M. et al. Climate-driven shifts in decapod larvae assemblages in a temperate estuary. **Marine Environmental Research**, v. 198, p. 106526, 2024.

Moore, C. J. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. **Environmental research**, v. 108, n. 2, p. 131-139, 2008.

Moraes, I. R. R. et al. Functional reproductive morphology of the snapping shrimp genus Synalpheus Spence Bate, 1888 (Decapoda, Alpheidae). **Current Zoology**, p. zoae053, 2024.

Moreira, C. Crustáceos do Brasil. Contribuição para o conhecimento da fauna brasileira. Arquivos do Museu Nacional Rio de Janeiro, p. 1–151, 1901.

Morozov, E. G. et al. Amazon River Plume in the Western Tropical North Atlantic. **Journal of Marine Science and Engineering**, v. 12, n. 6, p. 851, 2024.

Motoh, H. Sea foods of the Sea of Japan shrimps and crabs. **Ashigara Printing Co., Ltd, Kanagawa**, 1999.

Murray, F.; Cowie, P. R. Plastic contamination in the decapod crustacean Nephrops norvegicus (Linnaeus, 1758). **Marine pollution bulletin**, v. 62, n. 6, p. 1207-1217, 2011.

Nanjo, N. Occurrence of the pelagic shrimp Pasiphaea japonica (Decapoda: Pasiphaeidae) in gut contents of demersal predators in a submarine canyon (Toyama Bay, Japan). **Crustacean Research**, v. 45, p. 69-77, 2016.

Nagano, Y.; Nagahama, T. Fungal diversity in deep-sea extreme environments. **Fungal Ecology**, v. 5, n. 4, p. 463-471, 2012.

Nair, S. R. et al. Blooms of phytoplankton along the west coast of India associated with nutrient enrichment and the response of zooplankton. In: **Marine coastal eutrophication**. Elsevier, 1992. p. 819-828.

Nunes, E. S. C. L., et al. Avaliação da qualidade do camarão salgado seco (aviú) e da farinha de peixe (piracuí) comercializados em mercados varejistas da cidade de Belém, Pará. Rev Inst Adolfo Lutz. São Paulo, 2013.

Nunomura, N. et al. Biodiversity of Marine Animals: Introduction to Marine Animals with a Focus on Taxonomy. In: **Field Work and Laboratory Experiments in Integrated Environmental Sciences**. Singapore: Springer Nature Singapore, p. 47-74, 2024.

Omori, M. The biology of pelagic shrimps in the ocean. In: **Advances in marine biology**. Academic Press, p. 233-324.1975.

Osuna-Laveaga, D. R. et al. Micro-and nanoplastics current status: legislation, gaps, limitations and socio-economic prospects for future. **Frontiers in Environmental Science**, v. 11, p. 1241939, 2023.

Park, B. et al. Microplastic Contamination of a Benthic Ecosystem in a Hydrothermal Vent. **Environmental Science & Technology**, v. 58, n. 17, p. 7636-7642, 2024.

Paterson, H. Plastic habits–an overview for the collection ‘Plastics and Sustainable Earth’. **Sustainable Earth**, v. 2, p. 1-8, 2019

Pelegrini, K. et al. Micro-and nanoplastic toxicity: A review on size, type, source, and test-organism implications. **Science of The Total Environment**, v. 878, p. 162954, 2023.

Peña, M.; Hernández-León, S. Unveiling the bathypelagic zone with an acoustic vertical profiler. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 200, p. 104134, 2023.

Peng, X. et al. Microplastics contaminate the deepest part of the world’s ocean. **Geochem. Perspect. Lett**, v. 9, n. 1, p. 1-5, 2018.

Peng, G et al. The ocean’s ultimate trashcan: Hadal trenches as major depositories for plastic pollution. **Water research**, v. 168, p. 115121, 2020.

Pereira, R. T. et al. Reproductive strategy of the shrimp Nematopalaemon schmitti (Decapoda, Caridea, Palaemonoidea) on the southeastern coast of Brazil. **Nauplius**, v. 25, p. e2017003, 2017.

Phudhom, A. et al. Effect of Different Feeds on Growth and Survival of the Sergestid Shrimp Acetes vulgaris Hansen, 1919 (Decapoda: Sergestidae). **Agricultural Sciences**, v. 15, n. 1, p. 71-81, 2024.

Pilapitiya, N. T.; Ratnayake, A. S. The world of plastic waste: a review. **Cleaner Materials**, p. 100220, 2024.

Pinti, J. et al. Fear and loathing in the pelagic: How the seascape of fear impacts the biological carbon pump. **Limnology and Oceanography**, v. 67, n. 6, p. 1238-1256, 2022.

Plastics Europe. *Plastics—the fast facts 2022*. Brussels, Belgium: Plastics Europe. (acessado em 20 de Novembro de 2024)

Porter, A. et al. Role of marine snows in microplastic fate and bioavailability. **Environmental science & technology**, v. 52, n. 12, p. 7111-7119, 2018.

Prellezo, R. et al. Economic trade-offs of harvesting the ocean twilight zone: An ecosystem services approach. **Ecosystem Services**, v. 67, p. 101633, 2024.

Proud, R. et al. From siphonophores to deep scattering layers: uncertainty ranges for the estimation of global mesopelagic fish biomass. **ICES Journal of Marine Science**, v. 76, n. 3, p. 718-733, 2019.

Quero, G. M. et al. Inorganic and organic carbon uptake processes and their connection to microbial diversity in meso-and bathypelagic Arctic Waters (Eastern Fram Strait). **Microbial ecology**, v. 79, p. 823-839, 2020.

Ramos-Porto, M.; Coelho, P. Malacostraca. Eucarida. Caridea (Alpheoidea excluded). Catalogue of Crustacea of Brazil, Museu Nacional, Rio de janeiro, pp. 325–350, 1988.
RAMPELOTTO, P. H. Extremophiles and extreme environments. 2016.
Rebelein, A. et al. Microplastic fibers—underestimated threat to aquatic organisms?. **Science of the Total Environment**, v. 777, p. 146045, 2021.

Reis-Júnior, J.; Freire, K. M. F. Morphometric relationships for non-target shrimp marine species off northeastern Brazil. **Pan-American Journal of Aquatic Sciences**, v. 19, n. 1, p. 17-23, 2024.

Robertson, D. R. et al. Mechanisms of speciation and faunal enrichment in Atlantic parrotfishes. **Molecular phylogenetics and evolution**, v. 40, n. 3, p. 795-807, 2006.

Rodrigues, T. G. A.; Cardoso, I. A. First record of four Pasiphaea Savigny, 1816 (Crustacea, Decapoda, Pasiphaeidae) species from the southwestern Atlantic. **Zootaxa**, v. 4560, n. 2, p. 321-330, 2019.

Roch, S. et al. Uptake routes of microplastics in fishes: practical and theoretical approaches to test existing theories. **Scientific reports**, v. 10, n. 1, p. 3896, 2020.

Rochman, C. M et al. Rethinking microplastics as a diverse contaminant suite. Environmental toxicology and chemistry. v. 38, n. 4, p. 703–711. 2019.

Rodrigues, T. G. A. et al. A new species of Pasiphaea Savigny, 1816 (Crustacea, Decapoda, Pasiphaeidae) from the southwestern Atlantic. **Zootaxa**, v. 4418, n. 5, p. 493-498, 2018.

Ryan, P. G. Ingestion of plastics by marine organisms. **Hazardous chemicals associated with plastics in the marine environment**, p. 235-266, 2019.

Saborowski, R. et al. Shrimp and microplastics: A case study with the Atlantic ditch shrimp Palaemon varians. **Ecotoxicology and environmental safety**, v. 234, p. 113394, 2022.

Sanders, N. K.; Childress, J. J. Ion replacement as a buoyancy mechanism in a pelagic deep-sea crustacean. **Journal of Experimental biology**, v. 138, n. 1, p. 333-343, 1988.

Santos, C.F. et al. Marine spatial planning and oil spill risk analysis: fnding common grounds. Mar Pollution Bulletin. 2013.

Scacco, U. al. Microplastics in the deep: comparing dietary and plastic ingestion data between two Mediterranean bathyal opportunistic feeder species, Galeus melastomus, Rafinesque, 1810 and Coelorinchus caelorhincus (Risso, 1810), through stomach content analysis. **Journal of Marine Science and Engineering**, v. 10, n. 5, p. 624, 2022.

Schaerf, T. M. et al. Collective order and group structure of shoaling fish subject to differing risk-level treatments with a sympatric predator. **Royal Society Open Science**, v. 11, n. 5, p. 231511, 2024.

Schukat, A. et al. Pelagic decapods in the northern Benguela upwelling system: Distribution, ecophysiology and contribution to active carbon flux. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 75, p. 146-156, 2013.

Shakawi, A. M. H. et al. Modelling the environmental and biological cues for the bloom of sergestid shrimp acetes (decapoda: Sergestidae) in coastal water of Miri, Sarawak, Malaysian Borneo. **Malaysian Applied Biology**, v. 50, n. 3, p. 57-67, 2021.

Siddiqui, S. A. et al. Polystyrene microplastic particles in the food chain:

Characteristics and toxicity-A review. **Science of The Total Environment**, v. 892, p. 164531, 2023.

Silva, K. C. A. et al. Update on crustaceans known from the Amazonian continental shelf and adjacent oceanic areas. **Crustaceana**, v. 93, n. 7, p. 687-701, 2020.
SIMÕES, C. F. REVIZEE-MISSÃO CUMPRIDA?. **Revista Brasileira de Engenharia de Pesca**, v. 2, n. 1, p. 27-43, 2007.

Soares, C. V. O conhecimento científico do Oceano. Instituto Hidrográfico, conhecer o mar para que todos os possam usar. **Relações Internacionais**, 2020
Sources. IUCN International Union for Conservation of Nature, 2017.

Spalding, M. D. et al. Pelagic provinces of the world: A biogeographic classification of the world's surface pelagic waters. **Ocean & Coastal Management**, v. 60, p. 19-30, 2012.

Suh, H. Morphology of the gastric mill of the genus Thysanopoda (Euphausiacea). **Journal of Crustacean Biology**, v. 10, n. 3, p. 479-486, 1990.

Sui, Q. et al. Bioaccumulation of polycyclic aromatic hydrocarbons and their human health risks depend on the characteristics of microplastics in marine organisms of Sanggou Bay, China. **Journal of Hazardous Materials**, v. 473, p. 134622, 2024.

Suntsov, A.; Domokos, R. Vertically migrating micronekton and macrozooplankton communities around Guam and the Northern Mariana Islands. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 71, p. 113-129, 2013.

Sutton, T. T. et al. A global biogeographic classification of the mesopelagic zone. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 126, p. 85-102, 2017.

Tang, Y. et al. A review: Research progress on microplastic pollutants in aquatic environments. **Science of the Total Environment**, v. 766, p. 142572, 2021.

Taylor, M. L. et al. Plastic microfibre ingestion by deep-sea organisms. **Scientific reports**, v. 6, n. 1, p. 33997, 2016.

Tchamabi, C. C. et al. A study of the Brazilian Fernando de Noronha island and Rocas Atoll wakes in the tropical Atlantic. Ocean Model. 111, 9–18, 2017.

Terrazas-López, R. et al. The Occurrence of Microplastics in the Marine Food Web in Latin America: Insights on the Current State of Knowledge and Future Perspectives. **Sustainability**, v. 16, n. 14, p. 5905, 2024.

Teuten, E. L. et al. Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences*, v. 364, n. 1526, p. 2027–2045, 2007.

Thavasimuthu, R. et al. Enhanced classification of microplastic polymers (polyethylene, polystyrene, low-density polyethylene, polyhydroxyalkanoate) in waterbodies. **Polymers for Advanced Technologies**, v. 35, n. 7, p. e6506, 2024.

Thibault, H. et al. Modeling the contribution of micronekton diel vertical migrations to carbon export in the mesopelagic zone. **EGUsphere**, v. 2024, p. 1-30, 2024.

Thurber, A. R. et al. Ecosystem function and services provided by the deep sea. **Biogeosciences**, v. 11, n. 14, p. 3941-3963, 2014.

Thushari, G. G. N; Senevirathna, J. D. M. Plastic pollution in the marine environment. **Heliyon**, v. 6, n. 8, 2020.

Tian, W. et al. Microplastic materials in the environment: Problem and strategical solutions. **Progress in Materials Science**, v. 132, p. 101035, 2023.

Timilsina, A. et al. Effects of microplastics and nanoplastics in shrimp: Mechanisms of plastic particle and contaminant distribution and subsequent effects after uptake. **Science of the Total Environment**, v. 894, p. 164999, 2023.

Tirelli, V. et al. Microplastics in polar samples. In: **Handbook of Microplastics in the Environment**. Cham: Springer International Publishing, 2022. p. 281-322.

Tosetto, E. et al. The Amazon River plume, a barrier to animal dispersal in the Western Tropical Atlantic. **Scientific reports**, v. 12, n. 1, p. 537, 2022.

Trestrail, C. et al. Invertebrate responses to microplastic ingestion: Reviewing the role of the antioxidant system. **Science of the total environment**, v. 734, p. 138559, 2020.

Varona, H. L. et al. Amazon River plume influence on Western Tropical Atlantic dynamic variability. Dyn. Atmos. Ocean. 85, 1–15, 2019.

Valdez-Cibrián, A. et al. Microplastic ingestion in marine mesozooplankton species associated with functional feeding traits. **Marine Environmental Research**, v. 200, p. 106650, 2024.

Veloso, V.G. et al. Macrofauna bentônica da plataforma continental da Bacia de Campos. **Ambiente Bentônico: caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste**. v. 3. p. 227-258, 2017

Vereshchaka, A. L. Revision of the genus Sergestes (Decapoda: Dendrobranchiata: Sergestidae): taxonomy and distribution. **Galathea Report**, v. 22, p. 7-104, 2009.

Vereshchaka, A. et al. A novel approach reveals high zooplankton standing stock deep in the sea. **Biogeosciences**, v. 13, n. 22, p. 6261-6271, 2016.

Vereshchaka, A. et al. Global diversity and phylogeny of pelagic shrimps of the former genera Sergestes and Sergia (Crustacea, Dendrobranchiata, Sergestidae), with definition of eight new genera. **PloS one**, v. 9, n. 11, p. e112057, 2014.

Vereshchaka, A. et al. Assessing deep-pelagic shrimp biomass to 3000 m in the Atlantic Ocean and ramifications of upscaled global biomass. **Scientific Reports**, v. 9, n. 1, p. 5946, 2019.
VERLA, A. W. et al. Microplastic–toxic chemical interaction: a review study on quantified levels, mechanism and implication. **SN Applied Sciences**, v. 1, n. 11, p. 1-30, 2019.

Vestheim, H.; Kaartvedt, S. Vertical migration, feeding and colouration in the mesopelagic shrimp Sergestes arcticus. **Journal of plankton research**, v. 31, n. 11, p. 1427-1435, 2009.

Viana, D. L. et al. Ciências do Mar: dos oceanos do mundo ao Nordeste do Brasil. Via Design Publicações. v. 2, n. 1, p. 149-203, 2021

Vo, T. N. H. et al. The frequency of occurrence of fungal pathogens associated with water hyacinth (Eichhornia crassipes) in Ho Chi Minh City and its harmful effects on plants. **CTU Journal of Innovation and Sustainable Development**, v. 16, n. 1, p. 7-15, 2024.

Xing, Yi-fu et al. Toxic effects of microplastics and nitrite exposure on intestinal histology, digestion, immunity, and microbial community of shrimp Litopenaeus vannamei. **Marine Pollution Bulletin**, v. 200, p. 116077, 2024.

Wang, Q. et al. Uncovering the world’s largest carbon sink—a profile of ocean carbon sinks research. **Environmental Science and Pollution Research**, v. 31, n. 13, p. 20362-20382, 2024.
WANG, Y. et al. Biofilm alters tetracycline and copper adsorption behaviors onto polyethylene microplastics. **Chemical Engineering Journal**, v. 392, p. 123808, 2020.

Ward, A.; Webster, M.. **Sociality: the behaviour of group-living animals**. Berlin, Germany: Springer, 2016.

Ward, J. E. et al. Selective ingestion and egestion of plastic particles by the blue mussel (Mytilus edulis) and eastern oyster (Crassostrea virginica): implications for using bivalves as bioindicators of microplastic pollution. **Environmental science & technology**, v. 53, n. 15, p. 8776-8784, 2019.

Webb, T. J. et al. Biodiversity's big wet secret: the global distribution of marine biological records reveals chronic under-exploration of the deep pelagic ocean. **PloS one**, v. 5, n. 8, p. e10223, 2010.

Wehrtmann, I. S. et al. Deep-water shrimp fisheries in Latin America: a review. **Latin American Journal of Aquatic Research**, v. 40, n. 3, p. 497-535, 2012.

Willis, K. A. et al. Microplastic distribution at different sediment depths in an urban estuary. **Frontiers in Marine Science**, v. 4, p. 419, 2017.

Winnikoff, J. R. et al. Homeocurvature adaptation of phospholipids to pressure in deep-sea invertebrates. **Science**, v. 384, n. 6703, p. 1482-1488, 2024.

WoRMS Editorial Board. World register of marine species. Available at: http://www.marinespecies.org at VLIZ (acessado em 18 de Setembro de 2024).

Yagi, M. et al. Dive Deep: Bioenergetic Adaptation of Deep-Sea Animals. **Zoological Science**, v. 42, n. 1, 2025.

Yang, Z. et al. Degradation of microplastic in water by advanced oxidation processes. **Chemosphere**, p. 141939, 2024.

Yao, C. et al. Occurrence of microplastics in fish and shrimp feeds. **Bulletin of Environmental Contamination and Toxicology**, v. 107, p. 684-692, 2021.

Yin, J. et al. Microplastic pollution in wild populations of decapod crustaceans: A review. **Chemosphere**, v. 291, p. 132985, 2022.

Yu, Y. et al. Toxicities of polystyrene microplastics (MPs) and hexabromocyclododecane (HBCD), alone or in combination, to the hepatopancreas of the whiteleg shrimp, Litopenaeus vannamei. **Environmental Pollution**, v. 329, p. 121646, 2023.

Yuan, C. et al. The first complete mitochondrial genome of Notostomus gibbosus (Caridea, Acanthephyridae). **Mitochondrial DNA Part B**, v. 6, n. 7, p. 2050-2051, 2021.

Yuan, J. et al. Simple sequence repeats drive genome plasticity and promote adaptive evolution in penaeid shrimp. **Communications biology**, v. 4, n. 1, p. 186, 2021.

Zantis, L. J. et al. Marine mammals and microplastics: a systematic review and call for standardisation. **Environmental Pollution**, v. 269, p. 116142, 2021.

Zeb, A, et al. Microplastic pollution in terrestrial ecosystems: Global implications and sustainable solutions. **Journal of hazardous materials**, v. 461, p. 132636, 2024.

Zhang, H. Transport of microplastics in the environment: A review. *Environmental International*, v. 146, p. 106029, 2021.

Zhang, J. et al. Sight and blindness: The relationship between ostracod eyes, water depth, and light availability in the Arctic Ocean. **Limnology and Oceanography**, 2024.

Zhu, X. et al. Plastics in the deep sea–A global estimate of the ocean floor reservoir. **Deep Sea Research Part I: Oceanographic Research Papers**, v. 206, p. 104266, 2024.